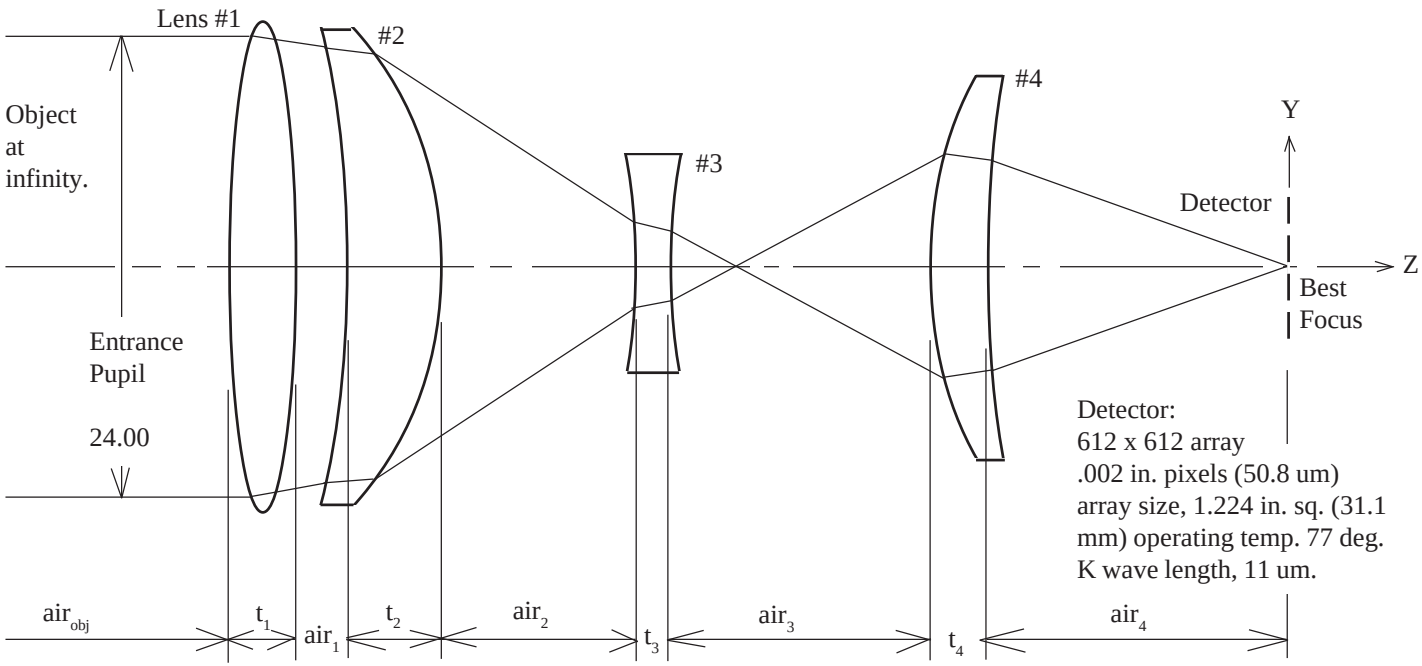
Tutorial 2

Correcting Thermal Focus Errors

This tutorial assumes that you have the results of Tutorial 1 available for use.
In this tutorial you will learn:

- how to calculate the effects of thermal expansion or contraction of the housing
- how to calculate the thermal change in focal length of a lens
- how to calculate the focus error caused by thermal effects on the lenses and the housing
- how to specify an adjustment mechanism to correct the focus errors

AEH.
Optomechanics



Your project, an infrared receiver defined in Tutorial 1, is concerned about the sensitivity of the focus to changes in temperature.

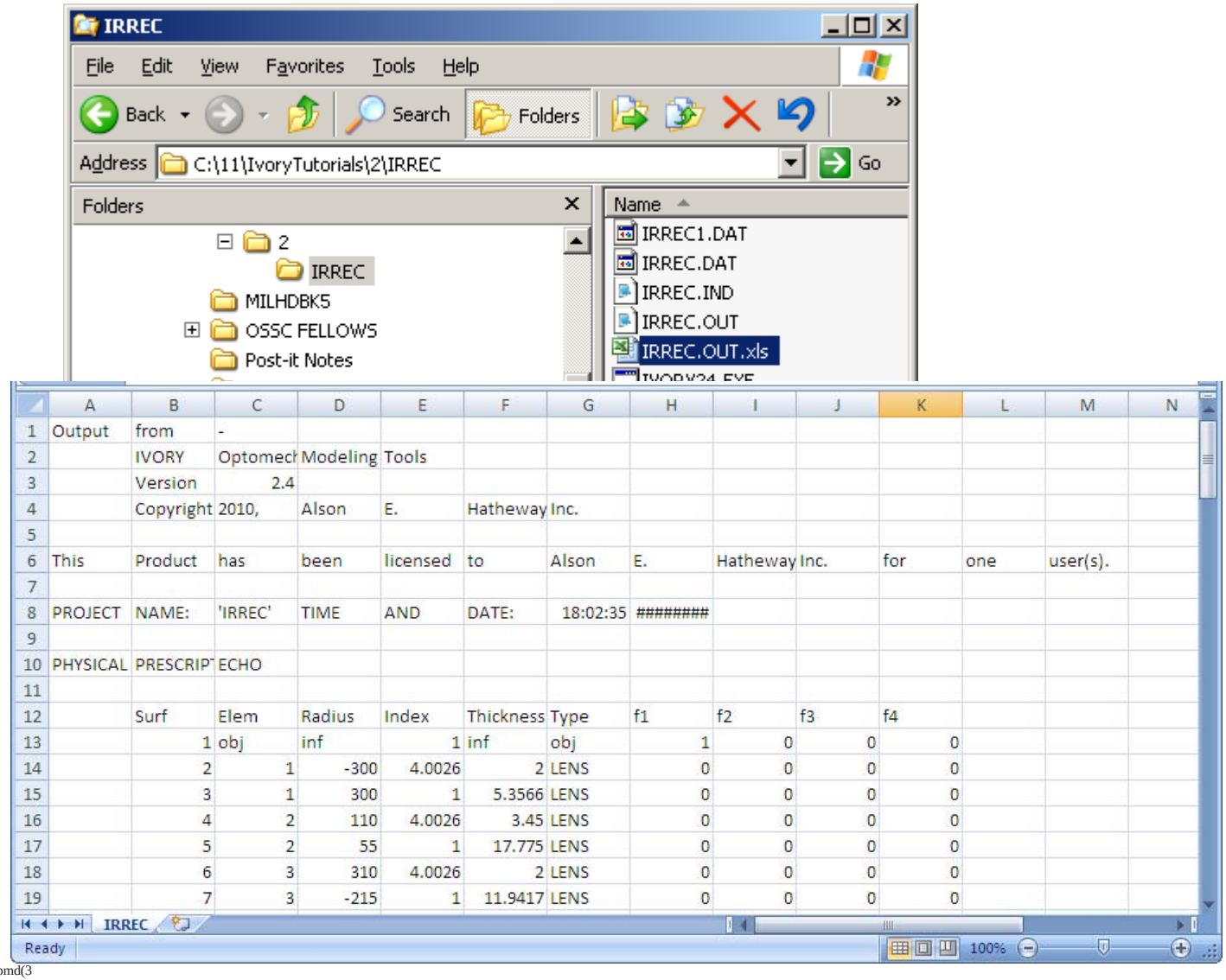
Task 1:

Detemine the focus shift caused by a temperature change of ±10 C degrees, assuming the housing is aluminum.

AEH.

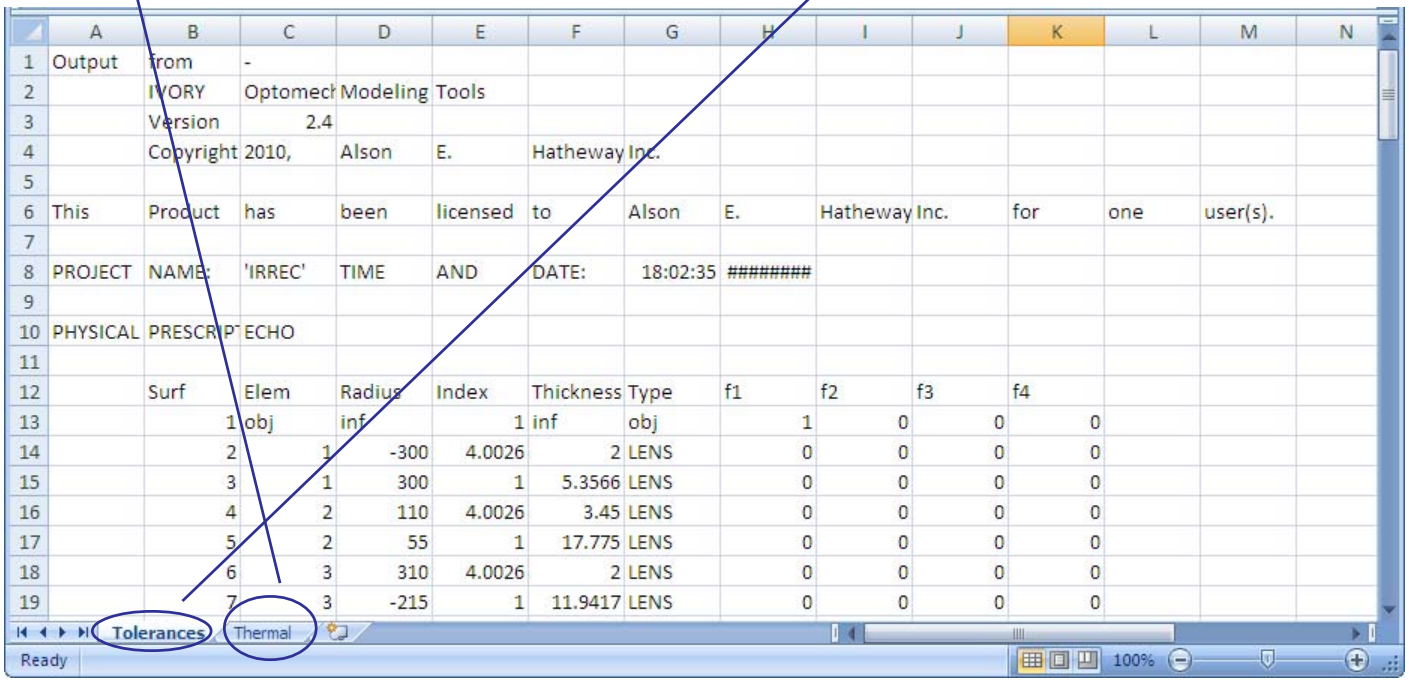
Optomechanics

In Tutorial 1 you ran Ivory to create the Optomechanical Constraint Equations. You then opened them in Excel and calculated the focus shift from the anticipated assembly tolerances. You will now open that Excel file from Internet Explorer:



2.pmd(3

You will re-name the first sheet from “IRREC” to “Toleraces”, add a second sheet and name it “Thermal.”



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Output	from	-											
2		IVORY	Optomech	Modeling	Tools									
3		Version	2.4											
4		Copyright	2010,	Alson	E.	Hatheway	Inc.							
5														
6	This	Product	has	been	licensed	to	Alson	E.	Hatheway	Inc.	for	one	user(s).	
7														
8	PROJECT	NAME:	'IRREC'	TIME	AND	DATE:	18:02:35	########						
9														
10	PHYSICAL	PRESCR	P ECHO											
11														
12		Surf	Elem	Radius	Index	Thickness	Type	f1	f2	f3	f4			
13		1	obj	inf	1	inf	obj	1	0	0	0			
14		2	1	-300	4.0026	2	LENS	0	0	0	0			
15		3	1	300	1	5.3566	LENS	0	0	0	0			
16		4	2	110	4.0026	3.45	LENS	0	0	0	0			
17		5	2	55	1	17.775	LENS	0	0	0	0			
18		6	3	310	4.0026	2	LENS	0	0	0	0			
19		7	3	-215	1	11.9417	LENS	0	0	0	0			

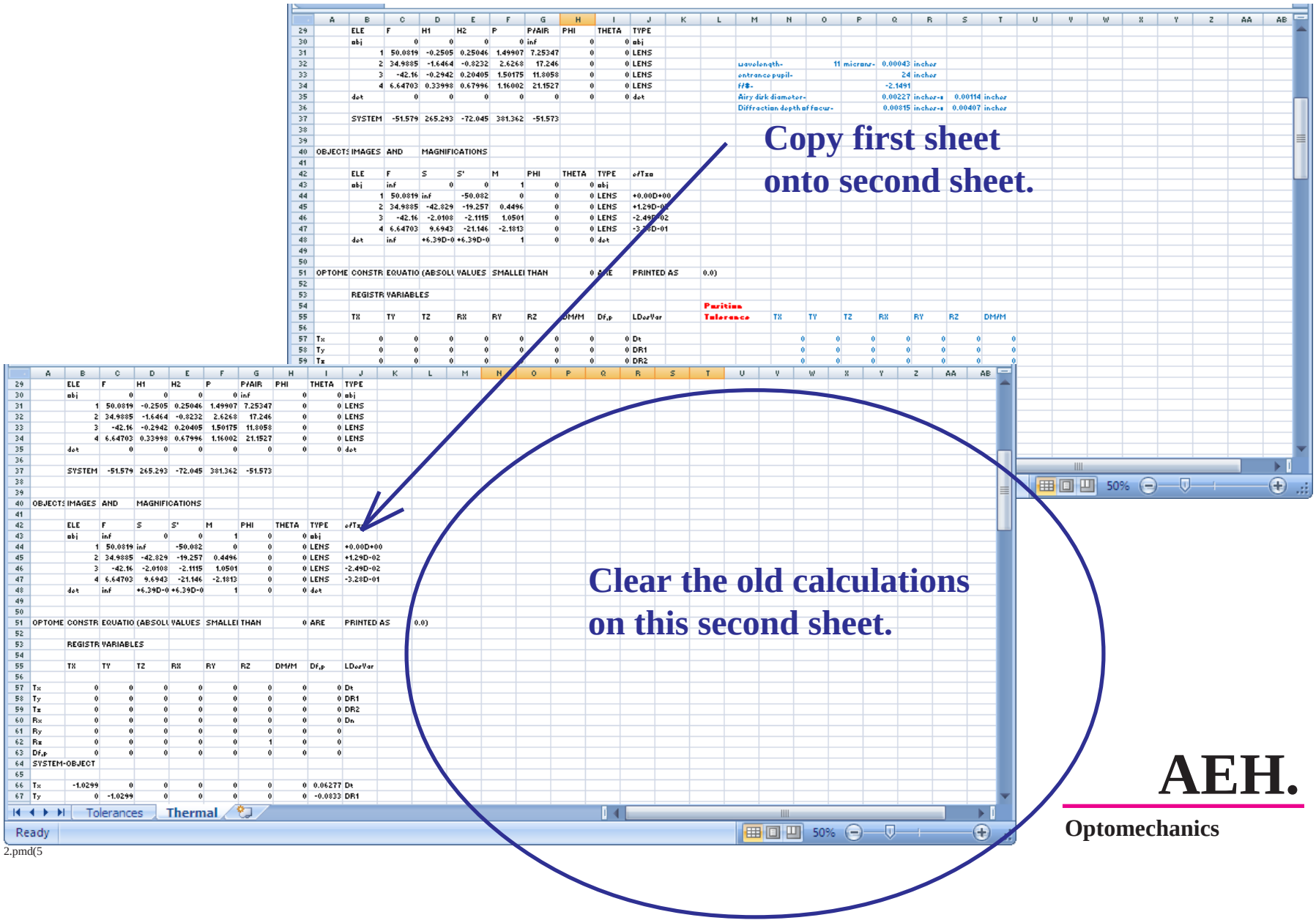
Tolerances | Thermal

Ready 100%

AEH.

Optomechanics

You will then copy the contents of the first sheet, Tolerances, onto the second sheet, Thermal. On the Thermal sheet erase all the calculations that were copied from the Tolerances sheet so you have only the Ivory output file data on the Thermal sheet.



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Optomechanics

The temperature change affects the focus of the system through thermal expansion or contraction of the aluminum housing, through the thermal expansion or contraction of the lenses and changes in the index of refraction of the lens material. The changes in the aluminum housing primarily affect the air spacing of the elements whereas the changes to the elements primarily affect their focal lengths. You will need the material properties for the aluminum and the germanium:

	dl/ldT (per C)	dn/dT (per C)
aluminum	23.4×10^{-6}	---
germanium	5.5×10^{-6}	4.0×10^{-4}

The first column is the coefficient of thermal expansion (CTE). The second column is the thermal coefficient of refractive index (TCRI).

Record these values at the top of the Thermal spreadsheet for future use.

See the next page for the results.

Material properties

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1	Output	from	-																					
2		IVORY	Optomec	Modeling	Tools																			
3		Version	2.4														Material Properties:							
4		Copyright	2010,	Alson	E.	Hathewa	Inc.												CTE	TCRI				
5																	aluminum		2.34E-05					
6	This	Product	has	been	licensed	to	Alson	E.	Hathewa	Inc.	for	one	user(s).				germanium		5.50E-06	4.00E-04				
7																								
8	PROJECT	NAME:	'IRREC'	TIME	AND	DATE:	18:02:35	########																
9																Housing								
10	PHYSICAL	PRESCRIP	ECHO													Distance								
11															Housing	from								
12		Surf	Elem	Radius	Index	Thickness	Type	f1	f2	f3	f4		Lenses	Spaces	Distance	Lens 1								
13		1	obj	inf	1	inf	obj	1	0	0	0				(in)	(in)								
14		2	1	-300	4.0026	2	LENS	0	0	0	0		L1			0								
15		3	1	300	1	5.3566	LENS	0	0	0	0			1-2	7.3566									
16		4	2	110	4.0026	3.45	LENS	0	0	0	0		L2			7.3566								
17		5	2	55	1	17.775	LENS	0	0	0	0			2-3	21.225									
18		6	3	310	4.0026	2	LENS	0	0	0	0		L3			28.5816								
19		7	3	-215	1	11.9417	LENS	0	0	0	0			3-4	13.9417									
20		8	4	-11	4.0026	1.5	LENS	0	0	0	0		L4			42.5233								
21		9	4	-22	1	20.4727	LENS	0	0	0	0			4-det	21.9727									
22		10	det	inf	1	0	det						det			64.496								
23																								
24	INDEXES	OF	REFRACTI	ARE	RELATIVE	TO	THE	VALUE	OF	1.00029														
25																								

Note:
We are assuming the vertex of lens #1 as the Z axis datum plane.

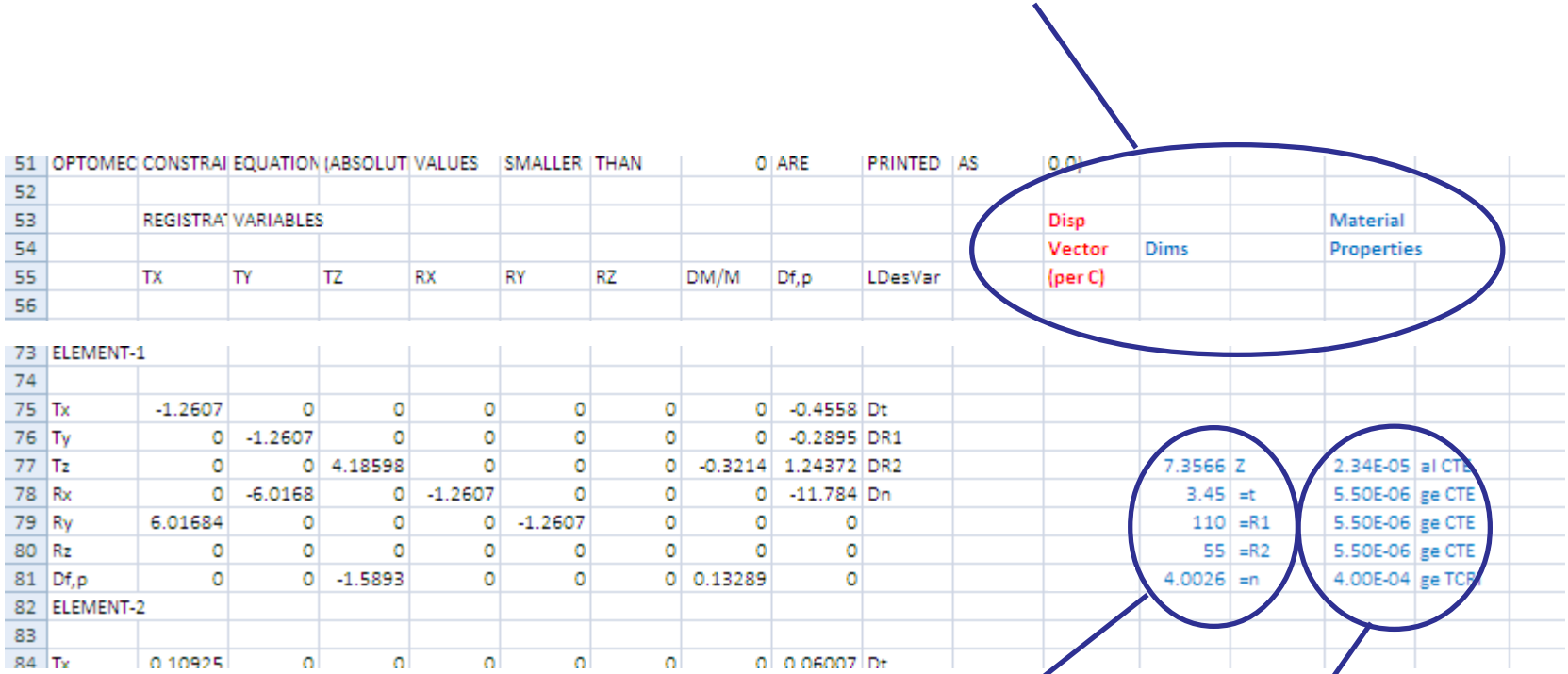
Next you need to calculate the length of the aluminum between the lenses that control the air spaces. You may *initially assume* the length between two lenses to be the distance between their first vertices. Calculate these distances on the spreadsheet next to the physical prescription data.

Then calculate the total distance of each lens from lens #1.

Of course you may wish to revisit any (or all) your assumptions later.

Now you must calculate the displacement vector per degree C. Lets start at lens 2.

First, at the top of the OCE you may set up three column headings as shown.



51	OPTOMEC	CONSTRAI	EQUATION	(ABSOLUT	VALUES	SMALLER	THAN	0	ARE	PRINTED	AS	Q,Q)			
52															
53		REGISTRA	VARIABLES									Disp			Material
54												Vector	Dims		Properties
55		TX	TY	TZ	RX	RY	RZ	DM/M	Df,p	LDesVar		(per C)			
56															
73	ELEMENT-1														
74															
75	Tx	-1.2607	0	0	0	0	0	0	-0.4558	Dt					
76	Ty	0	-1.2607	0	0	0	0	0	-0.2895	DR1					
77	Tz	0	0	4.18598	0	0	0	-0.3214	1.24372	DR2			7.3566	Z	2.34E-05 al CTE
78	Rx	0	-6.0168	0	-1.2607	0	0	0	-11.784	Dn			3.45	=t	5.50E-06 ge CTE
79	Ry	6.01684	0	0	0	-1.2607	0	0	0				110	=R1	5.50E-06 ge CTE
80	Rz	0	0	0	0	0	0	0	0				55	=R2	5.50E-06 ge CTE
81	Df,p	0	0	-1.5893	0	0	0	0.13289	0				4.0026	=n	4.00E-04 ge TCR
82	ELEMENT-2														
83															
84	Tx	0.10925	0	0	0	0	0	0	0.06007	Dt					

Second, enter the Tz distance from lens #1 to lens 2 and lens 2's prescription's dimensions from the Physical Prescription Echo.

Third, enter the material properties from the top of the sheet that apply to each of the dimensional quantities.

AEH.

Optomechanics

Fourth, calculate the Z axis displacement per C of lens 2:

Tz per C=(Z distance)(aluminum'sCTE)

51	OPTOMEC	CONSTRAI	EQUATION	(ABSOLUT	VALUES	SMALLER	THAN	0	ARE	PRINTED	AS	0.0)				
52																
53		REGISTRA	VARIABLES									Disp			Material	
54												Vector	Dims		Properties	
55		TX	TY	TZ	RX	RY	RZ	DM/M	Df,p	LDesVar		(per C)				
56																
73	ELEMENT-1															
74																
75	Tx	-1.2607	0	0	0	0	0	0	-0.4558	Dt						
76	Ty	0	-1.2607	0	0	0	0	0	-0.2895	DR1						
77	Tz	0	0	4.18598	0	0	0	-0.3214	1.24372	DR2		1.72E-04	7.3566	Z	2.34E-05	al CTE
78	Rx	0	-6.0168	0	-1.2607	0	0	0	-11.784	Dn			3.45	=t	5.50E-06	ge CTE
79	Ry	6.01684	0	0	0	-1.2607	0	0	0				110	=R1	5.50E-06	ge CTE
80	Rz	0	0	0	0	0	0	0	0				55	=R2	5.50E-06	ge CTE
81	Df,p	0	0	-1.5893	0	0	0	0.13289	0			-1.87E-02	4.0026	=n	4.00E-04	ge TCRI
82	ELEMENT-2															
83																
84	Tx	0.10925	0	0	0	0	0	0	0.06007	Dt						

(R2)(CTE)(df/dR2)

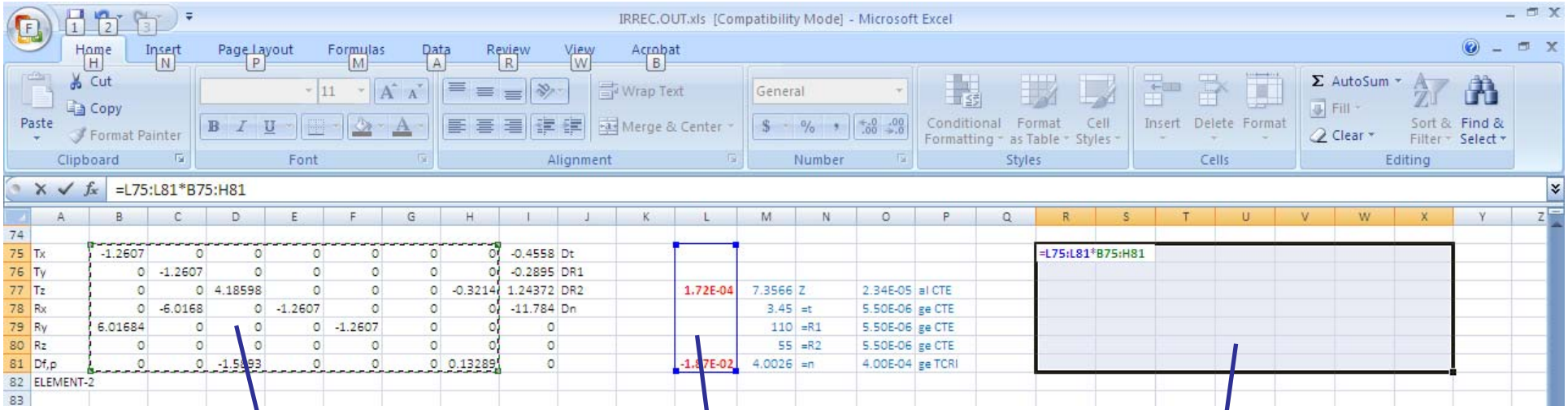
Fifth, calculate the change in focal length per C:

example of calculations

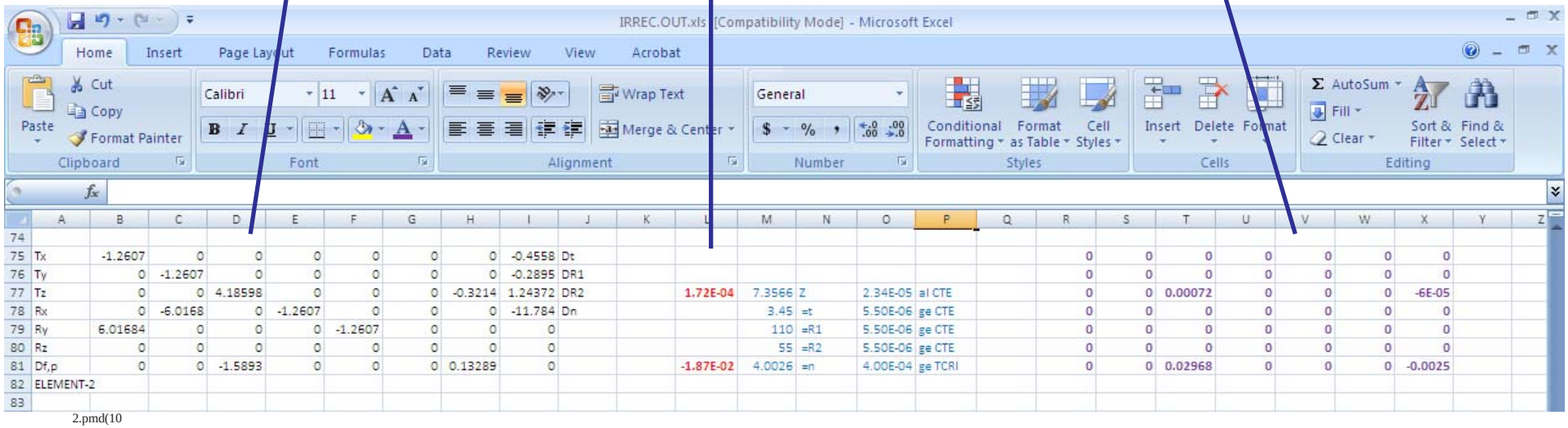
Δf per C=(t)(CTE)(df/dt)+(R1)(CTE)(df/dR1)+(R2)(CTE)(df/dR2)+(n)(TCRI)

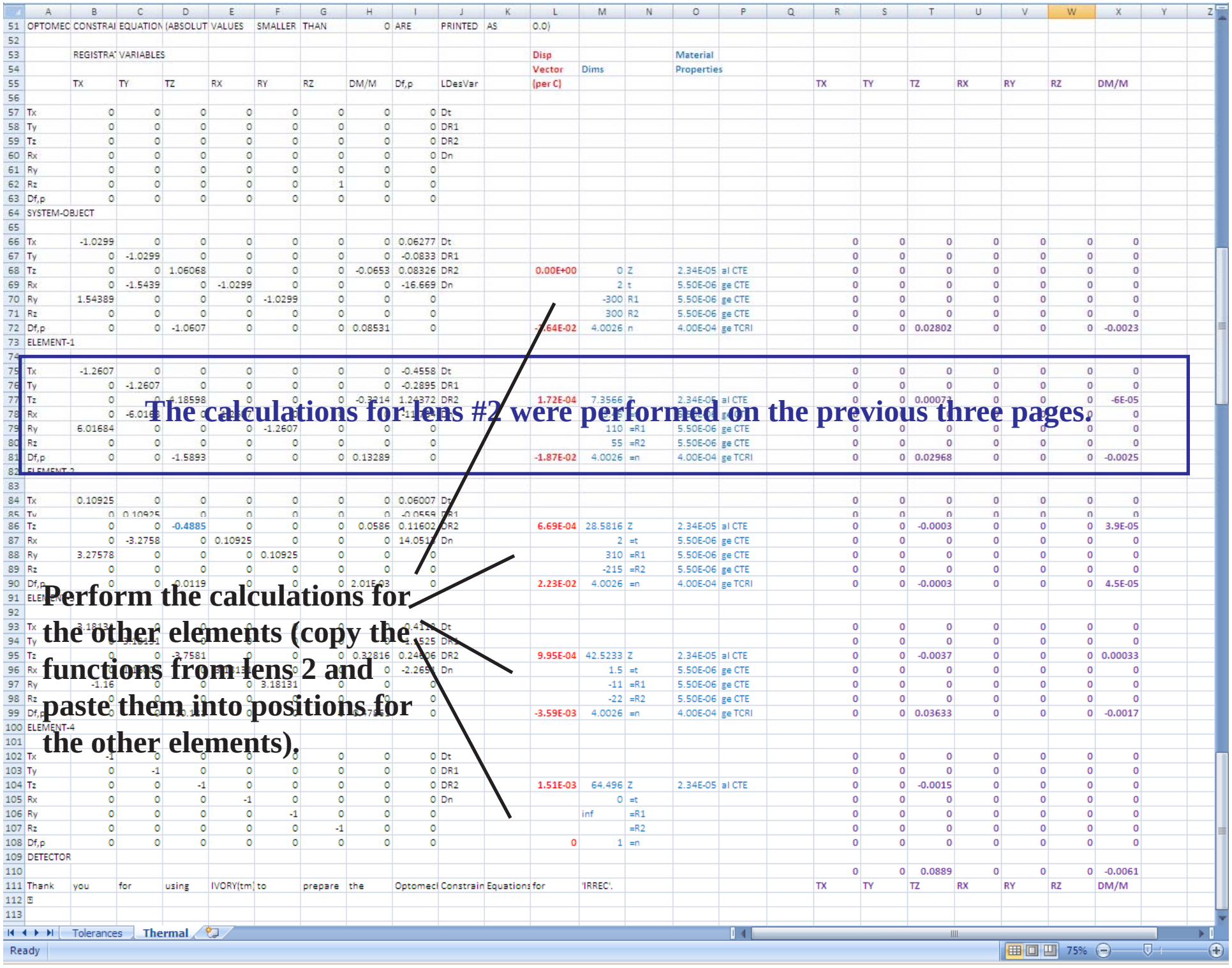
The change in focal length per C is the sum of the contributions from the four lens design vairables: the thickness, the first radius, the second radius and the index of refraction, as shown in the equation.

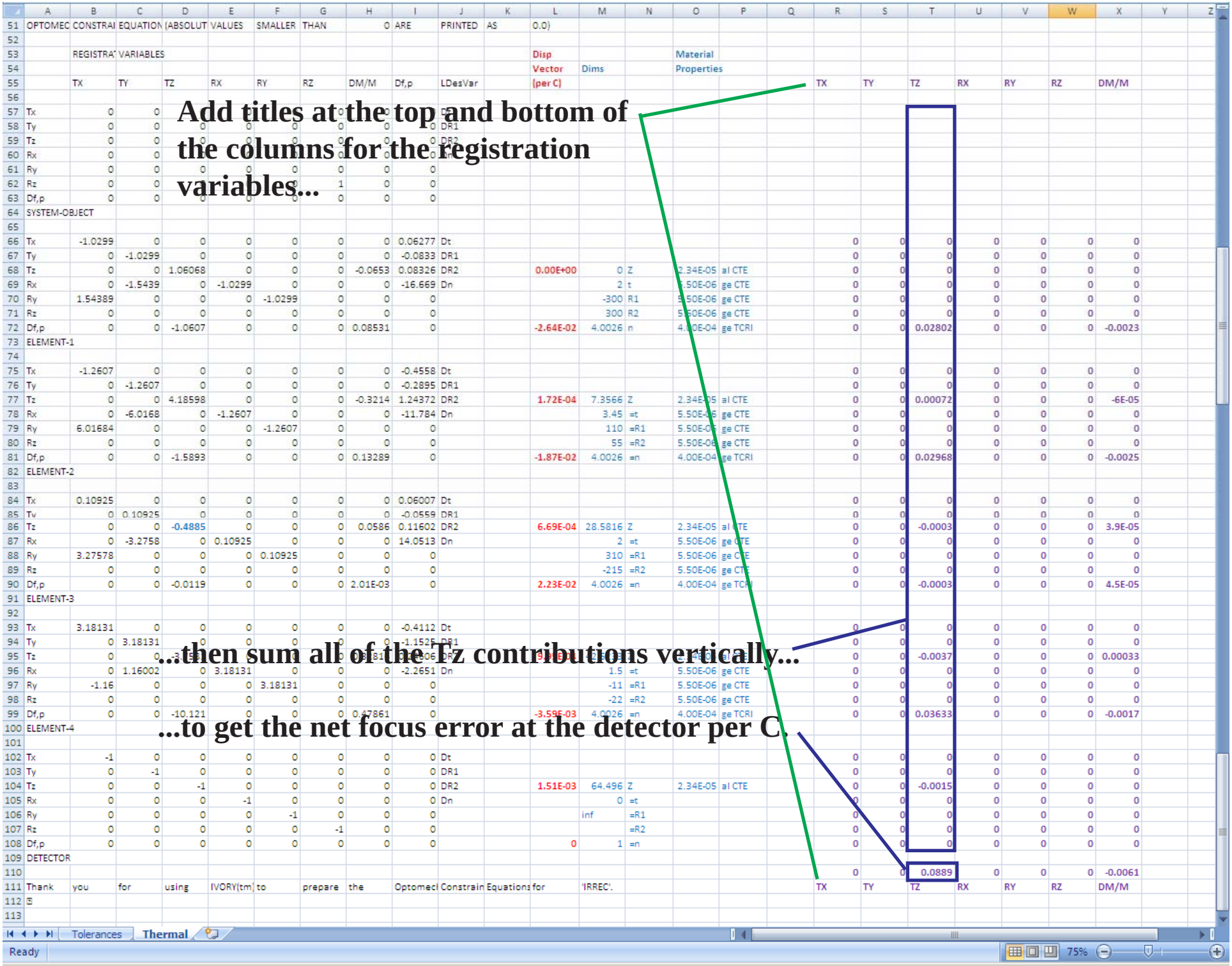
Now, to get the contribution of lens 2 to the image motion at the detector you multiply the influence coefficients for lens 2 by the displacement vector for lens 2, as shown.



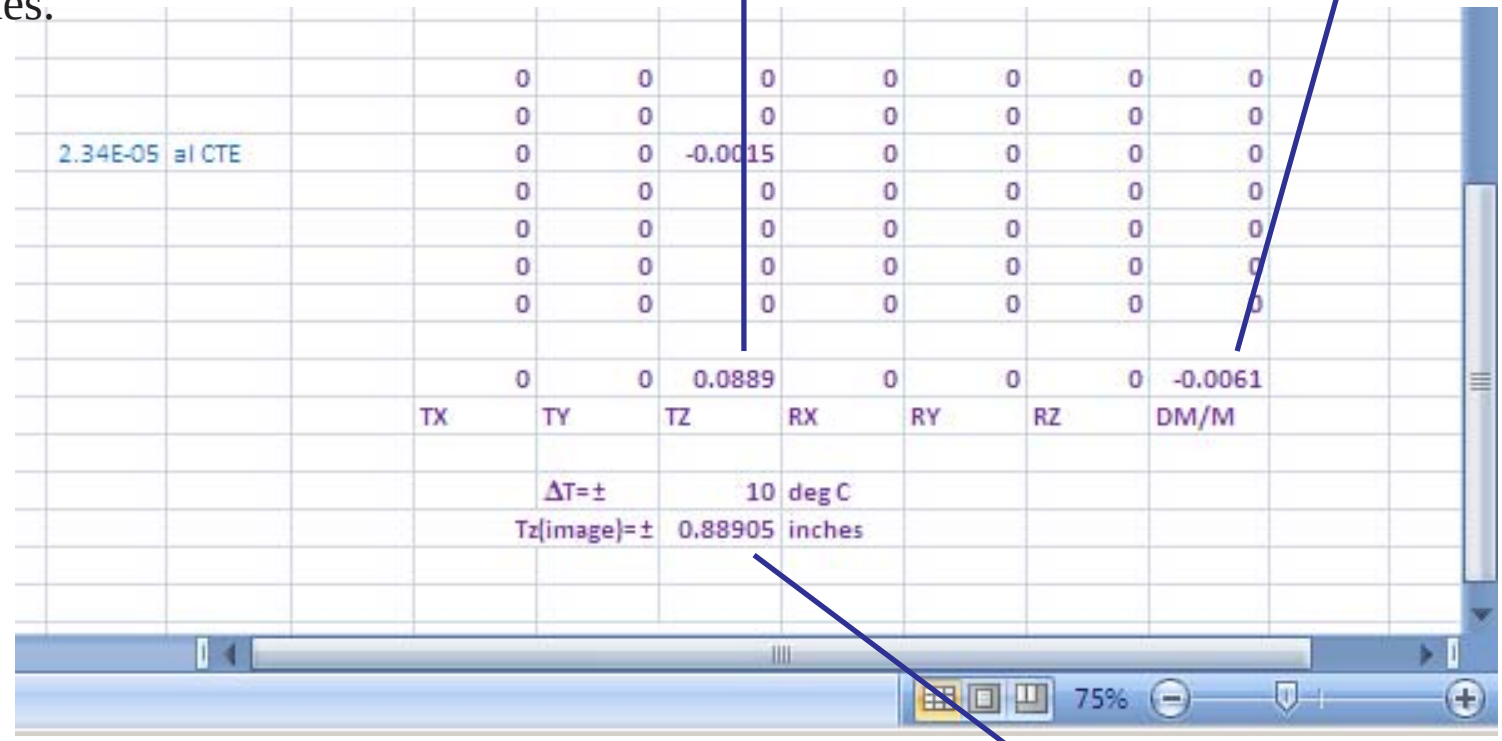
influence coefficients x displacement vector = image motion contributions




The calculations for lens #2 were performed on the previous three pages.
Perform the calculations for the other elements (copy the functions from lens 2 and paste them into positions for the other elements).


Add titles at the top and bottom of the columns for the registration variables...
...then sum all of the Tz contributions vertically...
...to get the net focus error at the detector per C.

Looking more closely at the net registration error we see that a 1 deg C increase causes the image to fall in front of the detector by 0.0889 inches. It also causes a 0.61% reduction in image size. Therefore for a ±10 deg C change in temperature the focus will shift ±0.889 inches.



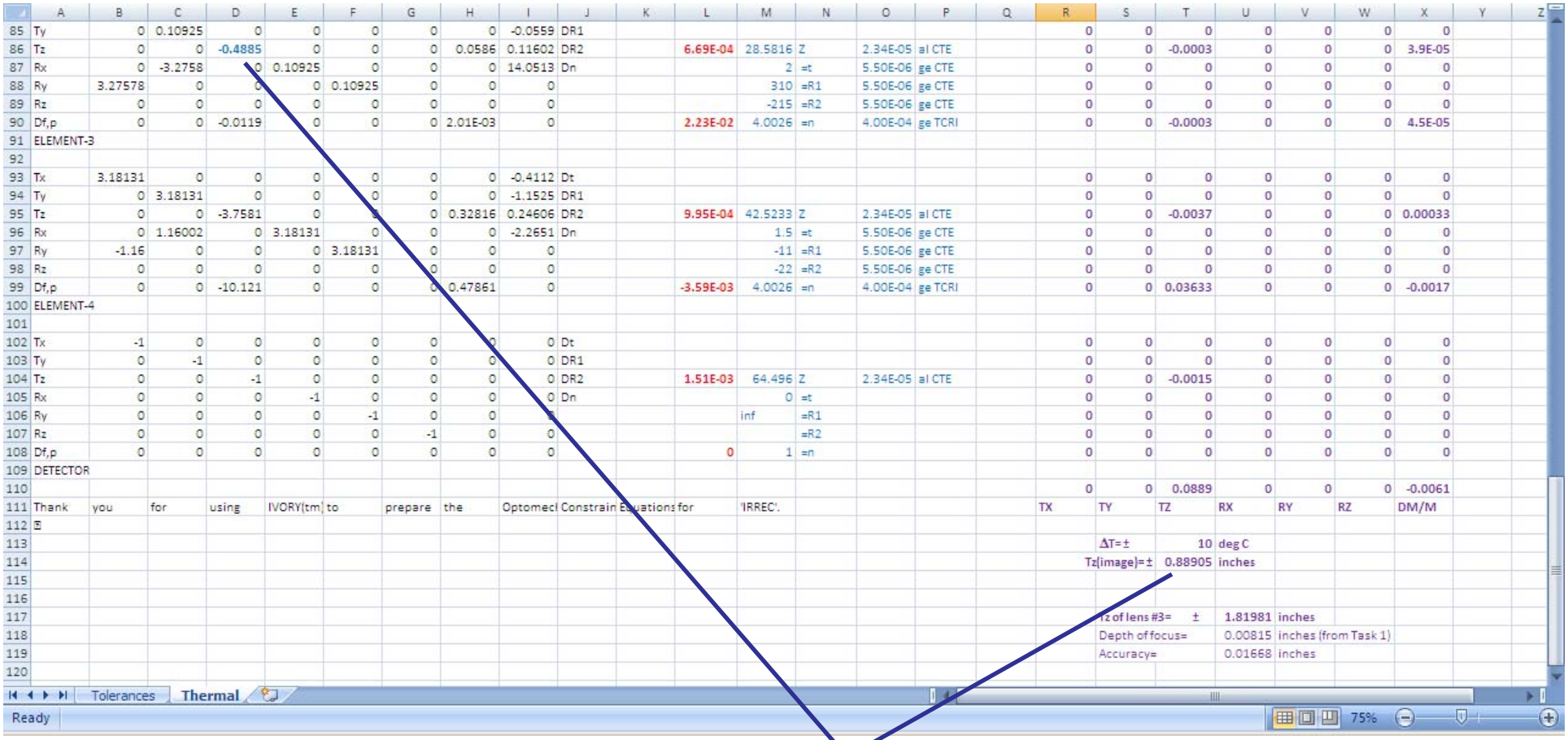
Answer to Task 1:

Tz of the image = ±10 deg C x ±0.0889 inches per deg C = ±0.889 inches.

AEH.

Optomechanics

Task 2: Specify the requirements of an actuator to move Lens 3 the correct the thermal focus errors.



85	Ty	0	0.10925	0	0	0	0	0	-0.0559	DR1							0	0	0	0	0	0	0		
86	Tz	0	0	-0.4885	0	0	0	0.0586	0.11602	DR2		6.69E-04	28.5816	Z	2.34E-05	al CTE		0	0	-0.0003	0	0	0	3.9E-05		
87	Rx	0	-3.2758	0	0.10925	0	0	0	14.0513	Dn			2	=t	5.50E-06	ge CTE		0	0	0	0	0	0	0		
88	Ry	3.27578	0	0	0	0.10925	0	0	0				310	=R1	5.50E-06	ge CTE		0	0	0	0	0	0	0		
89	Rz	0	0	0	0	0	0	0	0				-215	=R2	5.50E-06	ge CTE		0	0	0	0	0	0	0		
90	Df,p	0	0	-0.0119	0	0	0	2.01E-03	0			2.23E-02	4.0026	=n	4.00E-04	ge TCRI		0	0	-0.0003	0	0	0	4.5E-05		
91	ELEMENT-3																								
92																									
93	Tx	3.18131	0	0	0	0	0	0	-0.4112	Dt								0	0	0	0	0	0	0		
94	Ty	0	3.18131	0	0	0	0	0	-1.1525	DR1								0	0	0	0	0	0	0		
95	Tz	0	0	-3.7581	0	0	0	0.32816	0.24606	DR2		9.95E-04	42.5233	Z	2.34E-05	al CTE		0	0	-0.0037	0	0	0	0.00033		
96	Rx	0	1.16002	0	3.18131	0	0	0	-2.2651	Dn			1.5	=t	5.50E-06	ge CTE		0	0	0	0	0	0	0		
97	Ry	-1.16	0	0	0	3.18131	0	0	0				-11	=R1	5.50E-06	ge CTE		0	0	0	0	0	0	0		
98	Rz	0	0	0	0	0	0	0	0				-22	=R2	5.50E-06	ge CTE		0	0	0	0	0	0	0		
99	Df,p	0	0	-10.121	0	0	0	0.47861	0			-3.59E-03	4.0026	=n	4.00E-04	ge TCRI		0	0	0.03633	0	0	0	-0.0017		
100	ELEMENT-4																								
101																									
102	Tx	-1	0	0	0	0	0	0	0	Dt								0	0	0	0	0	0	0		
103	Ty	0	-1	0	0	0	0	0	0	DR1								0	0	0	0	0	0	0		
104	Tz	0	0	-1	0	0	0	0	0	DR2		1.51E-03	64.496	Z	2.34E-05	al CTE		0	0	-0.0015	0	0	0	0		
105	Rx	0	0	0	-1	0	0	0	0	Dn			0	=t				0	0	0	0	0	0	0		
106	Ry	0	0	0	0	-1	0	0	0				inf	=R1				0	0	0	0	0	0	0		
107	Rz	0	0	0	0	0	-1	0	0					=R2				0	0	0	0	0	0	0		
108	Df,p	0	0	0	0	0	0	0	0			0	1	=n				0	0	0	0	0	0	0		
109	DETECTOR																								
110																		0	0	0.0889	0	0	0	-0.0061		
111	Thank	you	for	using	IVORY(tm)	to	prepare	the	Optomech	Constrain Equations	for	'IRREC'.						TX	TY	TZ	RX	RY	RZ	DM/M		
112	⊞																								
113																			ΔT=±	10	deg C					
114																			Tz(image)=±	0.88905	inches					
115																									
116																									
117																			rz of lens #3=	±	1.81981	inches			
118																			Depth of focus=		0.00815	inches (from Task 1)			
119																			Accuracy=		0.01668	inches			
120																									

Tolerances | Thermal

Ready

75%

Answer to Task 2:

Stroke at Lens 3 = 2 x 0.889/0.4885 = 3.640 inches

Accuracy = 0.0167 inches (same as for Tolerances, Tutorial 1)

AEH.

Optomechanics