Proton Driver
Vacuum Chamber
Research and Development

ERRATA
7/20/2000

1. Following the Technical Design Review in April 2000, an error was discovered in one of the finite element simulations of the "Very Thin Rib Reinforced Tube." The operating temperature shown for this design in the charts and the graphical display of simulation results for this design are invalid. These errors resulted from a peculiarity in I–DEAS MS4 in the application of functionally distributed boundary conditions to surfaces of a model which is not analogous to the application of functionally distributed boundary conditions to model edges. Neither the heat load nor the convection boundary conditions were of the proper magnitudes. This error did not occur in other simulations as all functionally distributed boundary conditions in other models were applied to model edges only.

As time permits, corrected thermal models for the "Very Thin Rib Reinforced Tube" will be run and posted on this site.

2. Please note that none of the thermal simulations described in this presentation accounted for cooling via radiation.

3. The linear statics stress/displacement simulation result for the "Fiber Reinforced Epoxy Composite" do not take into account the reduction of material modulus with temperature. The simulation results shown are for room temperature conditions.

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4/19/2000

Proton Driver Vacuum Chamber Design Constraints

- ✗ Mechanical Stability Under Vacuum
- ✗ Vacuum Outgassing and Leak Rates
- ✗ Temperature Limitations / Eddy Current Heating
- ✗ Material Magnetization
- ✗ Eddy Current Induced Field Error
- ✗ Lorentz Pressure
- ✗ Resistive Wall Instability

Fiber Reinforced Epoxy Composite

- Inconel foil and epoxy impregnated Silicon Carbide filament are wound on a tubular form, and autoclave cured.
  - Permits very thin shielding, reducing eddy current
  - 6m long tube manufacturable in one piece
  - Uncertain outgassing and leak rates
  - Uncertain radiation and thermal durability
  - Less stiff but more strong than ceramic

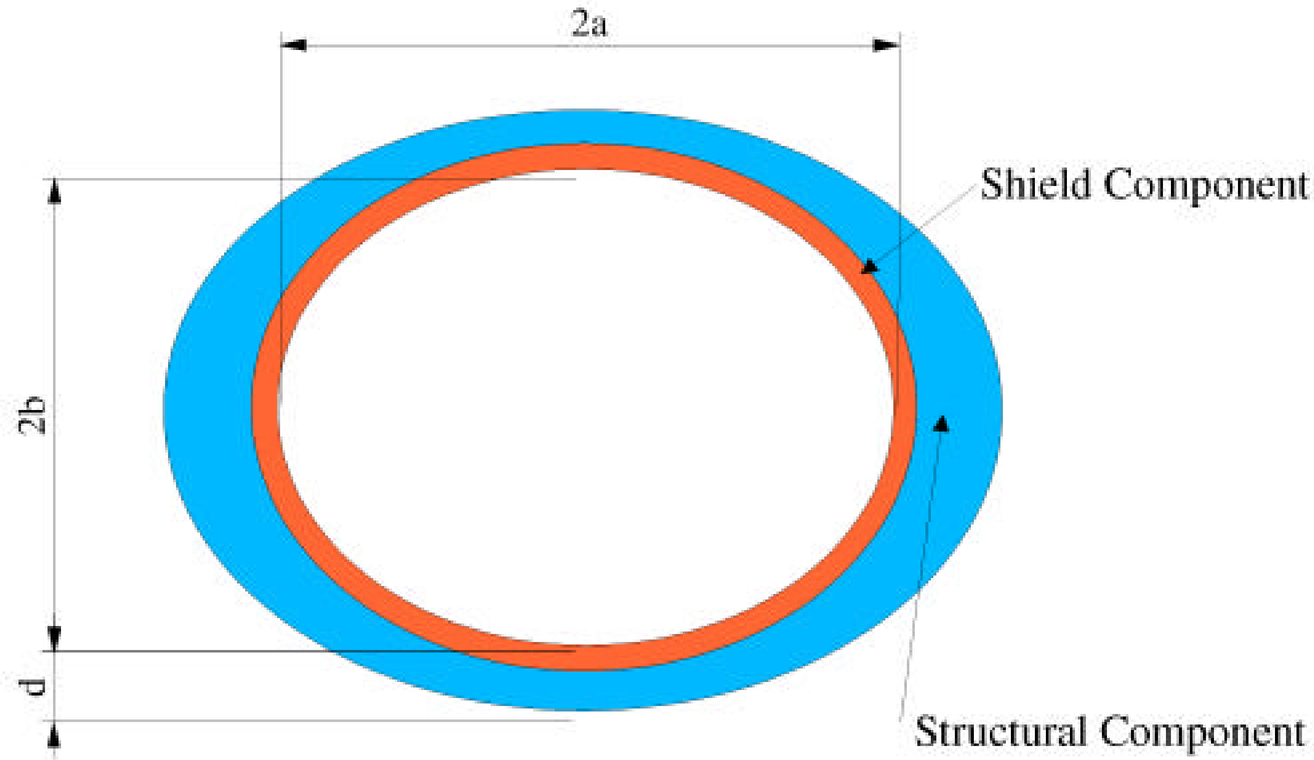
Very Thin Rib Reinforced Tube

- 0.13mm Inconel tube with 1mm thick Inconel ribs brazed to outside, ~50 ribs per meter
  - Very thin tube wall limits eddy current
  - Strength is adjustable via rib spacing
  - Thin materials complicate brazing operation
  - Fragile
  - Simulation suggests overheating inside dipole unless forced cooling is employed

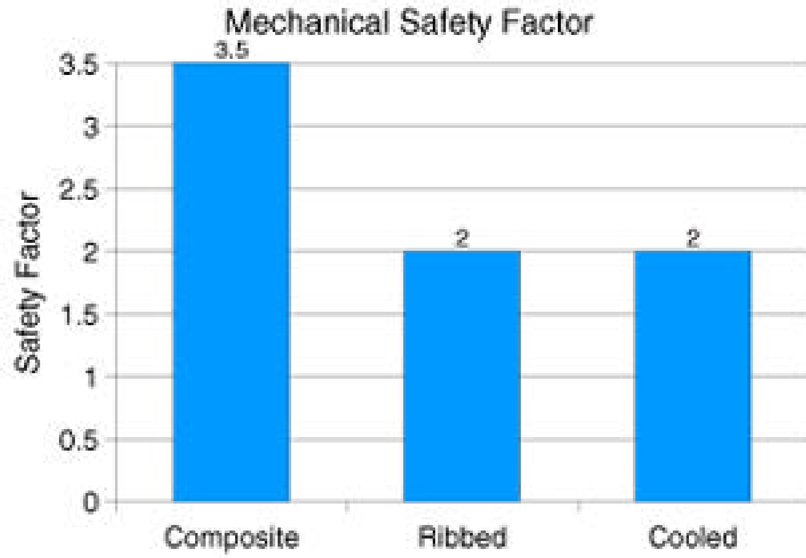
Water−Cooled Tube

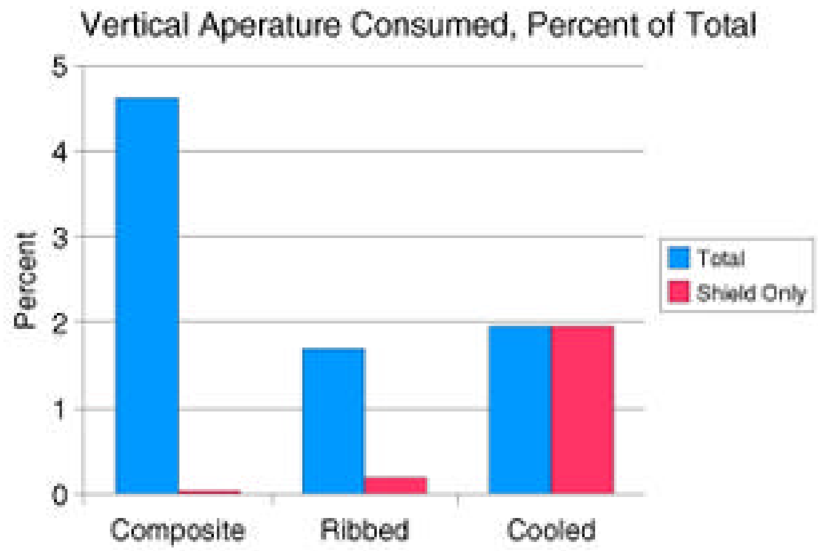
- 1.27mm thick Inconel tube surrounded by cooling tubes embedded in thermally conductive epoxy
  - Significant eddy currents and resultant heating
  - Very low vacuum leak and outgassing rates achievable
  - Radiation and thermal durability of epoxy bond is uncertain
  - Complicated assembly −under preload, or inside magnet

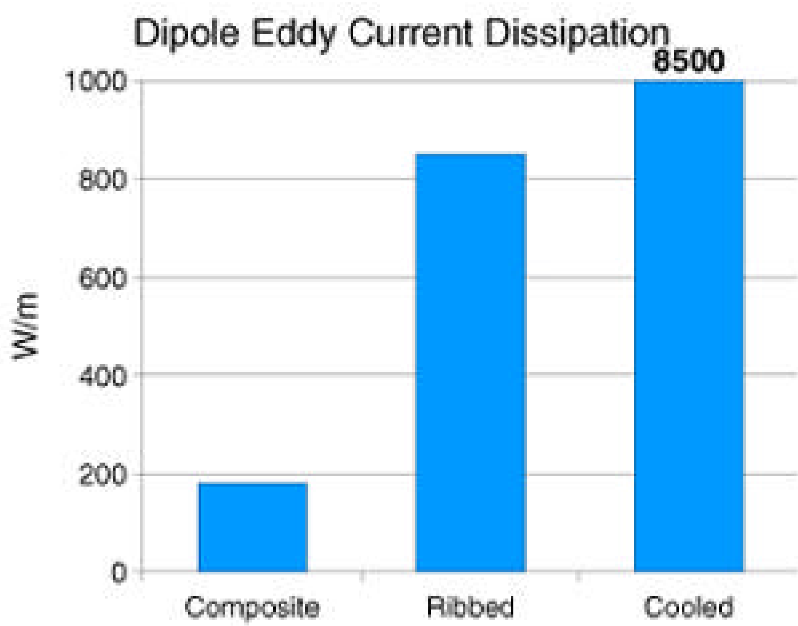
Typical Chamber

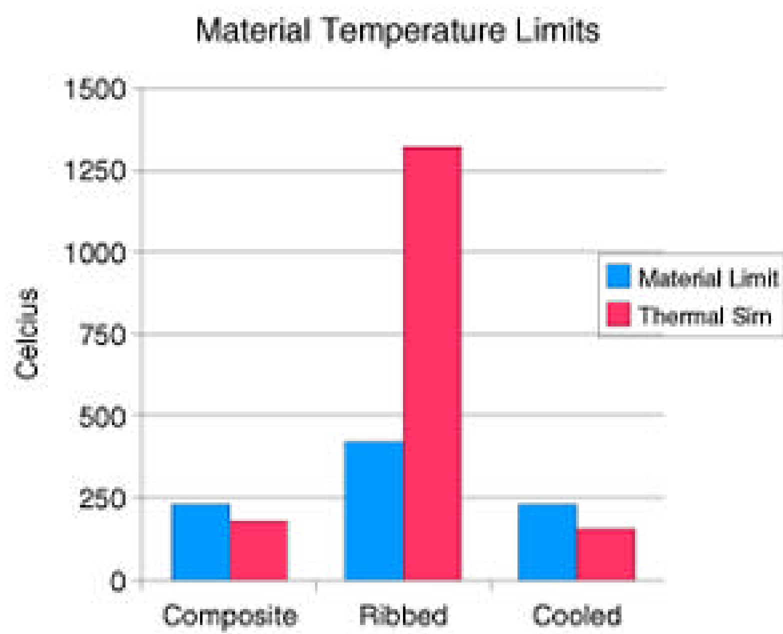


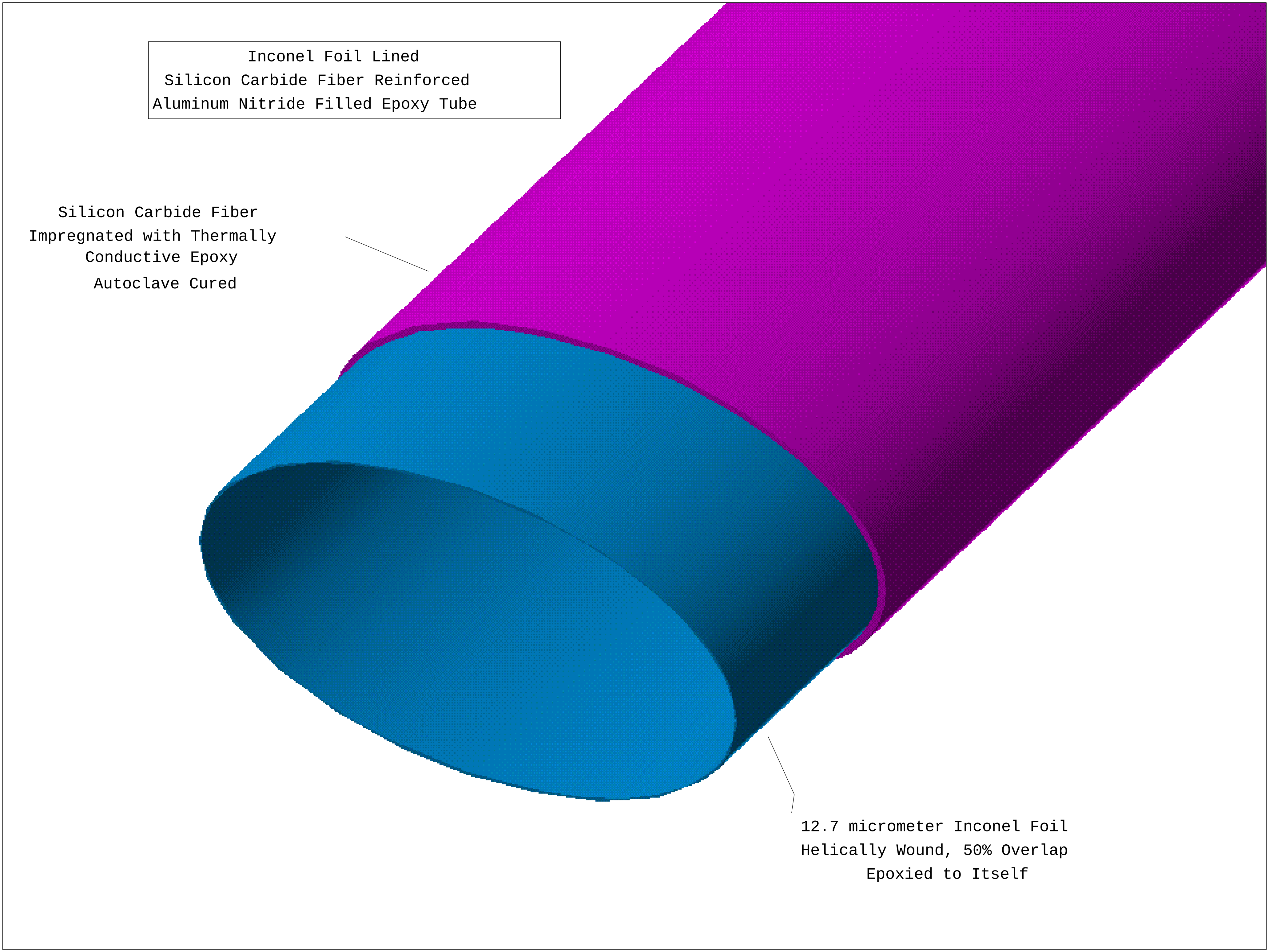
2b ~ 23cm
2a ~ 13cm
Vertical aperature consumed = 2d
Shield may provide entire structure


Mechanical Safety Factor
Safety Factor
3.5
2
2
0
0.5
1
1.5
2
2.5
3
3.5
Composite
Ribbed
Cooled


Vertical Aperature Consumed, Percent of Total
Percent
0
1
2
3
4
5
Total
Shield Only
Composite
Ribbed
Cooled


Dipole Eddy Current Dissipation
8500
W/m
0
200
400
600
800
1000
Composite
Ribbed
Cooled


Material Temperature Limits
Celcius
0
250
500
750
1000
1250
1500
Material Limit
Thermal Sim
Composite
Ribbed
Cooled


Inconel Foil Lined
Silicon Carbide Fiber Reinforced
Aluminum Nitride Filled Epoxy Tube
Silicon Carbide Fiber
Impregnated with Thermally
Conductive Epoxy
Autoclave Cured
12.7 micrometer Inconel Foil
Helically Wound, 50% Overlap
Epoxied to Itself

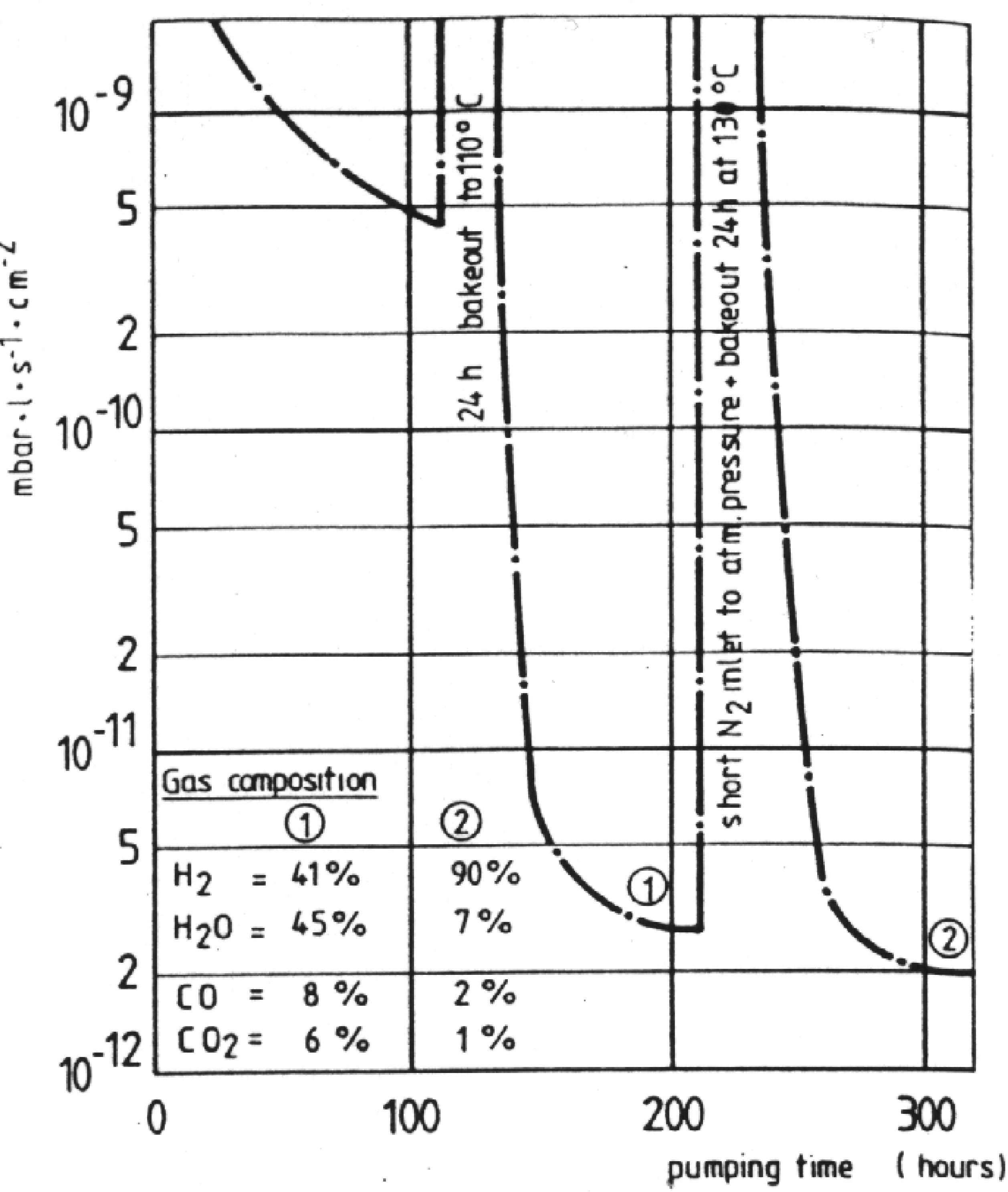
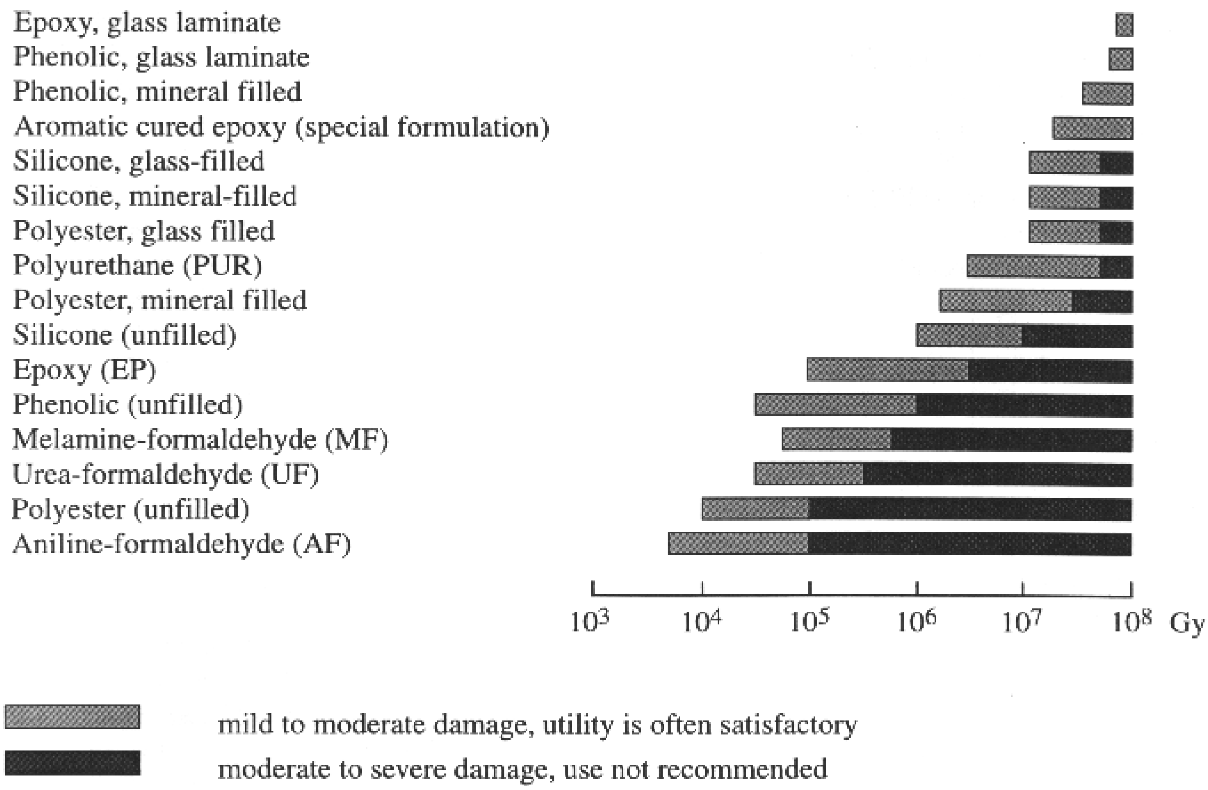


FIG. 2. Outgassing rates for a chamber in carbon fiber/epoxy composite with liner of Al ribbon, wound with 50% overlap.

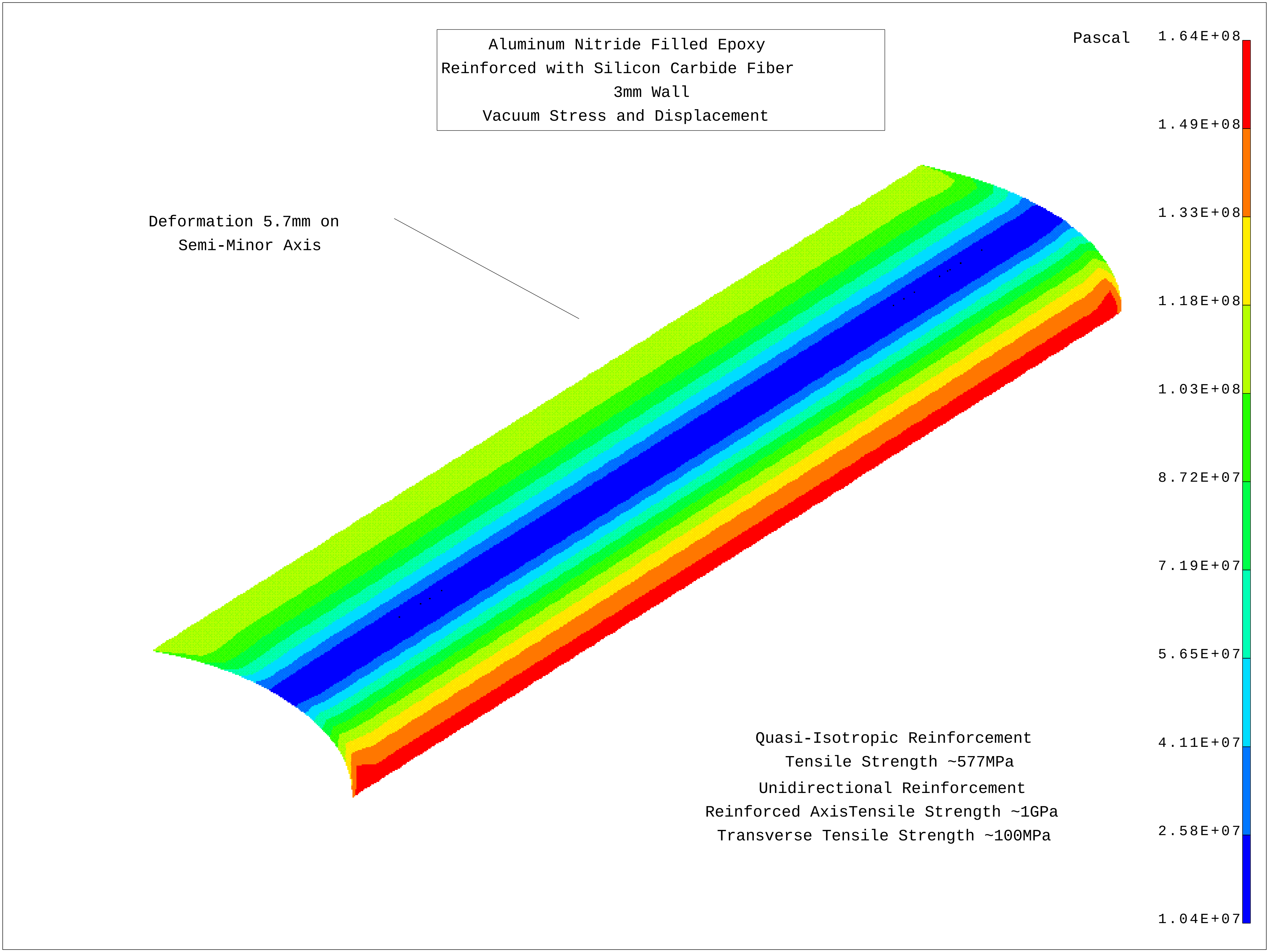
Table 2b

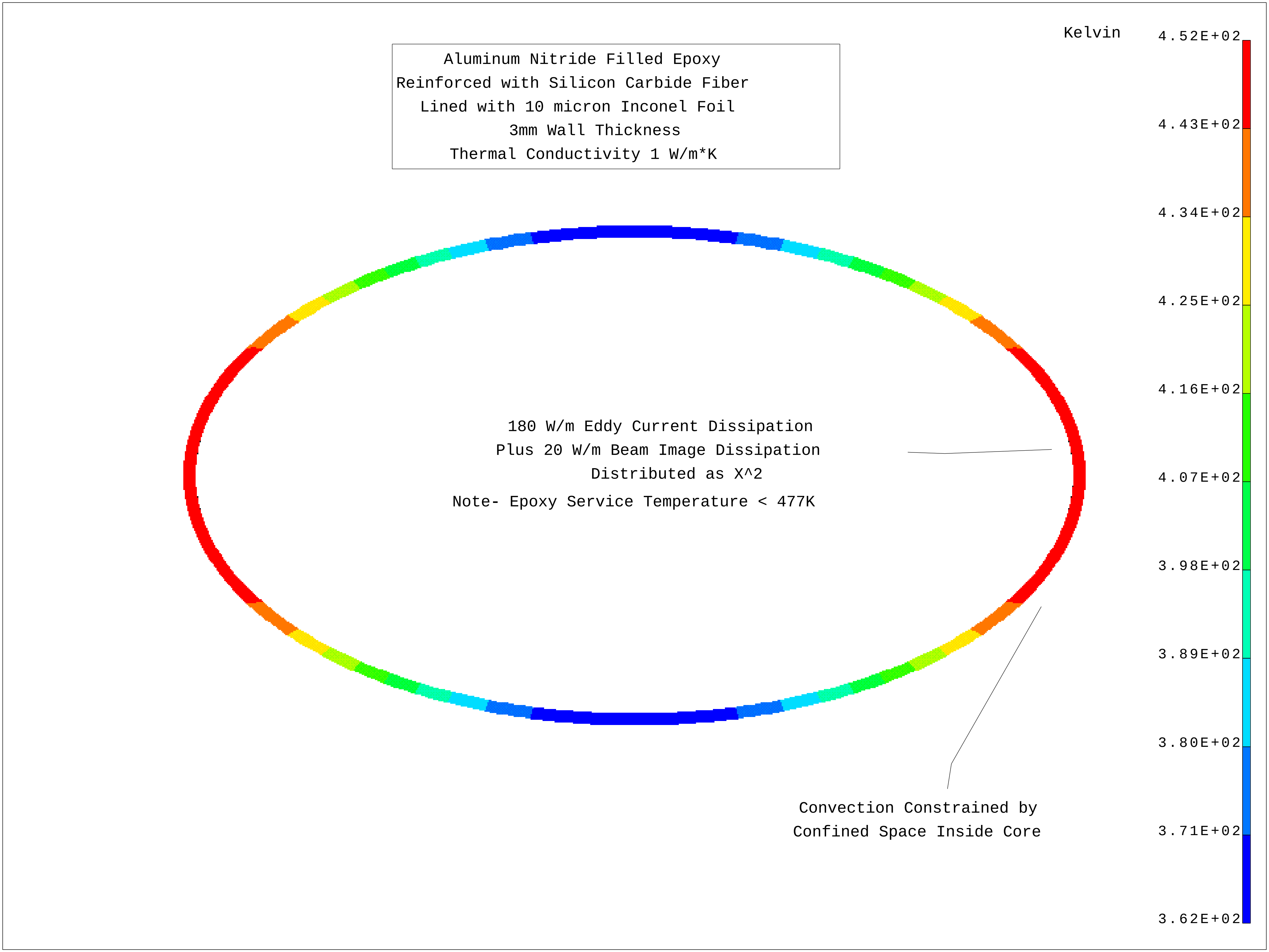
General classification of thermoset resins and composites with respect to their radiation resistence

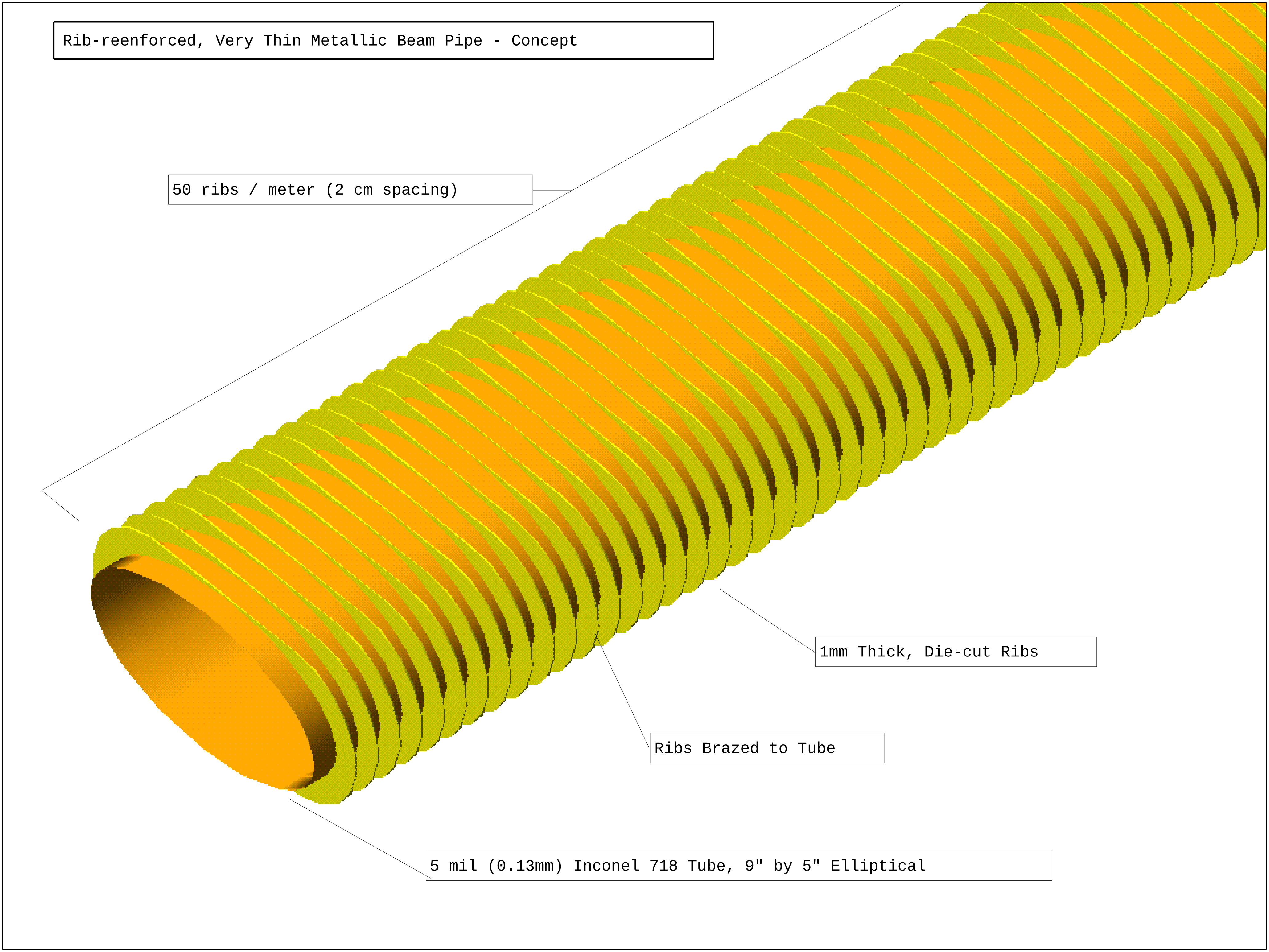


These appreciations can only serve as a general guideline; environmental conditions such as temperature, humidity and dose rate, as well as additives influence the radiation behaviour of materials.

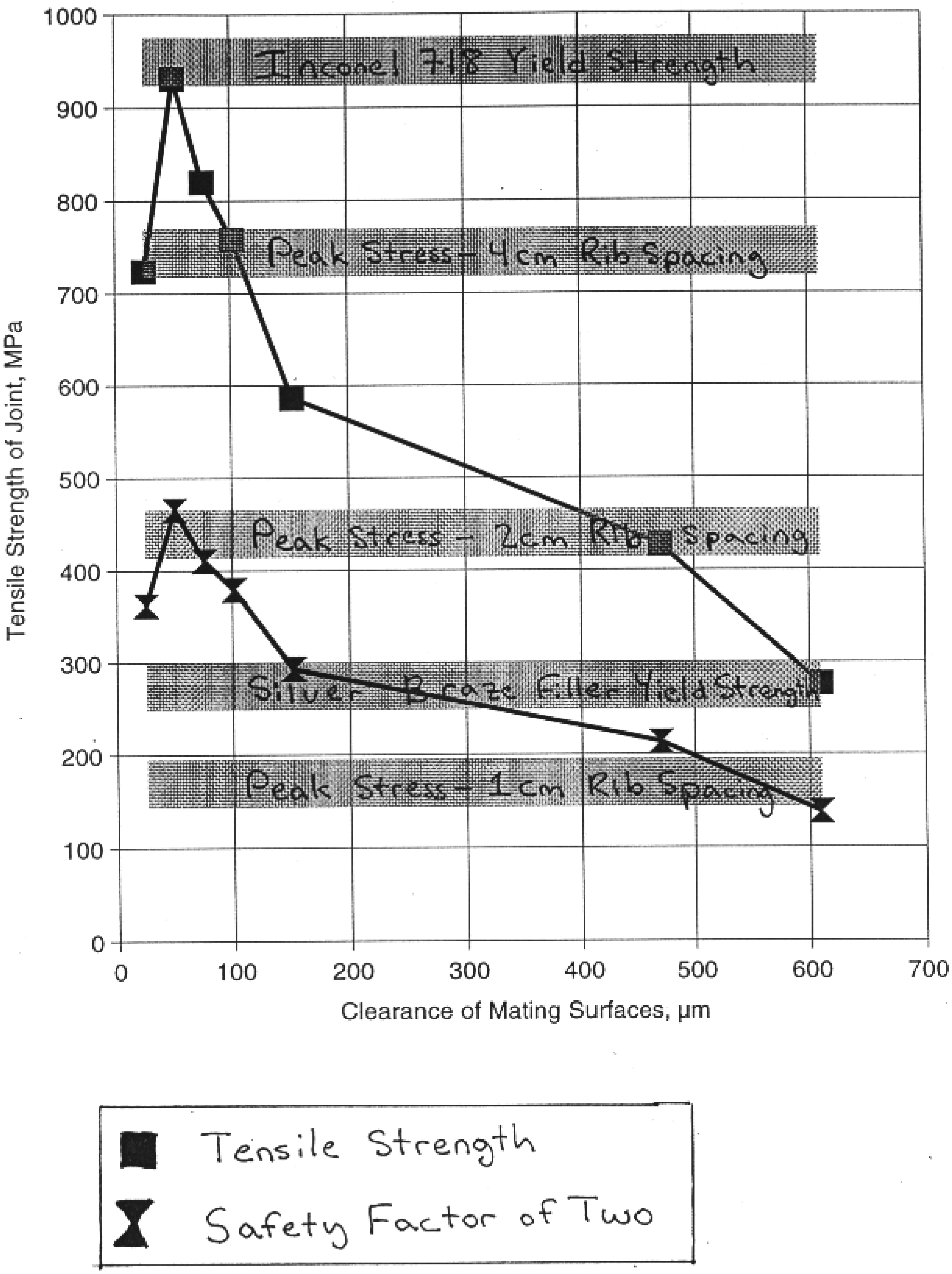
Fibre reinforced composites based on these resins can be at least one order of magnitude better (see Appendix 3).

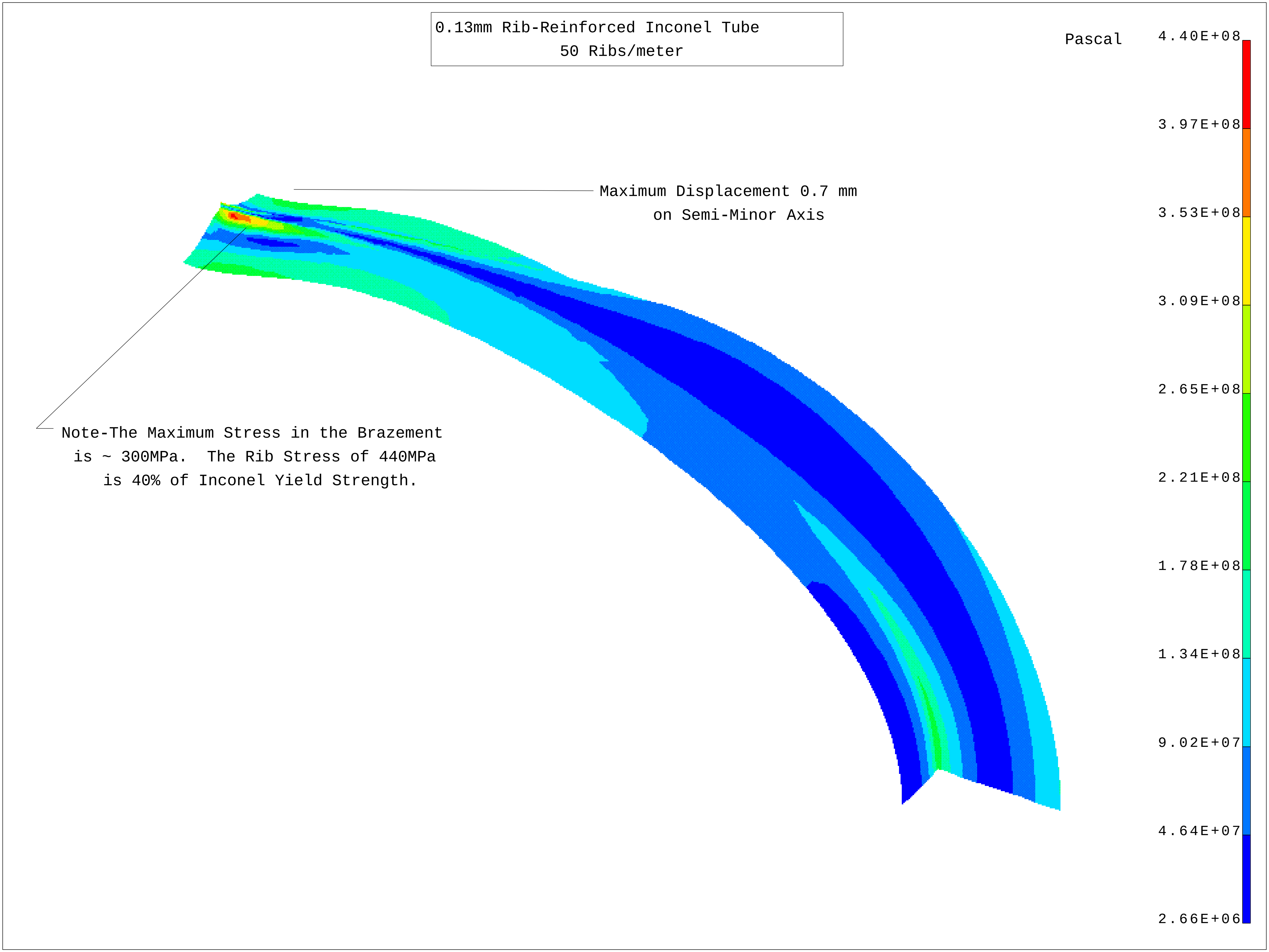

Aluminum Nitride Filled Epoxy
Reinforced with Silicon Carbide Fiber
3mm Wall
Vacuum Stress and Displacement
Pascal
1.64E+08
1.49E+08
1.33E+08
1.18E+08
1.03E+08
8.72E+07
7.19E+07
5.65E+07
4.11E+07
2.58E+07
1.04E+07
Deformation 5.7mm on
Semi-Minor Axis
Quasi-Isotropic Reinforcement
Tensile Strength ~577MPa
Unidirectional Reinforcement
Reinforced AxisTensile Strength ~1GPa
Transverse Tensile Strength ~100MPa

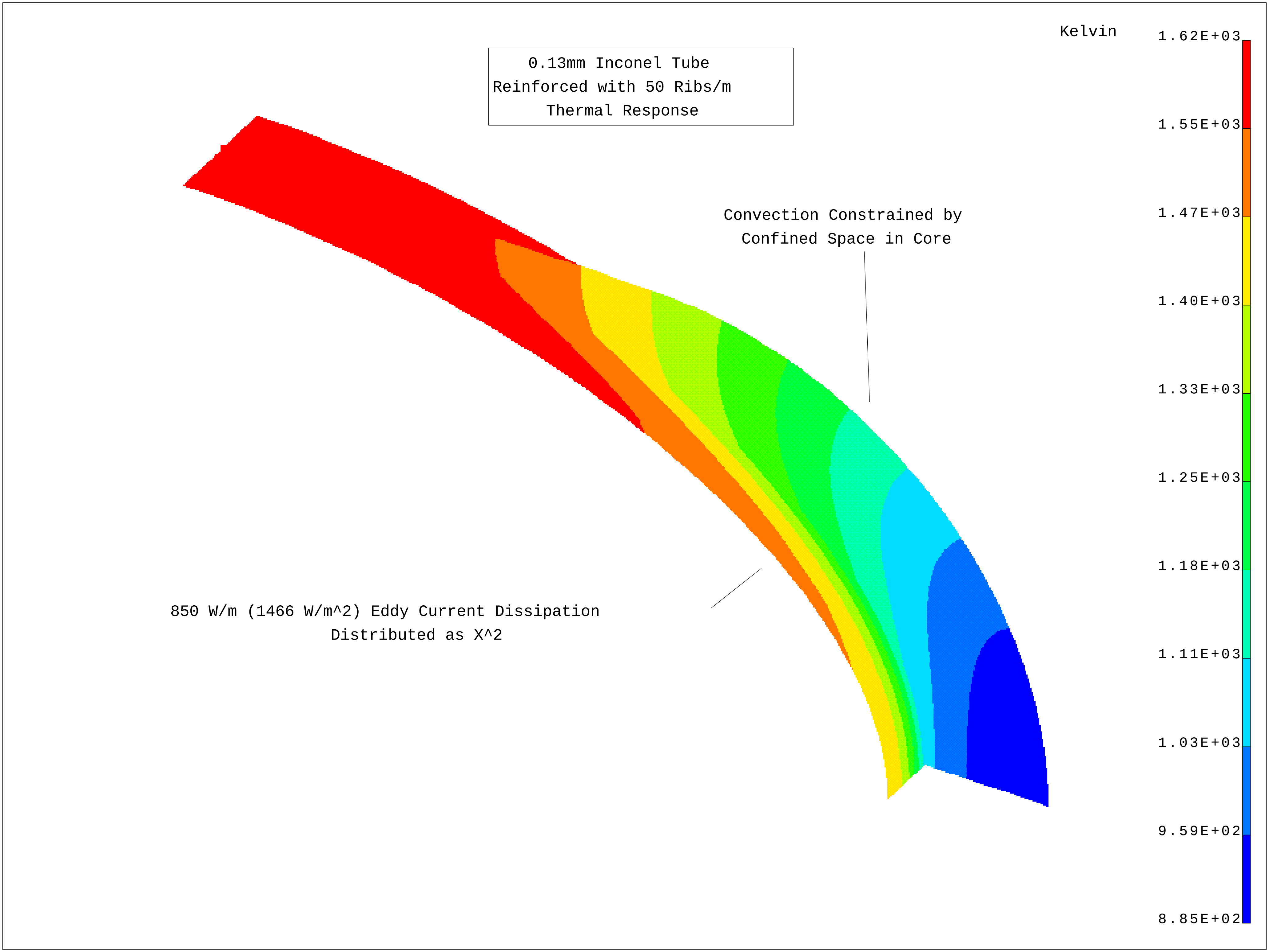

Aluminum Nitride Filled Epoxy
Reinforced with Silicon Carbide Fiber
Lined with 10 micron Inconel Foil
3mm Wall Thickness
Thermal Conductivity 1 W/m*K
Kelvin
4.52E+02
4.43E+02
4.34E+02
4.25E+02
4.16E+02
4.07E+02
3.98E+02
3.89E+02
3.80E+02
3.71E+02
3.62E+02
180 W/m Eddy Current Dissipation
Plus 20 W/m Beam Image Dissipation
Distributed as X^2
Note- Epoxy Service Temperature < 477K
Convection Constrained by
Confined Space Inside Core

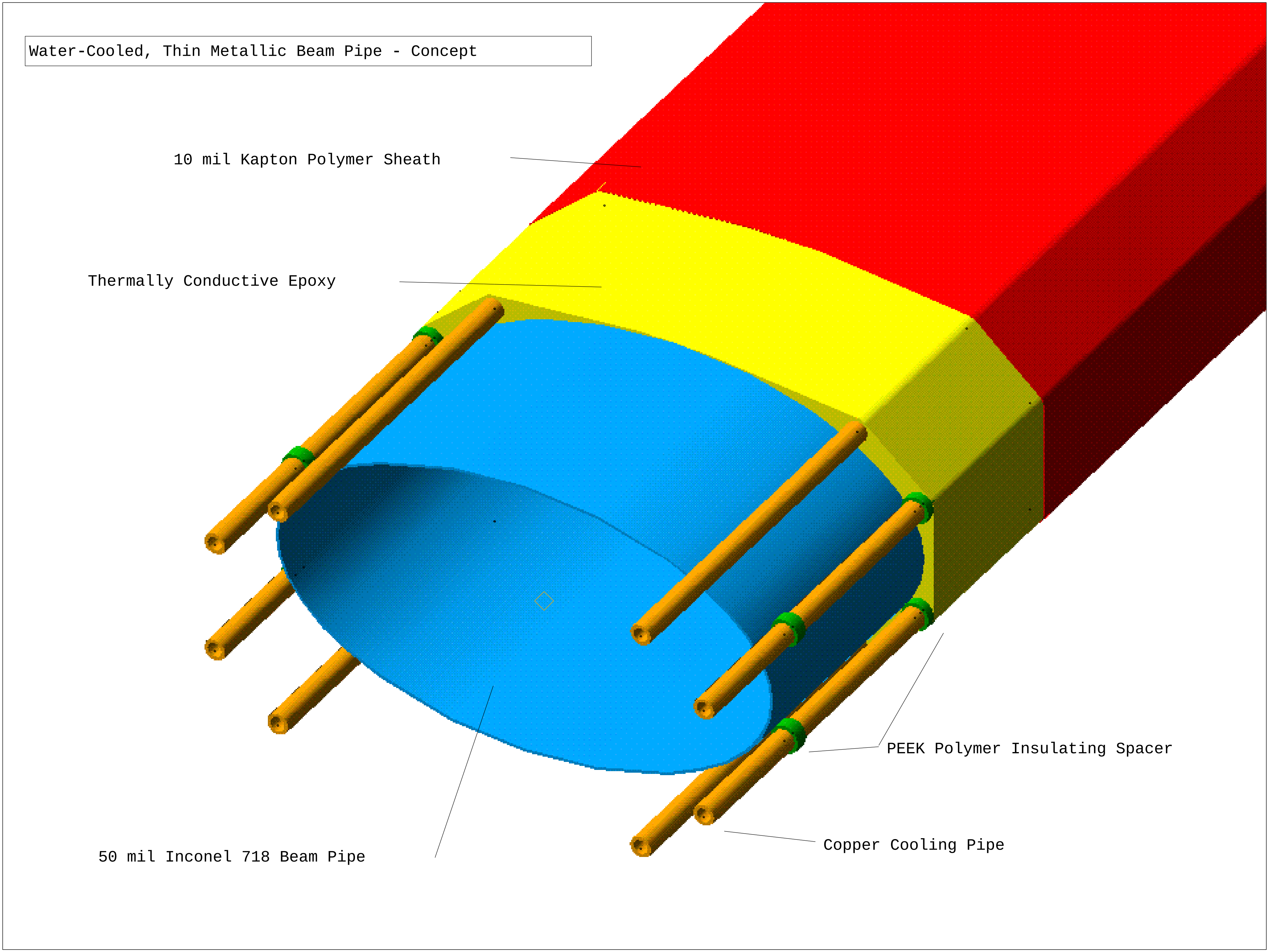

Rib-reenforced, Very Thin Metallic Beam Pipe - Concept
50 ribs / meter (2 cm spacing)
1mm Thick, Die-cut Ribs
Ribs Brazed to Tube
5 mil (0.13mm) Inconel 718 Tube, 9" by 5" Elliptical

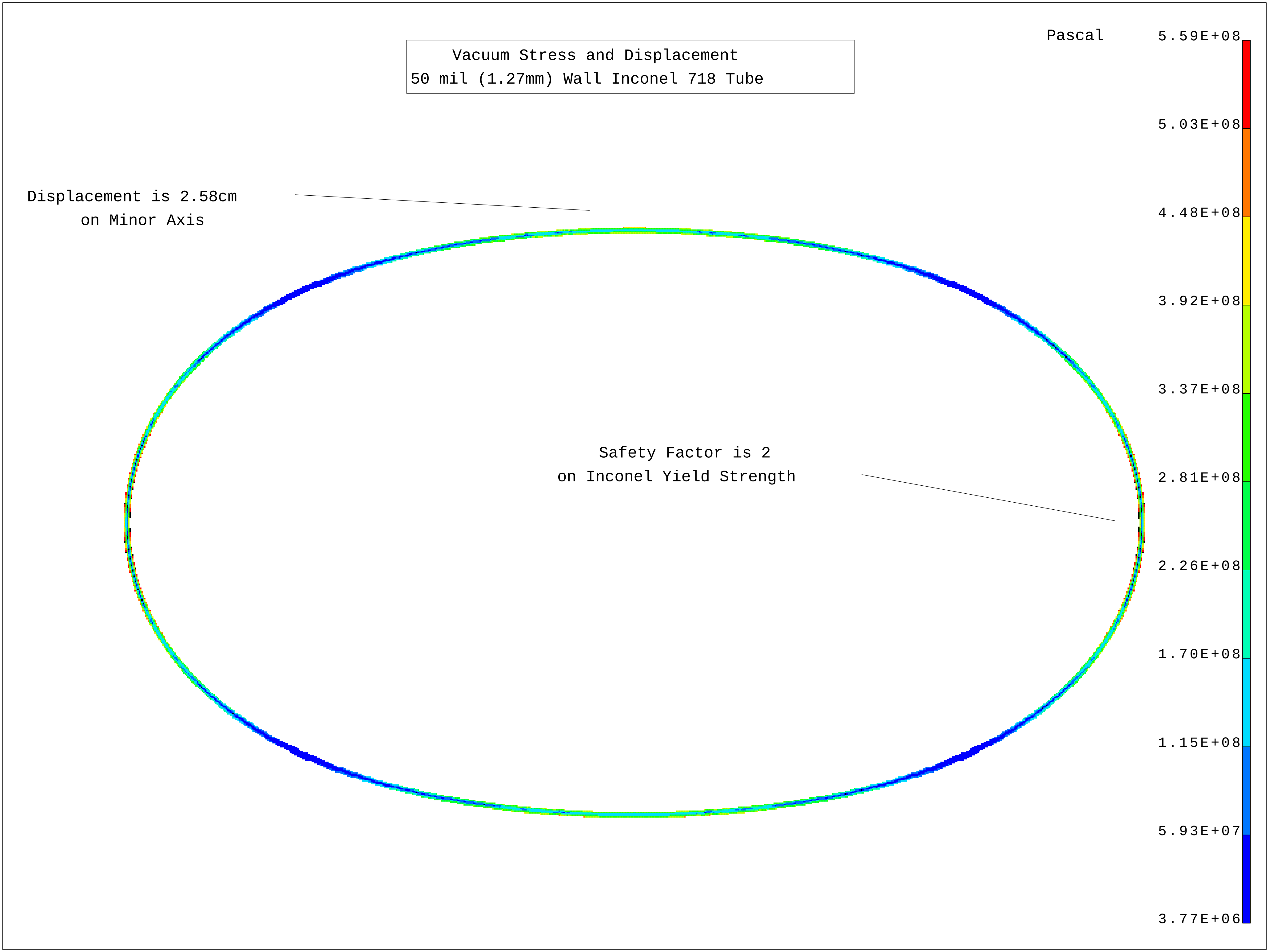
Relationship of Tensile Strength to Joint Clearance
(Data for Stainless Steel Brazed with BAg-1a Filler Metal,
Adopted from Brazing Handbook, American Welding Society

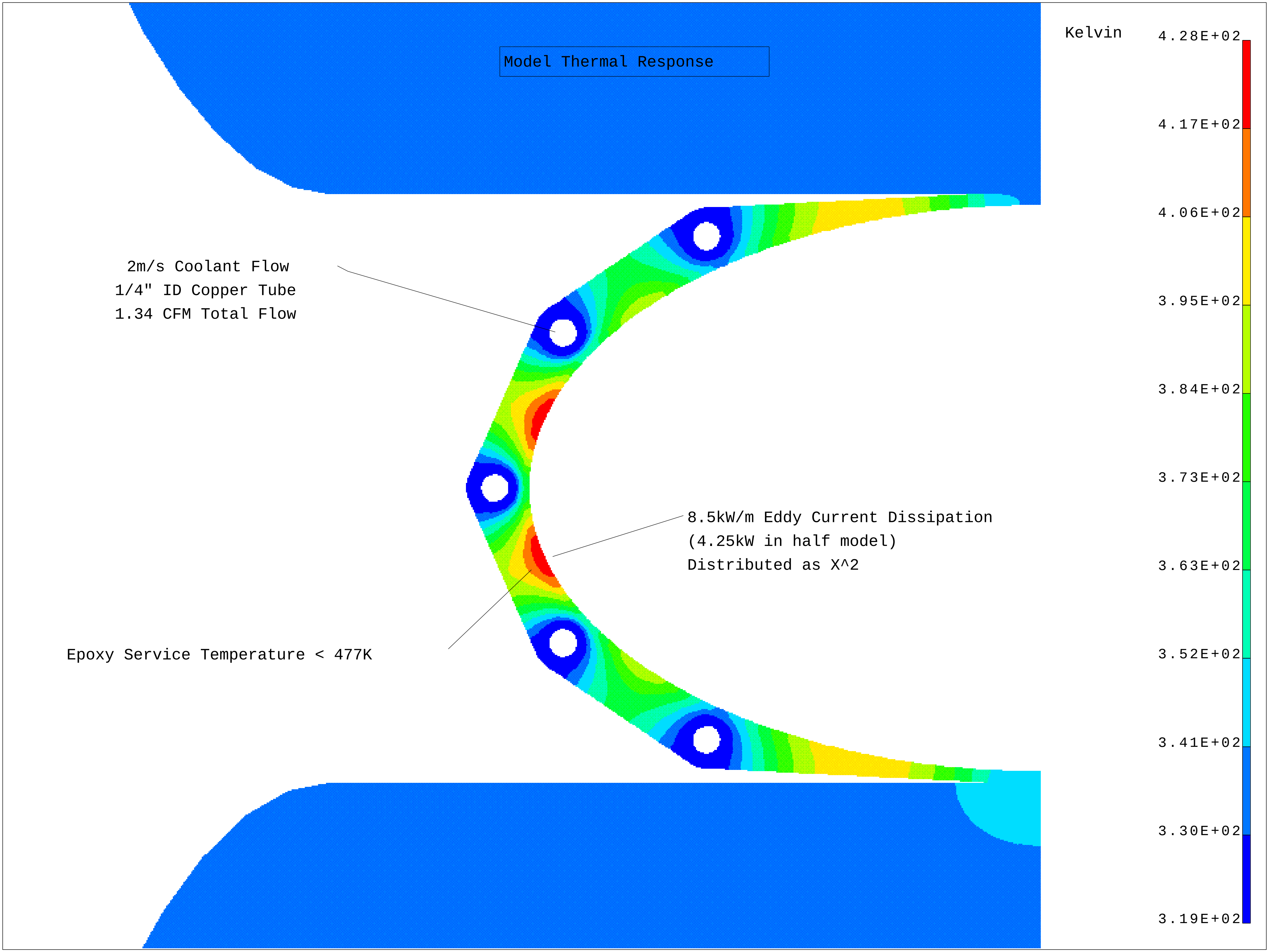



0.13mm Rib-Reinforced Inconel Tube
50 Ribs/meter
Pascal
4.40E+08
3.97E+08
3.53E+08
3.09E+08
2.65E+08
2.21E+08
1.78E+08
1.34E+08
9.02E+07
4.64E+07
2.66E+06
Maximum Displacement 0.7 mm
on Semi-Minor Axis
Note-The Maximum Stress in the Brazement
is ~ 300MPa. The Rib Stress of 440MPa
is 40% of Inconel Yield Strength.


0.13mm Inconel Tube
Reinforced with 50 Ribs/m
Thermal Response
Kelvin
1.62E+03
1.55E+03
1.47E+03
1.40E+03
1.33E+03
1.25E+03
1.18E+03
1.11E+03
1.03E+03
9.59E+02
8.85E+02
Convection Constrained by
Confined Space in Core
850 W/m (1466 W/m^2) Eddy Current Dissipation
Distributed as X^2


Water-Cooled, Thin Metallic Beam Pipe - Concept
10 mil Kapton Polymer Sheath
Thermally Conductive Epoxy
PEEK Polymer Insulating Spacer
Copper Cooling Pipe
50 mil Inconel 718 Beam Pipe


Vacuum Stress and Displacement
50 mil (1.27mm) Wall Inconel 718 Tube
Pascal
5.59E+08
5.03E+08
4.48E+08
3.92E+08
3.37E+08
2.81E+08
2.26E+08
1.70E+08
1.15E+08
5.93E+07
3.77E+06
Displacement is 2.58cm
on Minor Axis
Safety Factor is 2
on Inconel Yield Strength


Model Thermal Response
Kelvin
4.28E+02
4.17E+02
4.06E+02
3.95E+02
3.84E+02
3.73E+02
3.63E+02
3.52E+02
3.41E+02
3.30E+02
3.19E+02
2m/s Coolant Flow
1/4" ID Copper Tube
1.34 CFM Total Flow
8.5kW/m Eddy Current Dissipation
(4.25kW in half model)
Distributed as X^2
Epoxy Service Temperature < 477K