Radiation Tolerance of Thermal Interface Materials

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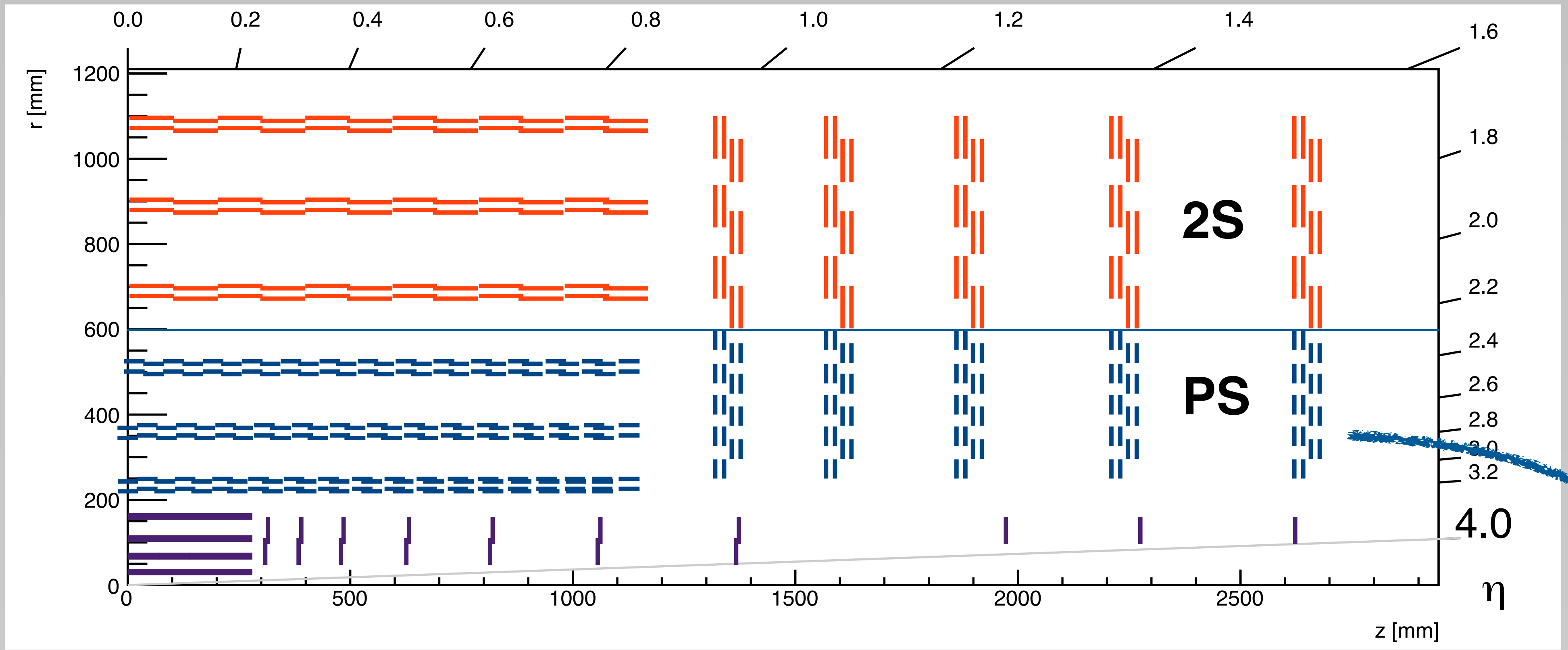
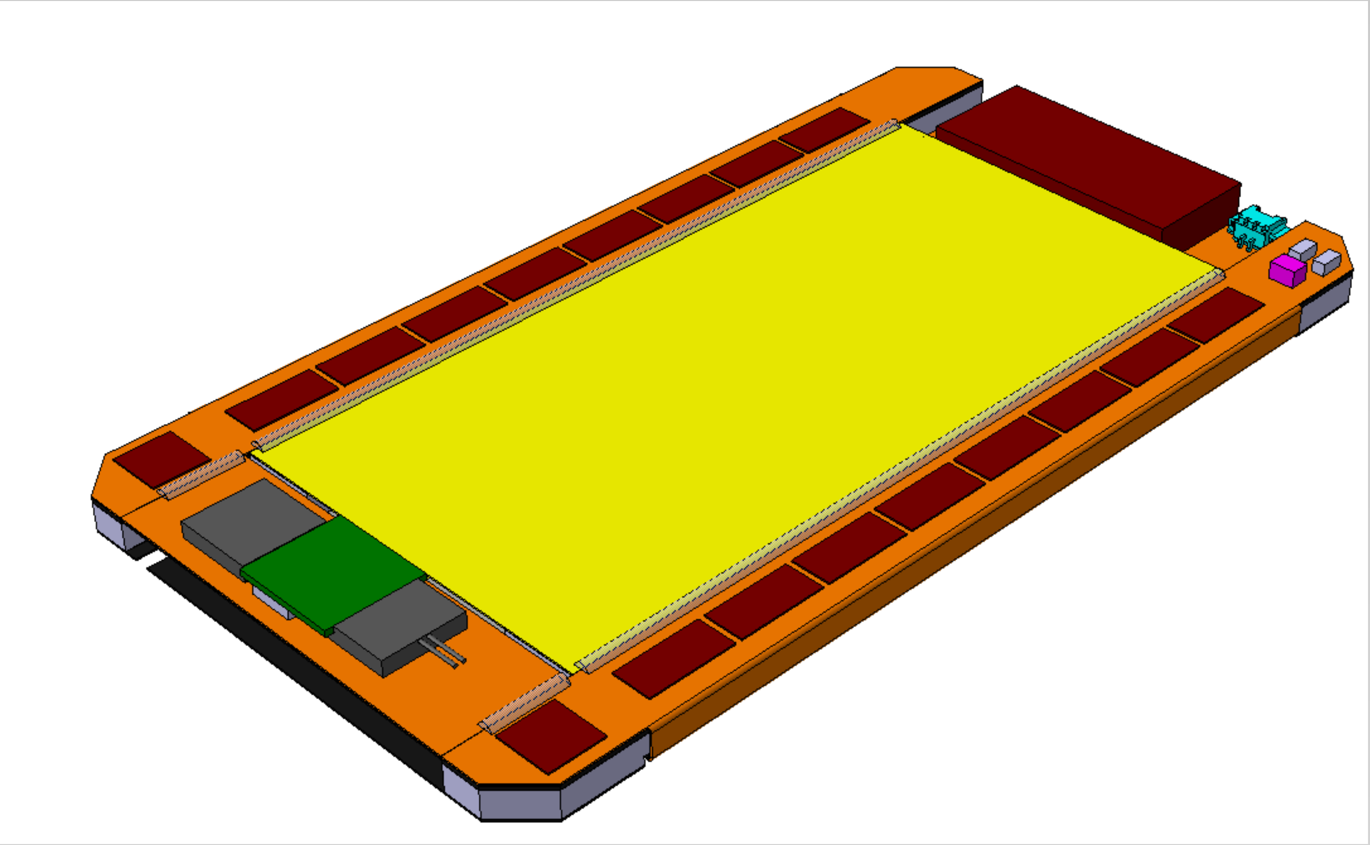
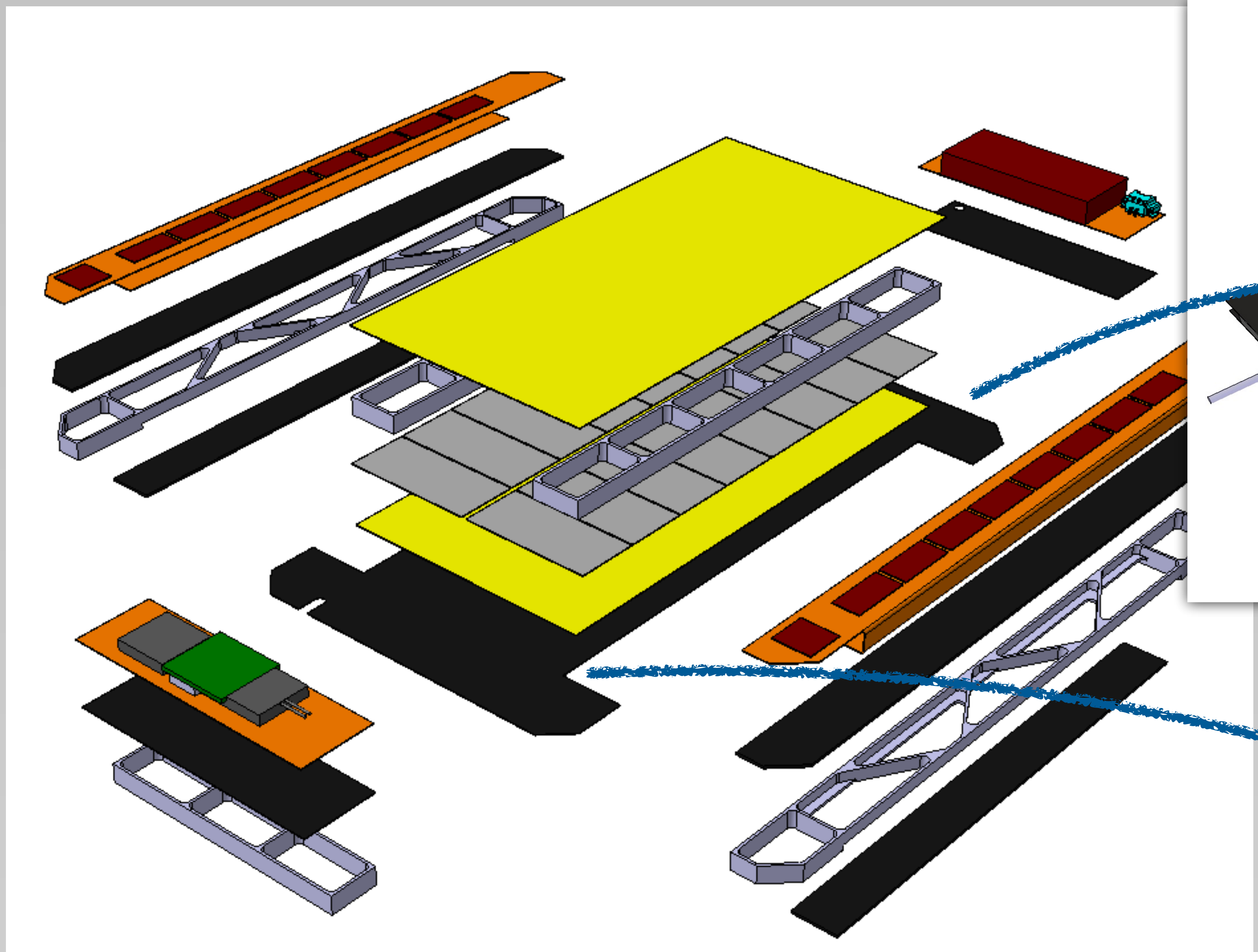
Introduction

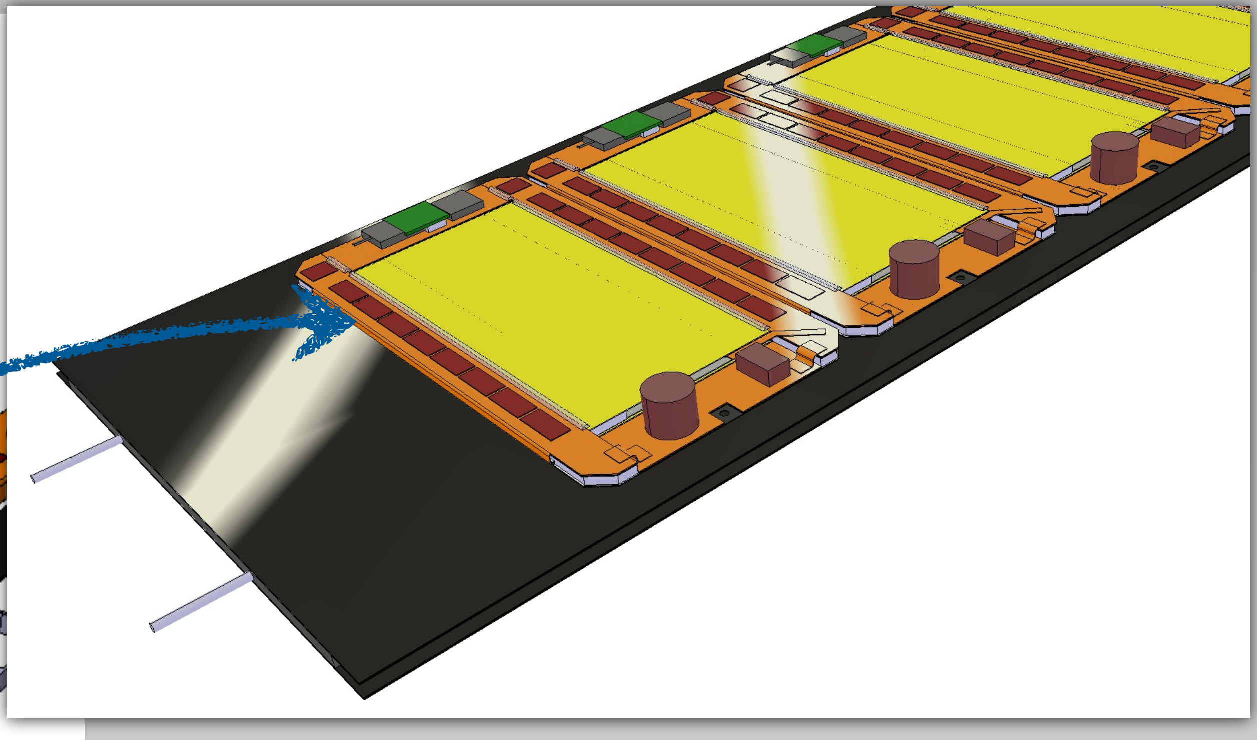


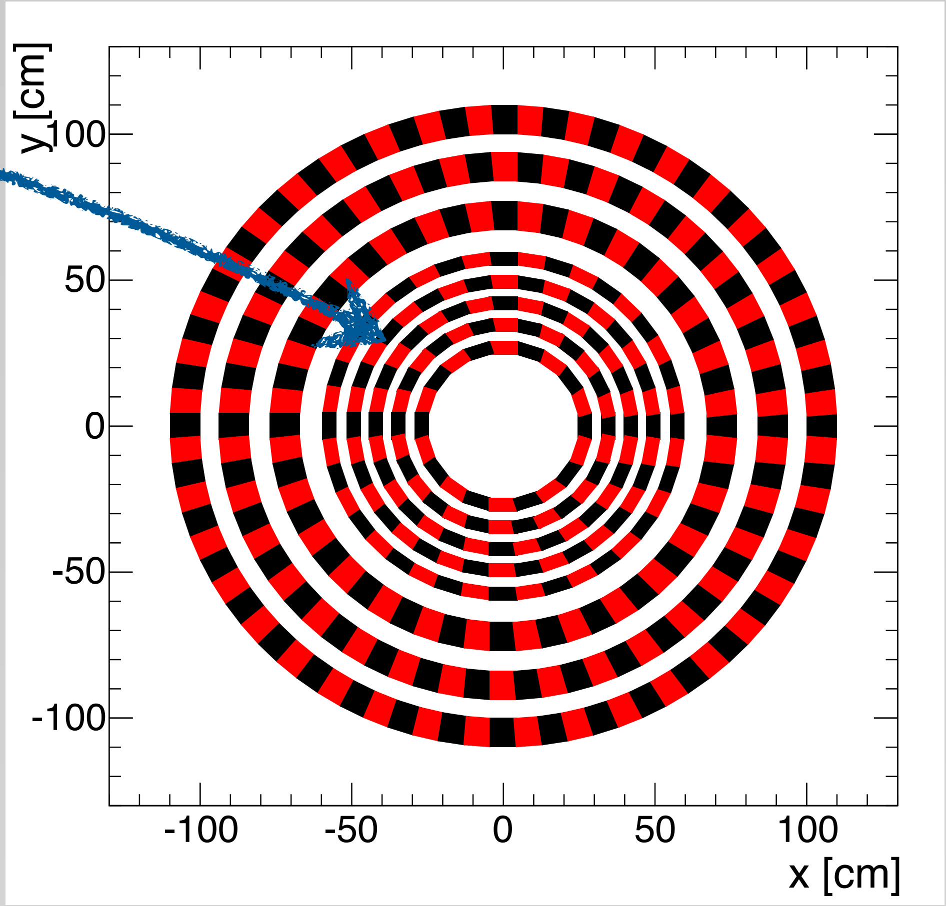


- new CMS tacker will be equipped with two module types
  - 2S modules at r > 60 cm
  - PS modules at r < 60 cm
- 2S modules have five cooling / mounting points
- PS modules require a large-area interface to the cooling structure
  - modules are directly ‚glued' to the support

Introduction







- 27 - 32 PS modules per barrel ladder
- 64 - 78 PS modules per end cap support structure
- we need a material with low thermal impedance …
  - high thermal conductivity and low thickness
- … that is radiation tolerant and reworkable
  - removal of module should not damage support structure

(Phase-Change) Thermal Interface Materials

Manufacturer	Glue	Thickness [mm]	Thermal conductivity [W/m/K]	phase change or burn-in temp.	Density [g/cc]	Operation range	Comment
Laird Technologies	Tpcm 905C	0.130	0.7	5 min @ 70°C	1.31	-25°C to +70°C	film
Laird Technologies	Tpcm 910	0.250	2.23	5 min @ 70°C	1.39	-25°C to +70°C	film
Laird Technologies	Tpcm 920	0.510	2.23	5 min @ 70°C	1.39	-25°C to +70°C	film
Laird Technologies	Tpcm 780SP		5.4	45°C to 70°C	2.48		printable paste
Laird Technologies	Tpcm 780	0.203 / 0.254 / 0.406 / 0.635	5.4	45°C to 70°C	2.48		film
Loctite	Isostrate 2000	-	0.45	60°C	-		on Kapton substrate
Honeywell	PCM45F	0.254	2.35	45°C	-		pad or tape
Parker Chomerics	Thermflow T725	0.125	1.41	55°C	1.1	-55°C to +125°C	film
Parker Chomerics	Thermflow T557	0.125	7.7	45°C / 62°C	2.4	-55°C to +125°C	film
Parker Chomerics	Thermflow T777	0.115	7.7	45°C / 62°C	1.95	-55°C to +125°C	film
Amec Thermasol	MPC 315	0.13	5.0	45°C	-	-40°C to 125°C	film
3M	5515	0.200 / 0.250	3.0	-	2.9	-	pad

- materials were selected based on
  - small thickness (< 0.150 mm)
  - low transition temperature (< ~60 °C)
  - minimum operation temperature < -35 °C
  - high thermal conductivity
  - low density
- tested materials are
  - T725
  - T557
  - T777
  - MPC 315

Test Samples and Irradiations

- TIMs are sandwiched between two Al plates - thermal test samples
  - 2 cm x 2 cm
  - Al plates are 1.5 mm thick
  - Al plates were glass pearl blasted to provide a uniform surface finish for all samples
- samples were ‚baked' at 65 °C for 90 minutes
  - no pressure was applied during process
  - this corresponds to the PS module use case
- additional samples for pull tests were prepared
  - first samples were already tested
  - unfortunately pull tester is not available at the moment
- samples were irradiated at Synergy Health Allershausen GmbH (near Munich)
  - with Cobalt 60 source to 1 MGy, 2 MGy and 3 MGy
  - two samples for each material

Handling

- all of the standard samples were prepared by Mitch Wagner
  - thermal samples: 4 materials x 4 irradiations x 2 samples = 32 samples
  - mechanical samples: 4 materials x 4 irradiations x 2 samples = 32 samples
  - gained quite some handling and production experience
- thermal reference samples were prepared by AM
  - 4 materials x 2 trials = 8 samples
  - some experience
- we both have a very personal opinion on each of the materials
- more ‚statistics‘ was needed

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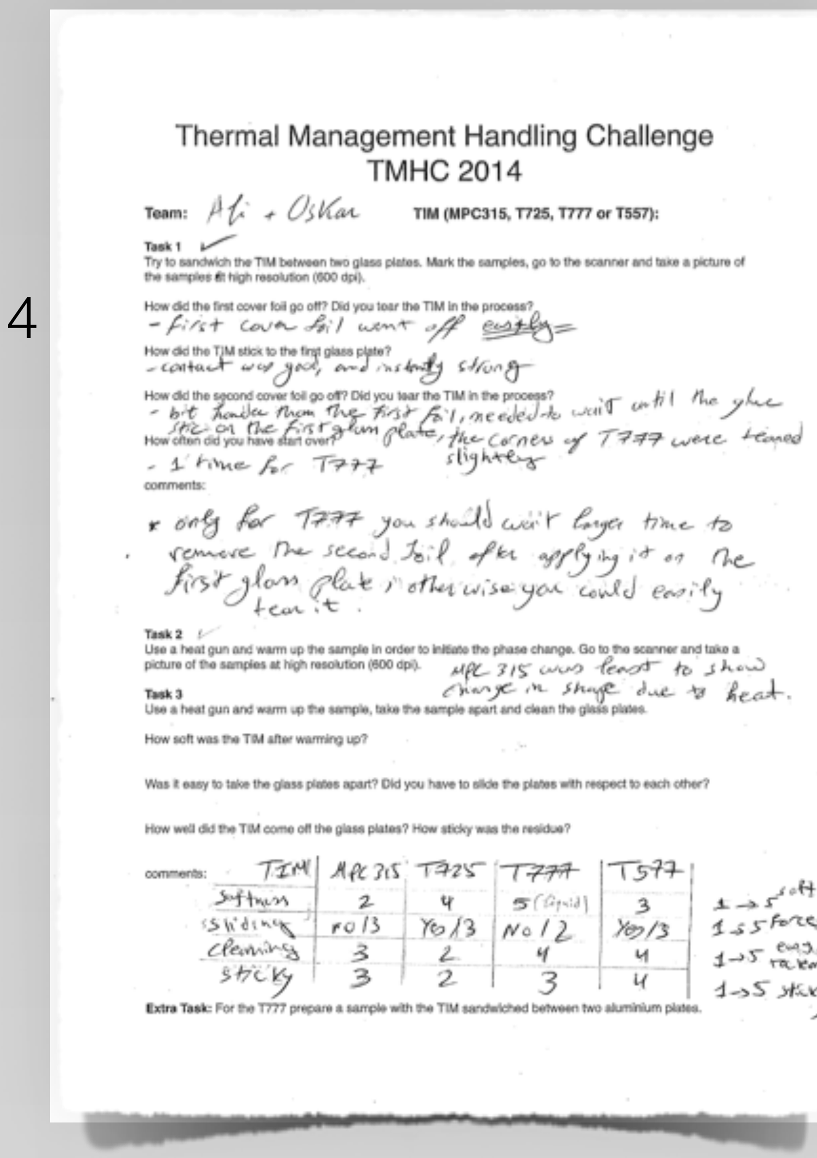
- call for TMHC2014 - Thermal Management Handling Challenge 2014
  - four teams
  - three tasks for each material:
    1. sandwich TIM between two glass plates
    2. heat sample to transition temperature
    3. re-heat sample and clean glass plates
  - every team had to
    - take pictures of the samples (before and after heating) and
    - answer questions after each task



Thermal Management Handling Challenge
TMHC 2014

Team: Ali + Oskar TIM (MPC315, T725, T777 or T557):

Task 1 ✓
Try to sandwich the TIM between two glass plates. Mark the samples, go to the scanner and take a picture of the samples at high resolution (600 dpi).

How did the first cover foil go off? Did you tear the TIM in the process?
- first cover foil went off easily

How did the TIM stick to the first glass plate?
- contact was good, and instantly strong

How did the second cover foil go off? Did you tear the TIM in the process?
- bit harder than the first foil, needed to wait until the glue stic on the first glass plate, the corners of T777 were teared slightly

How often did you have start over?
- 1 time for T777

comments:
* only for T777 you should wait longer time to remove the second foil after applying it on the first glass plate; otherwise you could easily tear it.

Task 2 ✓
Use a heat gun and warm up the sample in order to initiate the phase change. Go to the scanner and take a picture of the samples at high resolution (600 dpi).
MPC 315 was least to show change in shape due to heat.

Task 3
Use a heat gun and warm up the sample, take the sample apart and clean the glass plates.

How soft was the TIM after warming up?

Was it easy to take the glass plates apart? Did you have to slide the plates with respect to each other?

How well did the TIM come off the glass plates? How sticky was the residue?

comments:

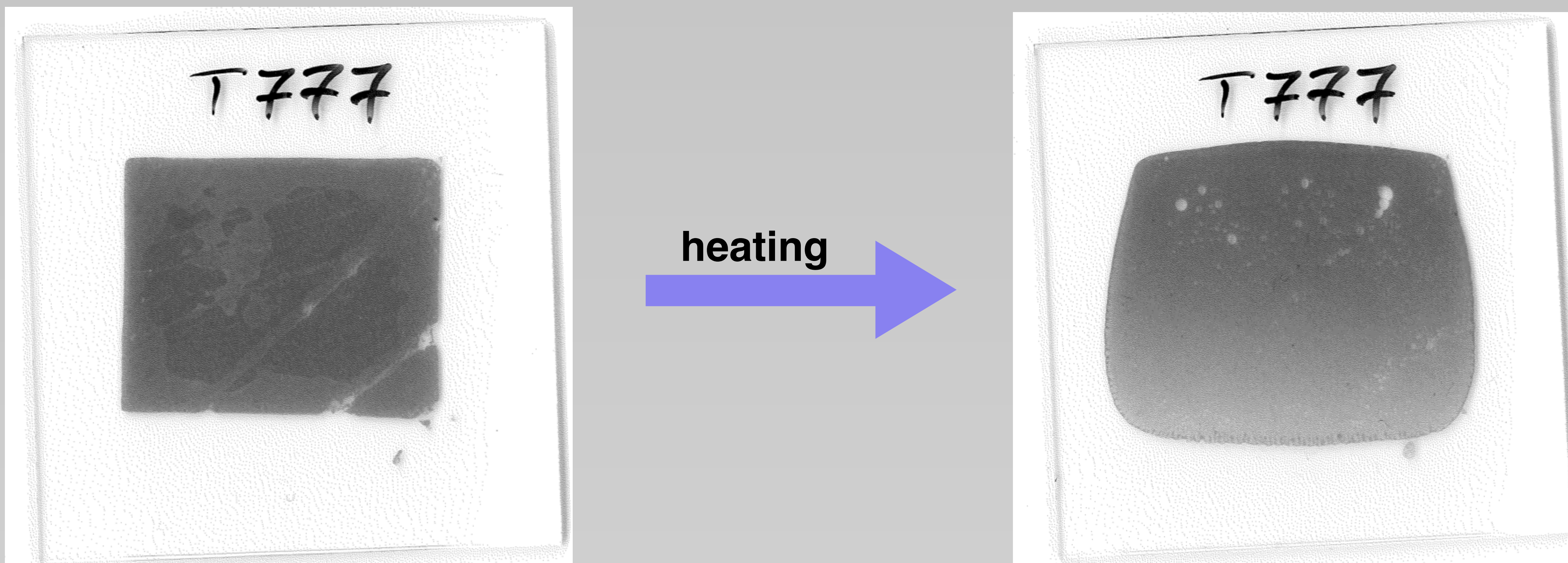
TIM	MPC315	T725	T777	T577	
Softness	2	4	5 (liquid)	3	1→5 soft
sliding	no/3	Yes/3	No/2	Yes/3	1→5 force
cleaning	3	2	4	4	1→5 easy to clean
sticky	3	2	3	4	1→5 sticky

Extra Task: For the T777 prepare a sample with the TIM sandwiched between two aluminium plates.

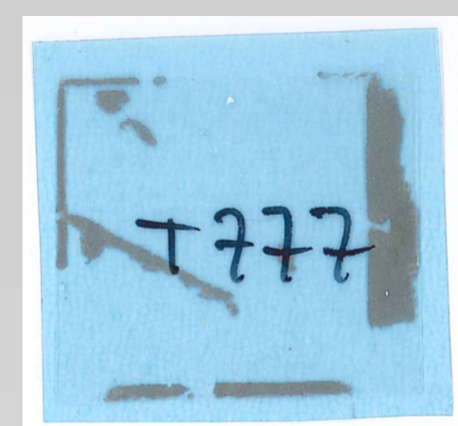
Handling of T777

Team	removal of first cover foil	stickness to glass	removal of second cover foil	number of trials
1 / 2 / 3 / 4	very easy / easy / well	3 x well	2 x ok, tearing / well	2 / 2 / 1

Team	softness of TIM after reheating	separability of glass plates	removal of TIM	residue
1 / 2 / 3 / 4	very soft / very soft / gum	2 x hard / easy	very easy / very easy / ok	3 x no



- only one sample is shown - all other samples show very similar features
- a few air bubbles visible after heating
- some tearing seen when second cover foil is removed
  - feature remains after heating
- team 4 prepared a second thermal sample instead



Handling of T725

Team	removal of first cover foil	stickness to glass	removal of second cover foil	number of trials
1 / 2 / 3 / 4	ok / easy / well / very easy	4 x well	4 x ok, tearing	2 / 1 / 1 / 1

Team	softness of TIM after reheating	separability of glass plates	removal of TIM	residue
1 / 2 / 3 / 4	quite soft / very soft / gum / very soft	2 x easy / 2 x very easy	3 x hard / 1 x very hard	4 x sticky

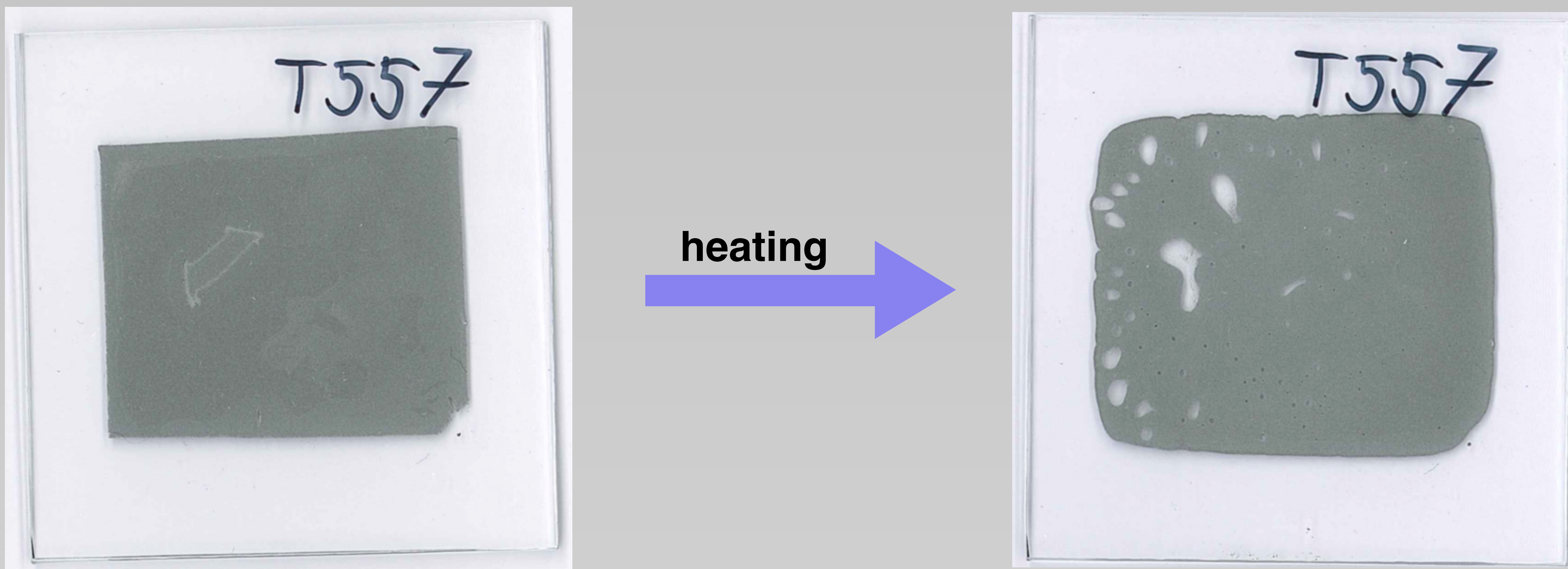
heating

- only one sample is shown - all other samples show very similar features
- many air bubbles visible after heating

Handling of T557

Team	removal of first cover foil	stickness to glass	removal of second cover foil	number of trials
1 / 2 / 3 / 4	3 x easy / well	4 x well	4 x ok , some tearing	2 / 1 / 1 / 1

Team	softness of TIM after reheating	separability of glass plates	removal of TIM	residue
1 / 2 / 3 / 4	3 x soft / gum	2 x hard / 2 x easy	3 x ok / smeary	2 x sticky / 2 x no

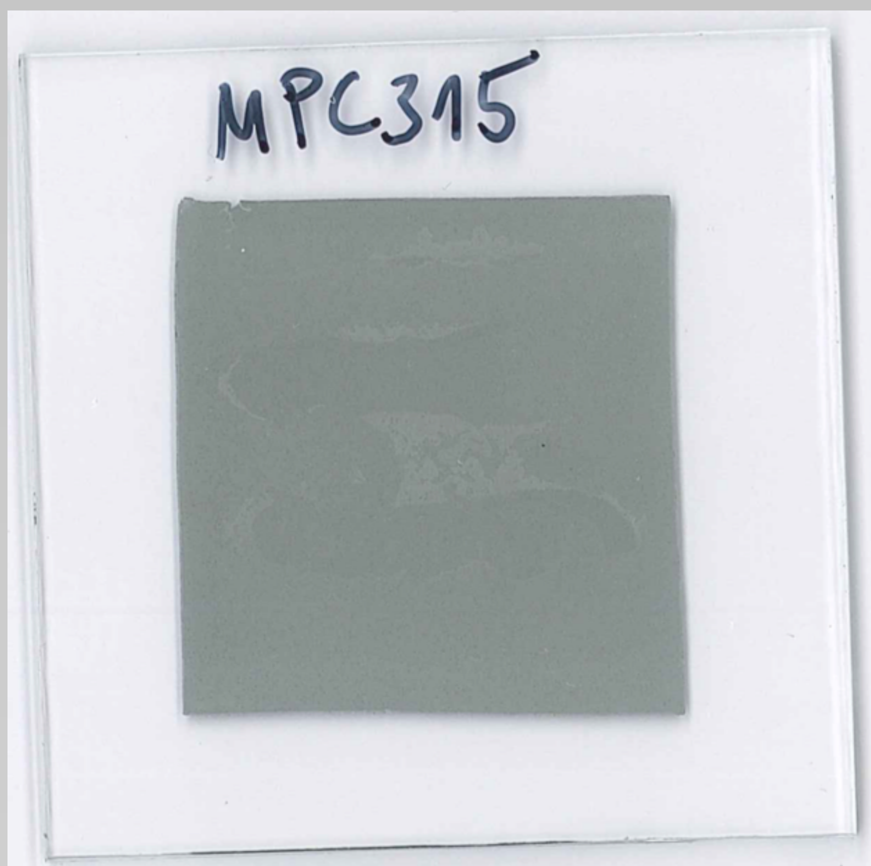


- only one sample is shown - all other samples show very similar features
- air bubbles visible after heating
- some tearing seen when second cover foil is removed
  - feature remains after heating

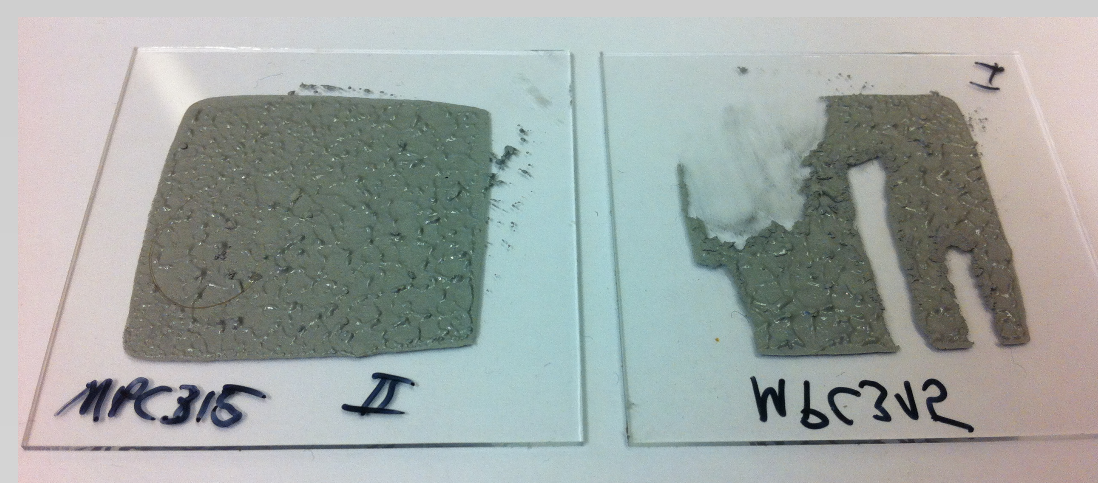
Handling of MPC315

Team	removal of first cover foil	stickness to glass	removal of second cover foil	number of trials
1 / 2 / 3 / 4	easy / easy / well / very easy	4 x well	ok / 3 x well	1 / 1 / 1 / 1

Team	softness of TIM after reheating	separability of glass plates	removal of TIM	residue
1 / 2 / 3 / 4	really soft / soft / plasticine / soft	4 x easy	very very easy / 2 x easy / very easy	4 x no



heating →

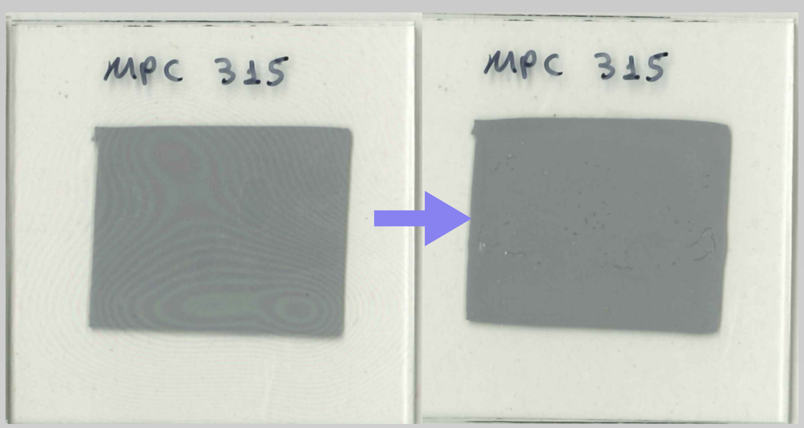


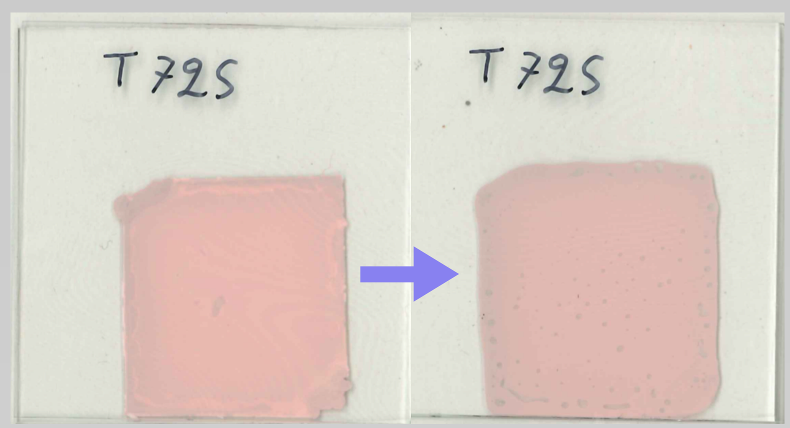
- only one sample is shown - all other samples show very similar features
- no air bubbles visible after heating

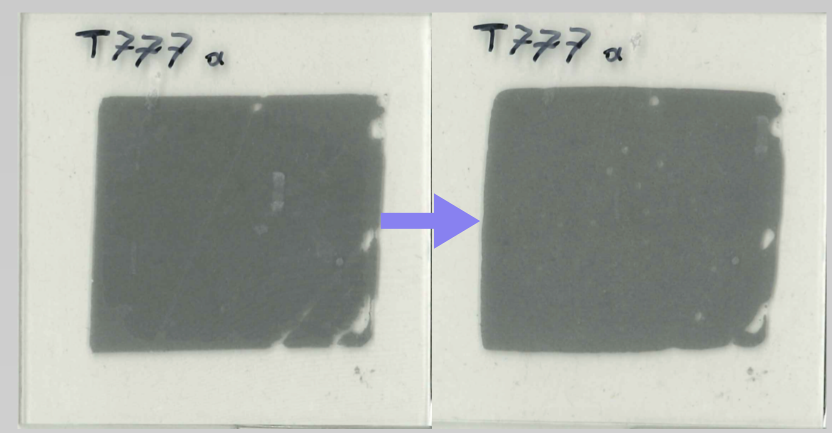
Handling

Material	removal of first cover foil	stickness to glass	removal of second cover foil	number of trials
T777	very easy / easy / well	3 x well	2 x ok, tearing / well	2 / 2 / 1
T725	ok / easy / well / very easy	4 x well	4 x ok, tearing	2 / 1 / 1 / 1
T557	3 x easy / well	4 x well	4 x ok , some tearing	2 / 1 / 1 / 1
MPC315	easy / easy / well / very easy	well / well / well / well	ok / well / well / well	1 / 1 / 1 / 1

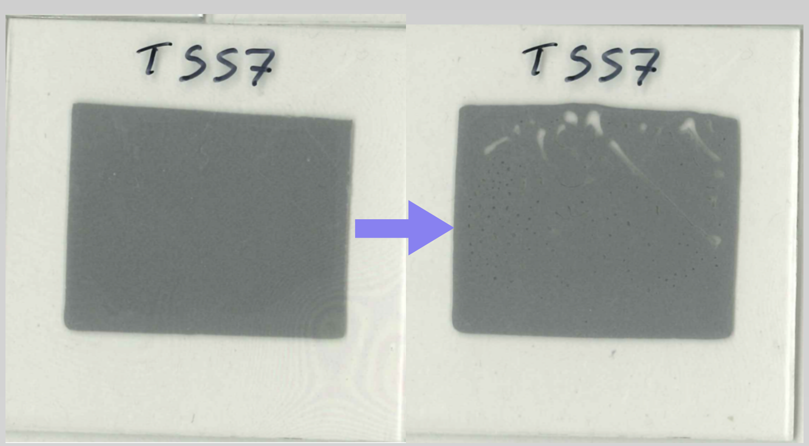
Material	softness of TIM after reheating	separability of glass plates	removal of TIM	residue
T777	very soft / very soft / gum	2 x hard / easy	very easy / very easy / ok	3 x no
T725	quite soft / very soft / gum / very soft	2 x easy / 2 x very easy	3 x hard / 1 x very hard	4 x sticky
T557	3 x soft / gum	2 x hard / 2 x easy	3 x ok / smeary	2 x sticky / 2 x no
MPC315	really soft / soft / plasticine / soft	easy / easy / easy / easy	very very easy / easy / easy / very easy	no / no / no / no



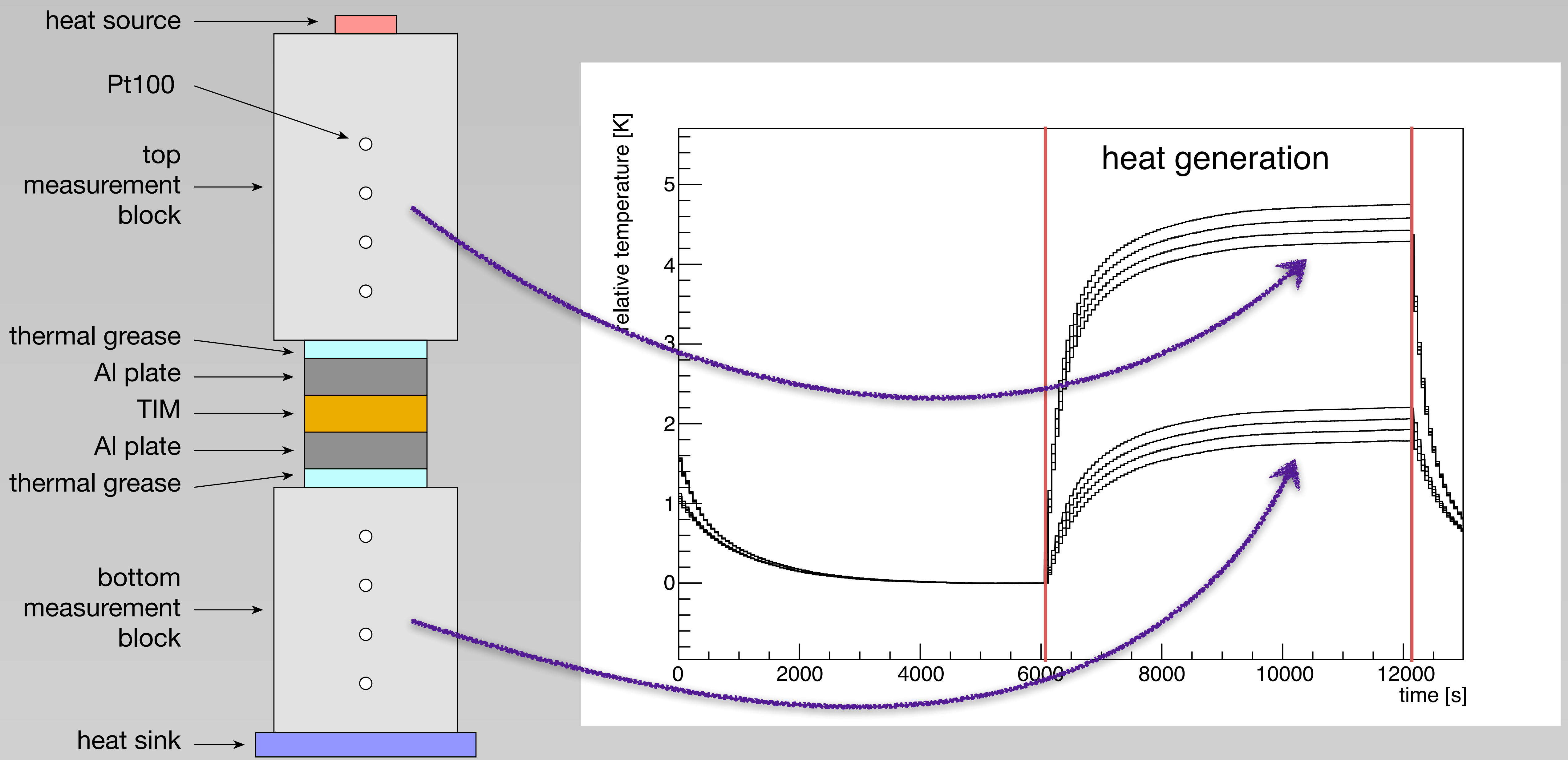




- handling-wise ranking is as follows
  1. MPC315
  2. T557
  3. T777
  4. T725
- handling becomes more tricky with rough surfaces (Al, CFRP)

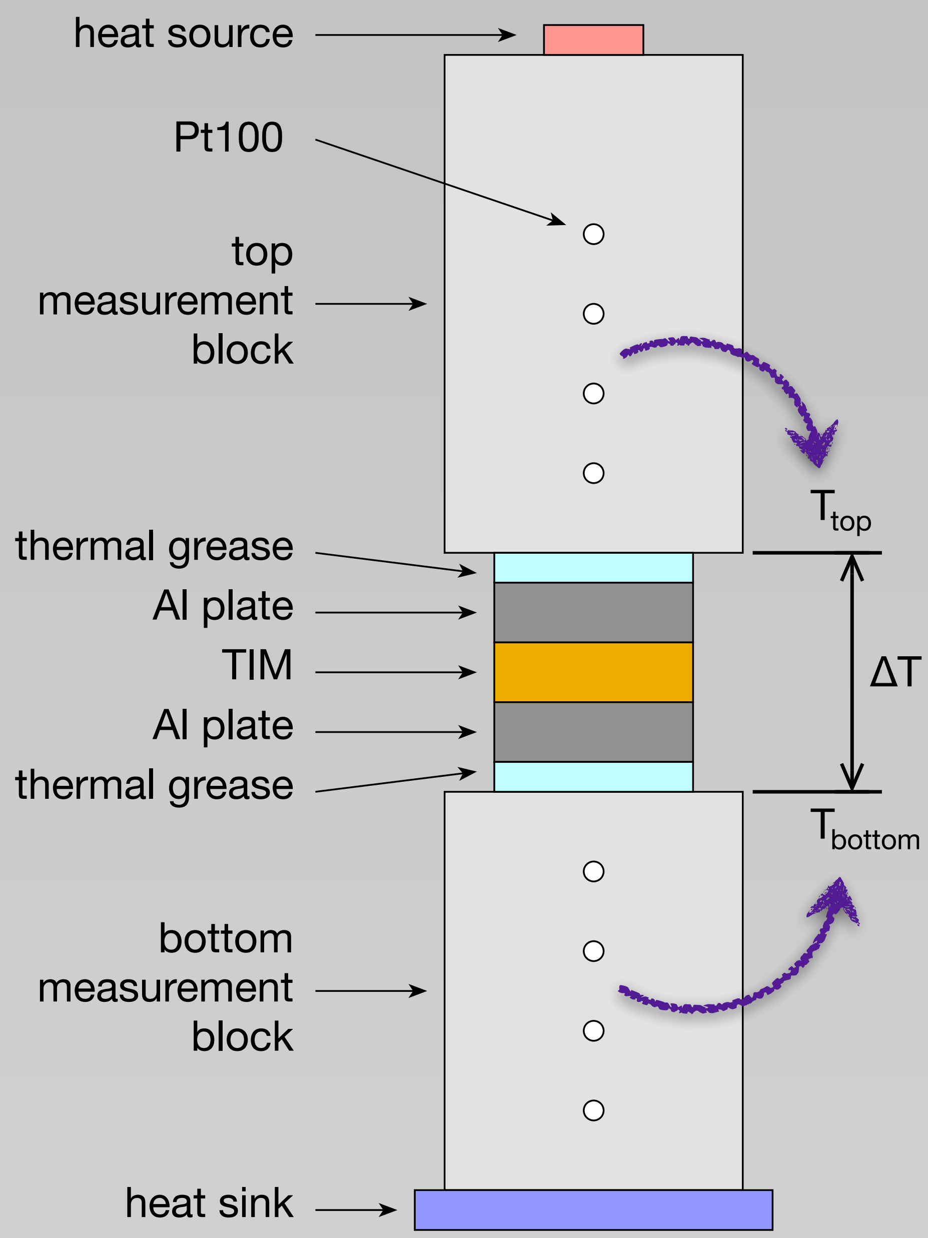


Measurement Principle



- sample is placed between two aluminum blocks
- four Pt100s are embedded in each block
- heat is generated by a resistor on the top block
- bottom block sits on a heat sink

Measurement Principle



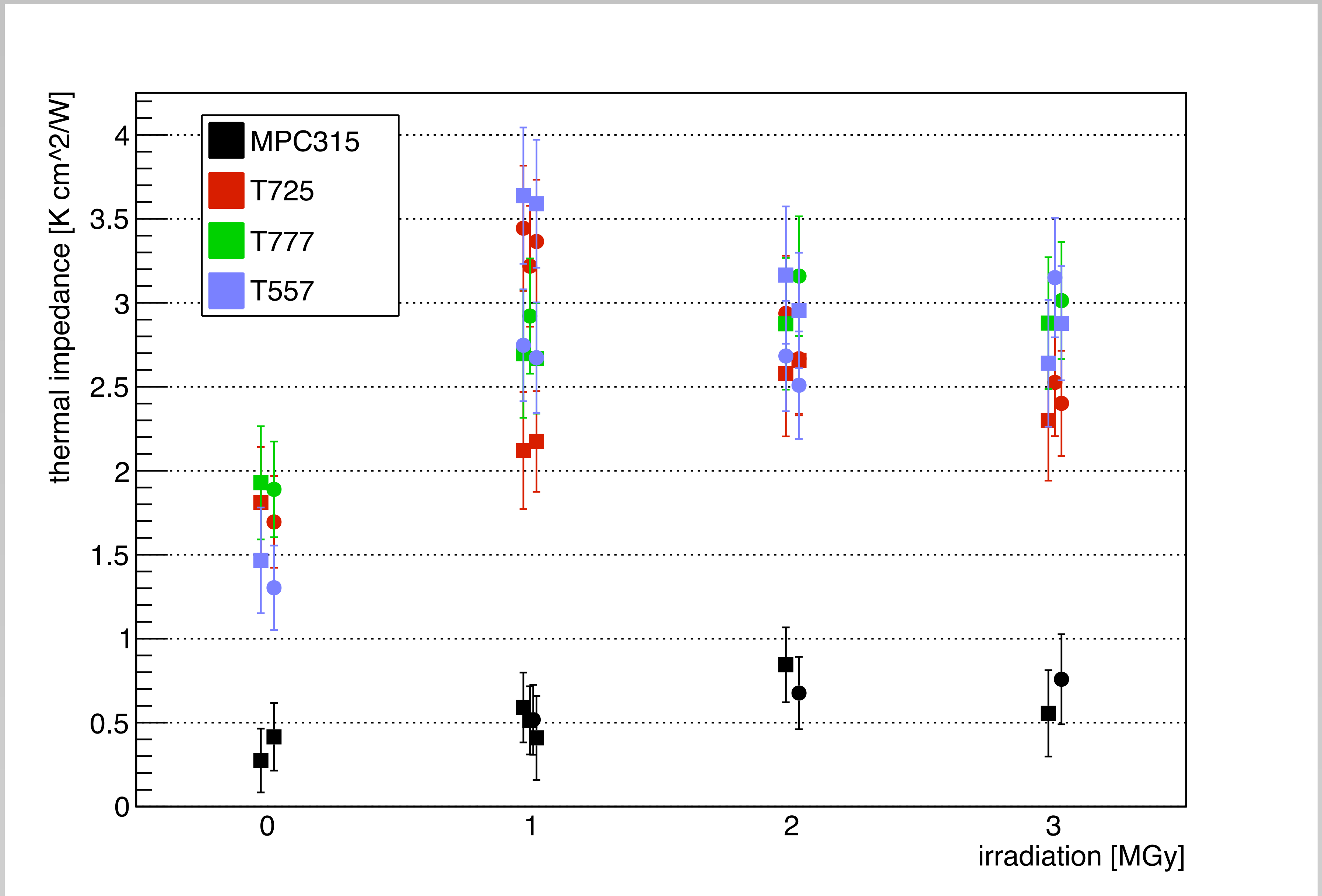
- temperature measurements in each block allows to determine T_{top} and T_{bottom}
  - plot T vs. position
  - extrapolate to the position of the surface

$$R_{total} = \frac{\Delta T \cdot A}{P} = R_{TIM} + 2 \cdot R_{Al} + 2 \cdot R_{grease}$$

$$R_{TIM} = \frac{\Delta T \cdot A}{P} - 2 \cdot R_{Al} - 2 \cdot R_{grease}$$

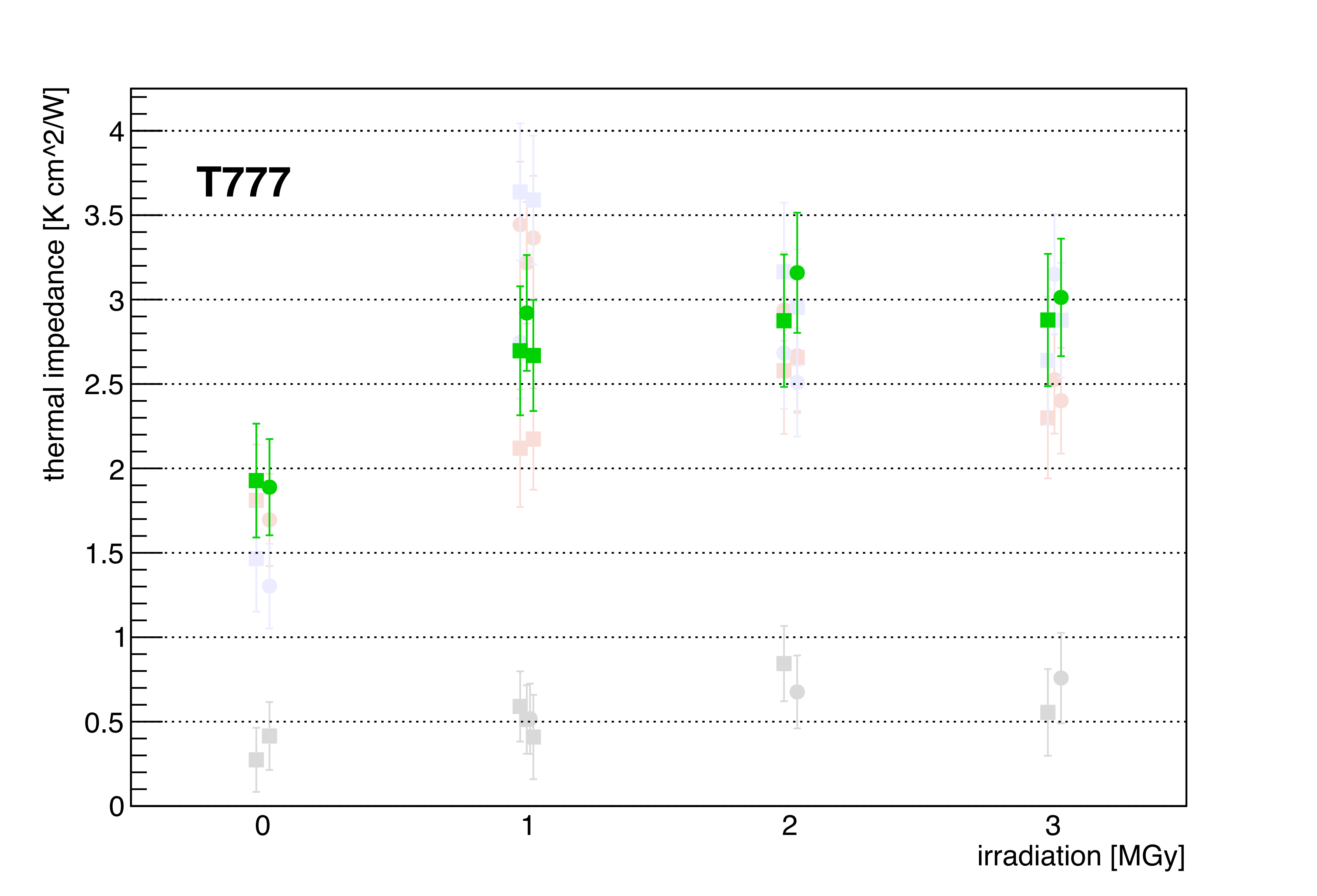
- total thermal resistance is sum of thermal resistances of individual layers
- thermal resistance of thermal grease layers was measured to be 0.08 K cm^2/W
- thermal resistance of Al plates was measured to be 0.11 K cm^2/W
  - consistent with calculated value for AlMg3 (130 - 170 W/m/K)

Results



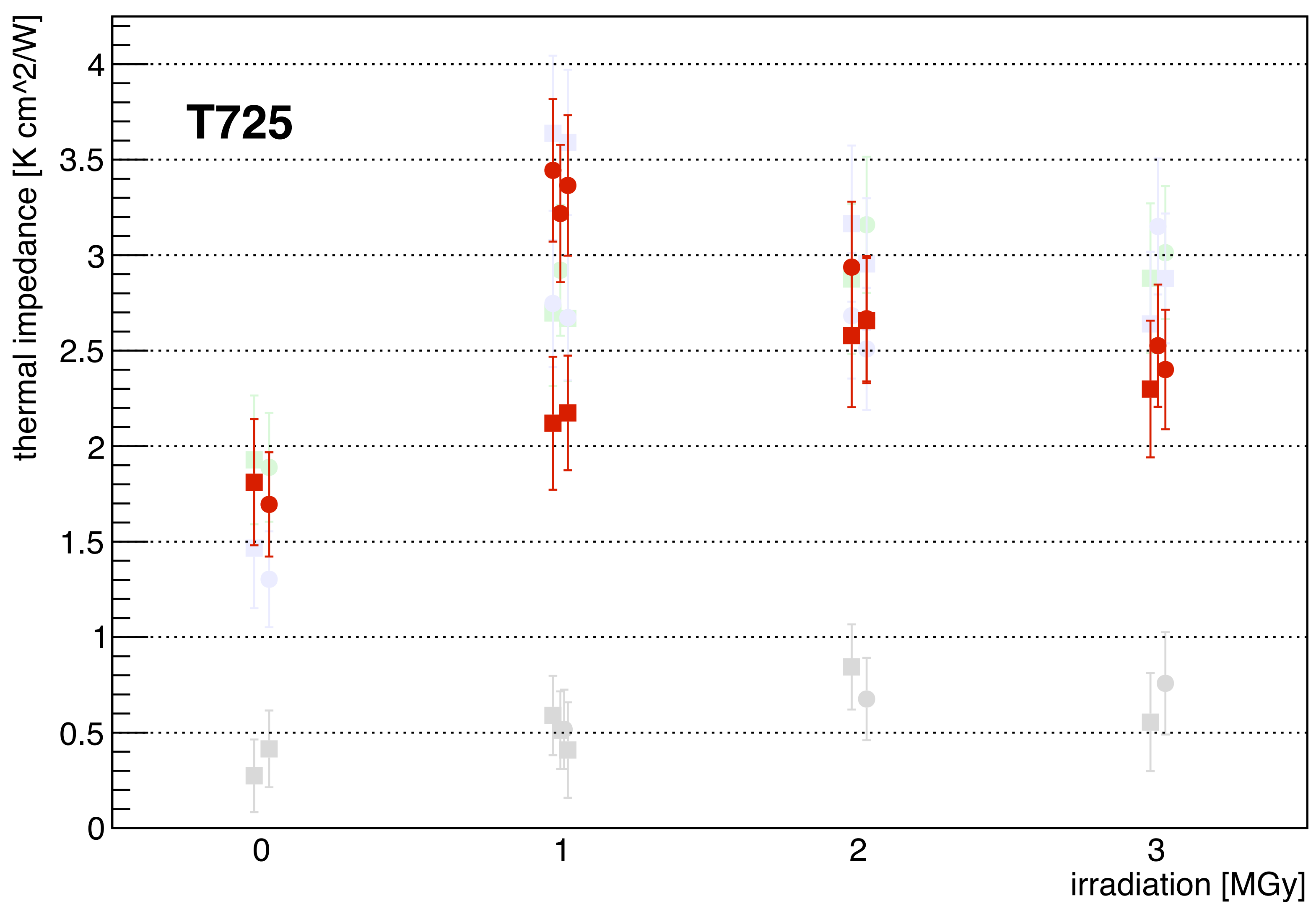
- filled boxes: sample **a**
- filled circles: sample **b**
- data points are spread around actual irradiation values for better visibility
- some samples were measured several times for cross checks
- individual results are shown on the next slides

T777 - Results



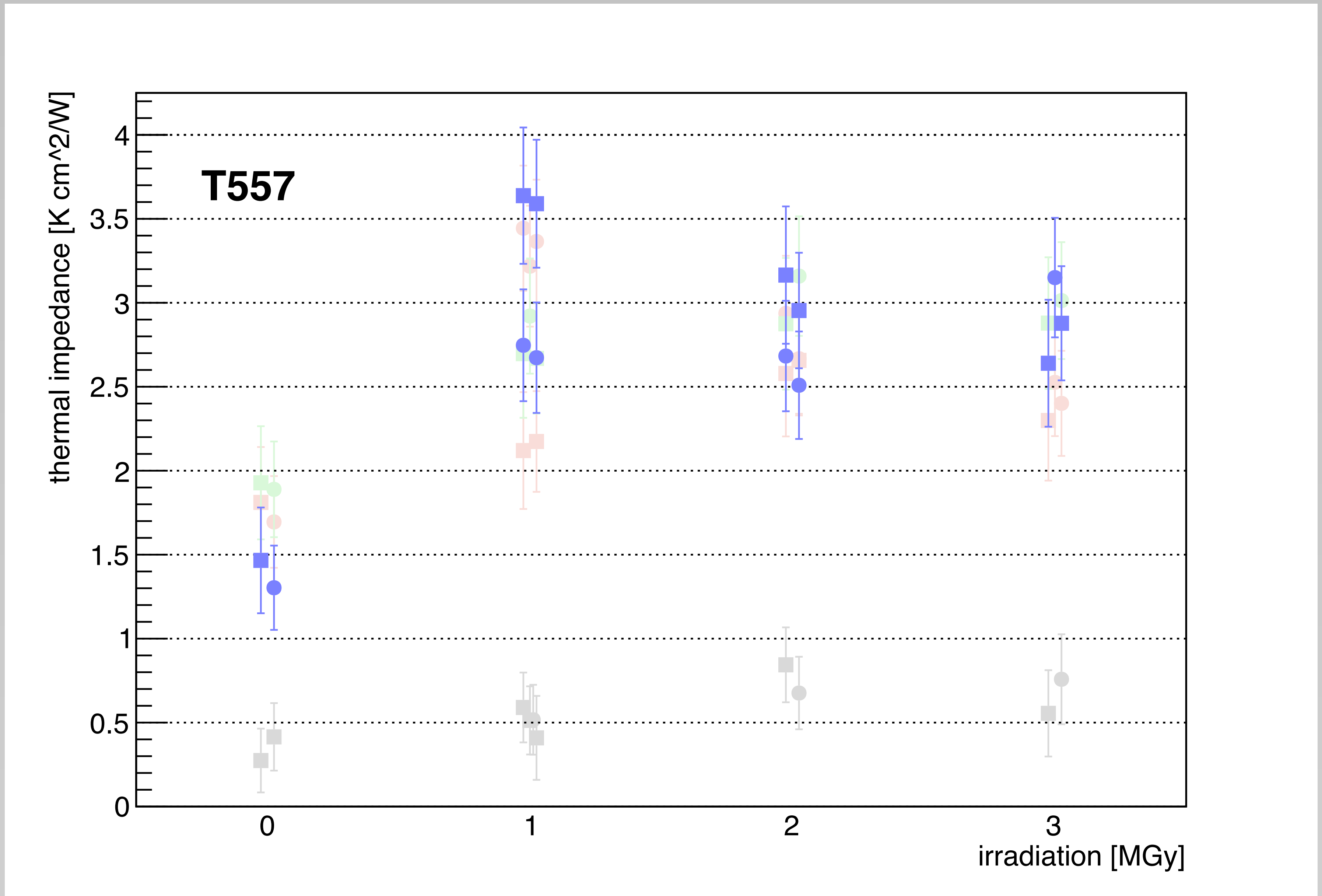
- results for samples **a** and **b** are similar for all irradiations
- increase in thermal impedance seen for the irradiated samples

T725 - Results



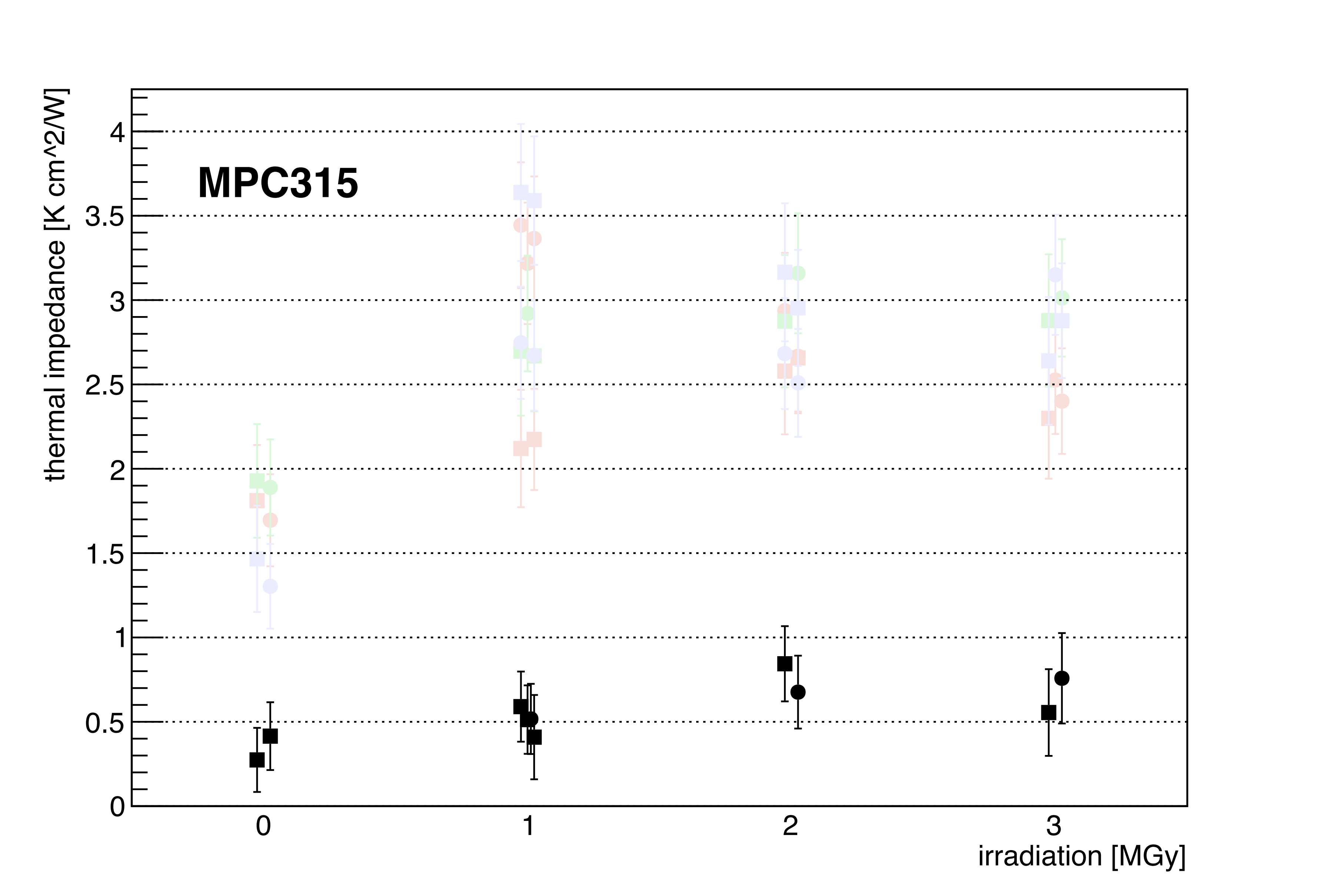
- results for samples **a** and **b**
  - are similar for 0 MGy, 2 MGy and 3 MGy
  - are different for 1 MGy - confirmed by repeated measurements
- difference is most likely related to handling issues during production of the samples
  - e.g. large gaps in sample **b**
- increase in thermal impedance is seen for the irradiated samples

T557 - Results



- results for samples **a** and **b**
  - are similar for 0 MGy and 3 MGy
  - are different for 1 MGy and 2 MGy - confirmed by repeated measurements
- difference is most likely related to handling issues during production of the samples
- increase in thermal impedance is seen for the irradiated sample - almost factor 2 compared to the unirradiated samples

MPC 315 - Results

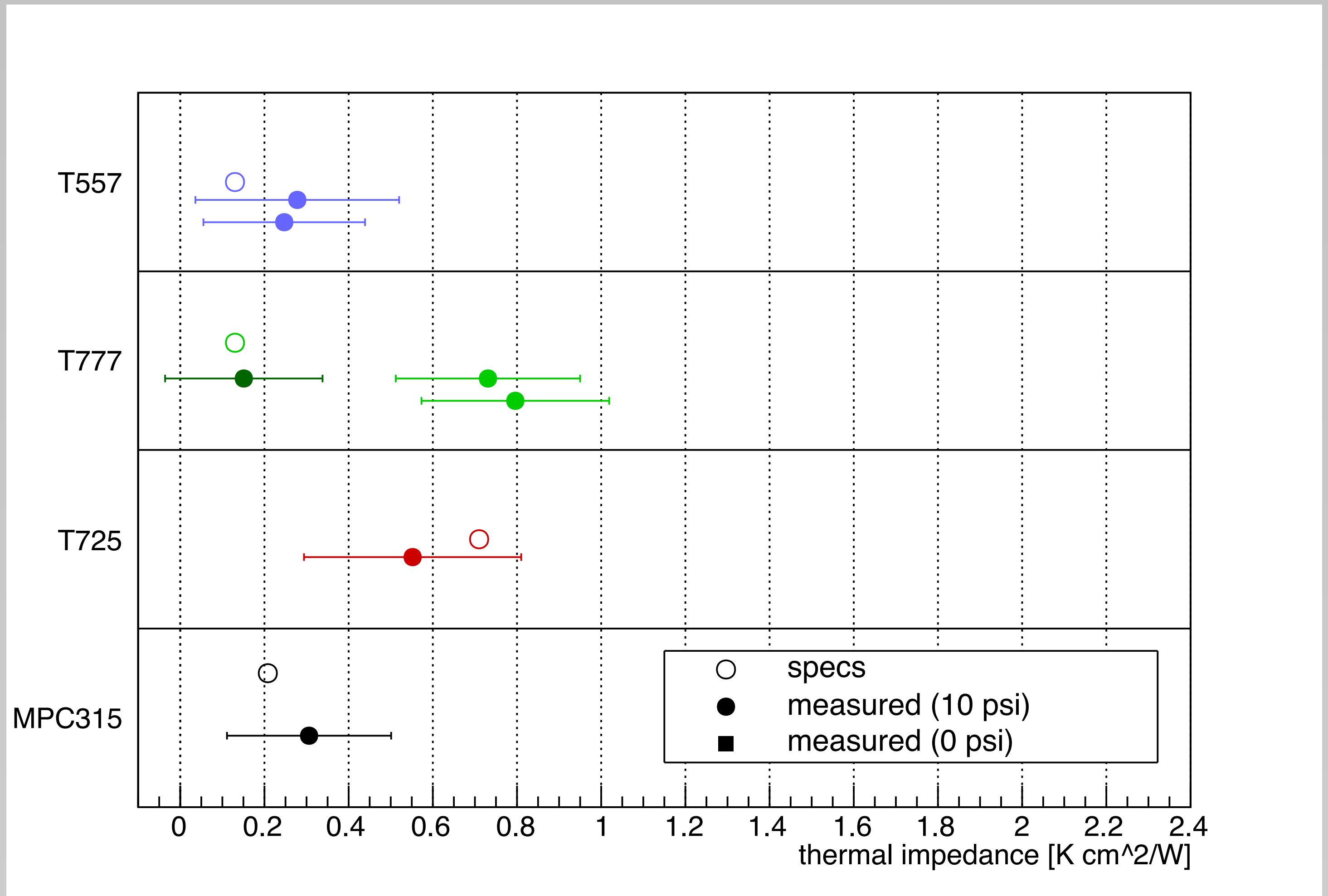


- results for samples **a** and **b** are similar for all irradiations
  - unirradiated sample **b** was broken
- slight increase in thermal impedance seen for the irradiated samples
- absolute value of the measured thermal resistance is much lower than the values for the other materials

Comparison

Specifications

Material	thermal impedance	pressure	pressure	force per 4 cm²
	[K cm²/W]	[psi]	[kPa]	[N]
MPC315	0.208	40	276	110.4
T725	0.71	10	69	27.6
T557	0.13	10	69	27.6
T777	0.13	10	69	27.6



- thermal impedances quoted in material specifications (circles) were confirmed by measurements (filled circles)
  - reference sample for MPC 315 was produced with 10 psi pressure
  - first reference sample for T777 showed significant difference to specs - handling and production issues

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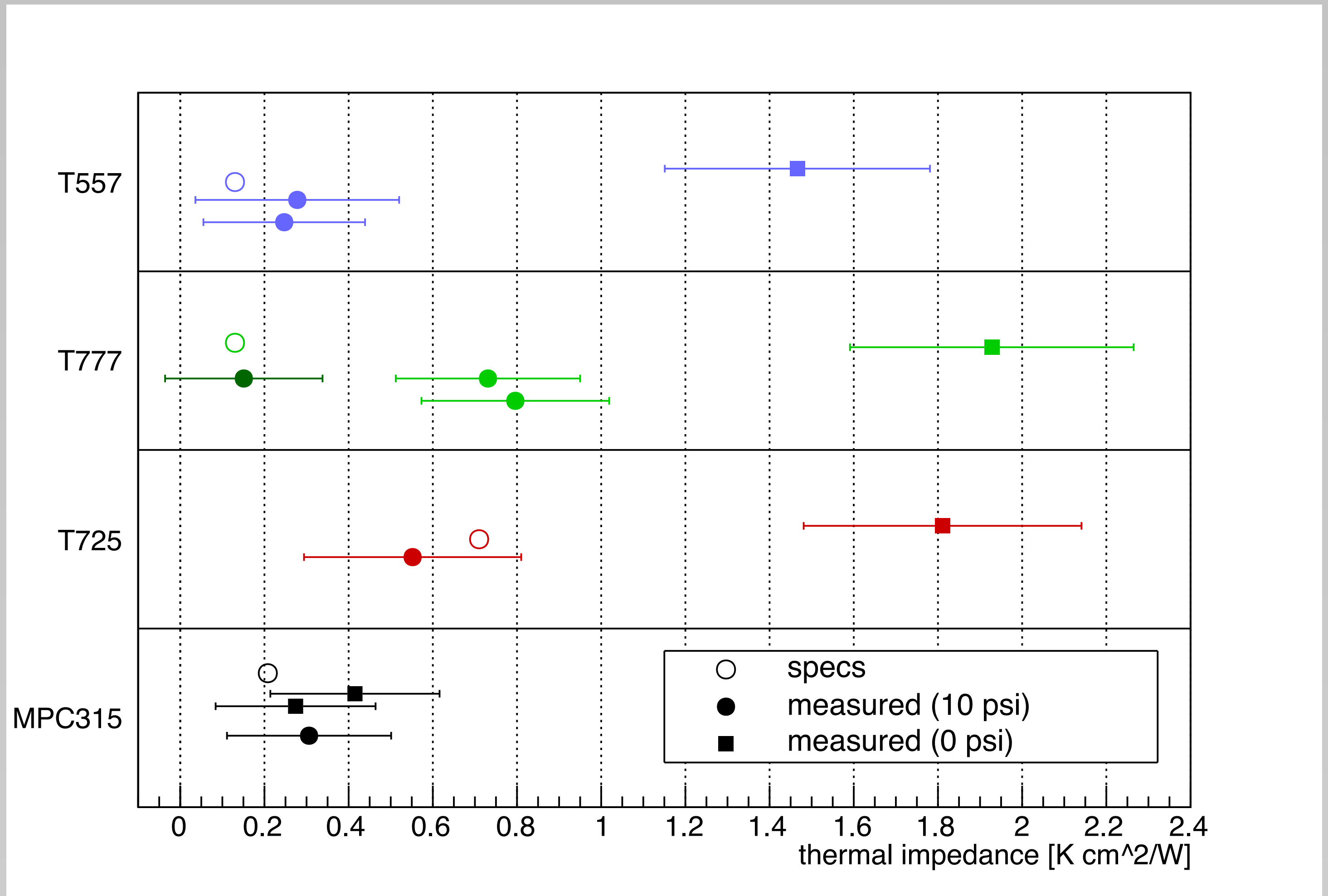

- thermal impedances quoted in material specifications (circles) were confirmed by measurements (filled circles)
  - reference sample for MPC 315 was produced with 10 psi pressure
  - first reference sample for T777 showed significant difference to specs - handling and production issues
- the standard samples (no pressure; filled boxes) for T725, T777 and T557 are not even close to the specifications
  - T series materials rely on pressure during baking
- the standard sample for MPC 315 is close to the specifications
  - thermal performance of material is not very sensitive to the pressure applied during baking

Summary

- thermal and mechanical test samples were produced and irradiated
  - four different phase-change TIMs - T557, T725, T777 and MPC315
  - four different irradiations - 0 MGy, 1 MGy, 2 MGy and 3 MGy
  - two samples per material and irradiation
- handling aspects were investigated by six different people or groups of people
  - applying the phase-change TIMs to rough surfaces is not easy
  - each investigated materials has its own special features
  - from handling point of view MPC315 seems to be the best choice for our application
- thermal samples were tested
  - all four tested materials show an increase in thermal impedance when irradiated
  - thermal impedances quoted in specifications were confirmed by measurements on reference samples
  - T-series materials show a large increase in thermal impedance when there is no pressure applied during phase-change
  - for MPC315 almost no increase in thermal impedance is seen when no pressure is applied during phase-change
- mechanical samples not yet tested
- thermal performance after re-heating has to be tested
- more handling tests
  - especially removal of module from support structure