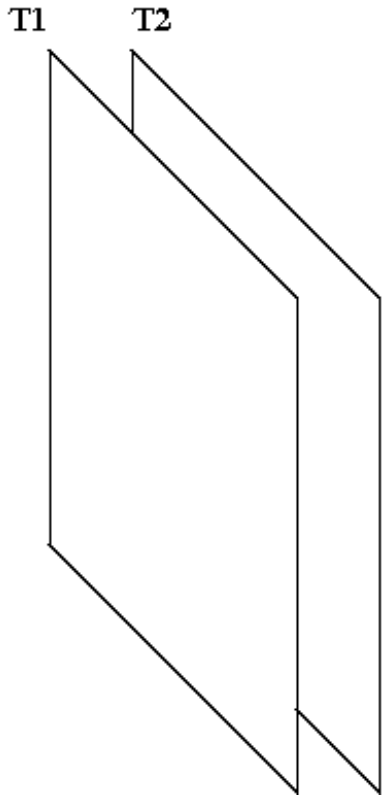
Random Thoughts on Thermal Design

2-D Thermal Energy Transfer



Radiation $5.46\text{x}10^{-12}\frac{E_1E_2}{E_1+E_2-E_1E_2}({T_1}^4-{T_2}^4)$

Conduction $\frac{k}{d}(T_1-T_2)$

Measured Emissivities

- Al (clean, polished foil)…. 0.011 to 0.055
- Al (highly oxidozed)……. 0.31
- Brass (clean polished)…… 0.018 to 0.1
- Copper (clean polished).. 0.035 to 0.062
- Chrome plate…….. 0.066 to 0.084
- Gold foil…….. 0.01 to 0.03
- Gold Plate…….. 0.028
- Ni (polished)……. 0.045
- Silver Plate……. 0.008 to 0.036
- Stainless Steel…….. 0.048 to 0.074
- Tin Foil (clean) …….. 0.013 to 0.06
- Soft Solder …… 0.03 to 0.047
- Glass…… 0.87 to 0.9
- Wood's Metal …….. 0.16

Radiation

T_1 = 300 K, T_2 = 20 K, $Emissivity_1$ = 0.01, $Emissivity_2$ = 0.2

0.36×10^{-3} W/cm^2

T_1 = 300 K, T_2 = 20 K, $Emissivity_1$ = 0.05, $Emissivity_2$ = 0.2

1.58×10^{-3} W/cm^2

Complex surfaces increase the effective emissivity

Frosted Surfaces:

T_1 = 300 K, T_2 = 20 K, $Emissivity_1$ = 0.9, $Emissivity_2$ = 0.9

36.2×10^{-3} W/cm^2

Frost Reflectivity

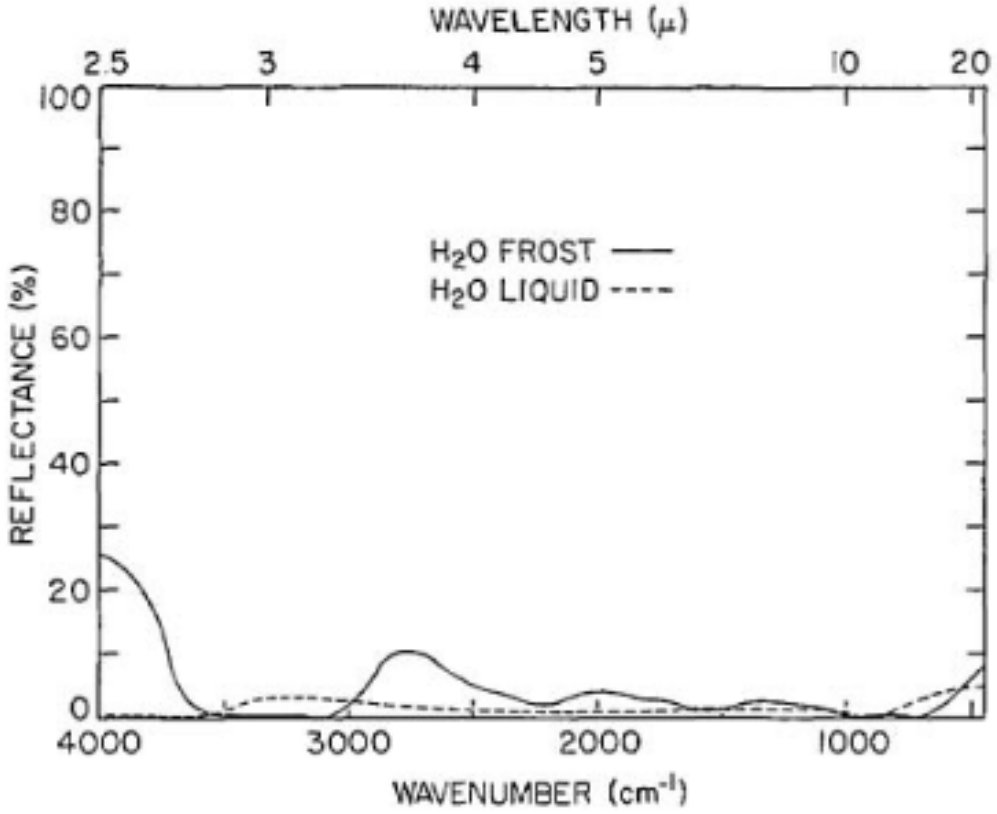


FIG. 1. Infrared spectral reflectance, 4000 to 450 cm^{-1}, of water frost (solid curve) at approximately the boiling point of nitrogen (−196°C). Also shown (dashed line) is the infrared spectral reflectance of a pool of distilled water (50-mm deep) at room temperature (approximately 25°C).

Gifford-McMahon refrigeration receiver systems use a 70 K heat shield to reduce the radiation loading on the 20 K components. The available cooling power is greater at 70 K. However, G-M systems require a lot of power and an external compressor.

Gas Conduction

Mean free path

$$l = \frac{1}{n \, \pi \, d^2}$$

n = molecules per unit volume

d = molecular diameter (2 x 10^{-8} cm for diatomic molecules)

At 273 K and 1 atmosphere (760 torr)

n = 2.8 x 10^{19} per cubic cm

then

$$l = \frac{2.16 \, x \, 10^{-2}}{P} \text{ cm}$$

where *P* is the pressure in torr.

Hence, the transition from high to low pressure conduction occurs at about 10^{-2} torr. At higher pressures, conductivity is roughly independent of pressure.

Low Pressure Gas Conduction

$$H = K\ a\ P\ (T_2 - T_1) \quad W/cm^2$$

Where a is the accommodation coefficient which quantifies how efficiently a molecule transfers energy to a wall. Typical values range from 0.2 to 0.8.

P is the pressure in torr.

$K \approx 2.8 \times 10^{-2}$ for helium

5.9×10^{-2} for hydrogen

1.6×10^{-2} for nitrogen or air

If $P = 10^{-3}$ torr, $a = 0.5$, $T_2 = 300K$, $T_1 = 20K$, then, for air

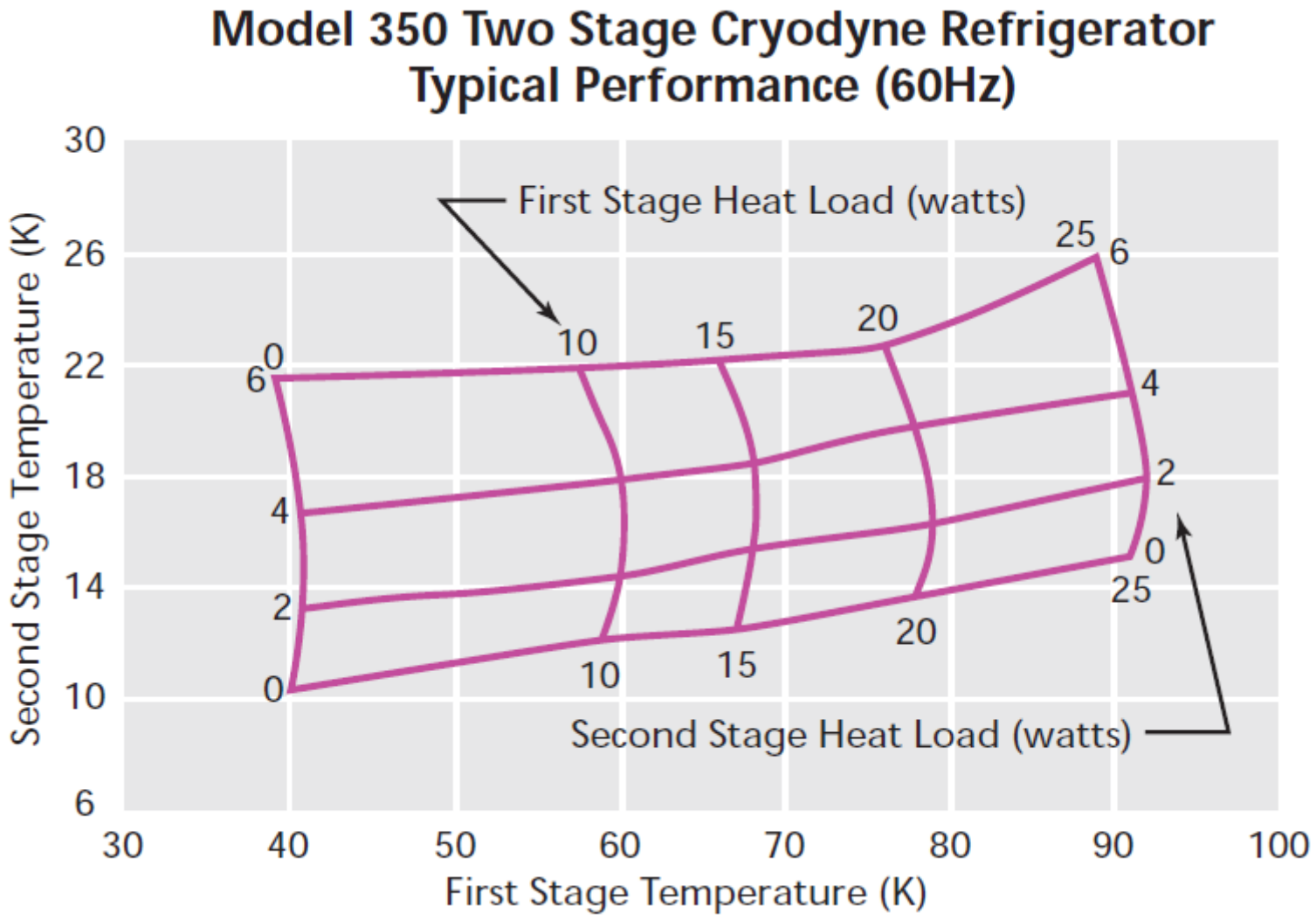
$H = 2.24 \times 10^{-3}$ W/cm^2

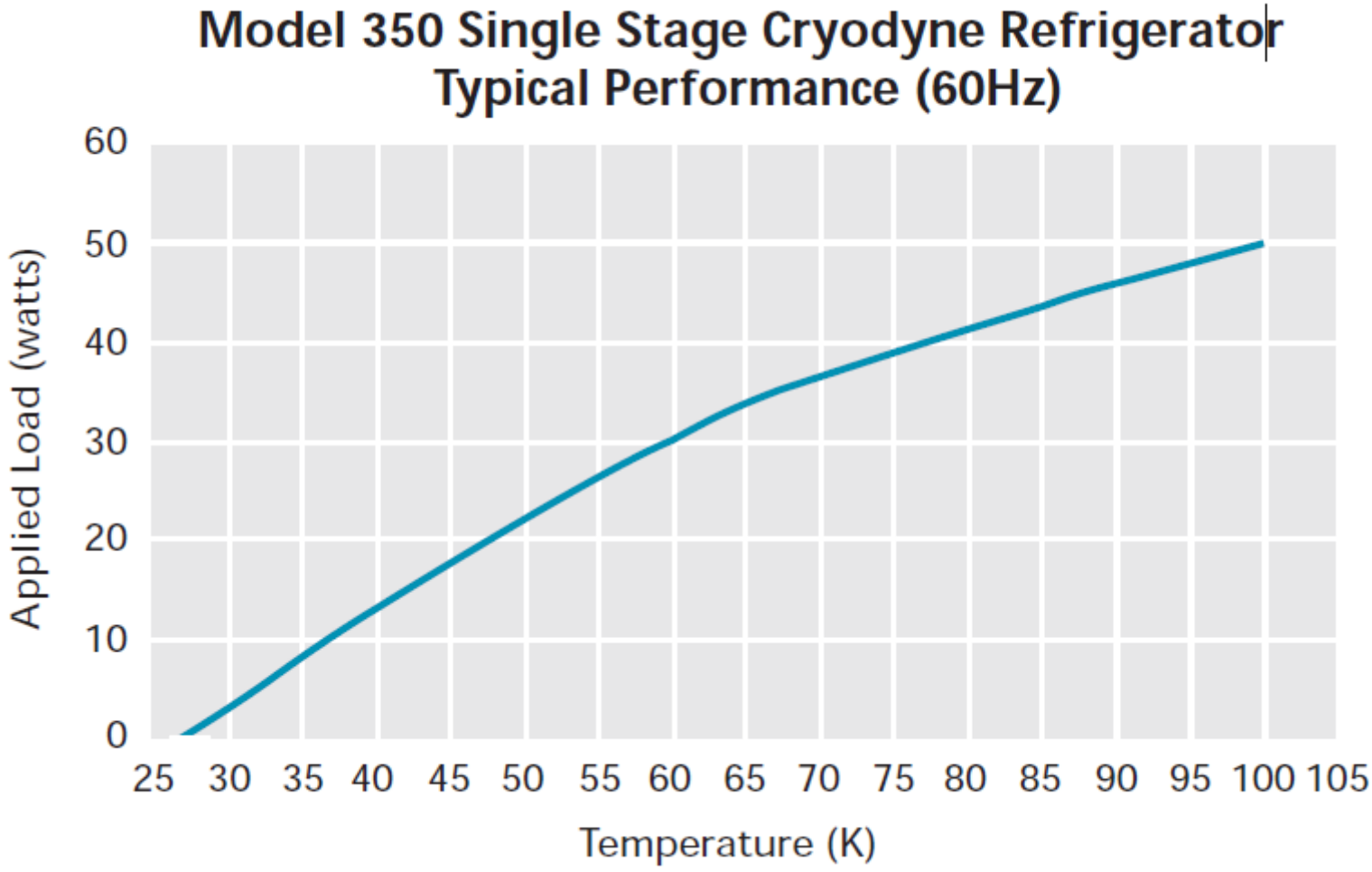
The conduction load of a 10 cm thickness of polystyrene foam is approximately 6×10^{-3} W/cm^2 for the same temperature difference.

Skin depth of copper at 1 GHz ≈ 2 microns

Heat flow lengthwise through a 6 micron thick copper strip

2.0 cm long x 0.2 cm wide ≈ 70×10^{-3} W


Model 350 Two Stage Cryodyne Refrigerator
Typical Performance (60Hz)
Second Stage Temperature (K)
30
26
22
18
14
10
6
First Stage Heat Load (watts)
0
6
10
15
20
25
6
4
2
0
Second Stage Heat Load (watts)
0
2
4
6
10
15
20
25
30
40
50
60
70
80
90
100
First Stage Temperature (K)


Model 350 Single Stage Cryodyne Refrigerator
Typical Performance (60Hz)
Applied Load (watts)
60
50
40
30
20
10
0
25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105
Temperature (K)

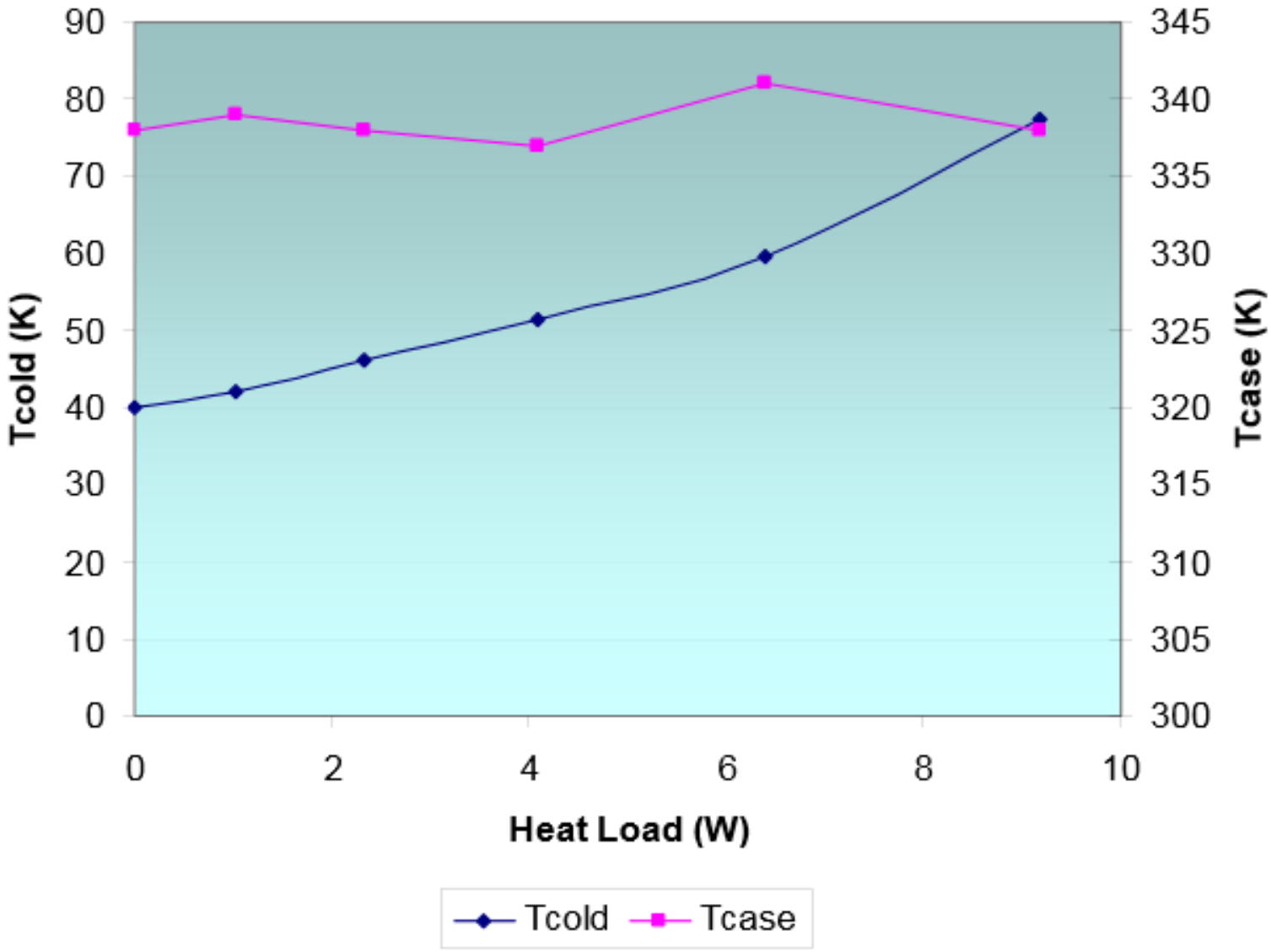
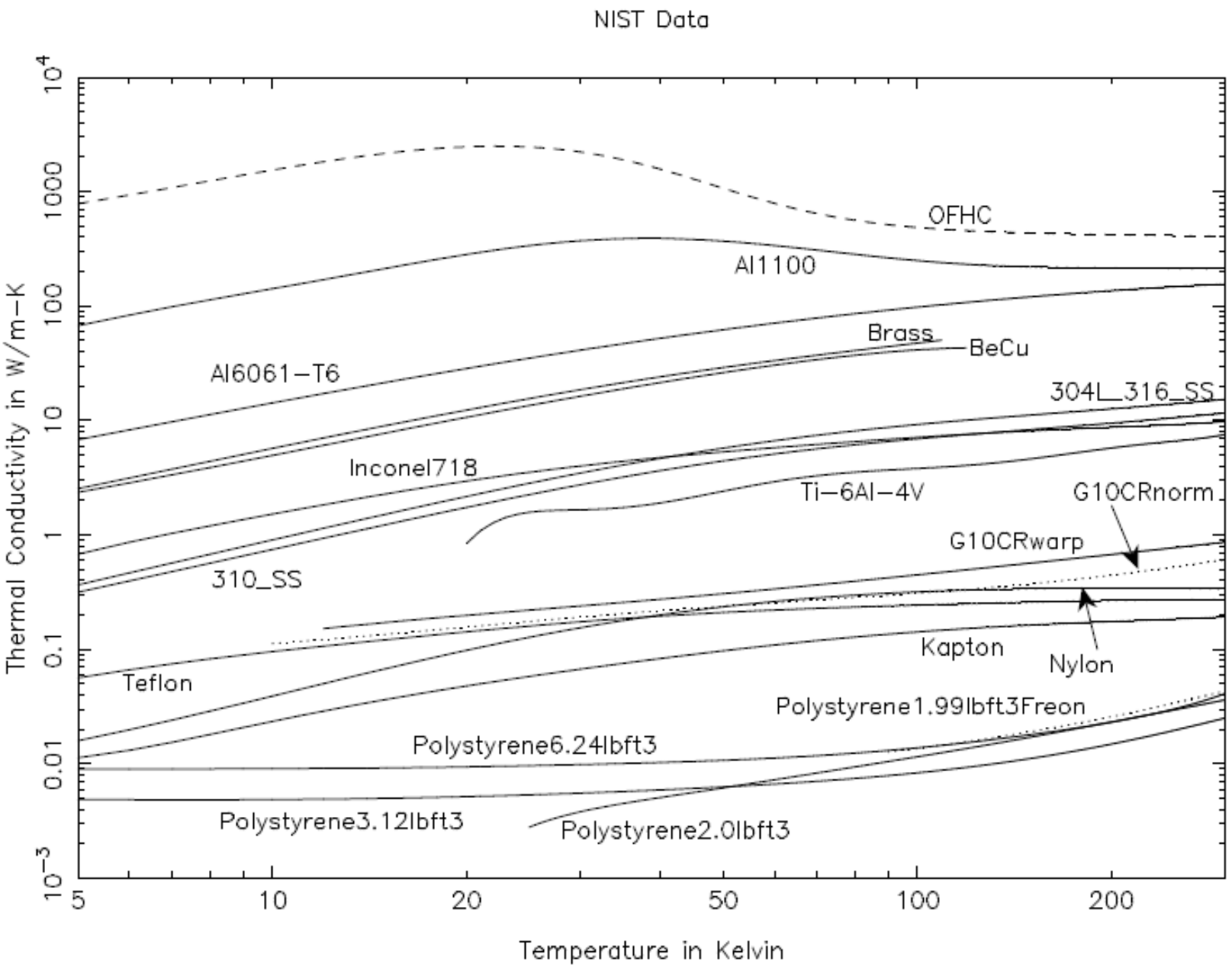
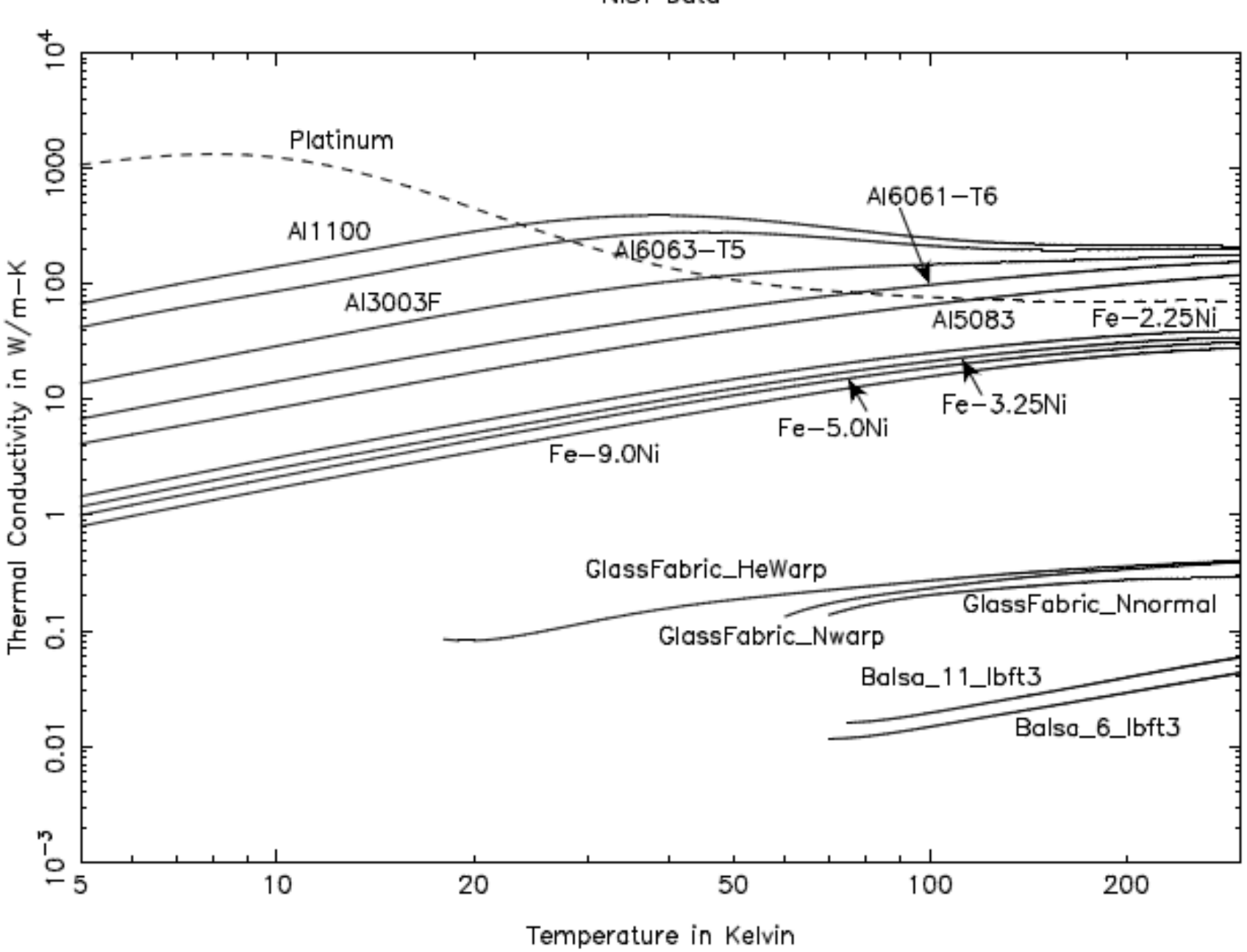
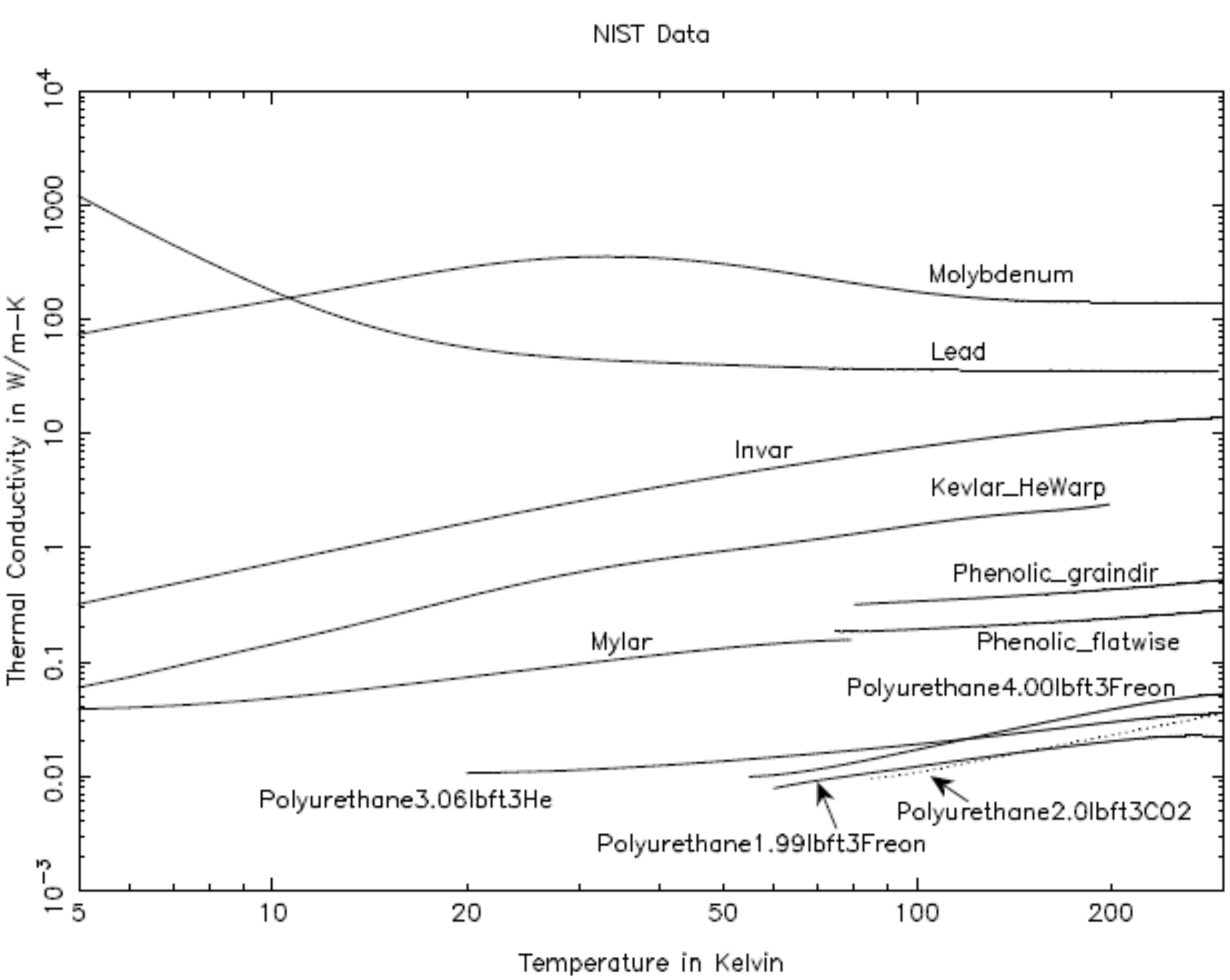

Sunpower GT Capacity Test
11 Jul 2008 - NRAO
Tcold (K)
Tcase (K)
Heat Load (W)
0
10
20
30
40
50
60
70
80
90
300
305
310
315
320
325
330
335
340
345
0
2
4
6
8
10
Tcold
Tcase

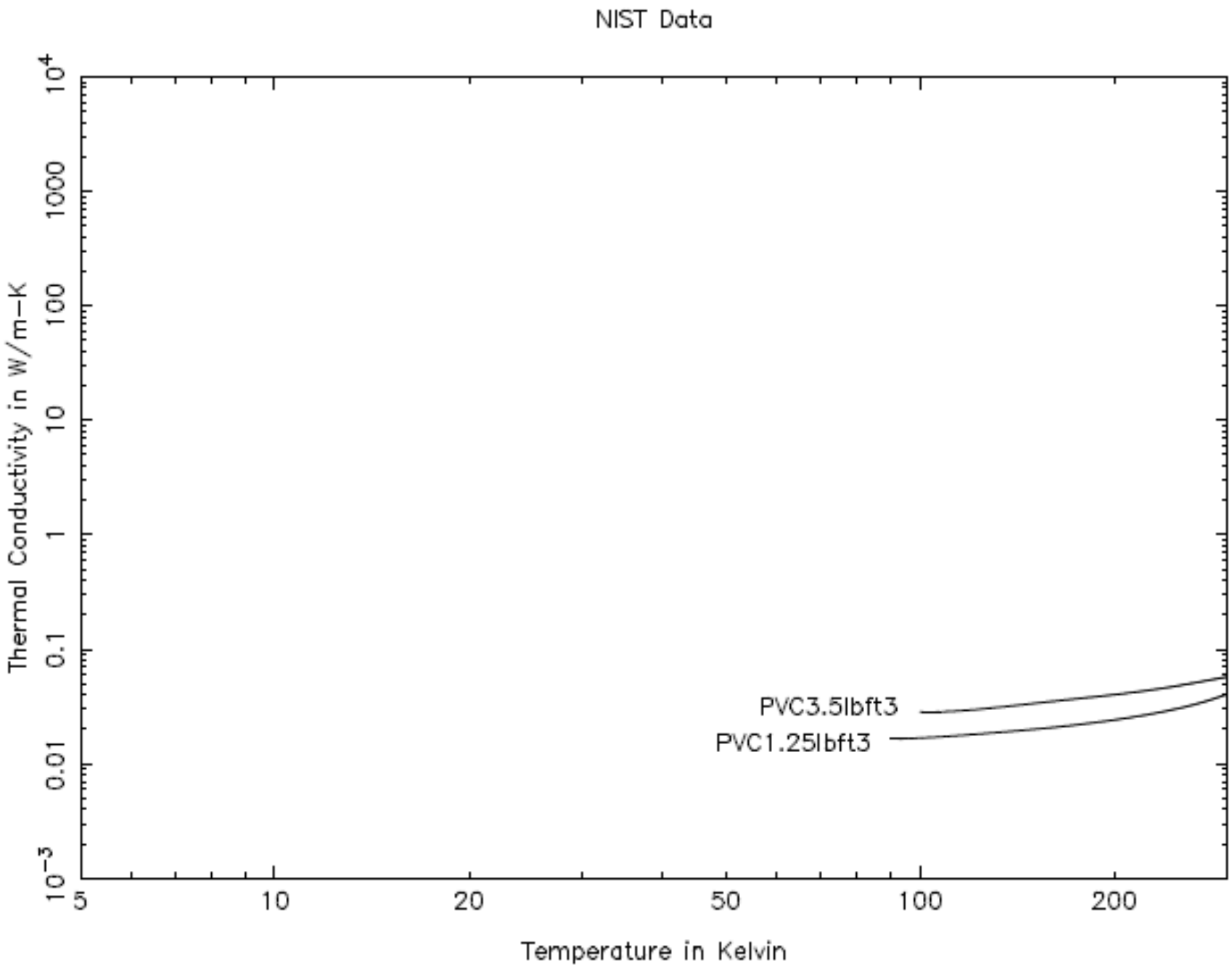
Table 2. Electrical Properties of ROHACELL HF				
Property	Frequency (GHz)	ROHACELL 31 HF	ROHACELL 51 HF	ROHACELL 71 HF
Dielectric Constant	2.5	1.050	1.057	1.075
	5.0	1.043	1.065	1.106
	10.0	1.046	1.067	1.093
	26.5	1.041	1.048	1.093
Loss Tangent	2.5	<0.0002	<0.0002	<0.0002
	5.0	0.0016	0.0008	0.0016
	10.0	0.0017	0.0041	0.0038
	26.5	0.0106	0.0135	0.0155

Table 1. Mechanical Properties of ROHACELL HF				
Property	Unit	ROHACELL 31 HF	ROHACELL 51 HF	ROHACELL 71 HF
Density	kg/m^3	32	52	75
	lbs./cu,ft.	2.00	3.25	4.68
Compressive Strength	MPa	0.4	0.9	1.5
	psi	58	130	217
Tensile Strength	MPa	1.0	1.9	2.8
	psi	145	275	406
Shear Strength	MPa	0.4	0.8	1.3
	psi	58	116	188
Elastic Modulus	MPa	36	70	92
	psi	5220	10150	13340
Shear Modulus	MPa	13	19	29
	psi	1885	2755	4205
Strain at Break	%	3.5	4.0	4.5


NIST Data
Thermal Conductivity in W/m-K
Temperature in Kelvin
OFHC
Al1100
Al6061-T6
Brass
BeCu
304L_316_SS
Inconel718
Ti-6Al-4V
G10CRnorm
G10CRwarp
310_SS
Kapton
Nylon
Teflon
Polystyrene1.99lbft3Freon
Polystyrene6.24lbft3
Polystyrene3.12lbft3
Polystyrene2.0lbft3


NIST Data
Thermal Conductivity in W/m-K
Temperature in Kelvin
Platinum
Al1100
Al6063-T5
Al6061-T6
Al3003F
Al5083
Fe-2.25Ni
Fe-3.25Ni
Fe-5.0Ni
Fe-9.0Ni
GlassFabric_HeWarp
GlassFabric_Nnormal
GlassFabric_Nwarp
Balsa_11_lbft3
Balsa_6_lbft3


NIST Data
Thermal Conductivity in W/m-K
Temperature in Kelvin
Molybdenum
Lead
Invar
Kevlar_HeWarp
Phenolic_graindir
Phenolic_flatwise
Mylar
Polyurethane4.00lbft3Freon
Polyurethane3.06lbft3He
Polyurethane2.0lbft3CO2
Polyurethane1.99lbft3Freon


NIST Data
Thermal Conductivity in W/m−K
10^{-3}
0.01
0.1
1
10
100
1000
10^{4}
5
10
20
50
100
200
Temperature in Kelvin
PVC3.5lbft3
PVC1.25lbft3

Dual LNA and Thermal Transition

NXP SiGe transistors.
Surface mount components.
Thin-wall SS tubular coax.
Quartz beads for vacuum seal and center conductor heat sink.

Est. input coax heat load 150 mW / chan.
Bias power 17 mW / chan.