Cool Down Study of 70 K Thermal Shield of 650MHz Cryomodule

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Outline of talk

Part I

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  - Description of 70 K thermal shields for first and Second generation TTF Cryostat
- **Heat transfer coefficient study and material properties**
- **Queries related to 650 MHz Cryomodule**

Part II

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- **Thermal Analysis**
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  - **Meshed Model used for computation**
  - **Results of thermal Analysis**
- **Future work**
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Part I

Initial Study and Other Queries

Literature survey

- There are only few publications since the first TTF cryostat was tested in 1997

  A. Cool down simulation for Tesla Test facility (TTF) cryostats
  B. Design of the thermal shield for the new improved version of Tesla Test facility (TTF) cryostat

  Both articles were published by D Barni and C Pagani in "***Advances in Cryogenic Engineering***", ***Vol. 43,(1998)***

- Coupled thermal and structural analysis for both 4K and 70k shield for both first an second generation cryomodules.
- Actual cool down results have not been discussed or co related with this analysis. There are also certain points that we did not understand in these articles.
- We do understand that FNAL has cooled the first cryomodule and so the results are available. It would be interesting to see the variation of these results from what is predicted by FEA .

First and second generation TTF Cryostat Thermal shields

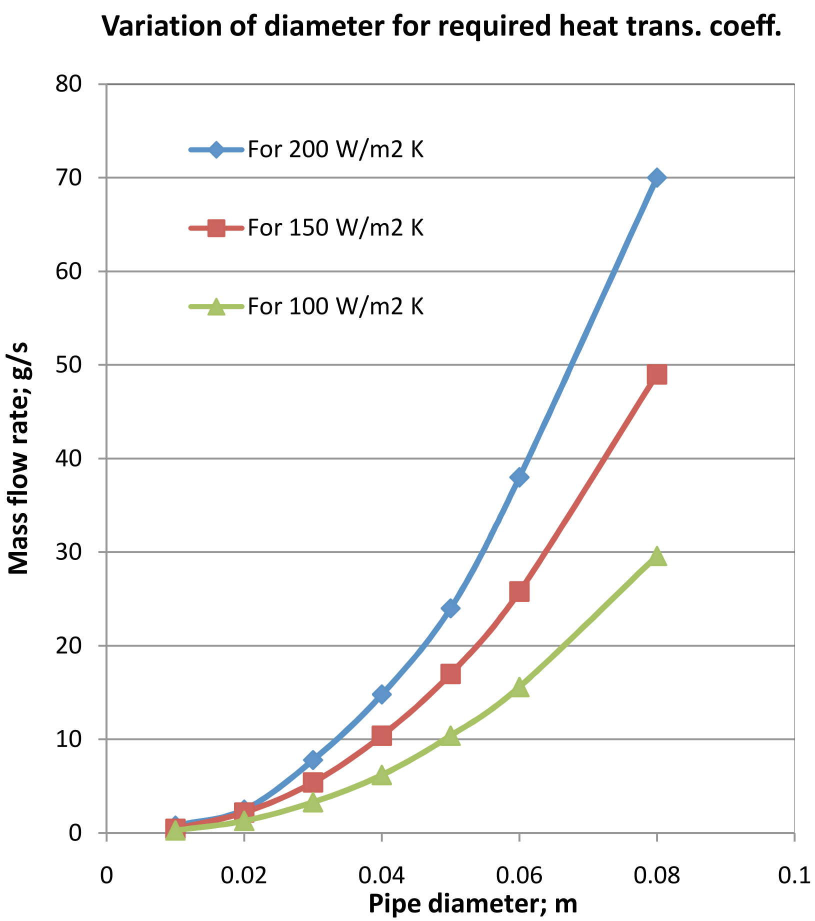
- **First generation TTF cryostat:**
  – Aluminum shields cooled by copper braids connected to stainless steel cooling pipes. The shields themselves were split into parts connected together by hundreds of threaded fasteners.

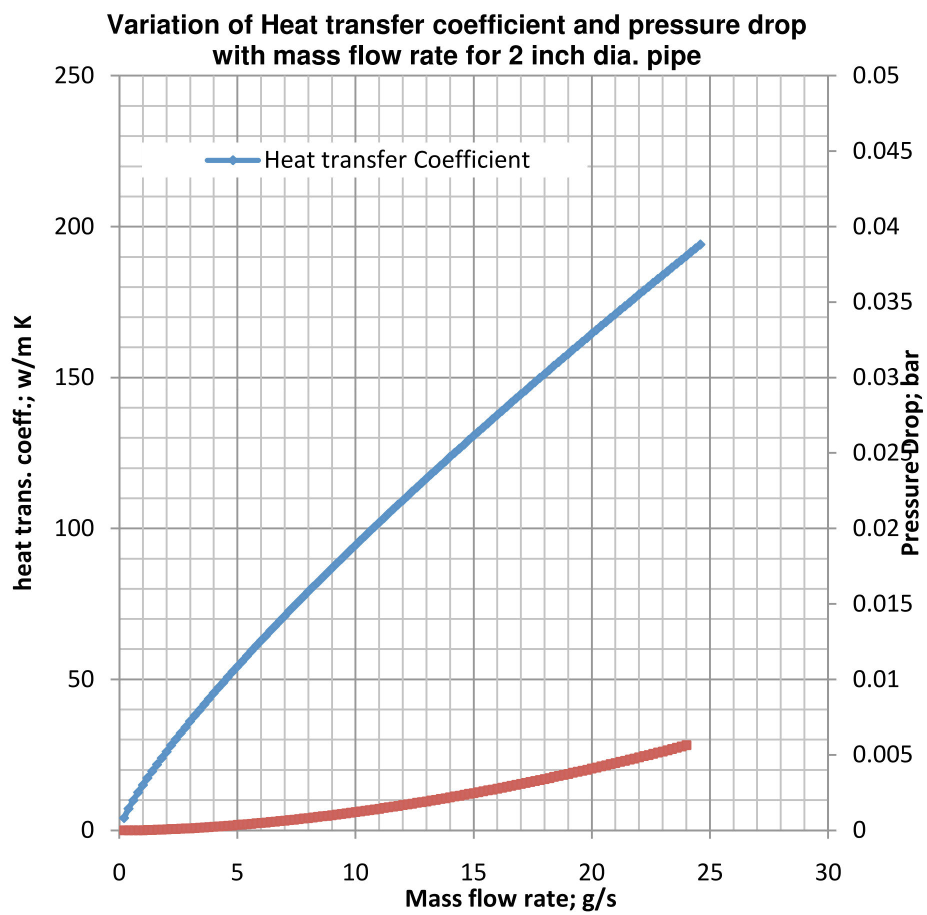
- **Second generation TTF cryostat:**
  – The cooling helium pipes are directly welded to the aluminum shields. Upper and Lower parts are connected with “Finger” welding to relieve stresses in the long shield during cooldown.

Difference between Numerical models of TTF 70K Shield

Parameter	First generation TTF cryomodule	Second generation TTF Cryomodule
Cooling Scheme	Fast cooldown: Cooling pipe brought immediately to 70 K temperature	Slow cool down: Linear decrease in inlet temperature of helium flowing in the pipe from 300 K to 70 in 40 hours
FEA Assumptions	• Shell elements are used • Surface convective heat load on helium pipe at fixed bulk temperature of 70 K • Thermal radiation only between 300 K & 70 K surfaces has been considered Material used : Aluminum 6082 alloy and Braids of ETP Copper	•Shell elements are used •Helium flowing in the cooling pipe linearly decreasing from the room temp of 300 K to 70 K in 40 hours •In model, fingers are not present ,but it considers the real heat transfer section •Radiation heat exchange between the shields and the surrounding environment is neglected •Material used : Aluminum 1050 alloy

Effect of mass flow rate and pipe dia. on heat transfer coefficient





(Pressure of 2 bar is considered as it is for one cryomodule and there is not much variation of h with pressure)

Temperature dependent material properties

Material properties

- Temperature dependent: Thermal conductivity, sp. heat, thermal expansion coefficient
- Temperature independent properties: density, elastic modulus, poission ratio, surface emissivity

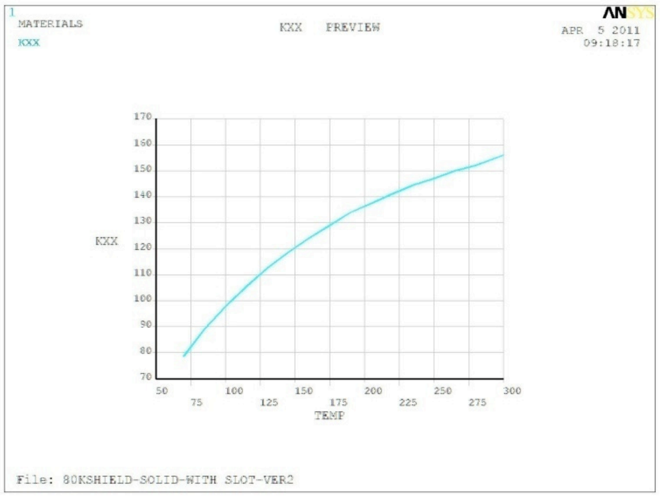


Fig (a) Thermal Conductivity with temperature

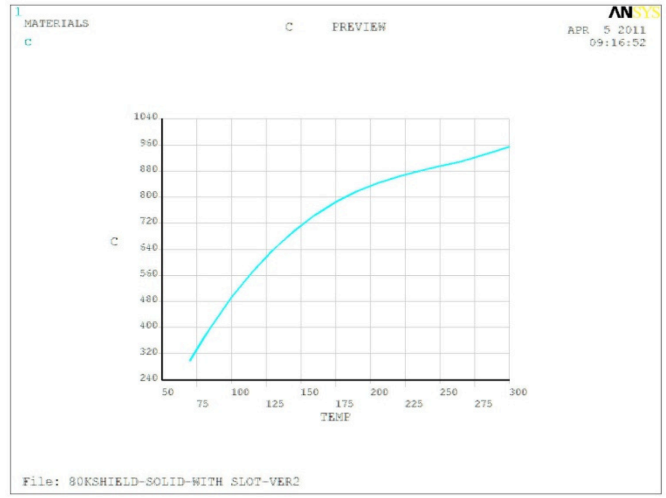


Fig. (b) Sp. Heat with temperature

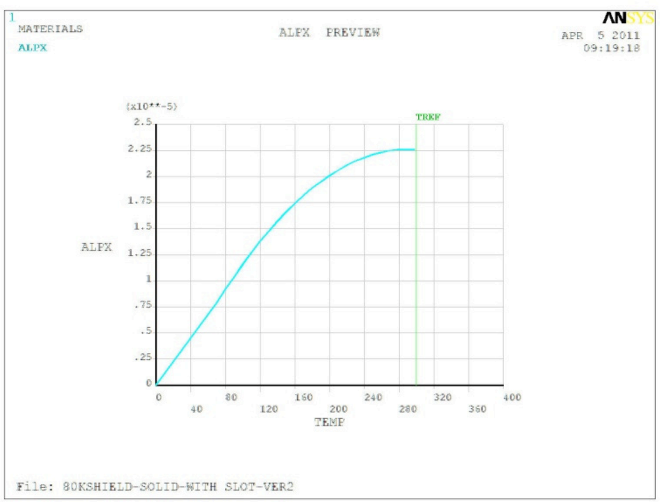
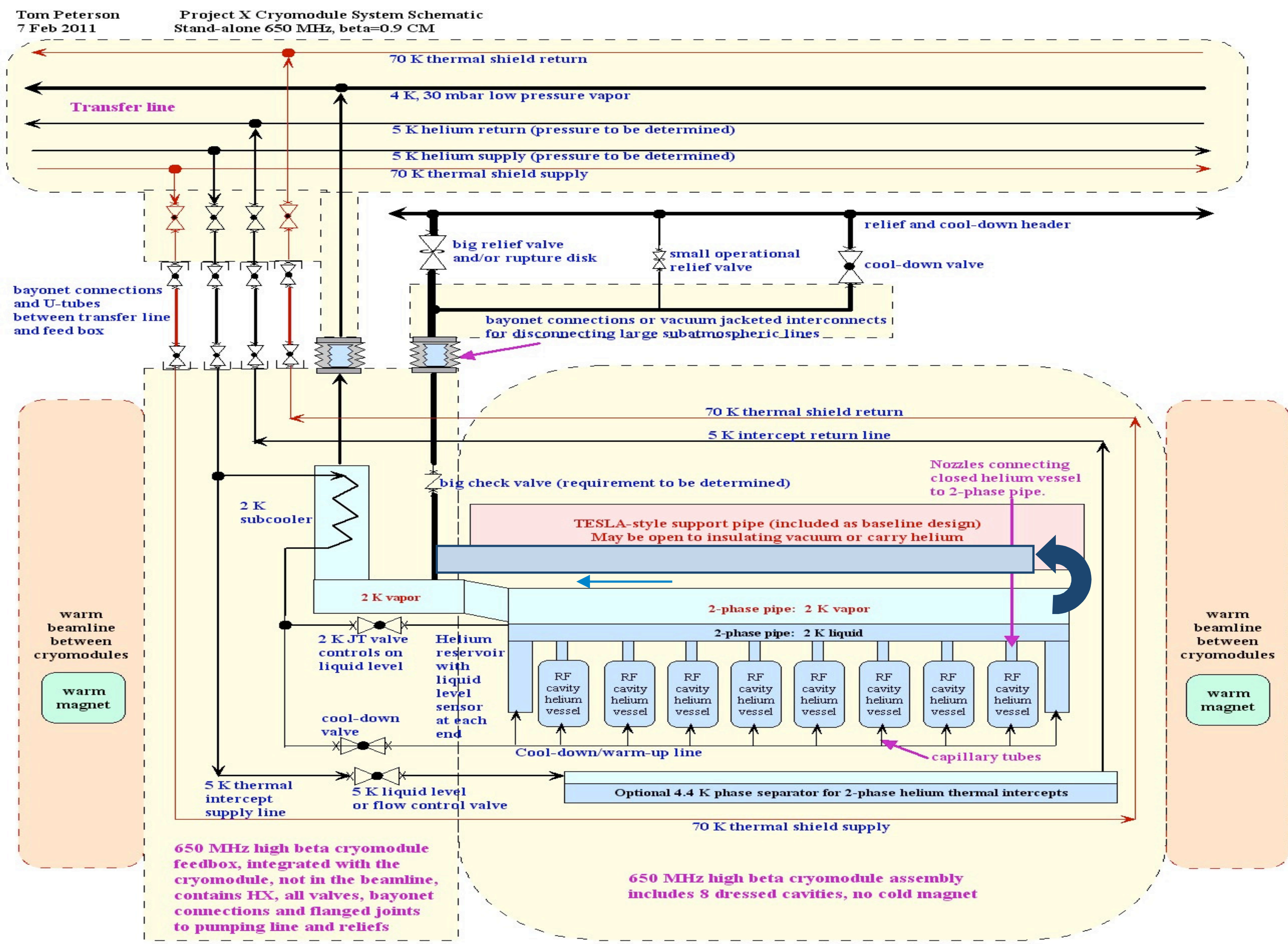


Fig. (c) Thermal Expansion Coefficient with Cryogenic Temperature

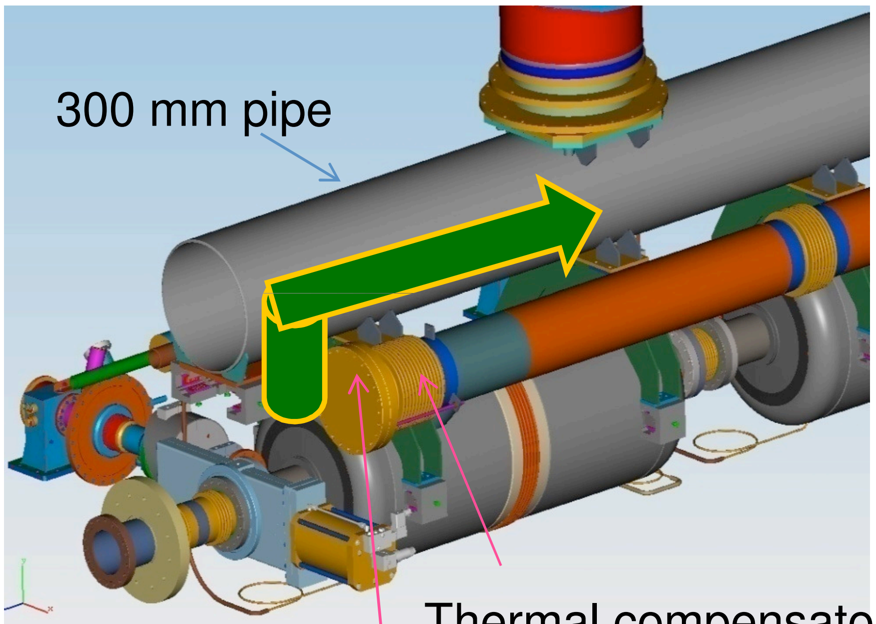
Apart from this analysis there is a question related to 650 MHz Cryomodule



- Can we think of connecting the 2K pipe to vent pipe at two locations at two ends ?

Perceived benefits:

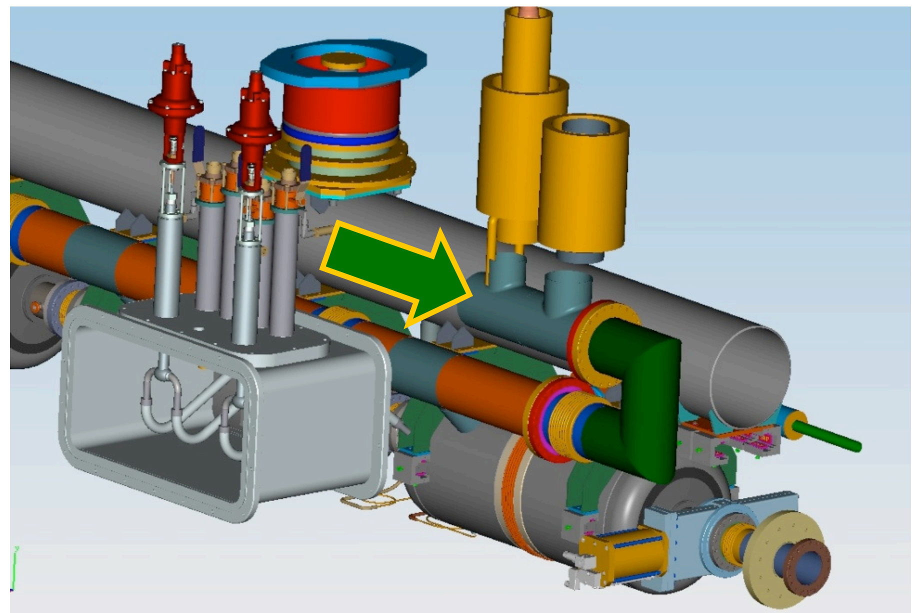
- Required size of 2-phase pipe may reduce and also have enough vapor volume (for emergency venting in a scenario of accidental loss of vacuum).
- The 2 K pipe gets totally supported on the HGR pipe and the chimney now becomes just a connection to helium vessel and not a weight carrying member.
- No end forces in pipe in case of emergency venting



DS end

Thermal compensator

Flange should have a "hard" connection with 300mm pipe



Part II

Thermal Analysis

Objectives

- We have studied the cool down simulation of two cryostat i.e. first generation TTF cryostat and second generation TTF cryostat.
- Now we want to simulate the 650MHz cryomodule's 70K thermal shield (which has a different size) and see how the cool down would take place.
- We want to create a platform (step by step), on which we can simulate the cool down of the cryomodule and check if there are some places where undesired displacements or intolerable stresses occur for this cryomodule.
- This is specially pertinent as this cryomodule has different size and in a way different configuration, (absence of 4k shield).

Thermal Analysis

- Assumptions
  - Constant radiation heat flux of 1.5 watt/m2 from 300 K vacuum vessel to 70 K shield is considered.
  - Cooling pipe is instantaneously filled with the 70 K liquid helium, neglecting any longitudinal temperature gradient.
  - Assumption of a rapid cool down procedure represents the worst possible operating case .
  - Thermal Losses to 4 K shields have been neglected

Finite Element Model

- Thermal Solid elements are used i.e. solid 90 (20 noded element)
- In thermal model instead of fingers, equivalent area of heat transfer between upper part and lower part of the shield is considered.
- Total no. of elements are approx 3.4 lakhs
- Element Size is taken: 21 mm
- Material Properties at cryogenic conditions:
  - Temperature dependent properties have been used for Thermal conductivity and specific heat
  - Whereas density ,elastic modulus and poission ratio have been considered independent of structure temperature

Material Properties	Aluminium 6061 T6
Young Modulus	70 GPa
Poisson's Ratio	0.3
Density	2700 Kg/m3

Loads on the 70 K shield

- Initial conditions and loads on the model: Initial temperature has been set to the room temperature of 300 K
- Deciding on Convective Boundary Condition

$$Nu = 0.026\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}$$ --------(Dittus-Boelter relation)

$$Nu = \frac{H_f D}{K} \qquad \mathrm{Re} = \frac{\rho V D}{} \qquad \mathrm{Pr} = \frac{C}{K}$$

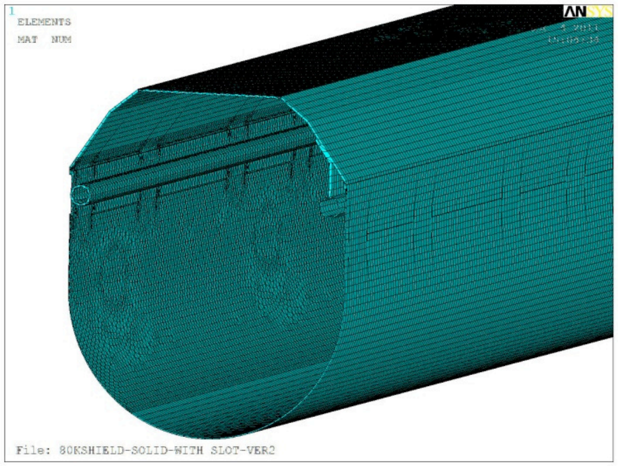
- Assuming helium mass flow rate of 24 gm/s and cooling pipe dia. 50 mm

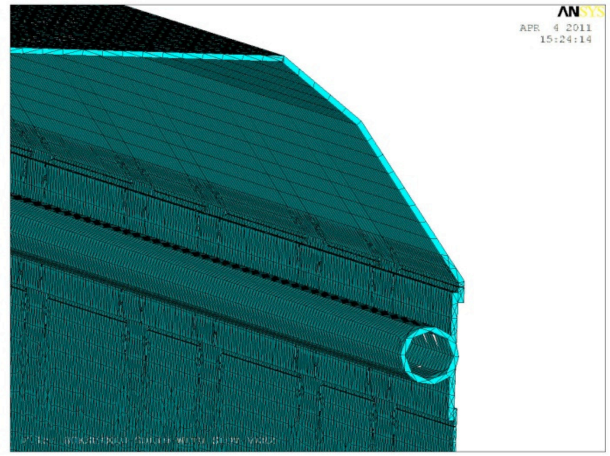
- Viscosity varying according to keesom relation $= 5.023 T^{0.647}$

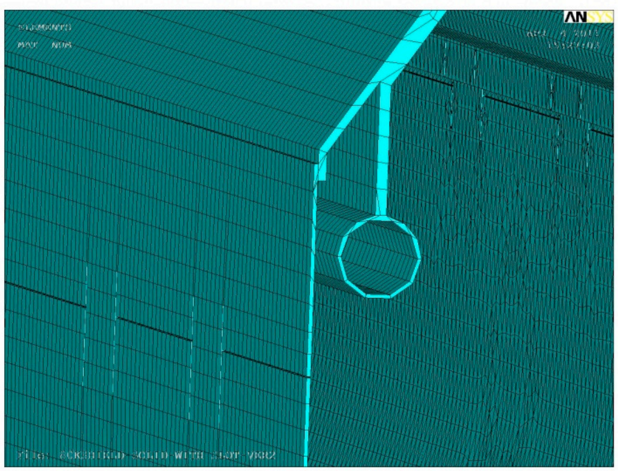
Computing from input data, Use heat transfer coefficient of ~ 200 W/m2-K

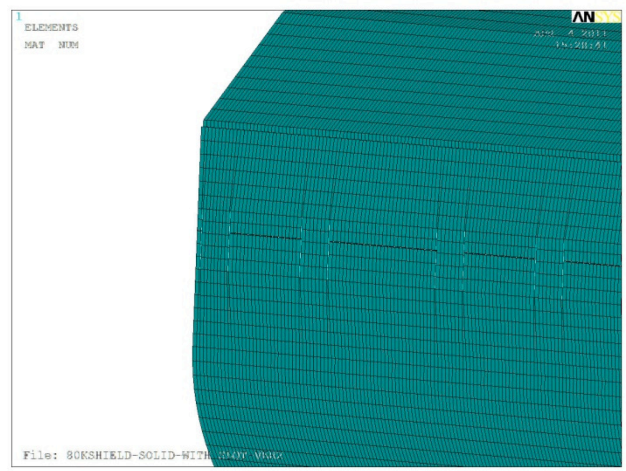
- Radiation flux from 300 K to 70 K shield with 30 layers of MLI : 1.5 W/m2
- Heat inleak from support post is:-
  - 10 watt from each support port
- Heat inleak from coupler port-
  - 2 watt from each coupler port

Meshed model used for computation



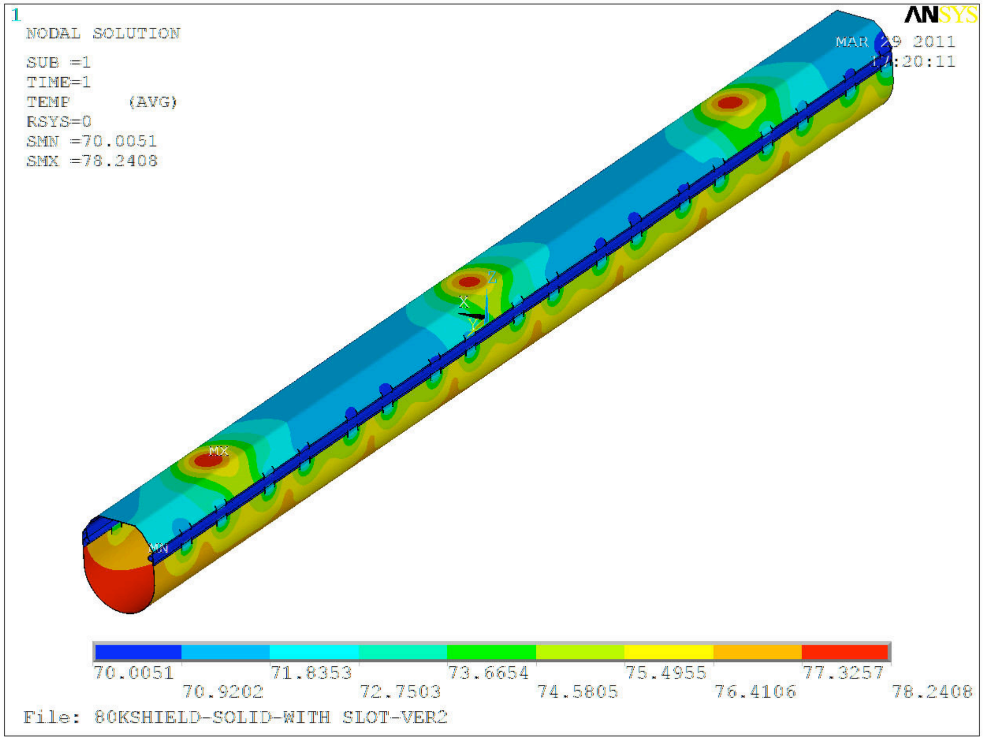






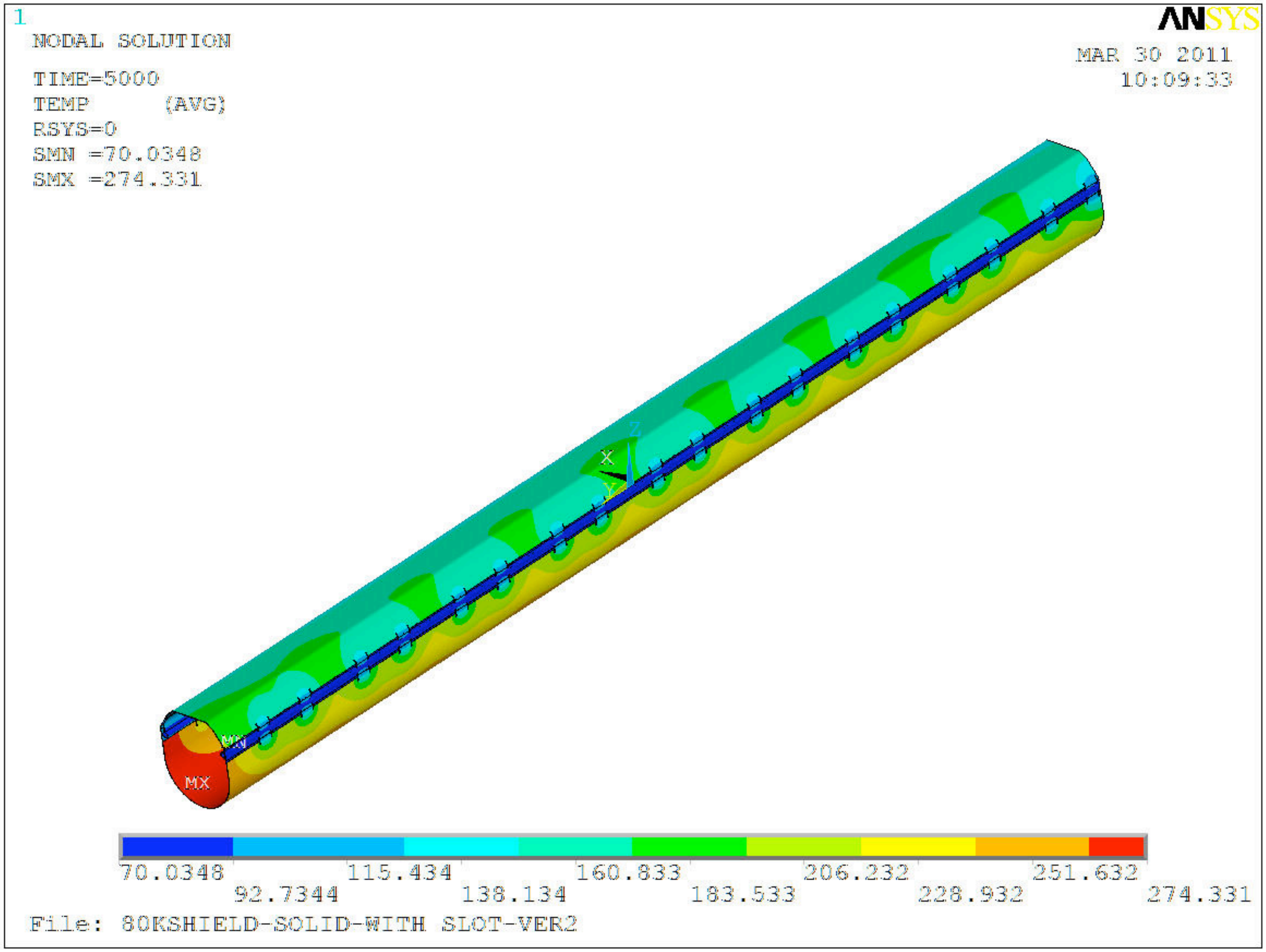
Results of Thermal Analysis

- Steady State Results



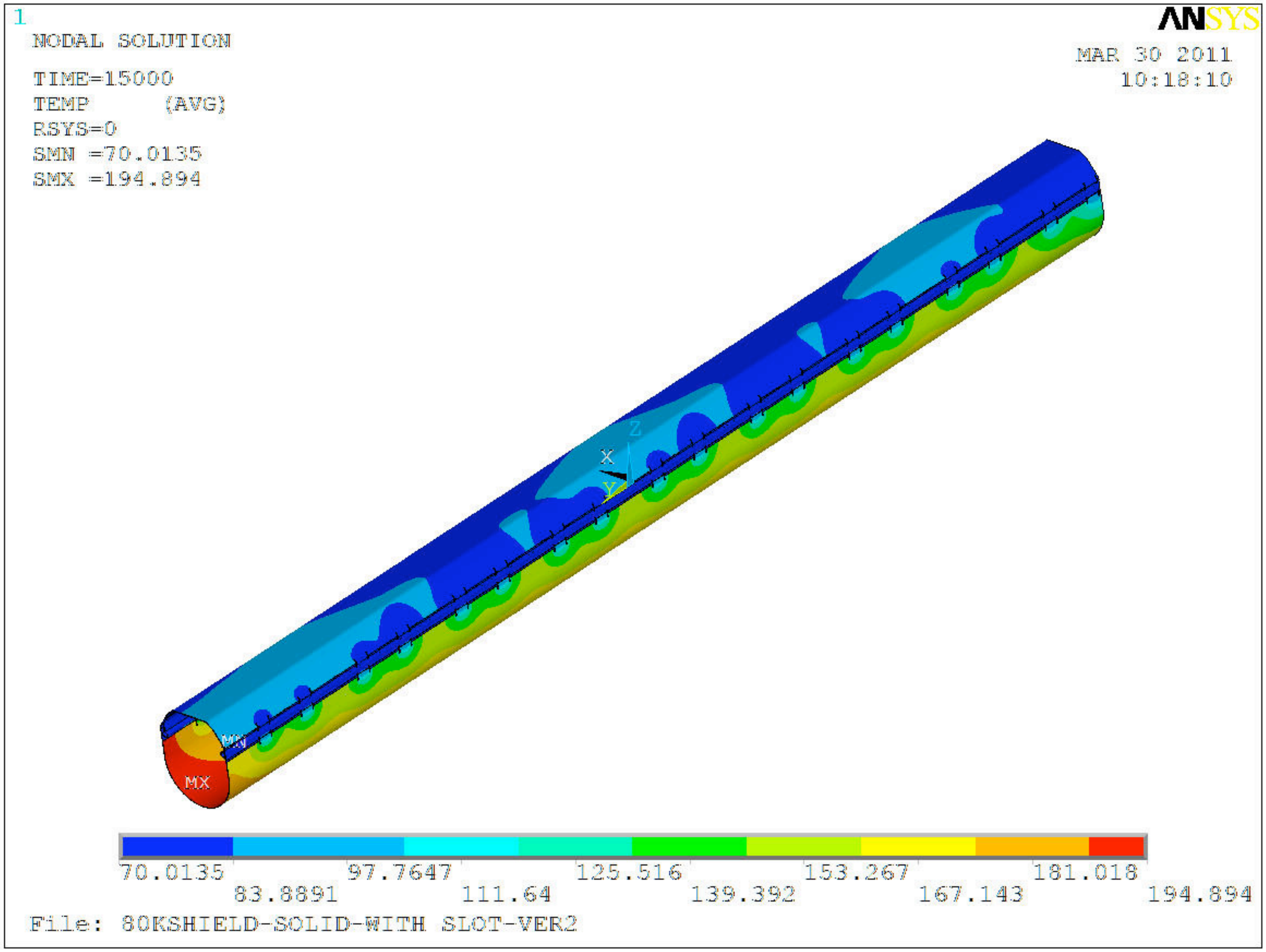
Figures shows temperature distribution and thermal gradient

In steady state results , It is seen that hottest region is at lower part of the shield i.e temperature of 78 K



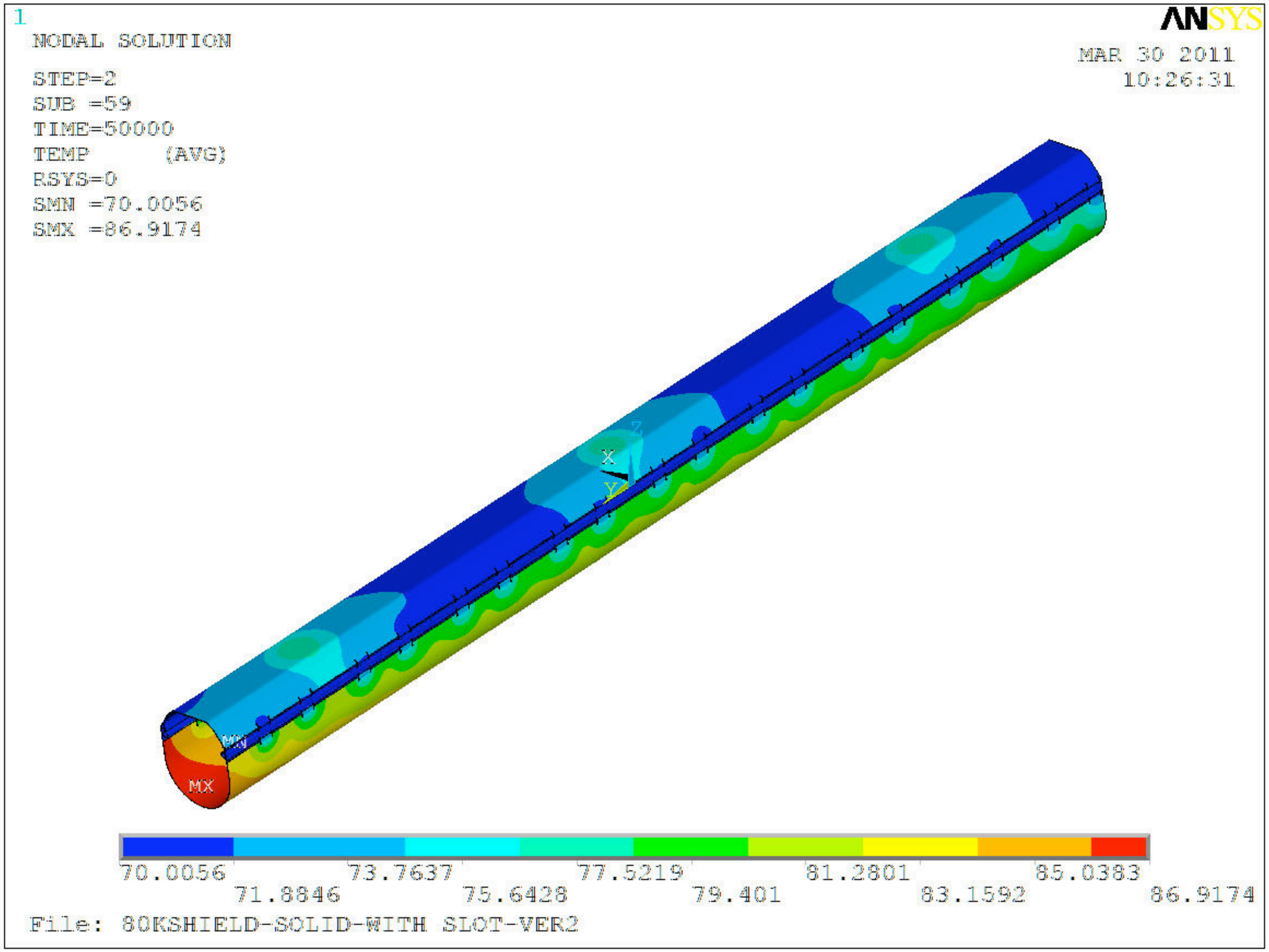
Temperature plot after 1.38 hours (5000 Seconds)

Cool down simulation of 70 K thermal shield for 650 MHz Cryo-Module



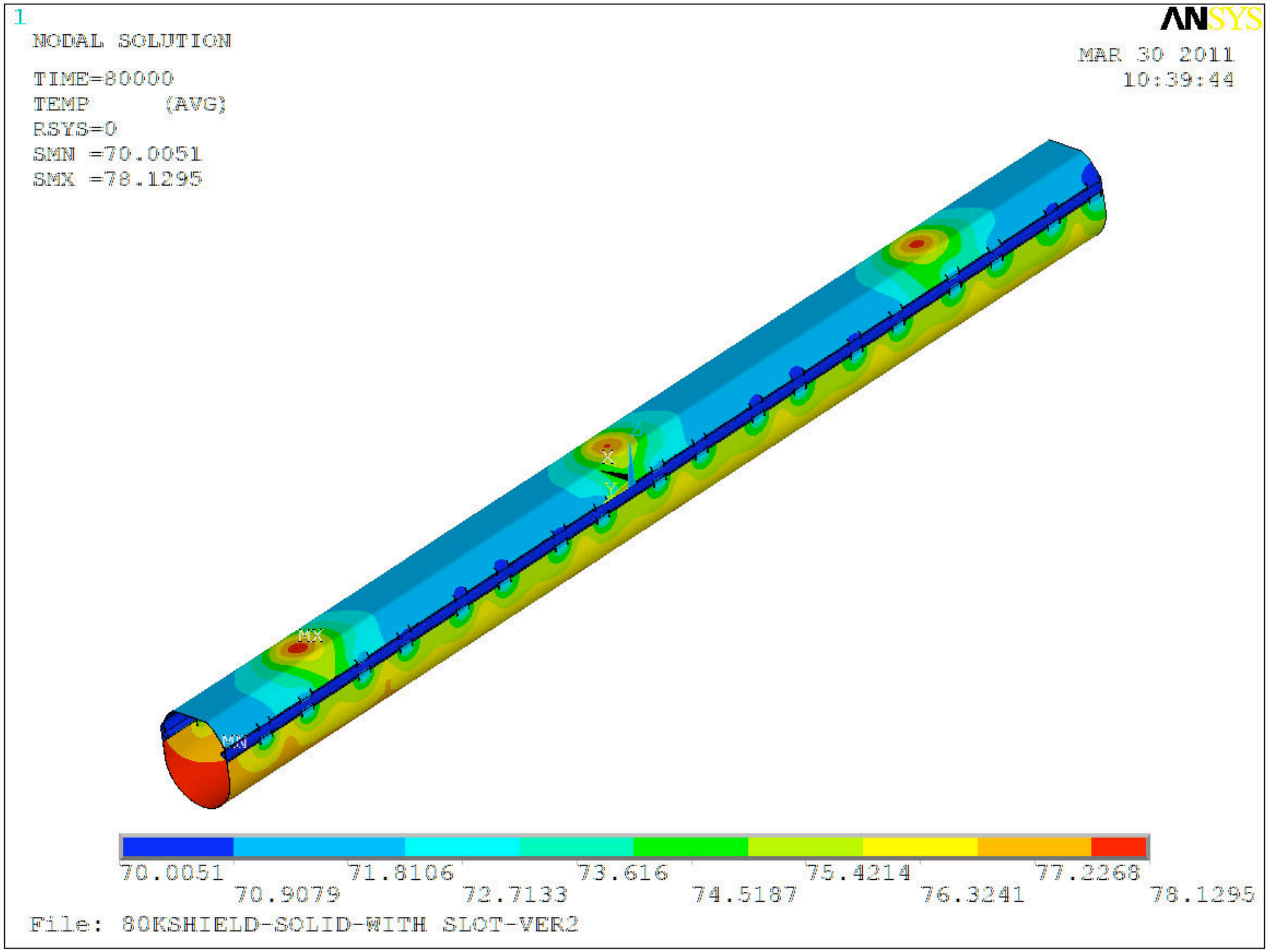
Temperature plot after 4.16 hours (15000 Seconds)

Cooldown simulation of 70 K thermal shield for 650 MHz Cryo-Module



Temperature plot after 13.88 hour (50000 Seconds)

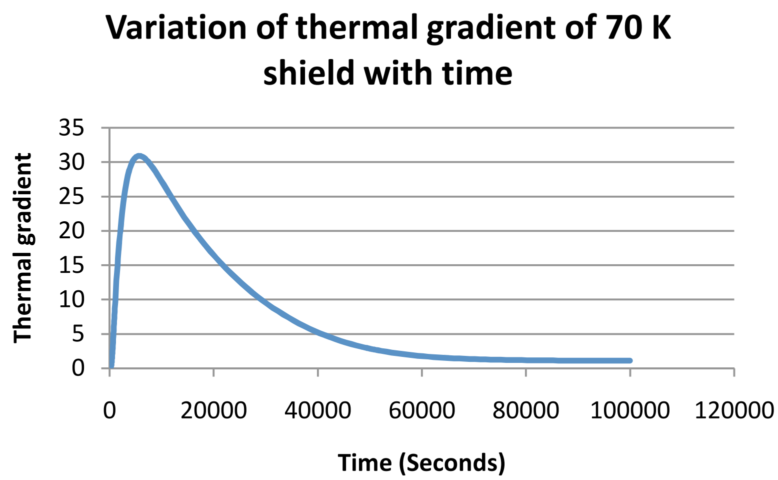
Cooldown simulation of 70 K thermal shield for 650 MHz Cryo-Module

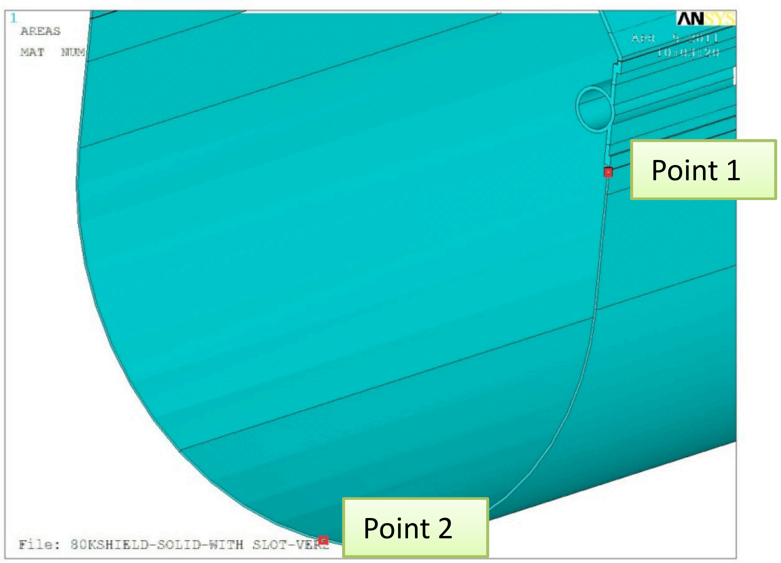


Temperature plot after 22.22 hours (80000 Seconds)

Cooldown simulation of 70 K thermal shield for 650 MHz Cryo-Module

Thermal Gradient





Results:

•Thermal gradient is based on temperature difference between(point 1) upper point of the lower part of the shield and (point 2) the lowest point on lower part of the shield as shown in figure.

•Maximum thermal Gradient is found to be 30 K after 1.5 hours

Future Work

- Sub-modeling of finger weld region has to be carried out for thermal –structural analysis
  - Tensile and shear stress across the finger weld region
- From the cool down simulation, we got maximum thermal gradient across the shield after 1.5 hours-
  - To study the deformation produced in the shield during cool down
  - To study the stresses produced in the shield during cool down
- Cool down simulation of 70 K shield with different pipe diameter
- Whatever Tom says?

Questions….

- In analysis , we have used the fast cool down scheme. Is there any need for also simulating the other scheme which considers linear decrease inlet in helium temperature?
- Any cool down time period to target? Why?
- Crucial region for monitoring maximum thermal gradient across the shield ?
- Material for Shield??
  - Aluminium 6061T6 or 1050 alloy???

THANK YOU