Power Absorption Profile from Vitaly

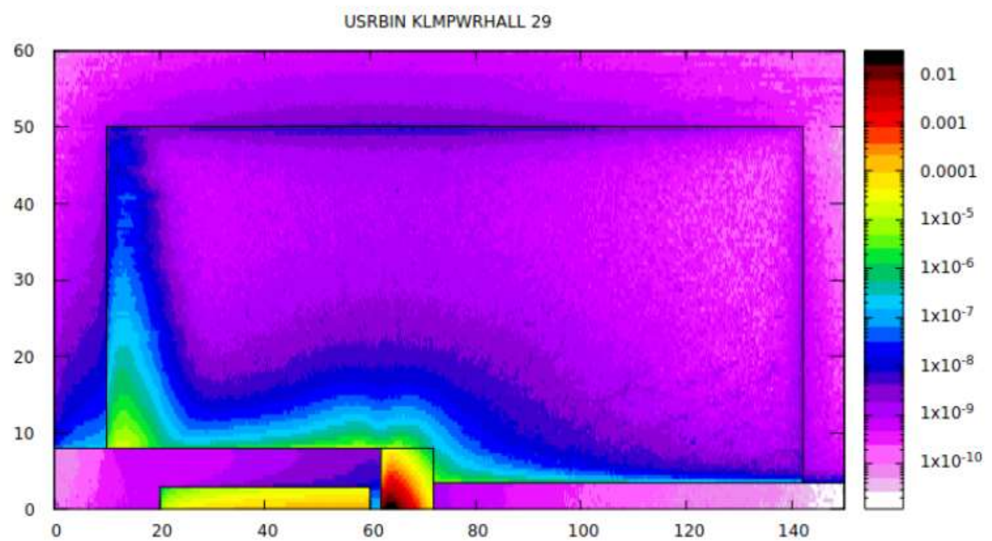


FIG. 5. Energy deposition map in the KLM Kaon Production Target without "black hole" collimator at the entry. Vertical scale – radial coordinate in *cm*, horizontal scale – *Z*-coordinate along the photon beam in *cm*. Color scale – energy deposition in $GeV/cm^3/electron$. The same, but course, map sized as $R \times Z = 60 \times 25$ is attached to this project as a numerical file – "KLMPWRHALL26plot.dat".

Power Absorption Profile from Vitaly
Every 1cm radius x .75cm in Z

Be&Tung_Power_absorption_v3 (Autosaved) - Excel

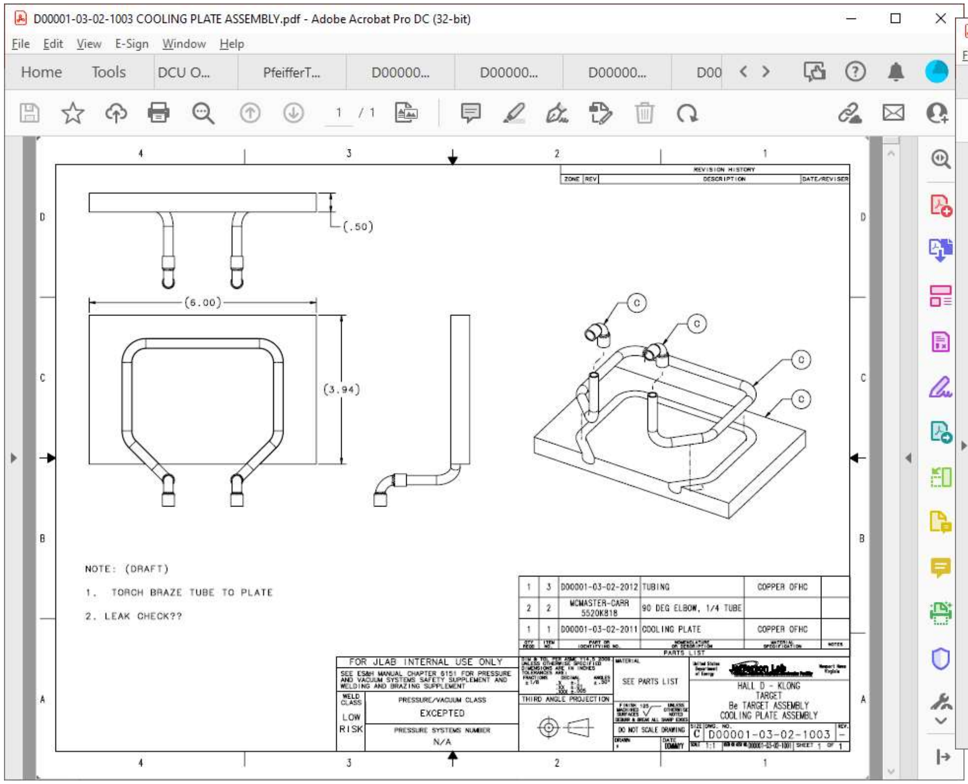
E685 =C685*D685*0.75

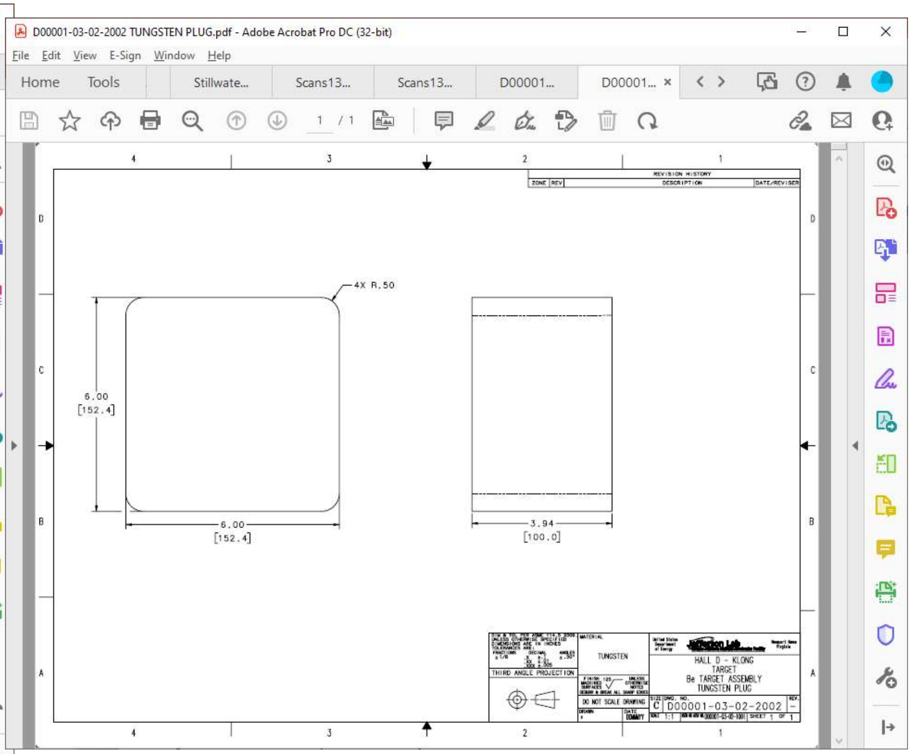
	A	B	C	D	E
1	Z cm	R cm	P W/cm3	Cross-section cm^2	power W/segment
674	62	0	93.02	0.7854	54.793431
675	62	1	15.98845	2.3562	28.25398942
676	62	2	6.63525	3.927	19.54247006
677	62	3	1.908705	5.4978	7.870258762
678	62	4	0.71291	7.0686	3.77945672
679	62	5	0.313156	8.6394	2.02910996
680	62	6	0.1566	10.2102	1.19918799
681	62	7	0.089528	11.781	0.791047026
682	62	8	0.011163	13.3518	0.111784608
683	62	9	0.003216	14.9226	0.035993311
684	62	10	0.003216		0
685	2		8	0	0
686	62.75	0	90.8945	0.7854	53.54140523
687	62.75	1	40.39895	2.3562	71.39100449
688	62.75	2	16.6021	3.927	48.89733503
689	62.75	3	5.8041	5.4978	23.93233574
690	62.75	4	2.16141	7.0686	11.45860704

Sheet1

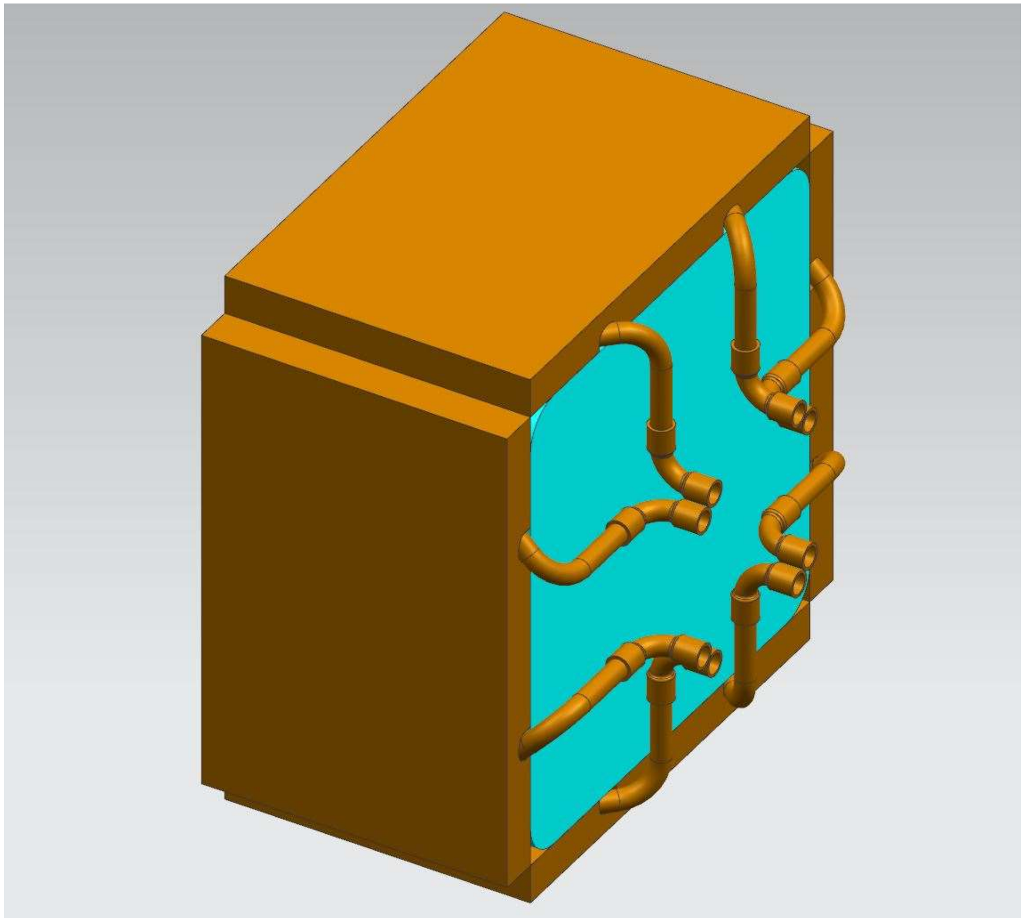
Ready 130%

Tungsten block and cooling plates





3D Rendering – cooling plates on 4 sides – Max water temp less than 100C



Cooling Water removing 6KW from Tungsten

KLong 6KW total, 2 circuits LCW

		Units		Units		Units			
d			4.6	mm	0.015092	ft	0.0046	M	ID of tube
L	10	m	10000	mm					
epsilon					0.000005	ft	e/d =	0.000331	
nu	0.0000155	ft^2/sec	at 5°C						
Coil Power	3	kW	3000	W					

$$v = -2\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}\log_{10}\left(\frac{\varepsilon}{3.7d} + \frac{2.51}{\frac{d}{\nu}\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}}\right)$$

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon}{3.7d} + \frac{2.51}{\frac{d}{\nu}\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}}\right)$$

$$\left(\frac{\varepsilon}{3.7d} + \frac{2.51}{\frac{d}{\nu}\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}}\right)$$

$$q\left(\frac{gpm}{circuit}\right) = v\frac{\pi d^2}{4} = v\left(\frac{ft}{sec}\right)\frac{\pi d^2}{4}(ft^2)\times\frac{gal}{0.1337\,ft^3}\times 60\,\frac{sec}{min}$$

$$Re = \frac{vd}{\upsilon}$$

$$\Delta T = \frac{3.8P}{q}$$

P=mCpdeltaT
3.8 factor= 1kg/s=15.83gpm
Cp = 4.18 KJ/Kg*K
KW=KJ/s=(kg/s)(kj/kg*C)C

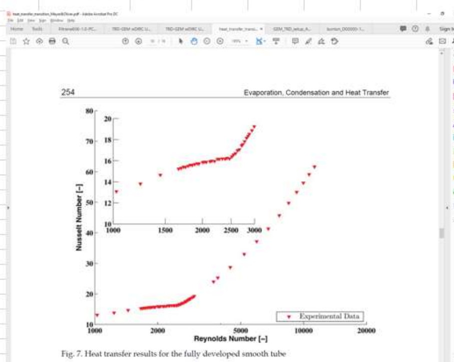
DeltaP	$\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}$			f	v	Re	q	DT
(psi)	(ft/sec)	(no units)	(no units)		(ft/sec)		(gpm)	(deg.C)
1.4	0.30948665	0.008419	4.149471	0.058078	1.284206	1250.391	0.10309323	110.5795
2.8	0.43768022	0.005979	4.446683	0.050574	1.946225	1894.978	0.156238684	72.96528
8	0.7398146	0.003574	4.893682	0.041757	3.620418	3525.087	0.290639162	39.2239
20	1.16974958	0.002293	5.279067	0.035883	6.175187	6012.586	0.495730411	22.99637
40	1.65427573	0.001648	5.566162	0.032277	9.207967	8965.509	0.73919534	15.42218
45	1.75462438	0.001559	5.614456	0.031724	9.851262	9591.865	0.790837652	14.4151
50	1.84953649	0.001483	5.657519	0.031243	10.46379	10188.26	0.840009882	13.57127
55	1.93981023	0.001418	5.696356	0.030818	11.04985	10758.89	0.887057683	12.85148
60	2.02606571	0.001362	5.73171	0.030439	11.61282	11307.04	0.932251779	12.22846
65	2.10879605	0.001312	5.764144	0.030097	12.1554	11835.33	0.975809042	11.68261
70	2.18840108	0.001268	5.794093	0.029787	12.6798	12345.92	1.017906478	11.19946
75	2.26521033	0.001228	5.821906	0.029503	13.18784	12840.59	1.058690854	10.76802
80	2.33949917	0.001191	5.847859	0.029242	13.68106	13320.82	1.098285514	10.37981
85	2.41150054	0.001159	5.872181	0.029	14.16077	13787.9	1.136795333	10.02819
90	2.48141359	0.001128	5.895061	0.028776	14.62808	14242.91	1.174310399	9.707825
95	2.54941011	0.001101	5.916655	0.028566	15.08398	14686.8	1.210908791	9.414417
100	2.61563959	0.001075	5.937098	0.028369	15.52931	15120.4	1.246658725	9.144443
105	2.680233	0.001051	5.956503	0.028185	15.96481	15544.44	1.281620225	8.894991
110	2.74330594	0.001029	5.974967	0.028011	16.39116	15959.56	1.315846445	8.663625
115	2.80496096	0.001009	5.992575	0.027847	16.80894	16366.34	1.349384735	8.448295
120	2.86528961	0.000989	6.009402	0.027691	17.21868	16765.29	1.382277488	8.247259
125	2.92437396	0.000971	6.025511	0.027543	17.62085	17156.87	1.414562851	8.059027
130	2.98228798	0.000954	6.04096	0.027402	18.01588	17541.5	1.446275296	7.882317
135	3.03909857	0.000938	6.055798	0.027268	18.40417	17919.56	1.477446103	7.716018
140	3.09486649	0.000922	6.070072	0.02714	18.78606	18291.4	1.508103761	7.559162
145	3.14964714	0.000908	6.083821	0.027018	19.16189	18657.33	1.538274307	7.410902
150	3.20349117	0.000894	6.097081	0.0269	19.53195	19017.64	1.567981616	7.270493

V	DP
3.620418	8
6.175187	20
9.207967	40
9.851262	45
10.46379	50
11.04985	55

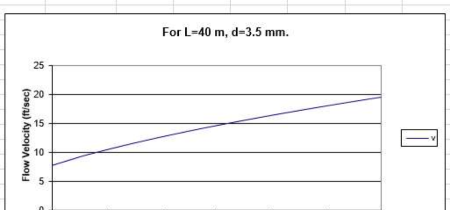
h

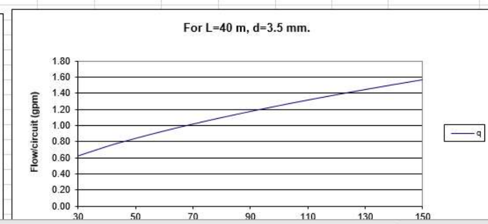
Heat Exchange with water at 70 psi DP

Twater =	37.59972858	C	average	
N_{ud} =	65		From Oliver & Meyer paper for Re + 5000	81.07461 from Dittus below
K =	0.623	W/MK	From White pg 550	
Pr =	4.84	extrapolate from White appendix F		
h =	Nud K/D	W/M^2 K		
h =	8803.26087			
q =	hA(Tw-Twall)	=	mCpdeltaT =	coil power
A =	piDL	use L for area inside cooling blocks, 2 per circuit L =		0.4 m
Twall =	96.55314416	C		



KW=KJ/s=(kg/s)(kj/kg*C)C





Forced convection in turbulent pipe flow [edit]

Gnielinski correlation [edit]

Gnielinski's correlation for turbulent flow in tubes:[7][10]

$$Nu_D = \frac{(f/8)(Re_D - 1000)\,Pr}{1 + 12.7(f/8)^{1/2}\left(Pr^{2/3} - 1\right)}$$

where f is the Darcy friction factor that can either be obtained from the Moody chart or for smooth tub

$$f = (0.79\ln(Re_D) - 1.64)^{-2}$$

The Gnielinski Correlation is valid for:[7]

$$0.5 \le Pr \le 2000$$
$$3000 \le Re_D \le 5\times10^6$$

Dittus-Boelter equation [edit]

The Dittus-Boelter equation (for turbulent flow) is an explicit function for calculating the Nusselt numbe across the fluid. It is tailored to smooth tubes, so use for rough tubes (most commercial applications)

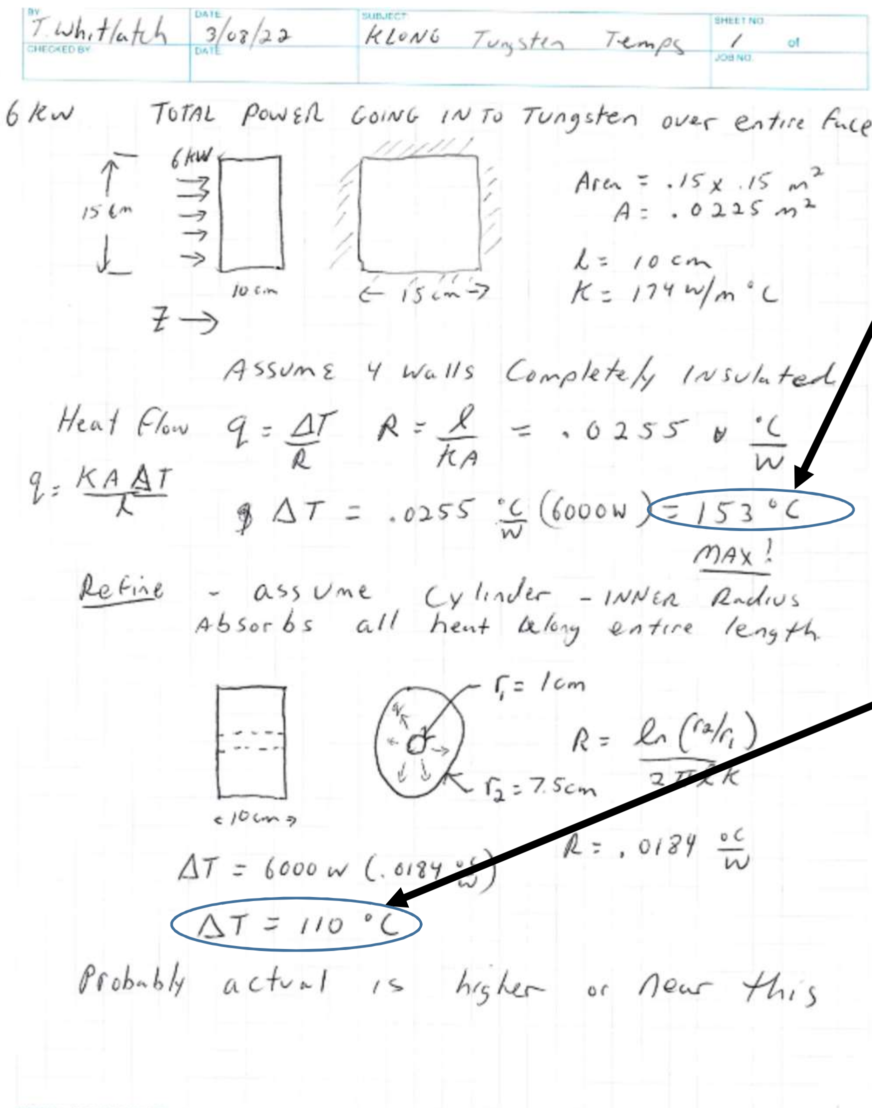
$$Nu_D = 0.023\,Re_D^{4/5}\,Pr^n$$

where:

D is the inside diameter of the circular duct
Pr is the Prandtl number
$n = 0.4$ for the fluid being heated, and $n = 0.3$ for the fluid being cooled.[8]

The Dittus-Boelter equation is valid for [11]

Napkin hand calculations



T. Whitlatch | DATE 3/08/22 | SUBJECT KLONG Tungsten Temps | SHEET NO. 1 of

6 kW TOTAL POWER GOING INTO Tungsten over entire face

6 kW, 15 cm, 10 cm, ← 15 cm →, Z →

Area = .15 x .15 m^2
A = .0225 m^2
l = 10 cm
K = 174 W/m °C

Assume 4 walls completely insulated

Heat Flow $q = \frac{\Delta T}{R}$ $R = \frac{l}{KA}$ = .0255 °C/W

$q = \frac{KA\Delta T}{l}$

ΔT = .0255 °C/W (6000 W) = 153 °C
MAX!

Refine - assume cylinder - INNER Radius absorbs all heat along entire length

r_1 = 1 cm
r_2 = 7.5 cm
← 10 cm →

$R = \frac{\ln(r_2/r_1)}{2\pi l k}$

R = .0184 °C/W

ΔT = 6000 W (.0184 °C/W)

ΔT = 110 °C

Probably actual is higher or near this

Delta Temp if no cooling and heat (6 Kw) comes from one end

Delta Temp if only R=1 cm of inner cylinder absorbs all heat for the full 10cm length

Assumes ends are insulated (no cooling)

Tungsten Properties

Physical Properties	Metric	English
Density	19.3 g/cc	0.697 lb/in^3
a Lattice Constant	3.165 Å	3.165 Å

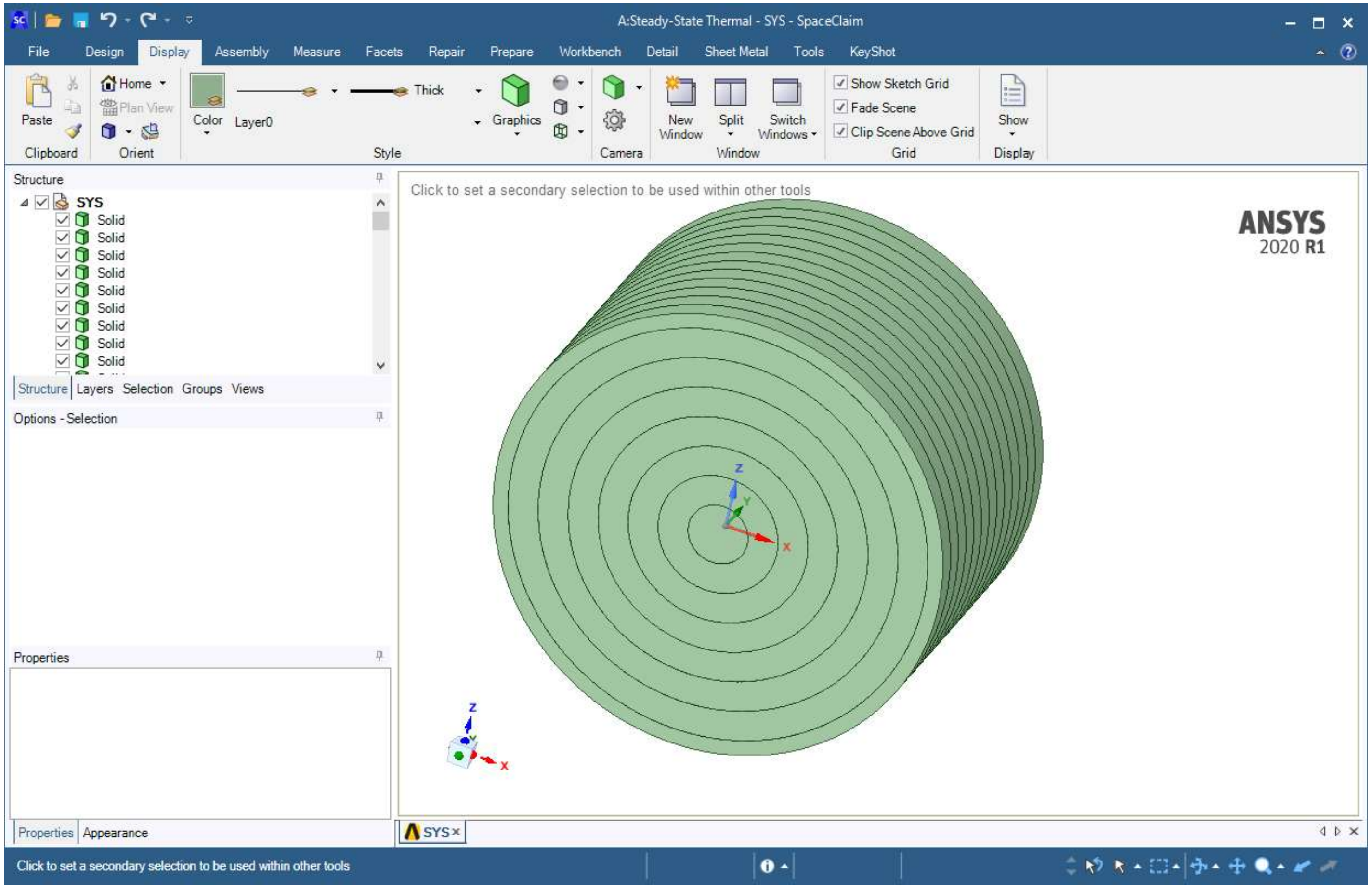
Chemical Properties	Metric	English
Atomic Mass	183.84	183.84
Atomic Number	74	74
Atomic Volume	1.59e-029	1.59e-029
Thermal Neutron Cross Section	19.2 barns/atom	19.2 barns/atom
X-ray Absorption Edge	0.17837 Å	0.17837 Å
	1.02497 Å	1.02497 Å
	1.07436 Å	1.07436 Å
	1.21529 Å	1.21529 Å
Electrode Potential	4.5 V	4.5 V
Electronegativity	1.7	1.7
Ionic Radius	0.620 Å	0.620 Å
	0.700 Å	0.700 Å
Electrochemical Equivalent	3.43 g/A/h	3.43 g/A/h

Mechanical Properties	Metric	English
Hardness, Brinell	294	294
Hardness, Knoop	318	318
Hardness, Rockwell A	66	66
Hardness, Rockwell C	31	31
Hardness, Vickers	310	310
Tensile Strength	172 MPa @Temperature 1650 °C	25000 psi @Temperature 3000 °F
Tensile Strength, Ultimate	980 MPa	142000 psi
Tensile Strength, Yield	750 MPa @Strain 0.200 %	109000 psi @Strain 0.200 %
Rupture Strength	47.0 MPa @Temperature 1650 °C, Time 36000 sec	6820 psi @Temperature 3000 °F, Time 10.0 hour
Modulus of Elasticity	400 GPa	58000 ksi
	300 GPa @Temperature 1800 °C	43500 ksi @Temperature 3270 °F
	350 GPa @Temperature 1200 °C	50800 ksi @Temperature 2190 °F
	370 GPa @Temperature 800 °C	53700 ksi @Temperature 1470 °F
Poissons Ratio	0.28	0.28
Shear Modulus	156 GPa	22600 ksi
Shear Strength	400 MPa	58000 psi

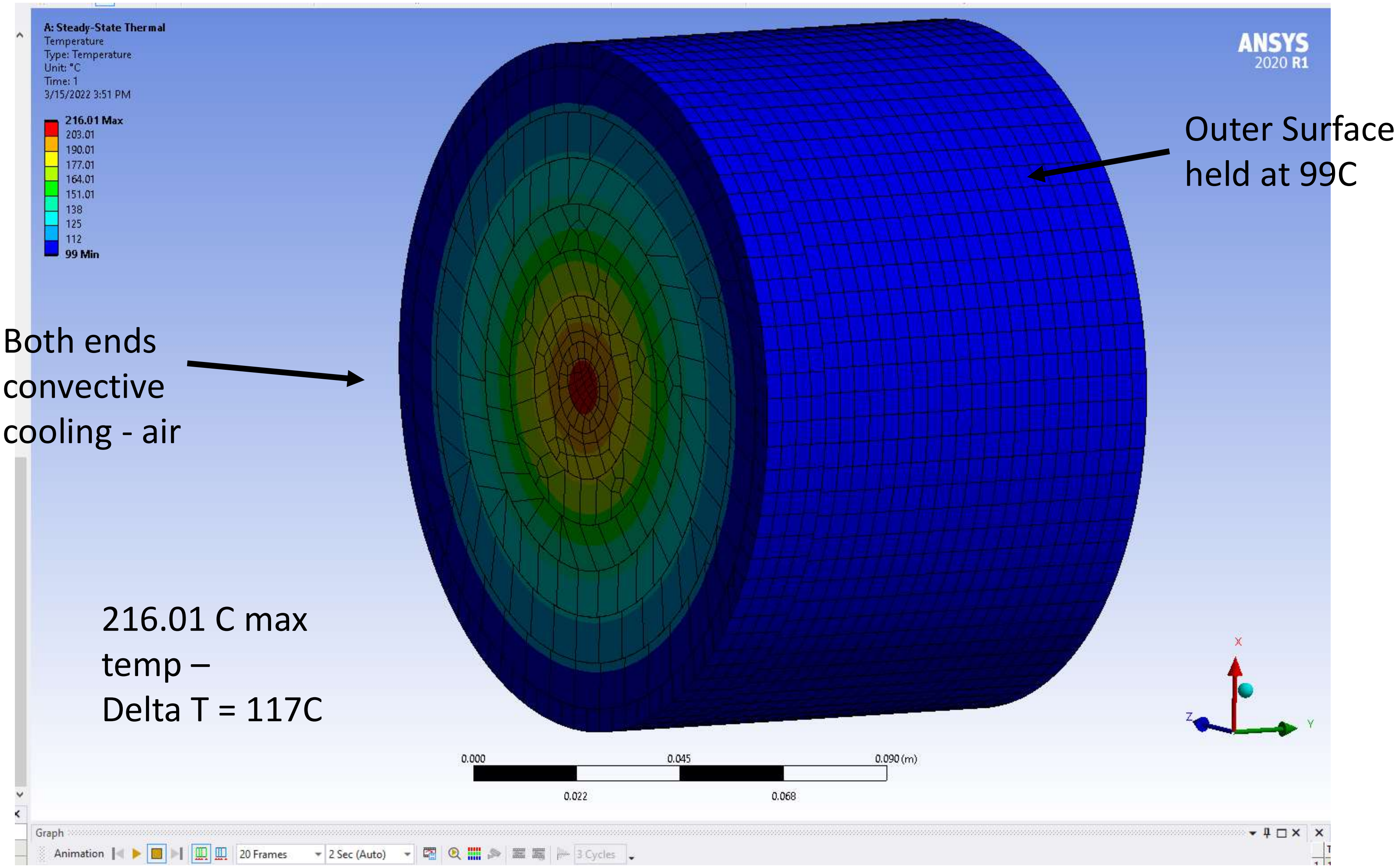
Electrical Properties	Metric	English
Electrical Resistivity	0.00000565 ohm-cm	0.00000565 ohm-cm
Magnetic Susceptibility	3.3e-7	3.3e-7
Critical Magnetic Field Strength, Oersted	1.12 - 1.18	1.12 - 1.18
Critical Superconducting Temperature	0.0149 - 0.0159 K	0.0149 - 0.0159 K

Thermal Properties	Metric	English
Heat of Fusion	184.2 J/g	79.24 BTU/lb
CTE, linear	4.40 µm/m-°C @Temperature 20.0 - 100 °C	2.44 µin/in-°F @Temperature 68.0 - 212 °F
Specific Heat Capacity	0.134 J/g-°C	0.0320 BTU/lb-°F
Thermal Conductivity	163.3 W/m-K	1133 BTU-in/hr-ft^2-°F
	117 W/m-K @Temperature 1000 °C	812 BTU-in/hr-ft^2-°F @Temperature 1830 °F
	128 W/m-K @Temperature 600 °C	888 BTU-in/hr-ft^2-°F @Temperature 1110 °F
	146 W/m-K @Temperature 200 °C	1010 BTU-in/hr-ft^2-°F @Temperature 392 °F
Melting Point	3370 °C	6100 °F
Boiling Point	5900 °C	10700 °F

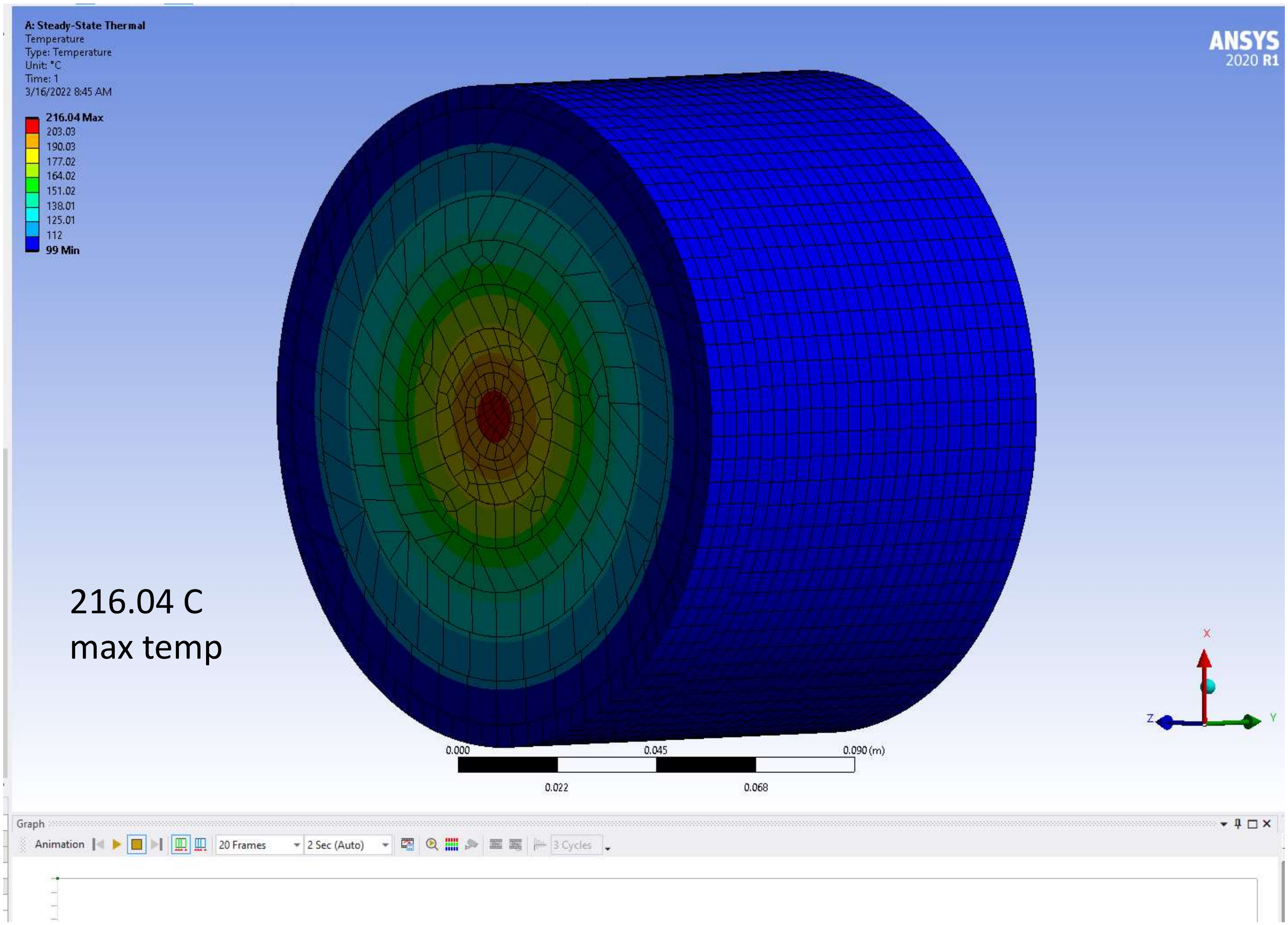
3D ANSYS model mirrors Vitaly bins, 1cm radii x .75 cm deep volumes



5.2 KW total input - 2 W/m^2 convection US face - 80C air temp

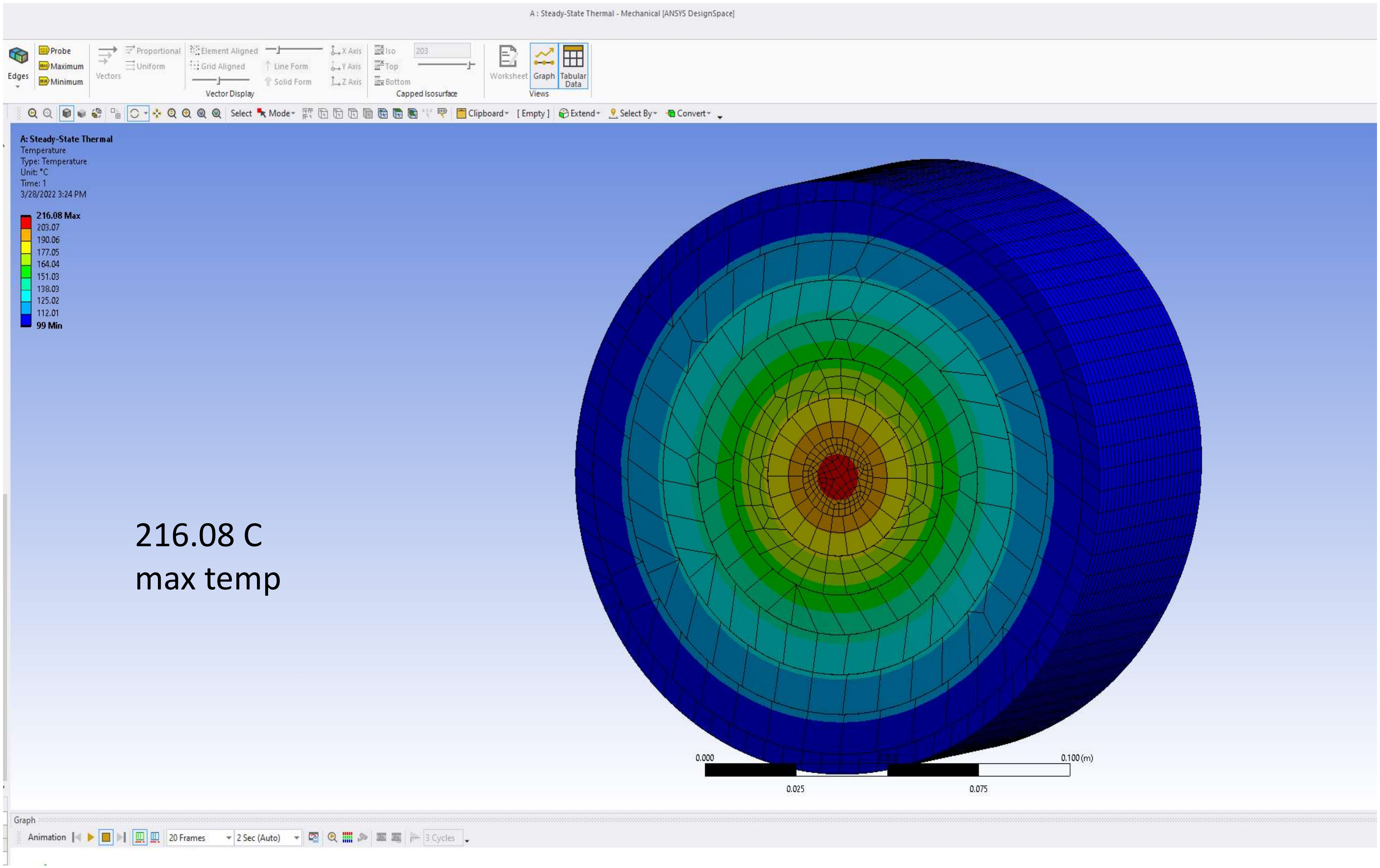


No Convection on ends - insulated



216.04 C
max temp

Finer Mesh did not change much



Berylium Properties

Physical Properties	Metric	English
Density	1.844 g/cc	0.06662 lb/in³

Chemical Properties	Metric	English
Atomic Mass	9.012182	9.012182
Atomic Number	4	4
Thermal Neutron Cross Section	0.0090 barns/atom	0.0090 barns/atom
X-ray Absorption Edge	110.68 Å	110.68 Å
Electrode Potential	-1.70 V	-1.70 V
Electronegativity	1.57	1.57
Ionic Radius	0.350 Å	0.350 Å
	0.440 Å	0.440 Å

Mechanical Properties	Metric	English
Hardness, Rockwell B	75 - 85	75 - 85
Tensile Strength, Ultimate	370 MPa	53700 psi
Tensile Strength, Yield	240 MPa	34800 psi
Elongation at Break	3.0 %	3.0 %
Modulus of Elasticity	303 GPa	43900 ksi
Compressive Yield Strength	270 MPa	39200 psi
Poissons Ratio	0.070 - 0.18	0.070 - 0.18
Fatigue Strength	160 MPa @# of Cycles 1.00e+7	23200 psi @# of Cycles 1.00e+7
	240 MPa @# of Cycles 1.00e+7	34800 psi @# of Cycles 1.00e+7
	240 MPa @# of Cycles 10000	34800 psi @# of Cycles 10000
Fracture Toughness	10.6 - 12.3 MPa-m½	9.65 - 11.2 ksi-in½
Shear Modulus	135 GPa	19600 ksi
Shear Strength	345 MPa	50000 psi
	480 MPa	69600 psi
Charpy Impact	1.50 - 5.50 J	1.11 - 4.06 ft-lb

Electrical Properties	Metric	English
Electrical Resistivity	0.00000430 ohm-cm	0.00000430 ohm-cm
Magnetic Susceptibility	-1.00e-6	-1.00e-6
Critical Superconducting Temperature	0.0260 K	0.0260 K

Thermal Properties	Metric	English
Heat of Fusion	1133 J/g	487.4 BTU/lb
Heat of Vaporization	24770 J/g	10660 BTU/lb
CTE, linear	11.5 µm/m-°C @Temperature 25.0 °C	6.39 µin/in-°F @Temperature 77.0 °F
	14.5 µm/m-°C @Temperature 25.0 - 300 °C	8.06 µin/in-°F @Temperature 77.0 - 572 °F
	16.5 µm/m-°C @Temperature 25.0 - 600 °C	9.17 µin/in-°F @Temperature 77.0 - 1110 °F
	18.4 µm/m-°C @Temperature 25.0 - 1000 °C	10.2 µin/in-°F @Temperature 77.0 - 1830 °F
Specific Heat Capacity	1.925 J/g-°C	0.4601 BTU/lb-°F
Thermal Conductivity	216 W/m-K	1500 BTU-in/hr-ft²-°F
Melting Point	1273 - 1283 °C	2323 - 2341 °F
Boiling Point	2471 °C	4480 °F

Optical Properties	Metric	English
Emissivity (0-1)	0.61	0.61