S1 global: thermal analysis

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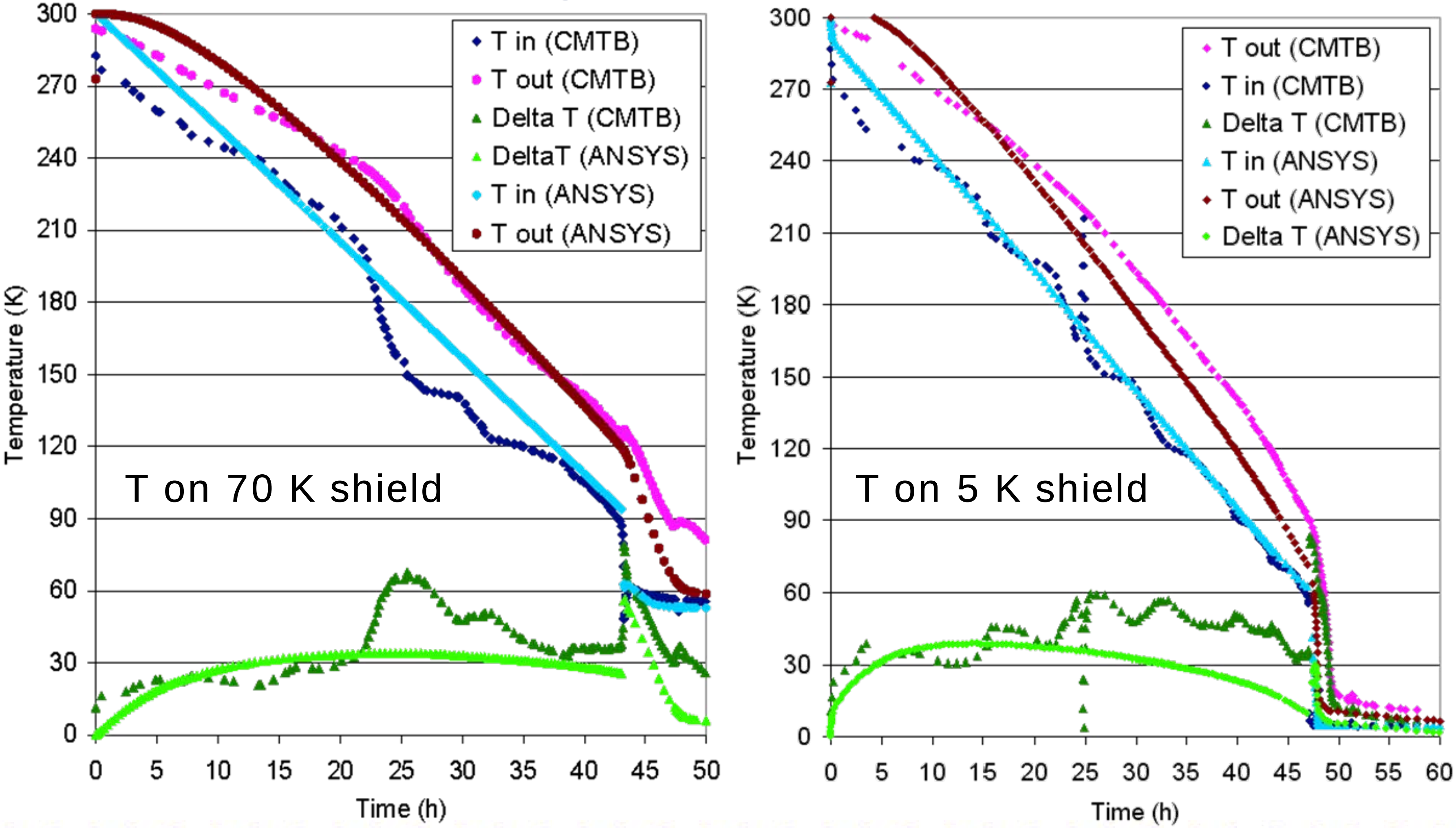
Motivation

- Transient thermal modeling of the cooldown behavior of SRF cryomodules can be pushed to include many effects and seems to reproduce data from measurements with sufficient approximation
  - **e.g. WEPD038 at EPAC08 for DESY data**
- Models can be developed with increasing complexity as model refinement progresses
  - **e.g. from “lumped” loads to realistic conduction paths, from convective film coefficients to heat exchange with 1-D fluid channels...**

- ANSYS FEA against DESY CMTB data



S1-Global

- The S1-Global will have many thermal sensor for the measurement of all heat loads to the cold mass (see Norihito talk), so it make sense to try now pushing our modeling capabilities and see where we end in the comparison
  - **aim is not the load budget, but mainly temperature distribution**
  - **validate models and explore design variations more cheaply and rapidly (e.g. 5 K yes/no experiments)**
- work in progress, benchmarking model

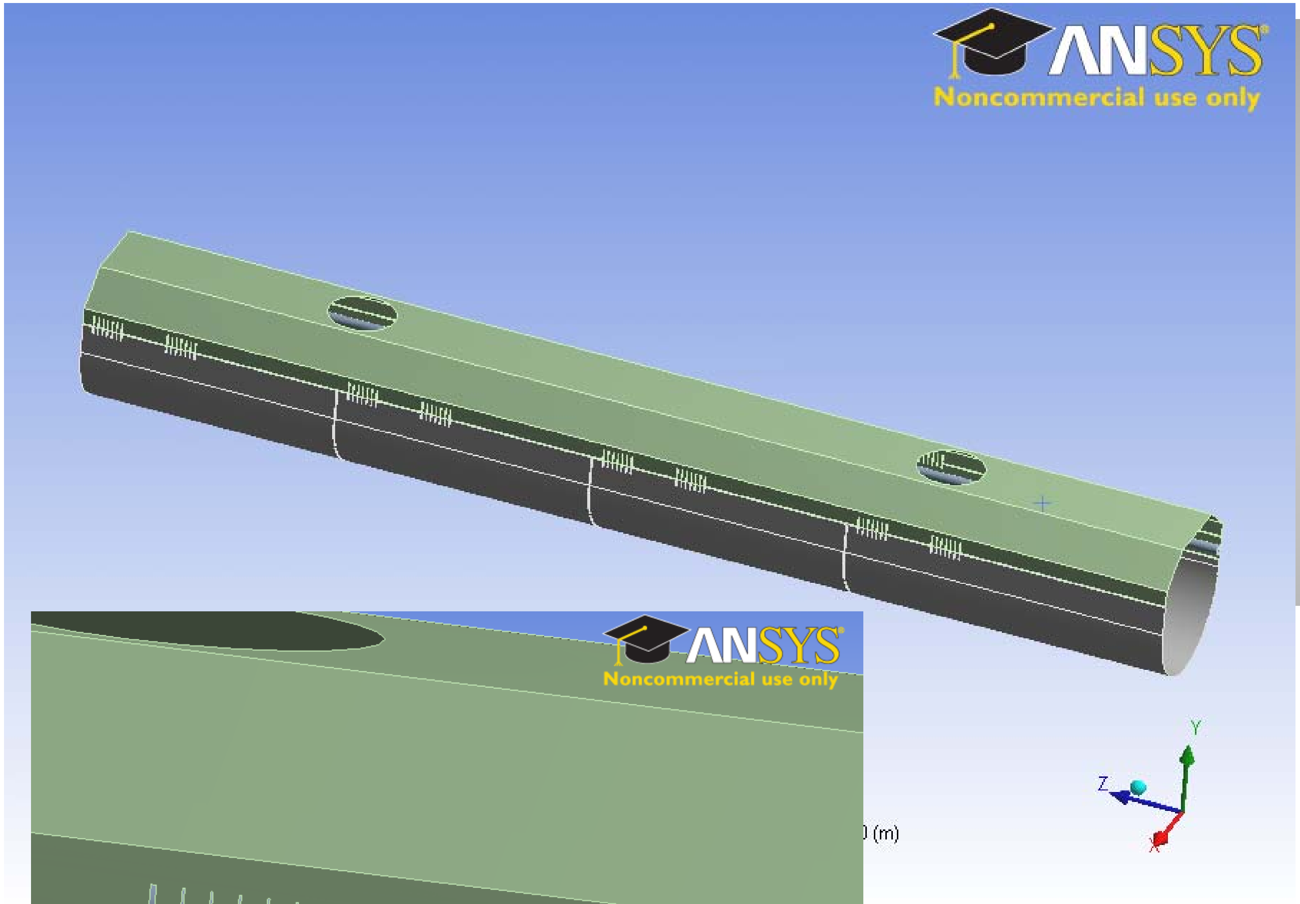
S1-Global model

- Module C: 3D CAD simplified model
  - **“heavy” defeaturing of nuts, bolts, fillets…**
- Included components:
  - **2 support posts**
  - **70 K/ 5 K shields (integrated cooling channels)**
  - **Gas Return Pipe (including cavity supports)**
  - **Invar rod (fixed at GRP, fixing cavity z pos)**
  - **Cavities in Helium tanks, separated by bellows**
  - **Simplified model for coupler conduction paths to shield and 2 K level**
- Large use of frictionless “contacts”

Thermal modeling

- Full non-linear material properties vs T
- Conduction
  - **Explicitly modeled conduction path for the support of the cold mass through the posts**
  - **Couplers: simplified concentrated heat loads from tabular data at the different T intercepts**
- Convection
  - **In increasing complexity, first boundary T on pipes, then exchange through film coeff. (later)**
    - detail only relevant when cooling rate gets faster...
- Radiation
  - **as a flux on cold surfaces, assuming MLI**

70 K shield


ANSYS
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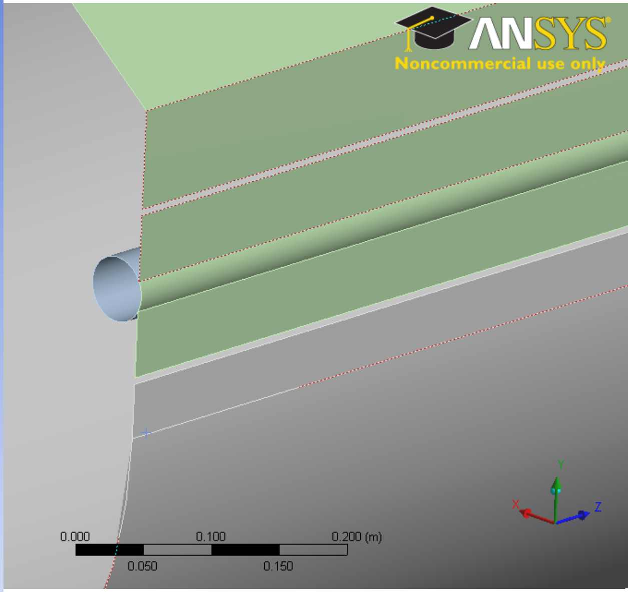
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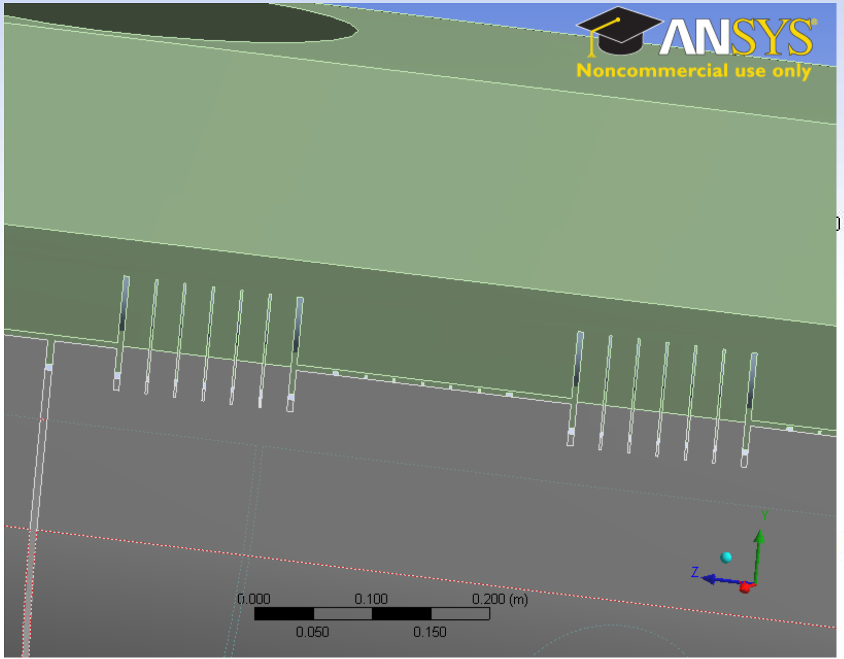
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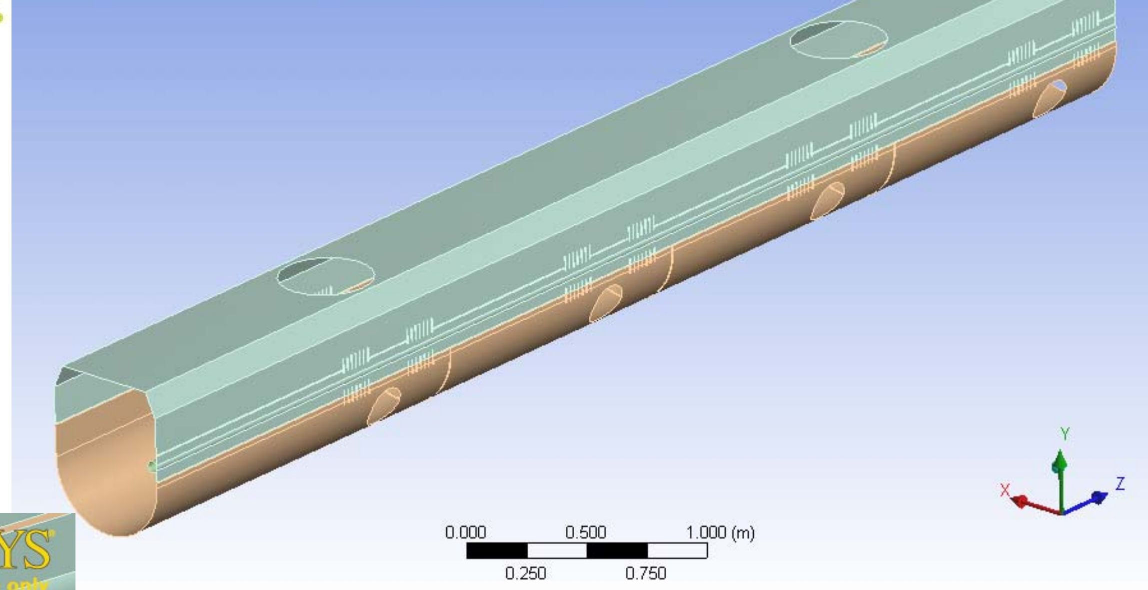
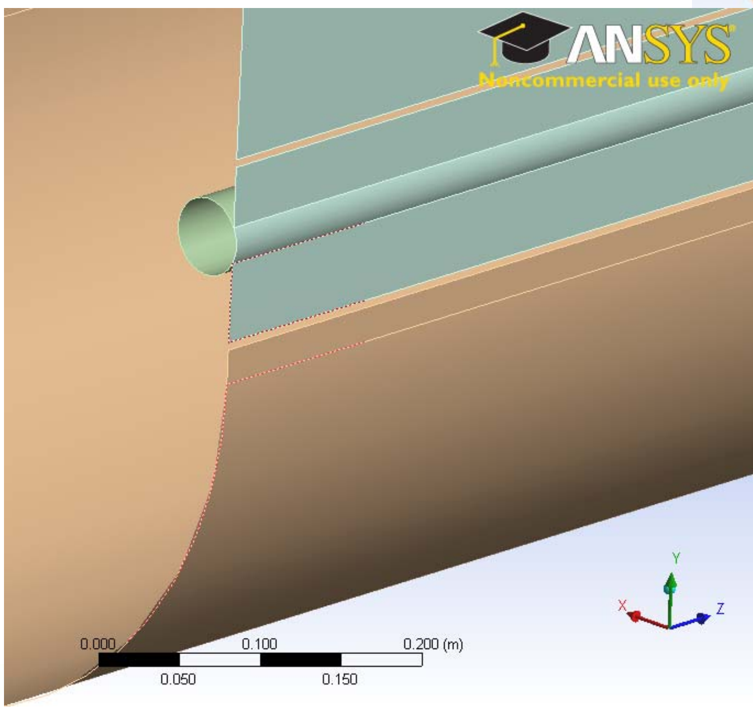
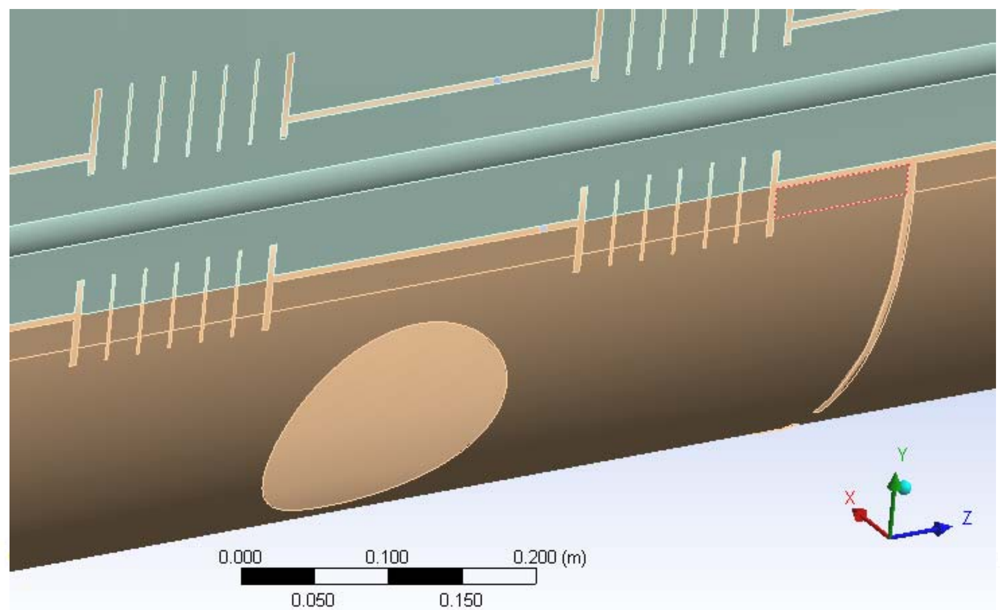
4 K shield

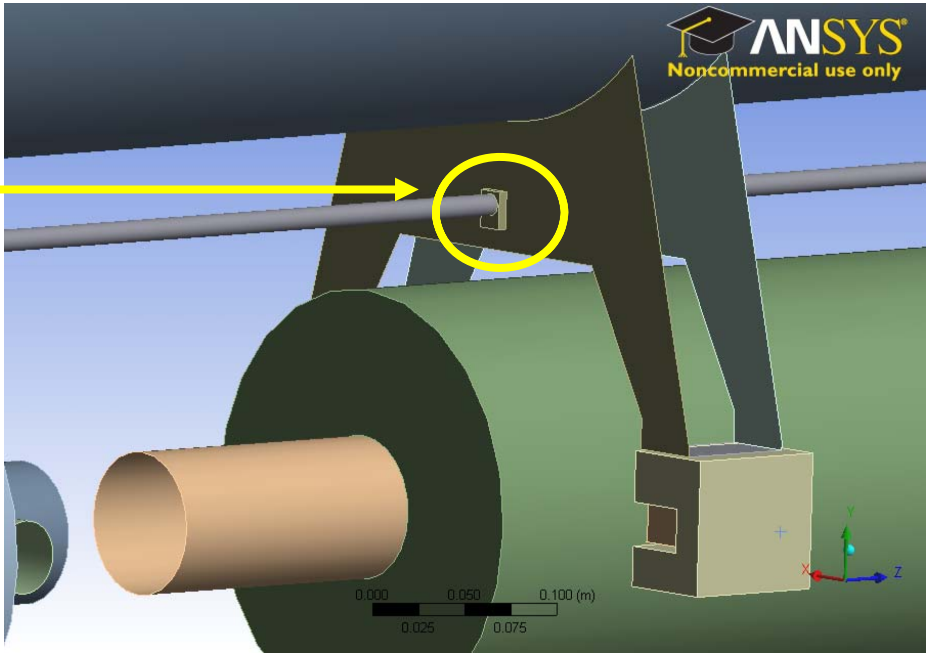




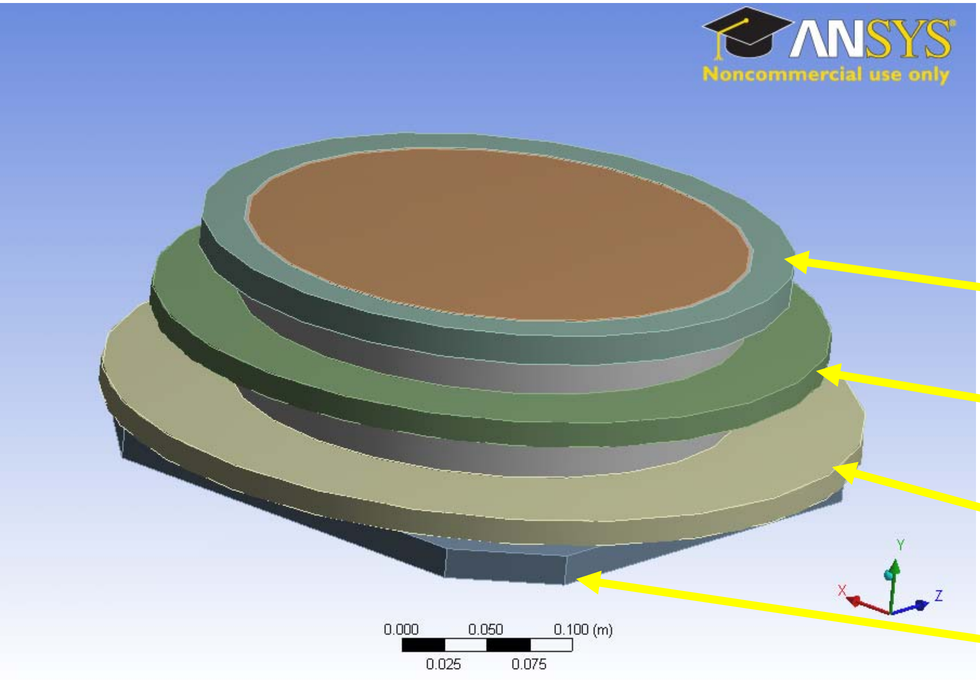
S1_Global: thermal analysis



Post and invar rod



Fixed invar rod position to GRP



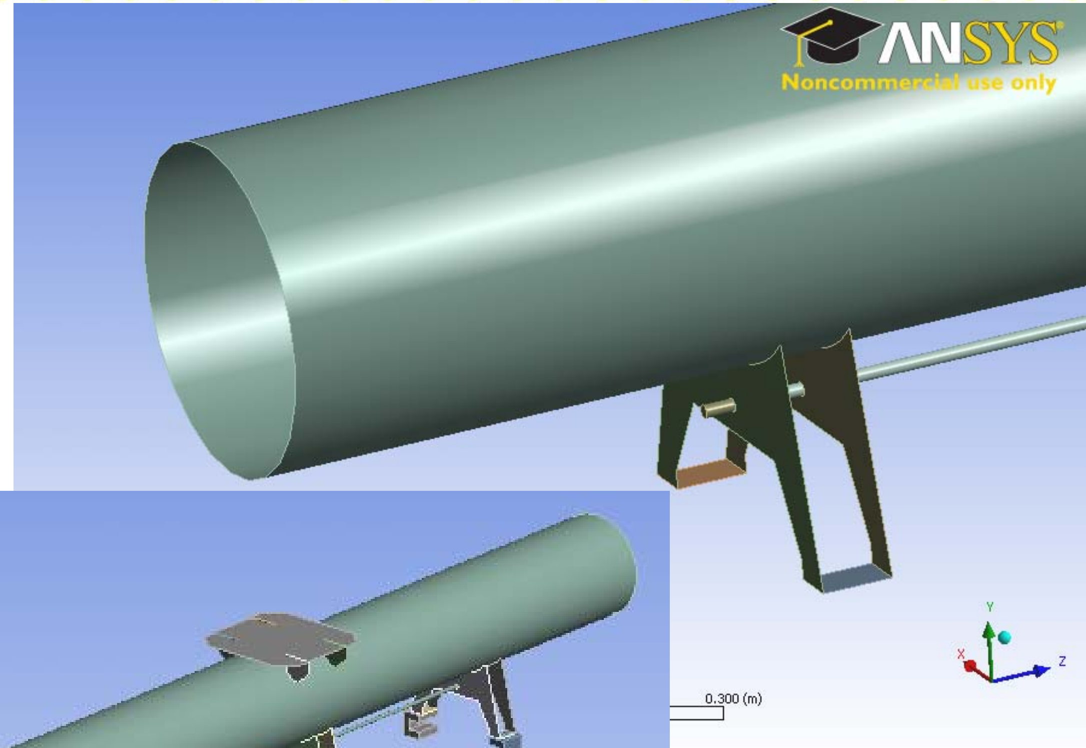
300 K

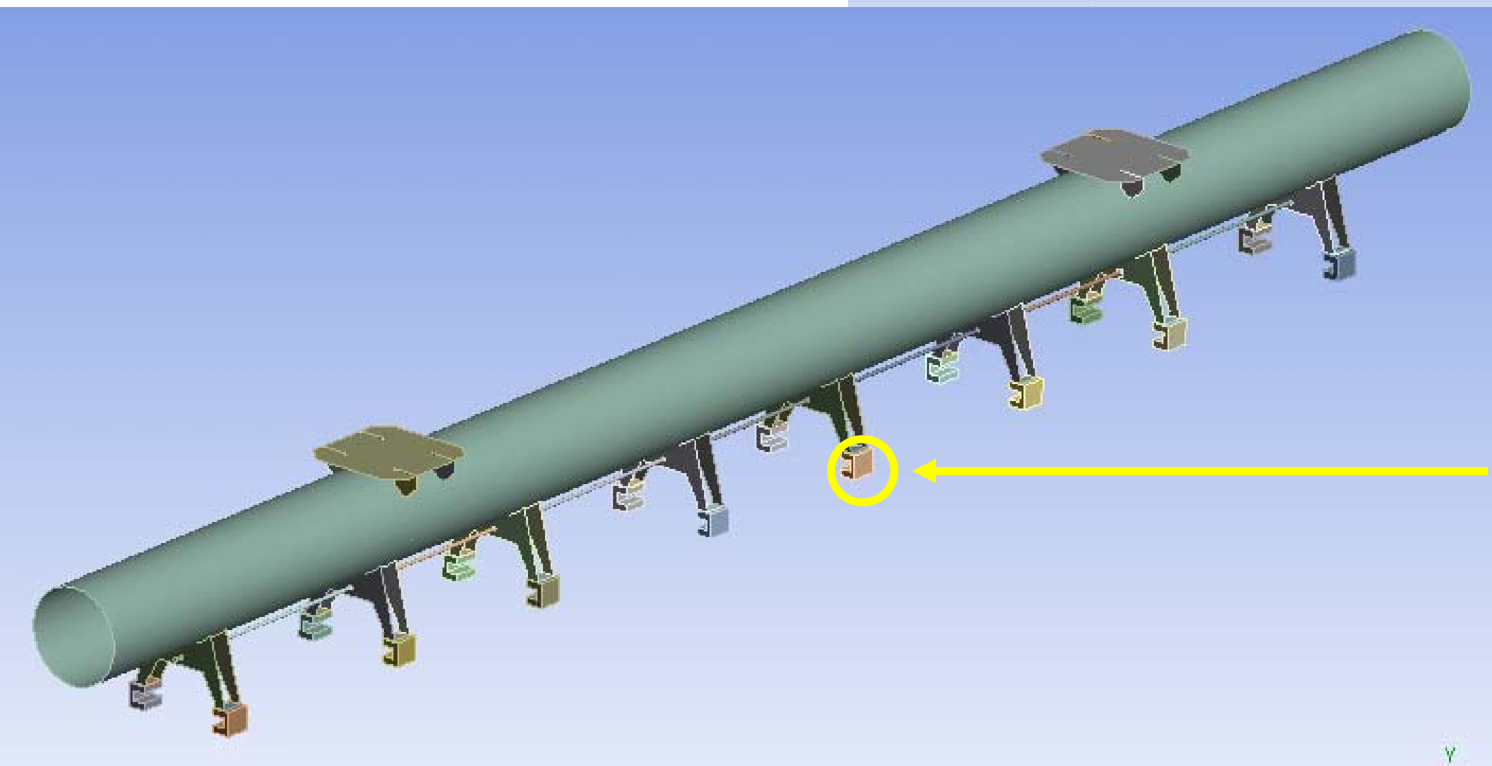
70 K

5 K

2 K

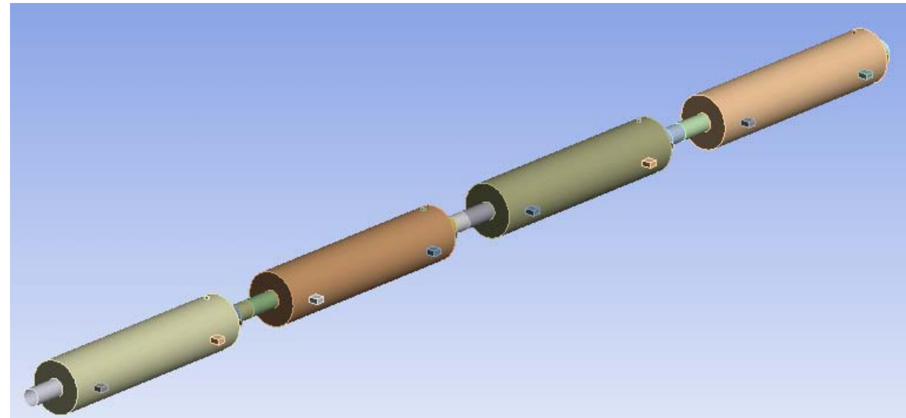
GRP and string support parts



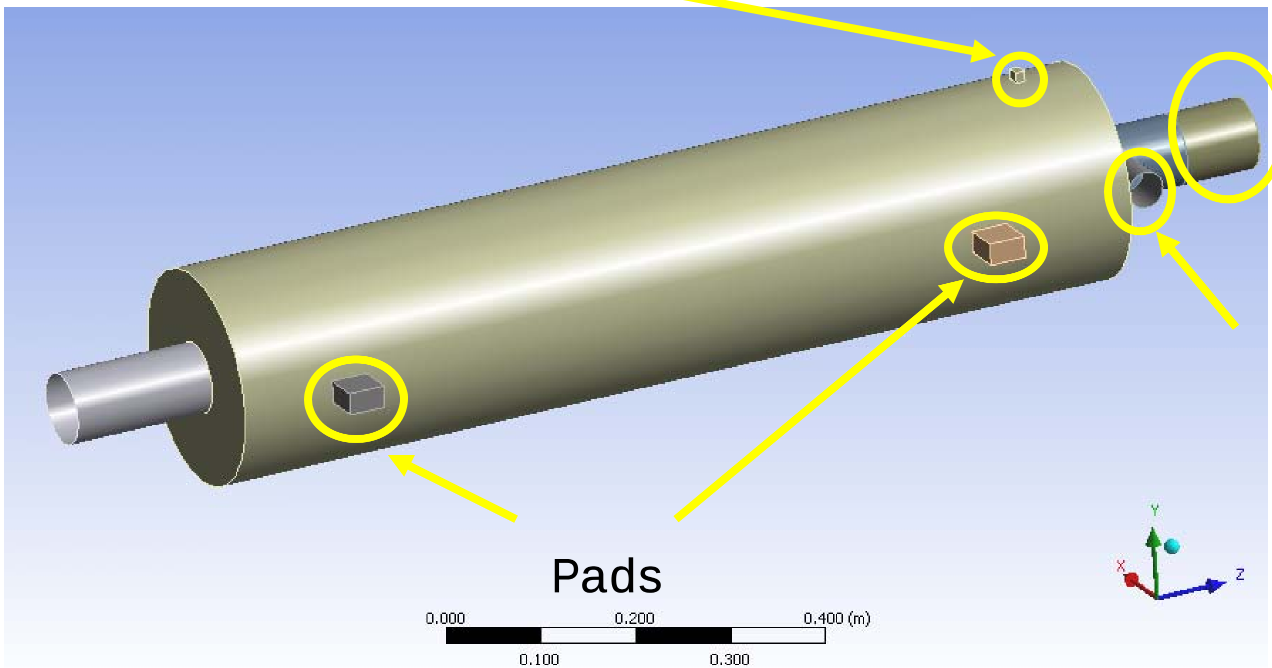


C-block for supporting cavity at pads (as frictionless contacts)

Cavities (simplified)



Connection to invar rod



Beam pipe bellow (very soft component)

Coupler port (Heat sink for tabular 2 K load...)

1° case: Static Loads

- Imposed boundary temperatures:
  - **300 K at upper post surface**
  - **77 K at shield cooling pipe surface**
  - **5 K at shield cooling pipe surface**
  - **2 K at GRP and tank surfaces**
- Heat flux (radiation through MLI):
  - **1 W/m^2 at 77 K shield surface**
  - **0.05 W/m^2 at 5 K shield surface**
- Heat flow (conduction of RF cables/couplers):
  - **0.1 W at 2 K coupler port on cavity**
  - **1.0 W at the thermalization on 5 K shield**
  - **8.9 W at the thermalization on 77 K shield**

Data for static loads

Data from Tom Petersen (FNAL)

2K	*notes*
RF load	=0 (static)
Supports	Through model
Input coupler	See table
HOM coupler (cables)	See table
HOM absorber	= 0
Beam tube bellows	= 0
Current leads	= 0 (no quad)
HOM to structure	= 0
Coax cable	= 0
Instrumentation taps	= 0

5K / 77K	
Radiation	From MLI data
Supports	Through model
Input coupler	See table
HOM coupler (cables)	See table
HOM absorber	= 0
Current leads	= 0 (no quad)
Diagnostic cable	to be calculated

Literature data

Radiation	*W/m^2*	heat flux at shield surfaces
2K	-	
5K	0.05	
77K	1	

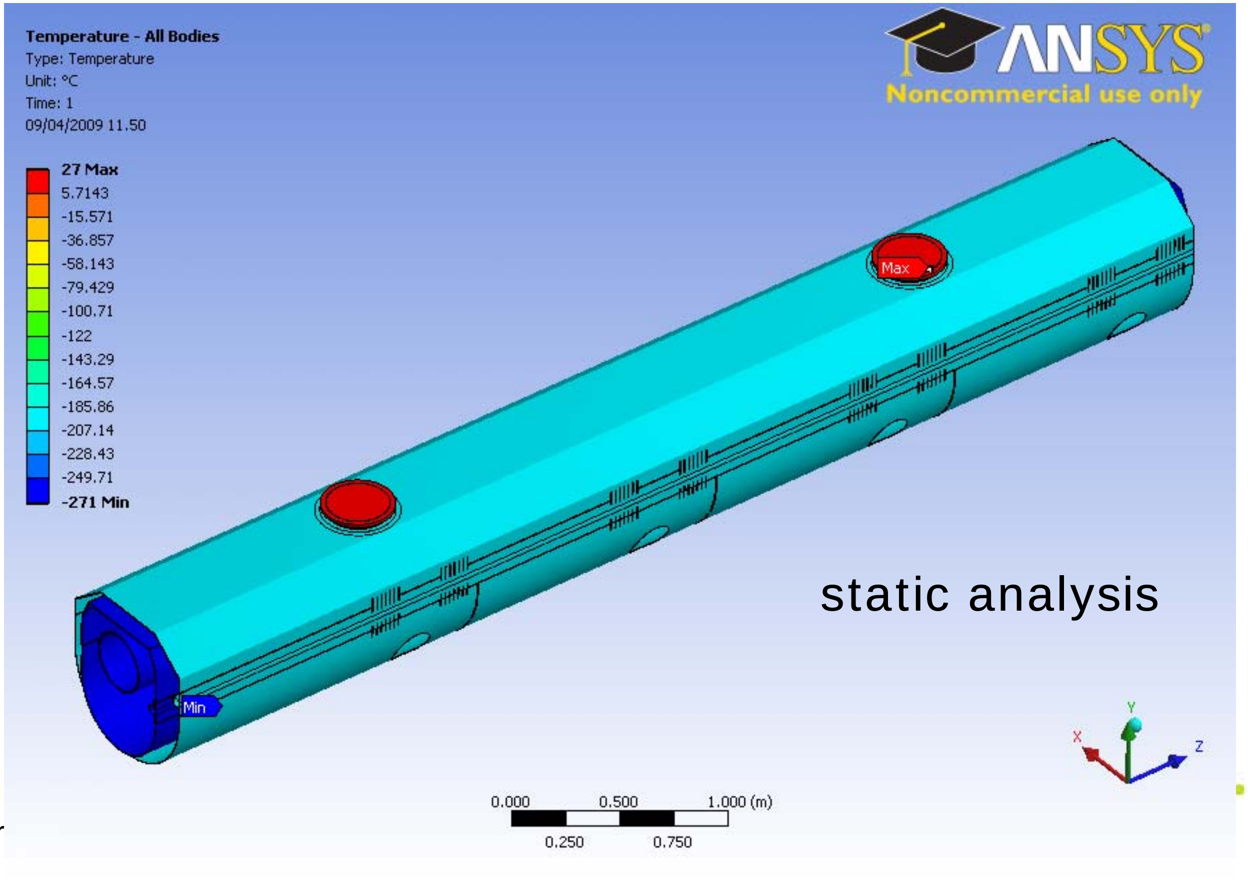
Conduction at couplers	*W*	heat flow on coupler thermal intercepts
2K	0.08	Scaled from TTF data presented at Linac04
5K	0.8	
77K	7.6	

Conduction of RF cables	*W*	heat flow on coupler thermal intercepts
2K	0.005	Scaled from Tesla TDR data
5K	0.2	
77K	1.275	

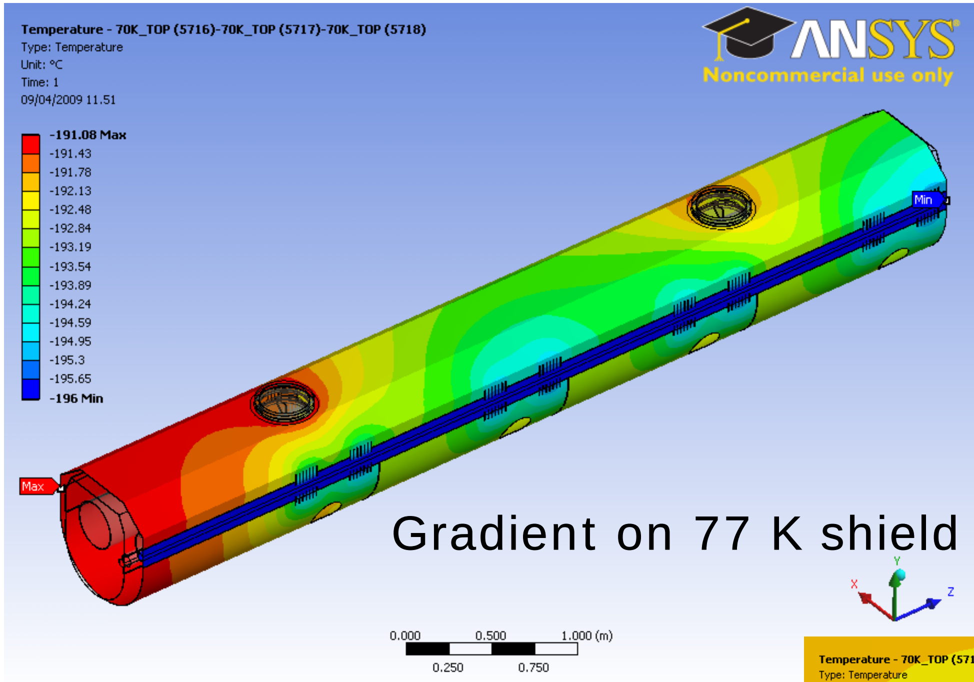
Total conduction at coupler	*W*	effective heat flow on the model
2K	0.1	
5K	1.0	
77K	8.9	

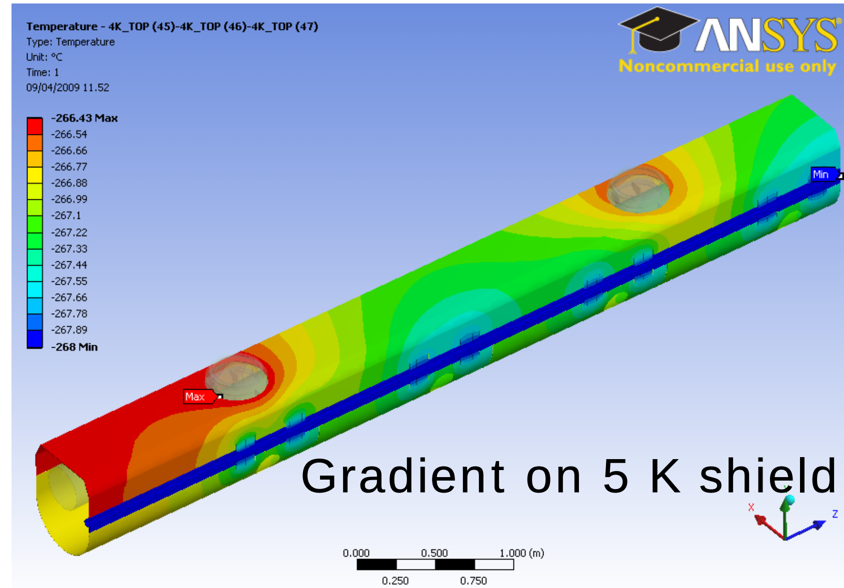
Computed static heat loads

- At 2 K: 0.14 W
- At 5 K: 4.0 W (radiation ~0.7 W)
- At 77 K: 43.3 W (radiation ~ 16 W)

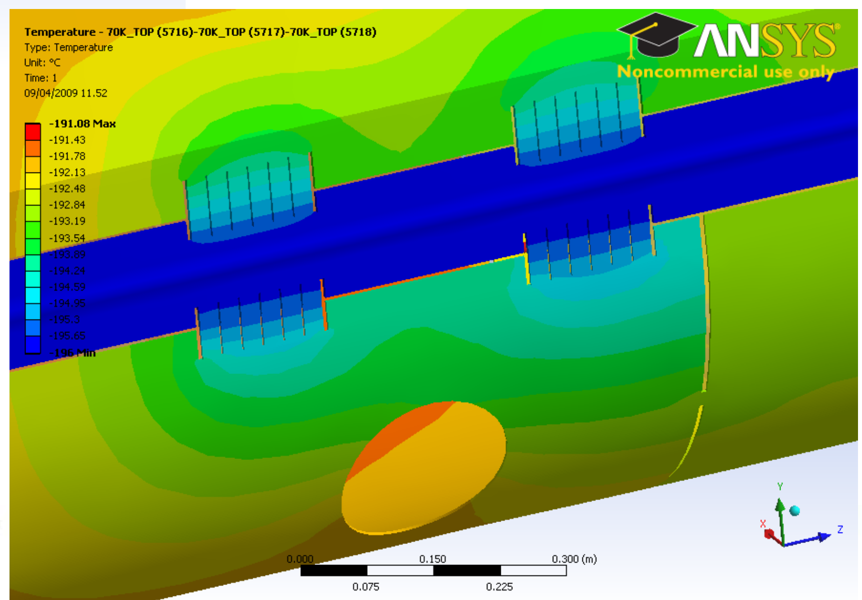


Static simulation: results

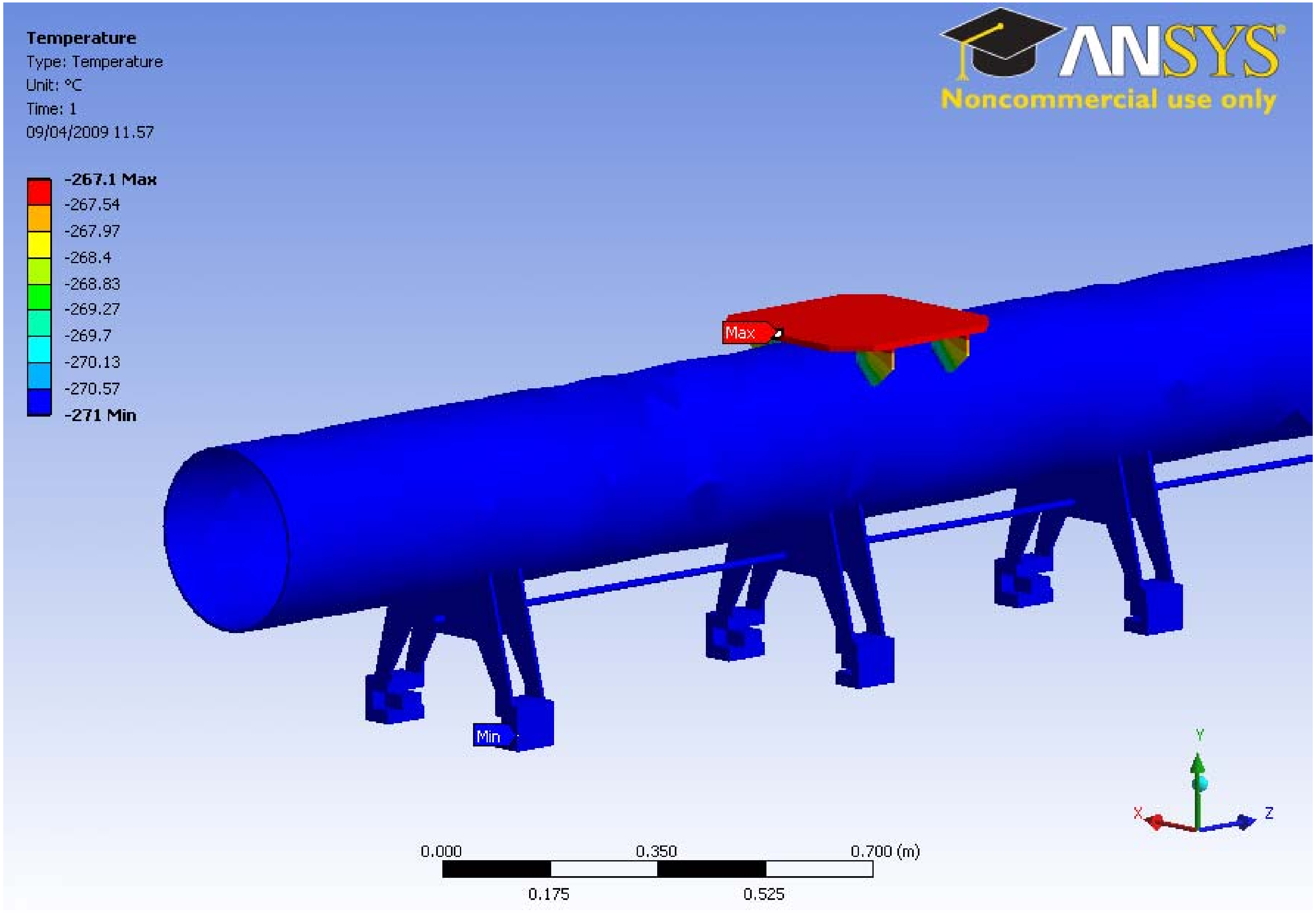




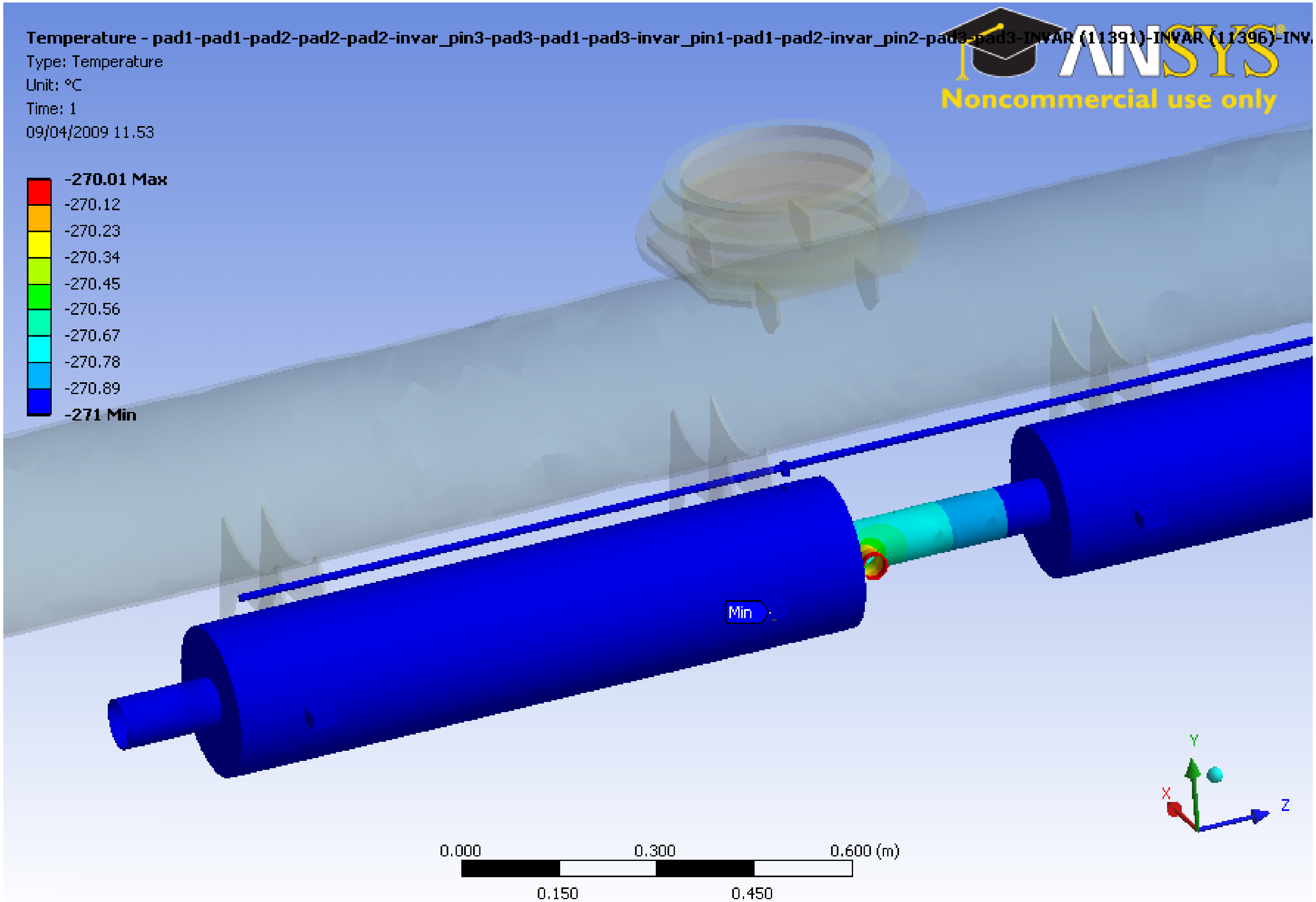
Conduction path only through welded fingers
(worst case of no thermal contact between mating surfaces ands strong choking of thermal flux)



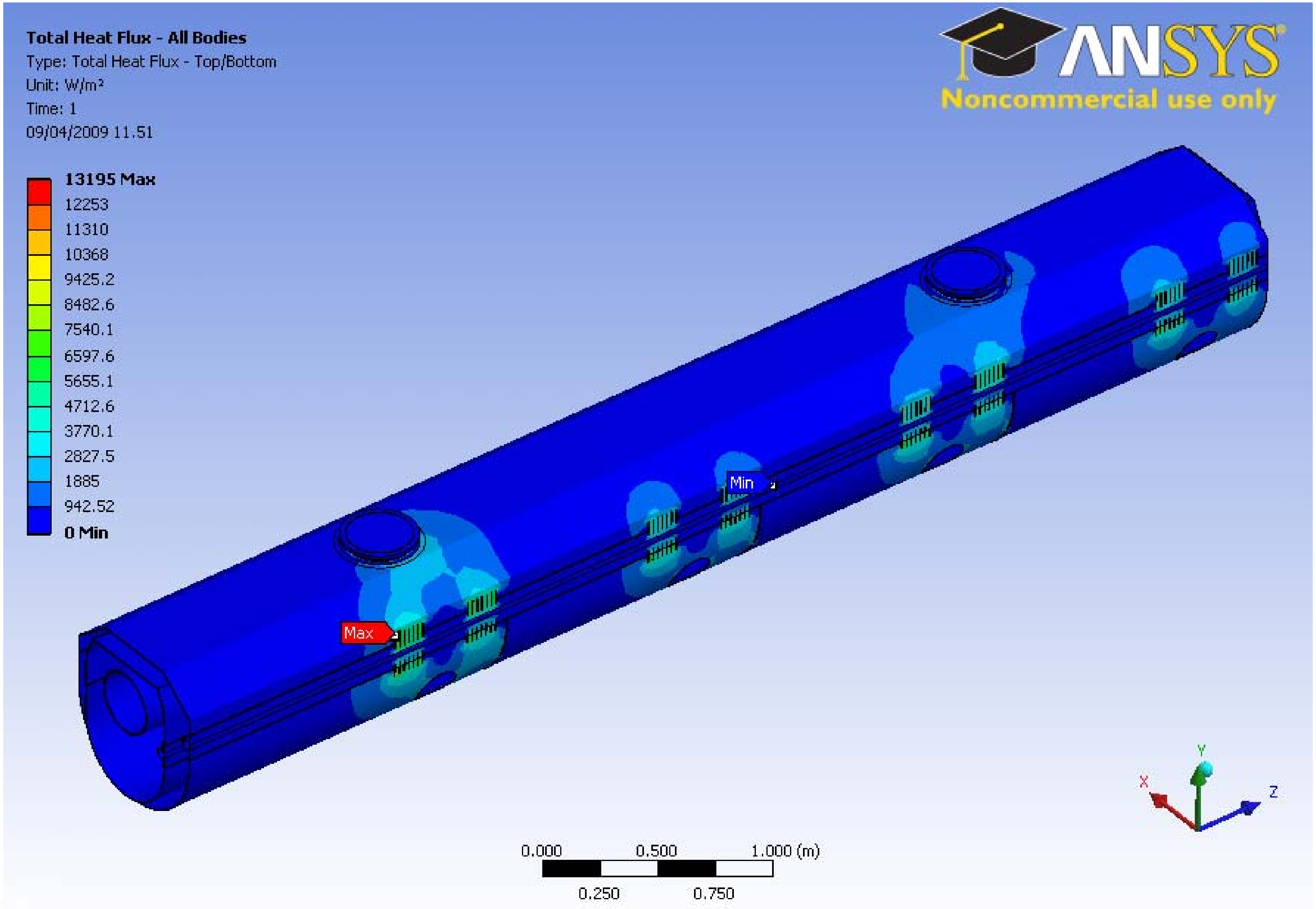
Results: GRP, shapes, invar



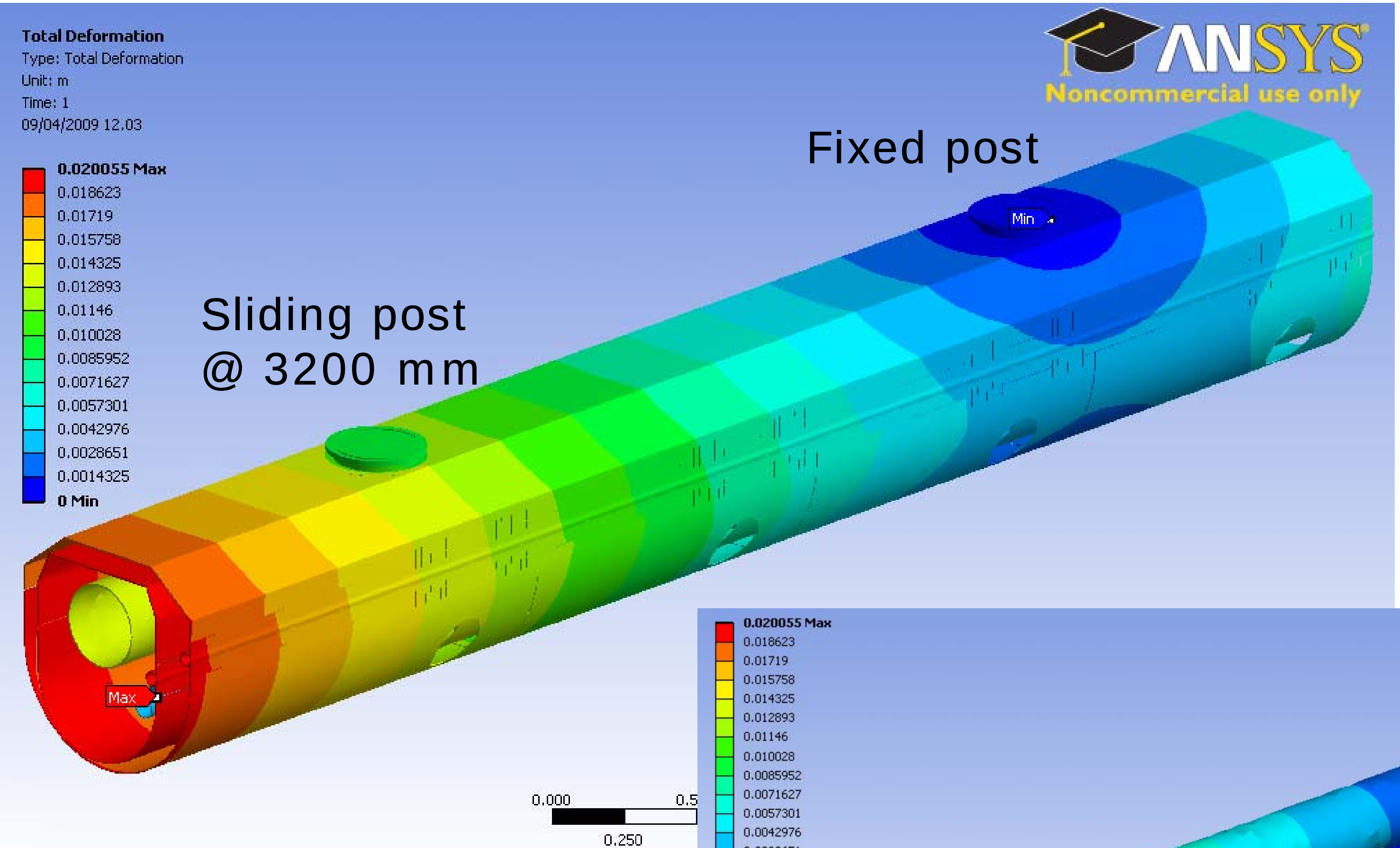
Results: cavity string

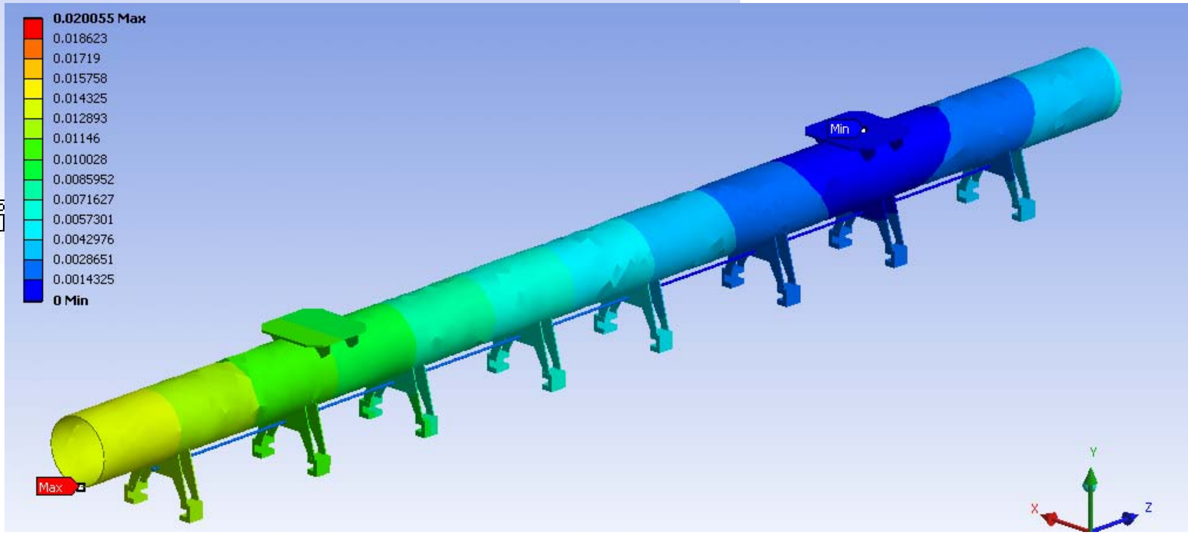


Results: heat flux

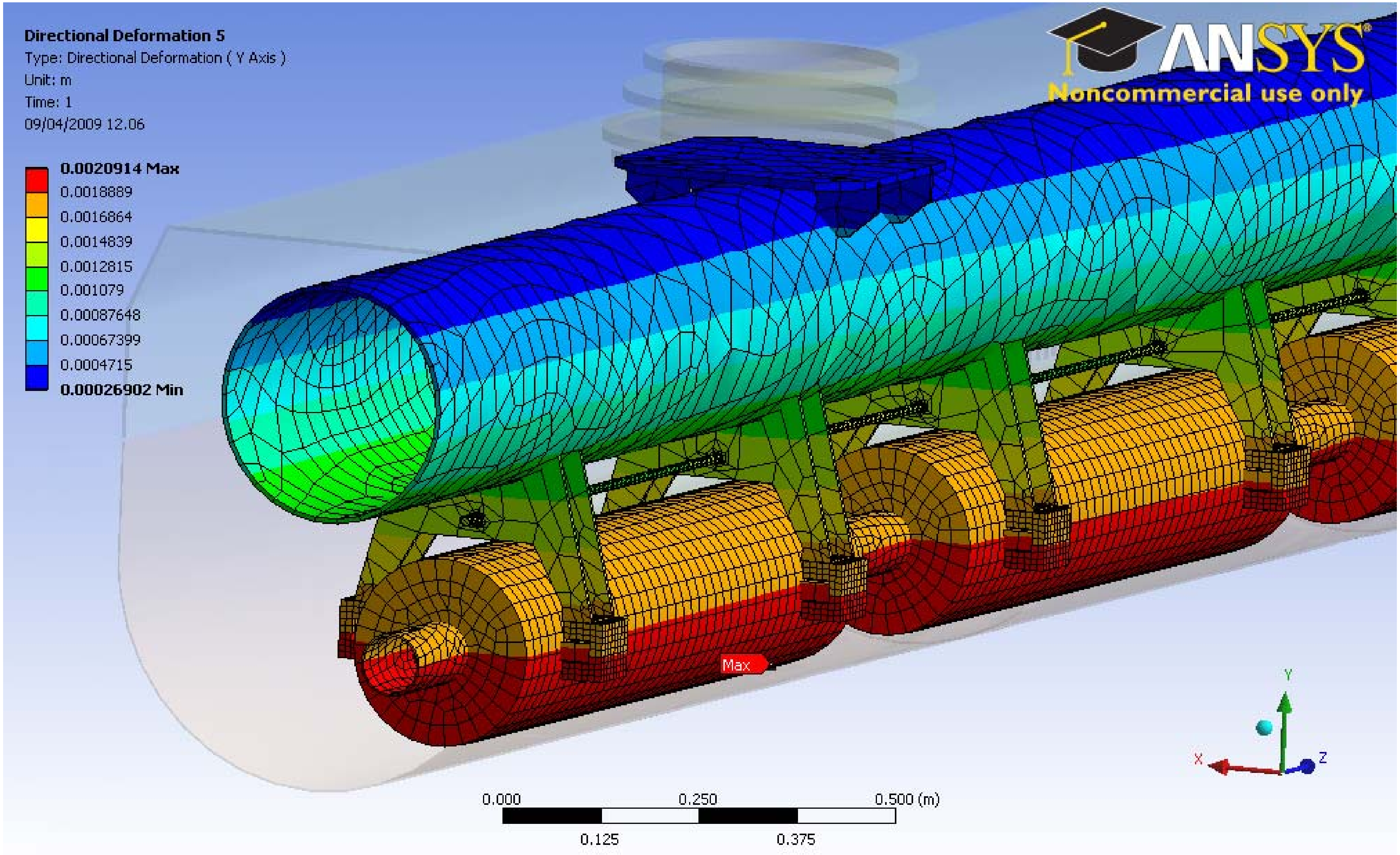


Structural analysis, deformations

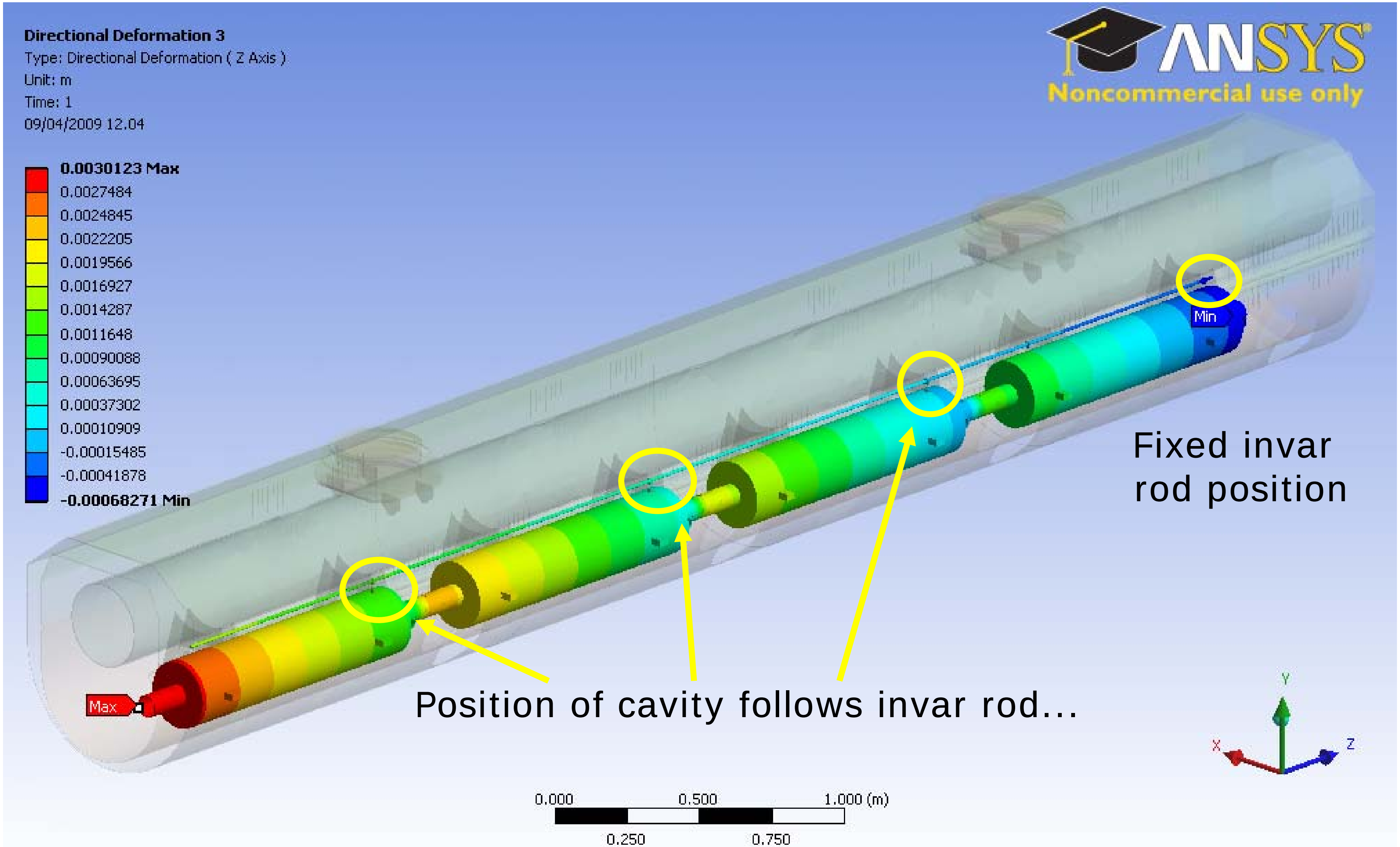




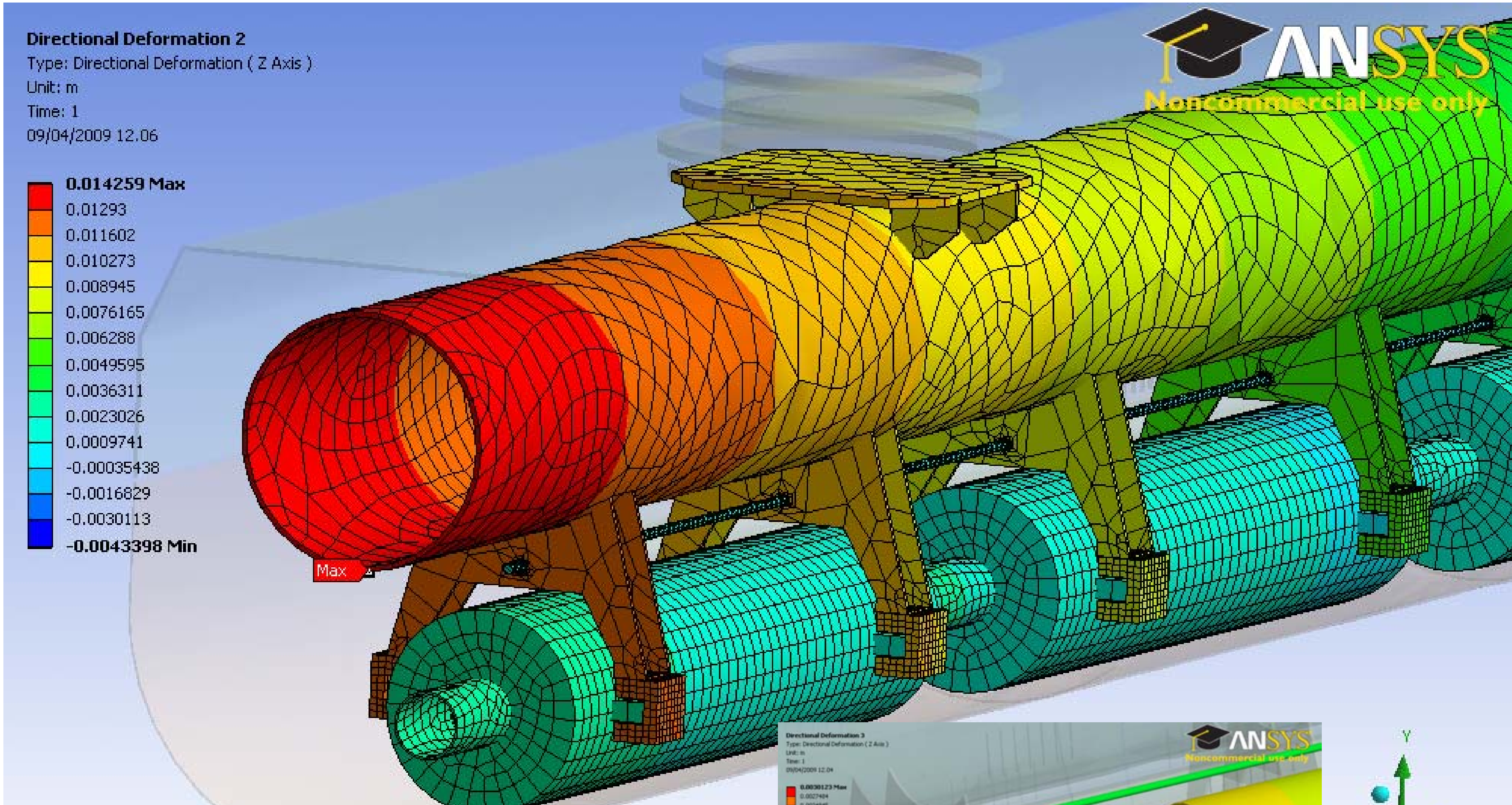
Vertical displacement…



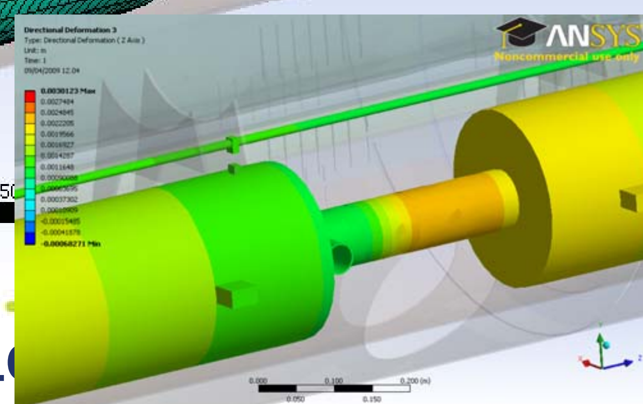
Longitudinal behavior



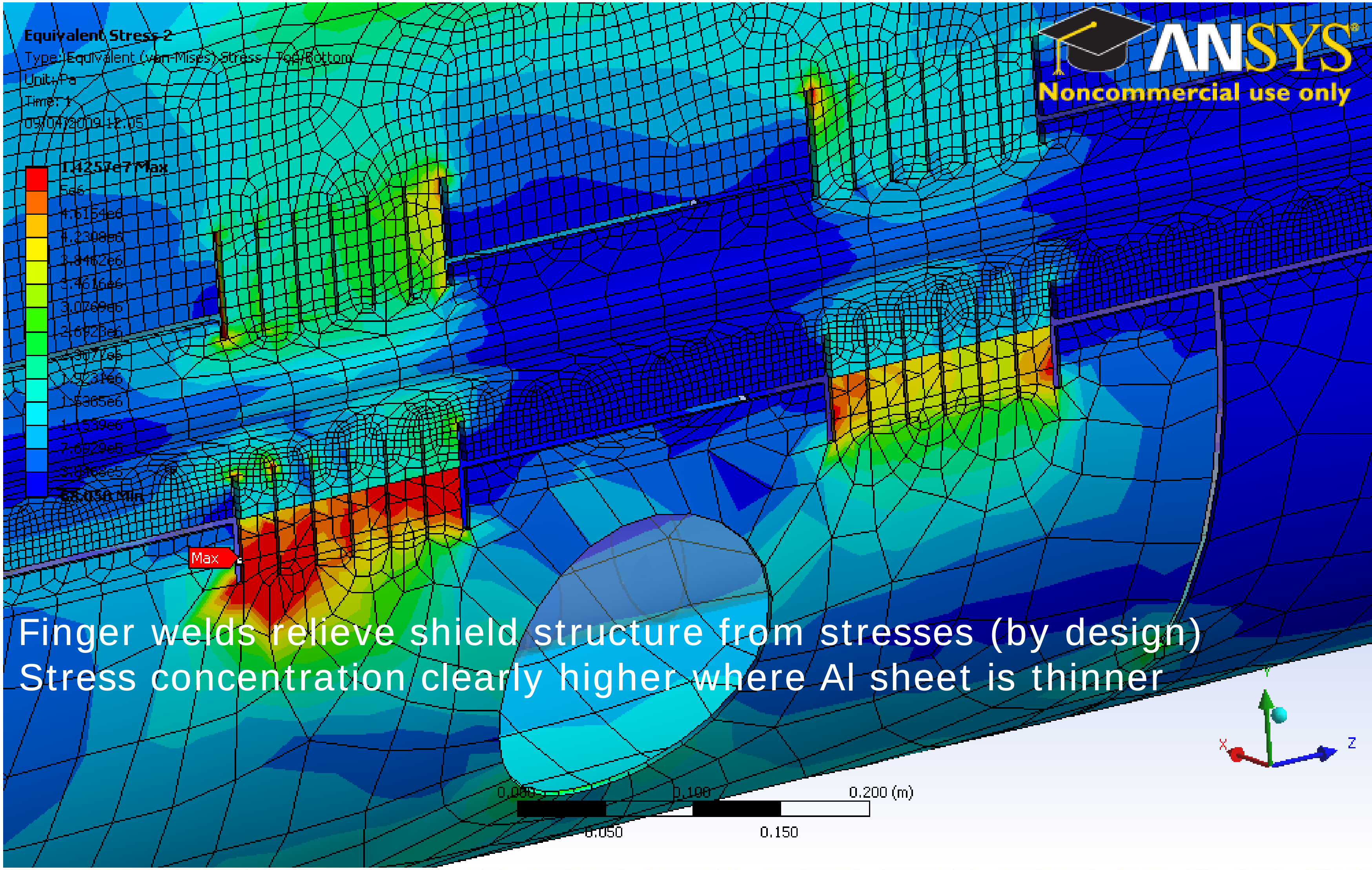
Evident comparing with GRP



Longitudinal cavity position decoupled from GRP, follows invar



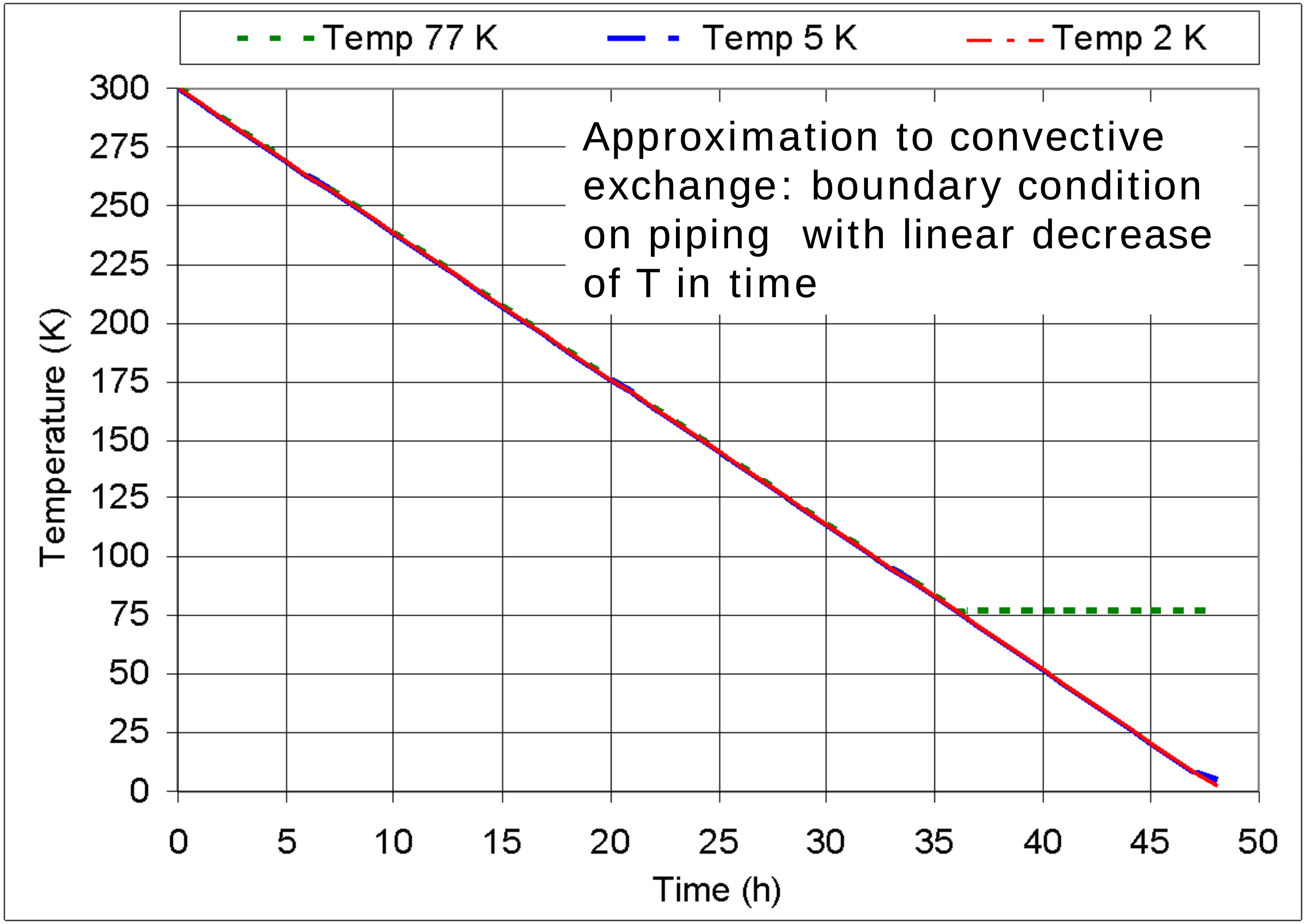
Structural analysis, stresses



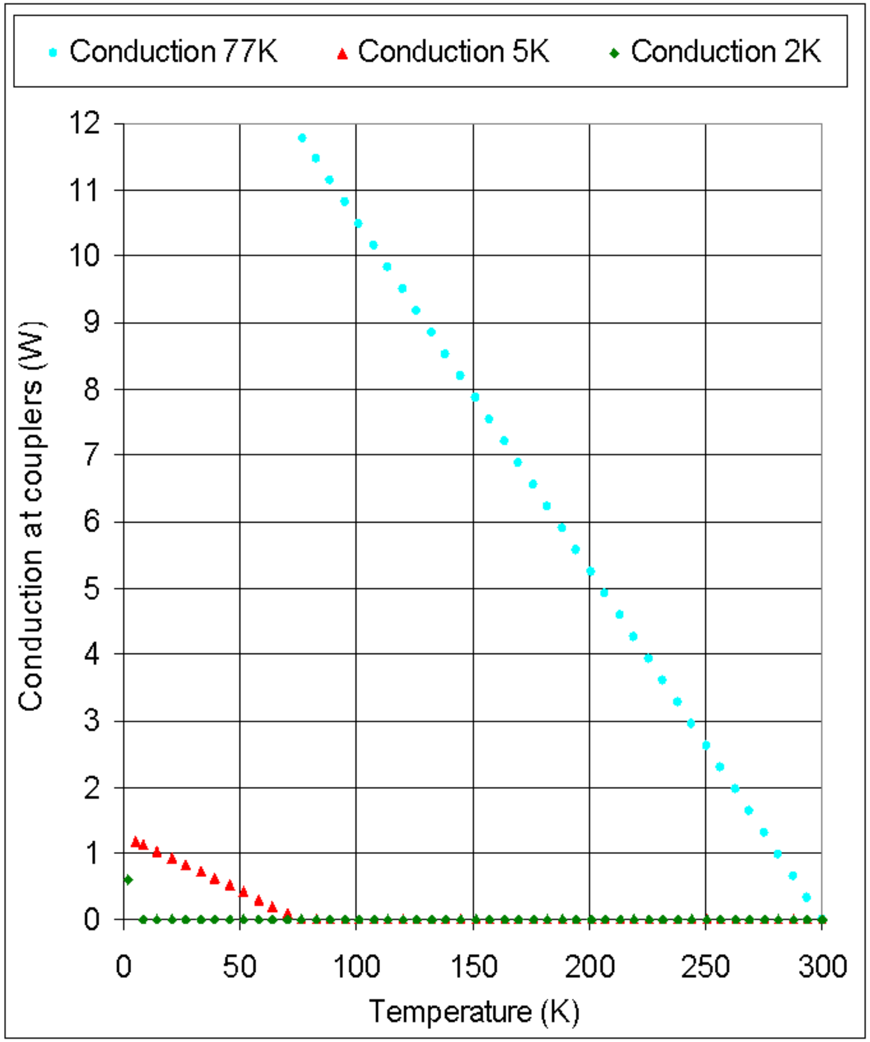
Finger welds relieve shield structure from stresses (by design)

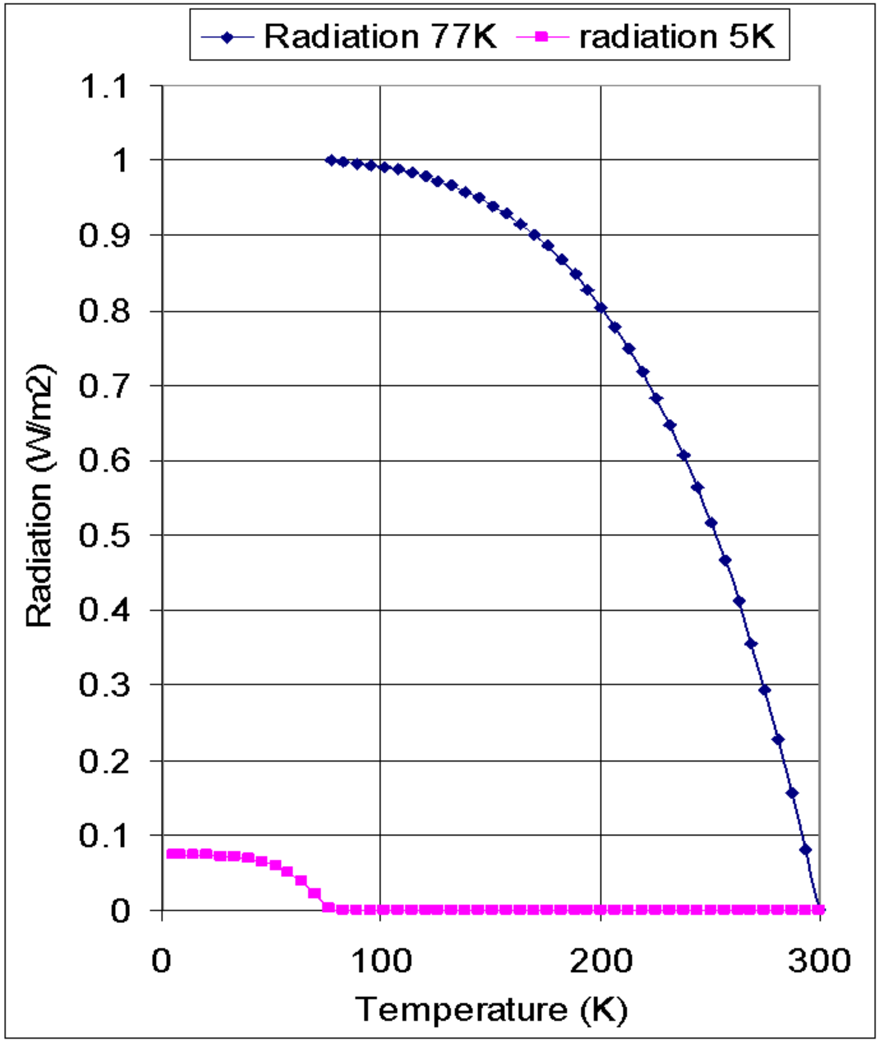
Stress concentration clearly higher where Al sheet is thinner

Transient loads: T decrease

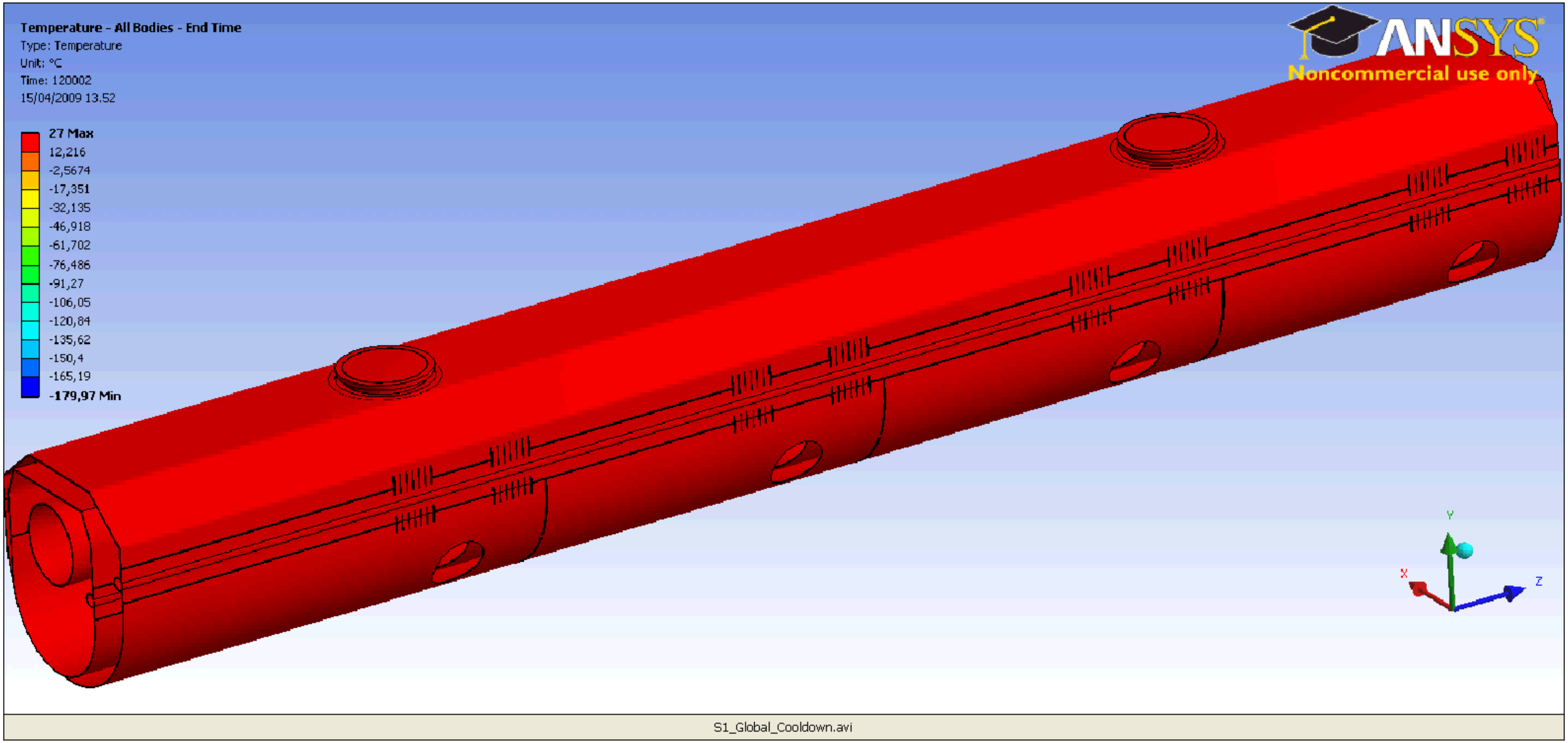


Scaling of transient loads

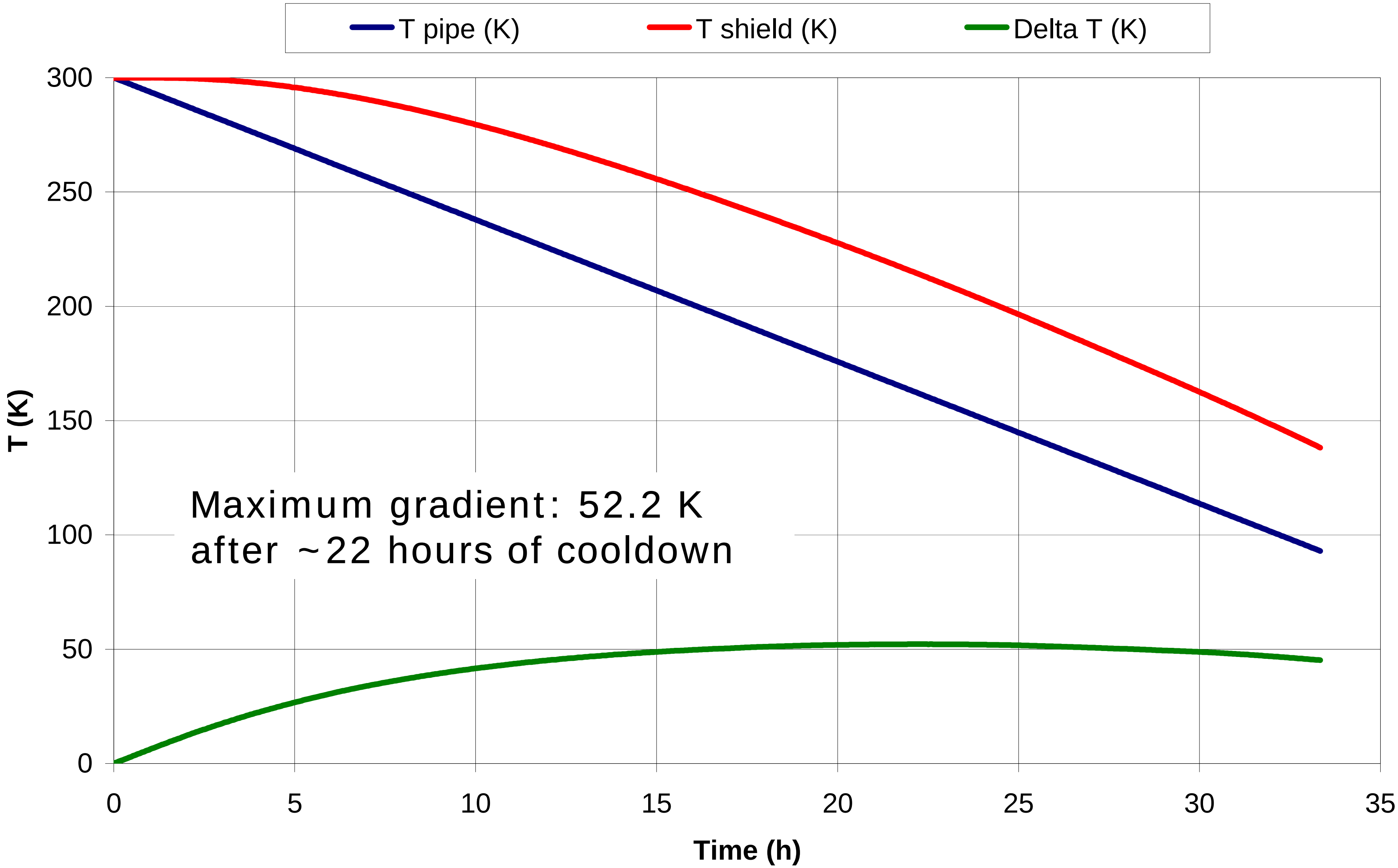




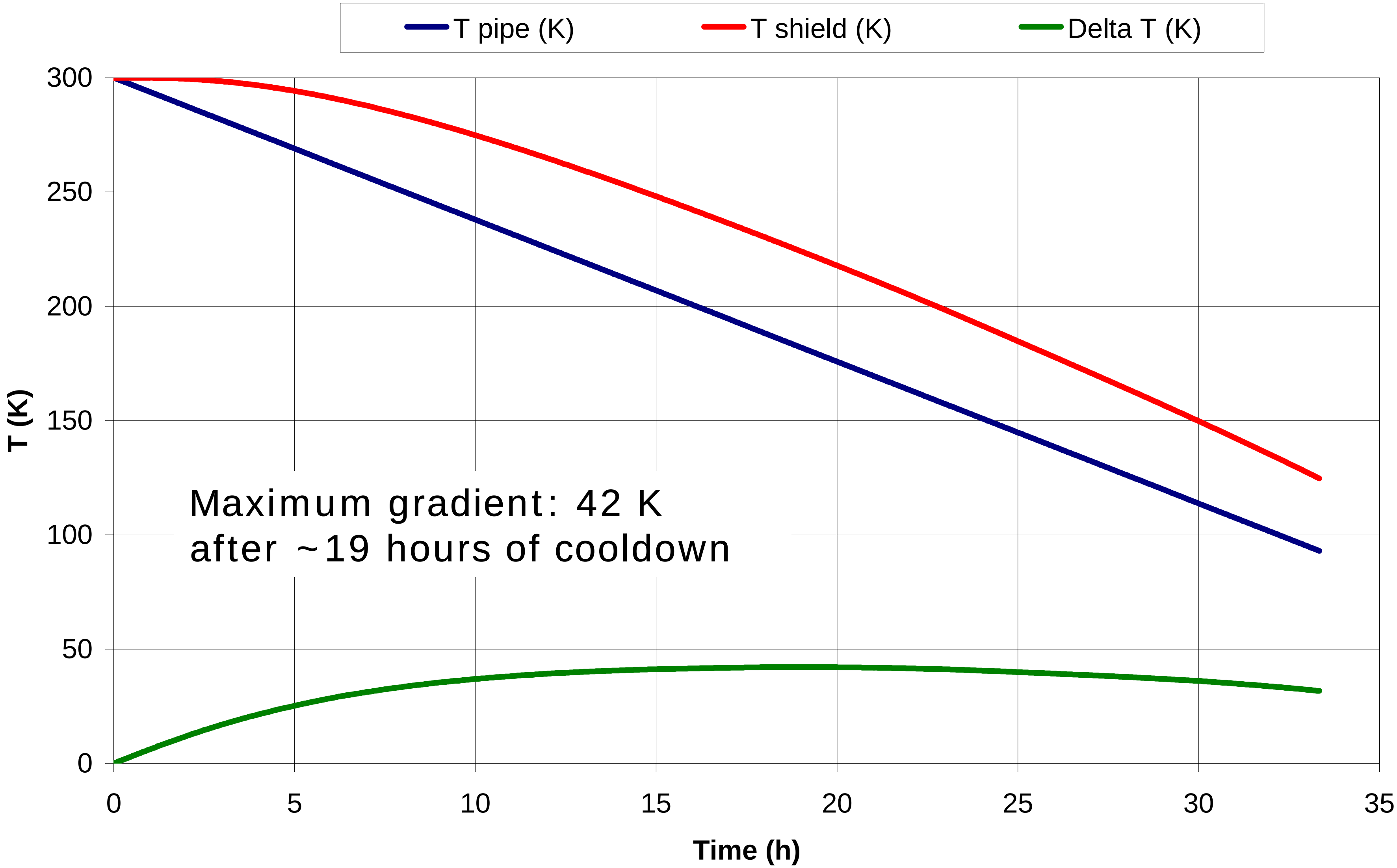
Transient simulation: results



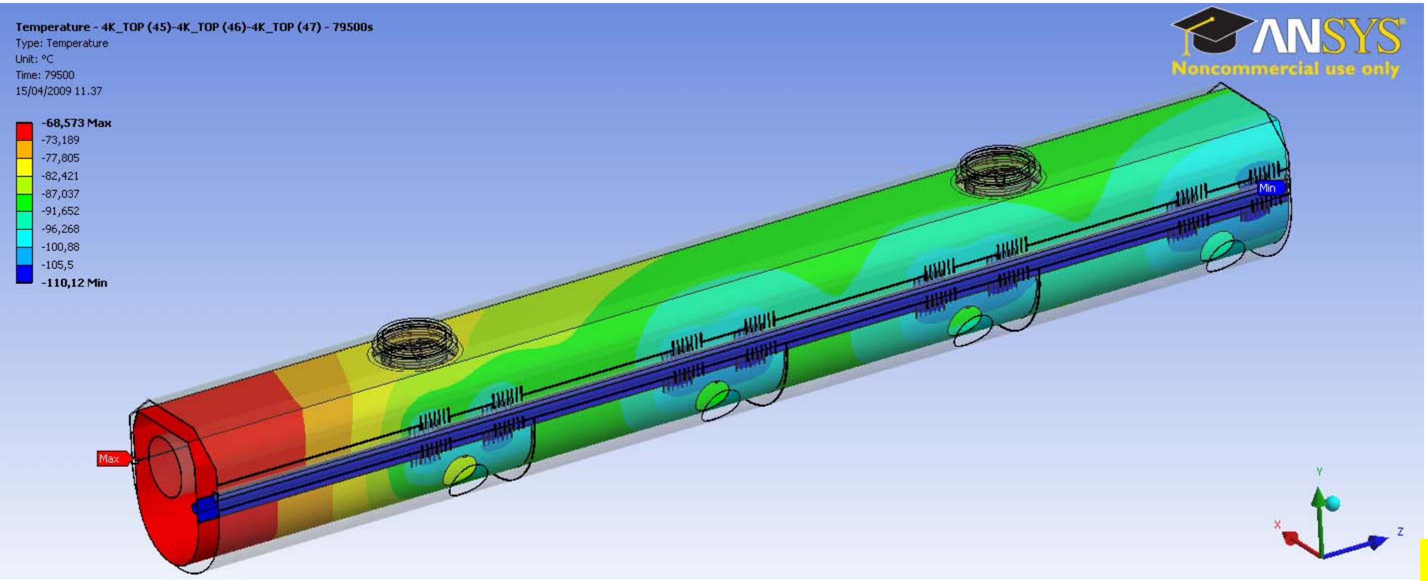
Transient ΔT on the 77 K shield



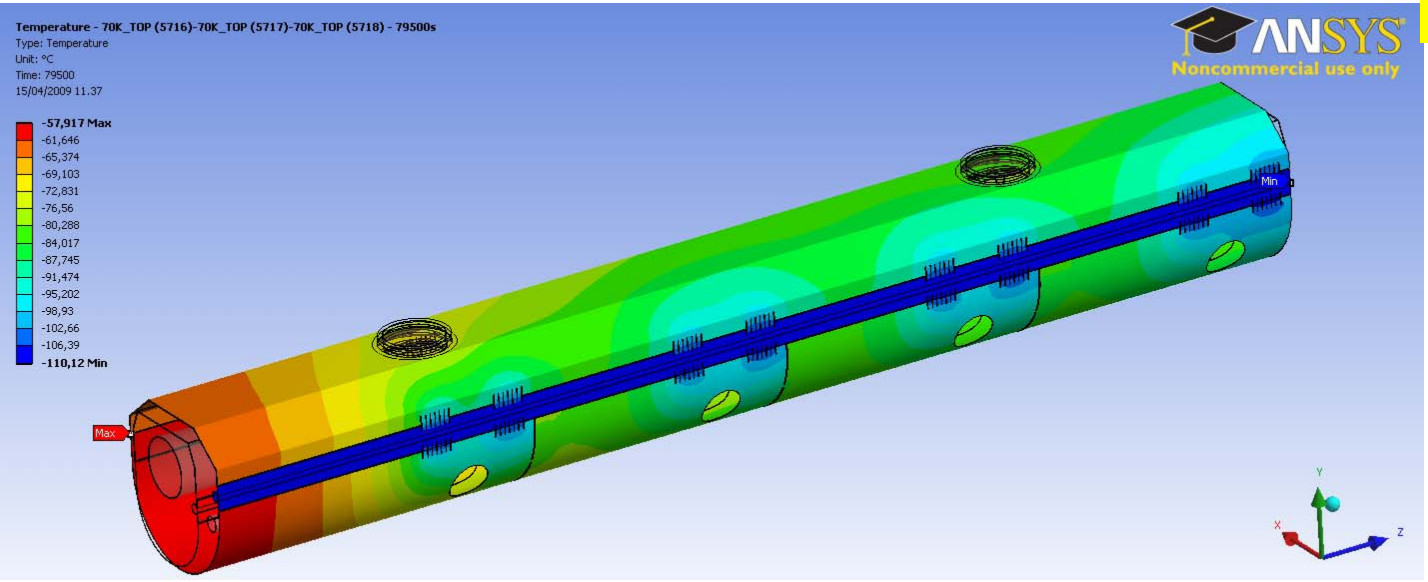
Transient ΔT on the 5 K shield



T distribution at max ΔT



5 K shield



77 K shield

to do → Stress analysis at max gradient on structures

Next steps: on model

- Perform stress analysis with temperature distribution corresponding to the maximum gradient on the inner cold mass components

- Increasing model complexity
  - **Perform simulations with convective exchange at pipe surfaces (instead of fixed temperatures)**
    - Later, possibly coupled to 1-D fluid elements for longitudinal gradients and heat exchange with fluid flowing in cooling channels
  - **More accurate conduction paths (couplers?)**

Next steps: analysis & benchmark

- Use KEK cooldown procedure as input data for the transient simulation
  - **gather all fluid parameters and evolution with time (mass flow, pressure condition, etc.)**

- Verification of analysis with experimental data collected at KEK by S1_Global collaboration during cryomodule tests
  - **How far can we rely on simulations with increasing complexity for the assessment of different module designs?**