Correction to Module Cooling

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5/1/02

I believe I have found an error in the calculation Bruce Baller did for module cooling in the case of no water flow to either module #3 or #4 on the NuMI absorber[1]. Here is an extract from Bruce's email (italics).

I used the CRC Handbook of tables for Applied Engineering Science, 2nd Edition. Table 5-39 gives the heat transfer coefficient for combined radiation and convection from dull metal surfaces (emissivity = 0.45) for various delta T's. I assumed vertical walls with cooling on both sides. I assumed the temperature of the adjacent cooled modules is 100 deg F. Here is the table from the handbook and the calculated heat transfer for the delta T's given in the table:

Delta T (deg F)	*Transfer Coefficient (BTU/(hr ft^2 deg F)*	*Heat Transfer (kW)*
50	*1.2*	*0.65*
100	*1.4*	*1.53*
200	*1.7*	*3.71*
300	*2.0*	*65.4*

Table 1

The heat transfer values are plotted with a smooth curve in the attached postscript file. Note that the temperature is plotted: not Delta T. I'm not sure if the dip is due to the interplay between convection and radiation or if it's due to rounding errors in the table.

Looking carefully at these numbers, I think that the last value of 65.4 is high by a factor of 10. The basis for this assertion is given below.

	A	B	C	D	E	F	G	H	I	J
1	Delta T	Transfer Coefficient (h)	Heat Transfer	Heat Transfer (check)	log delta T	log h	fit	Transfer Coefficient (h)	h (Zemansky)	BB T
2	(deg F)	(BTU/(hr ft^2 deg F)	(kW)	(kW)				watts/m^2 deg K		
3	50	1.2	0.65	0.66	1.70	0.08	0.07	6.8	4.1	150
4	100	1.4	1.53	1.54	2.00	0.15	0.16	7.9	4.8	200
5	200	1.7	3.71	3.74	2.30	0.23	0.24	9.7	5.8	300
6	300	2	65.4	6.60	2.48	0.30	0.29	11.4	6.4	400
7	400	2.11		9.26	2.60		0.32	12.0	6.9	500
8										
9		1055	joules/BTU							
10		4.1868	joules/calorie							

Table 2: A study with MS Excel

[1] See link at http://www-numi.fnal.gov/numwork/reviews/nov_20.html.

Rows 3 to 6 for Columns A and B are taken from Table 1 (Bruce's email). Row 7 is an extrapolation based upon the fit shown in Figure 1 (below). It was done so as to get a heat transfer value above 8 KW. Column I are heat transfer coefficients for natural convection in air from a vertical surface, taken from a Thermodynamics text I have by Zemansky. Column H values are simply a units change from column B. Column J are the temperature (not delta T) values used by Bruce in his plot.

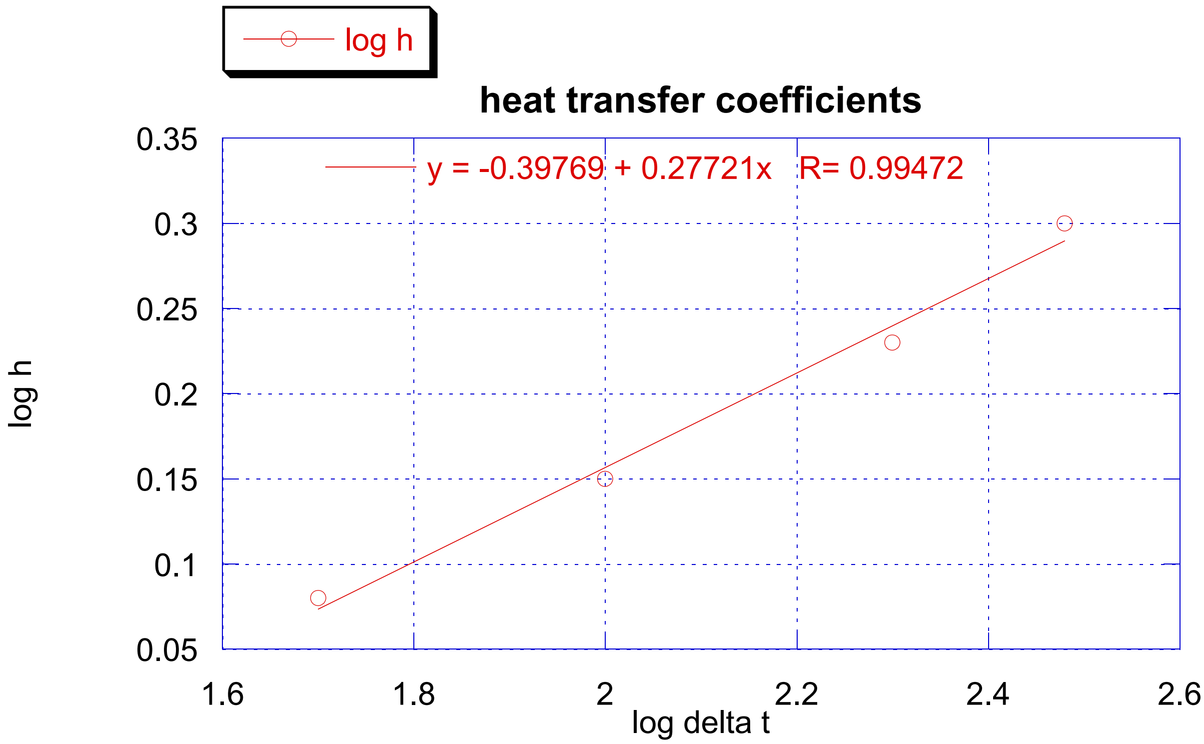

Figure 1: A log-log plot of the heat transfer coefficient vs delta t

Figure 1 is a plot of the log of column B of Table 2 versus column A of Table 2. A text I have at home by Zemansky states that the natural convection heat transfer coefficients vary as $(\Delta t)^{\frac{1}{4}}$; the linear fit in Fig. 1 suggests that the coefficients from Column B vary with t almost in that manner[2]. The linear fit was used in column G of Table 2 in order to extrapolate[3] to a delta T value of 400 degrees F.

Finally, Figure 2 shows a new plot of heat transfer from the module without water cooling versus temperature:

[2] I'm guessing that radiative heat transfer isn't yet significant at these temperatures.
[3] This extrapolation wouldn't be necessary, I surmise, if I borrowed Bruce's reference from him.

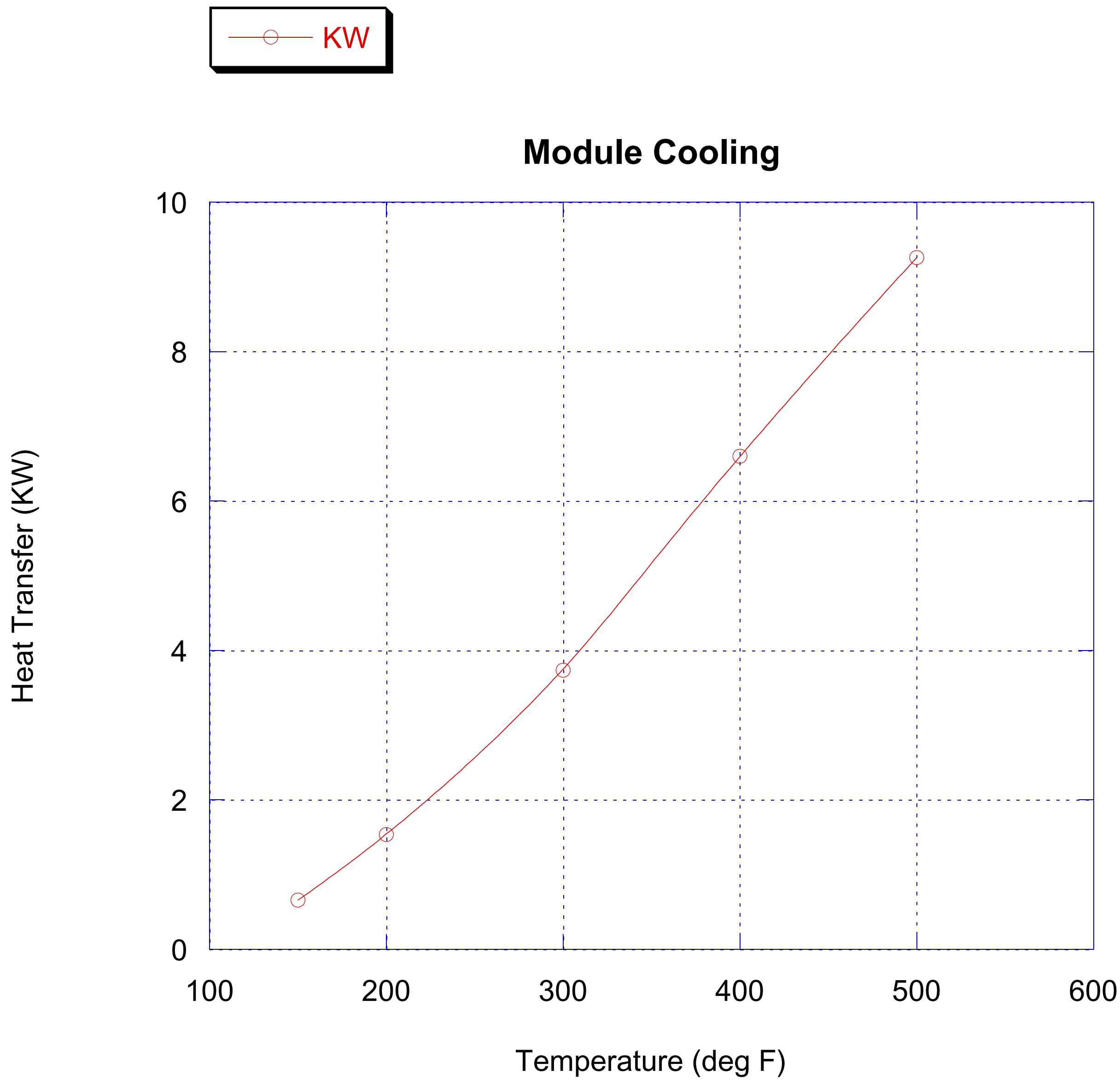

Figure 2: Module Cooling

Reading from Figure 2, 8 KW corresponds to 450 °F.