Material characterization campaign for tracker upgrades

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Motivation

- HL-LHC will produce *charged-hadron* fluences up to 10^{17} n_{eq}/cm^2
- Radiation damage in material occurs basically through
  - Cross-linking (IEL – *Ionizing Energy Loss*)
  - Chain-scission (IEL)
  - Displacement (NIEL – *Non ionizing energy loss*)
- Layman's rules
  - If there are free electrons (metals, semiconductors) IEL is mainly recoverable
  - If there are no free electrons (polymers, etc) IEL is not recoverable
  - Displacement occurs all the time.
- Abe (1970) proved that Polyimide is more damaged by neutrons than gammas (often quoted) but:
  - This applies to neutron-deposited doses of 10^7 Gy (corresponding to ~10^22 n/cm2)
  - At this dose level, the displacement damage is already measured in DPA (displacements per atom) – far from our regime

- Charge hadrons produce in polymers more damage from ionization than displacement… (take-home message)

Irradiation options (for our applications)

Particle type	Advantages	Disadvantages
Neutrons	?	– Activates materials – No significant IEL damage
Protons	Close to HL-tracker environment	– Large area/high multiplicity irradiations are difficult – Scarce penetration (exception GeV protons) Significant activation
Photons	No NIEL damage	– No activation – Large samples/high multiplicity possible

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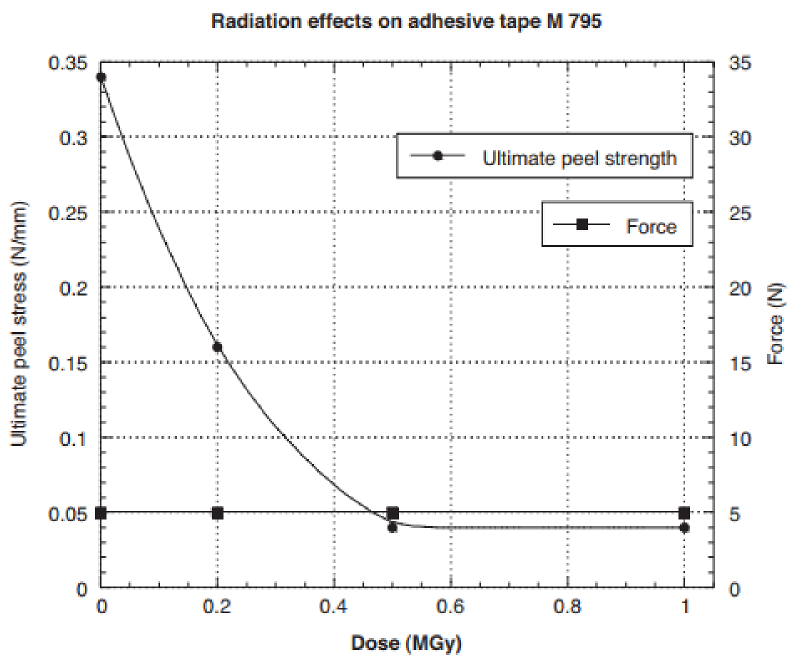
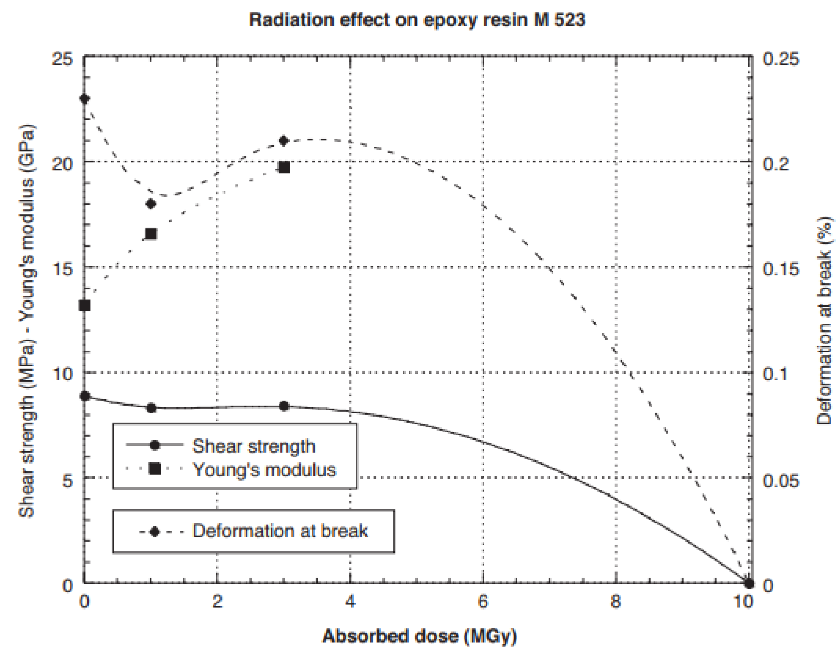
Existing data

- CERN Yellow reports (pre-LHC)
- Many materials have been characterized, but mainly to doses up to ~3 MGy
- New glues/interface materials have been deployed since, and no data is available (yet)
- Materials like epoxies have a wide variability from type to type (e.g. Araldite AV/HV 1580 has been characterized up to 30 MGy, but it's a pretty unique case)
- For other materials (e.g. phase change materials) radiation data is scarce or non-existing altogether

Radiation degradation examples (yellow reports)





- Scarce data on thermal performances or none available

Campaign scope

- Characterize structural materials and thermal interfaces after irradiation at high doses in view of their use in tracker systems
  - Stage 1: **activation studies** to determine their suitability for hadron-dominated environment for radiation safety issues
  - Stage 2.1: qualification of **(relative) mechanical properties degradation**
  - Stage 2.2 qualification of thermal properties **(conductivity) degradation**
  - Stage 3 (TBD – not discussed here): qualification of the degradation of absolute mechanical properties of the material for harder materials as of stage 2.1

Material selection

Iterative selection of materials based on need and availability.
Current "final" list:

Composite Resin (2 types) – Mechanical test
All comp K9 carbon foam – Mechanical test
3M VHB 5909 – Mechanical test
AMEC Thermasol MPC25 – Thermal test
Dow Corning SE4445 – Mechanical and thermal tests
Dow Corning 186 – Mechanical test
Dymax 9001 – Mechanical test
Dymax 9-20801 – Mechanical test
Huntsman Araldite 2011 – Mechanical and thermal tests
Huntsman Araldite AV/HV1580 – Mechanical test
Huntsman Araldite 2020 – Mechanical test
Isoltronic Gap-Pad 3000S30 – Thermal test
Isoltronic Gap-Pad V0 Ultra Soft – Thermal test
Kunze KU-BGDX – Thermal test
Parker Chomeric T725 – Thermal test
Parker Chomeric Gel30 – Thermal test
Polytec TC418 – Mechanical and thermal test
PPI RD-577F – Mechanical test
Prima-bond EG7655 – Mechanical and thermal tests
Prima-bond EG7658 – Mechanical and thermal tests
Stycast 2850FT – Mechanical test
Tesafix 4962 – Mechanical test
UHU Endfest 300 – Mechanical test

- Material types so far
  - Epoxies
  - Silicone-based adhesives
  - Phase Change Materials
  - Potting compounds
  - Composite resins
  - Carbon foams

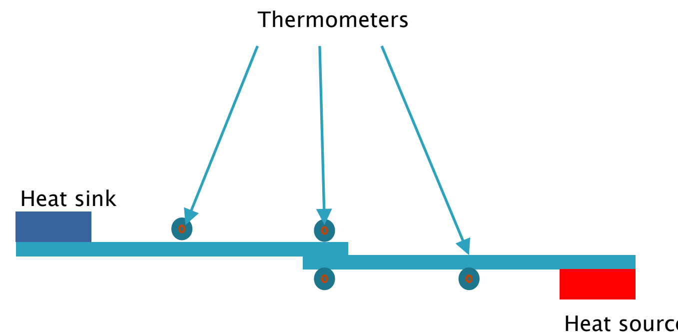
Stage 1: activation studies

- Irradiation at Ljubljana Triga reactor (access granted through AIDA)
- Materials were molded in coin-shaped samples and irradiated with reactor neutrons to a fluence of 1e16 n/cm^2
- Samples cooled down on-site for ~2 weeks to allow decay of short-half life isotopes (of little interest)
- The most active samples were characterized with gamma spectroscopy at the reactor site
- Least active samples shipped to CERN, pending by-item spectroscopy by CERN-RP

- Most active samples after 2 weeks (~0.5g):
  - AMEC Thermasol MPC25: 3 uSv/h
  - LAIRD TPCM 583: 8 uSv/h
  - Electrolube ER2074: 4 uSv/h
  - Electrolube ER2220: 5 uSv/h
  - Araldite 2012: 1 uSv/h
  - Gap-pad 3000S30: 6 uSv/h

Stage 2: Conductivity and thermal tests

- For each material/dose step
  - Tensile machine tests
  - Thermal tests (using available TFM setups or others – <u>low accuracy</u>)
- Lap joints multiplicity:
  - 3/dose for mech. tests
  - 1/dose for therm. tests
  - 3/material for reference

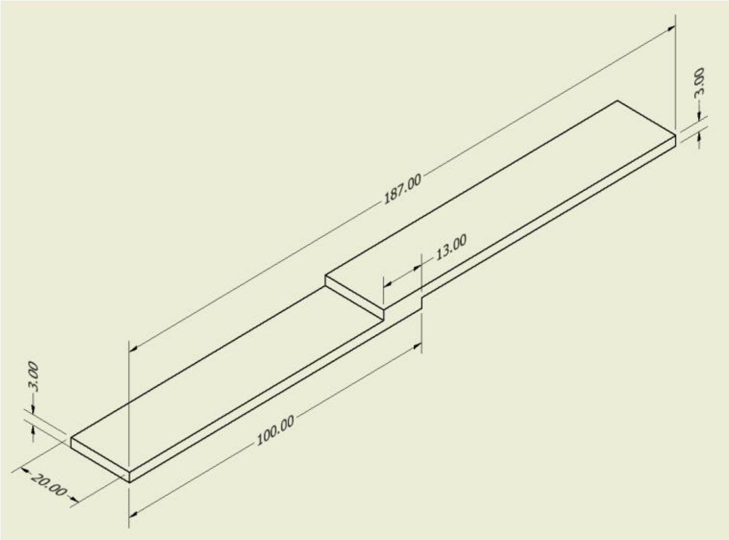


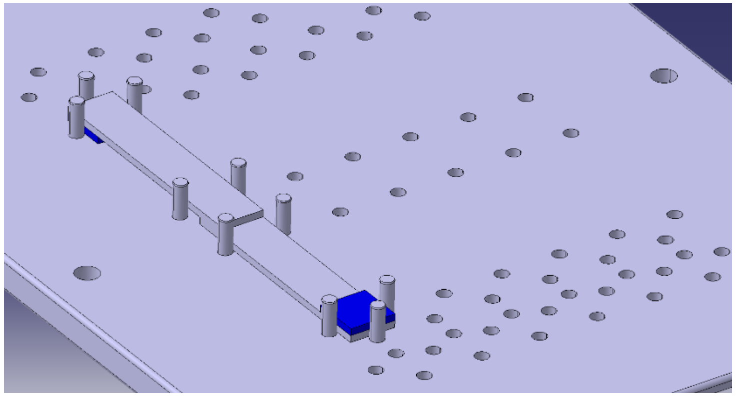
Notes:

- Single lap-joints have been chosen because of **lower material budget** (gamma ray attenuation) and no significant disadvantage w.r.t. double lap-joints for <u>relative measurements (should use dog-bone samples for absolute measurements</u>)
- Laser-flash analysis on coin-samples at RT for accurate conductivity measurements
- Thermal measurements on lap-joints for coarse verification at low temperatures

Samples preparation

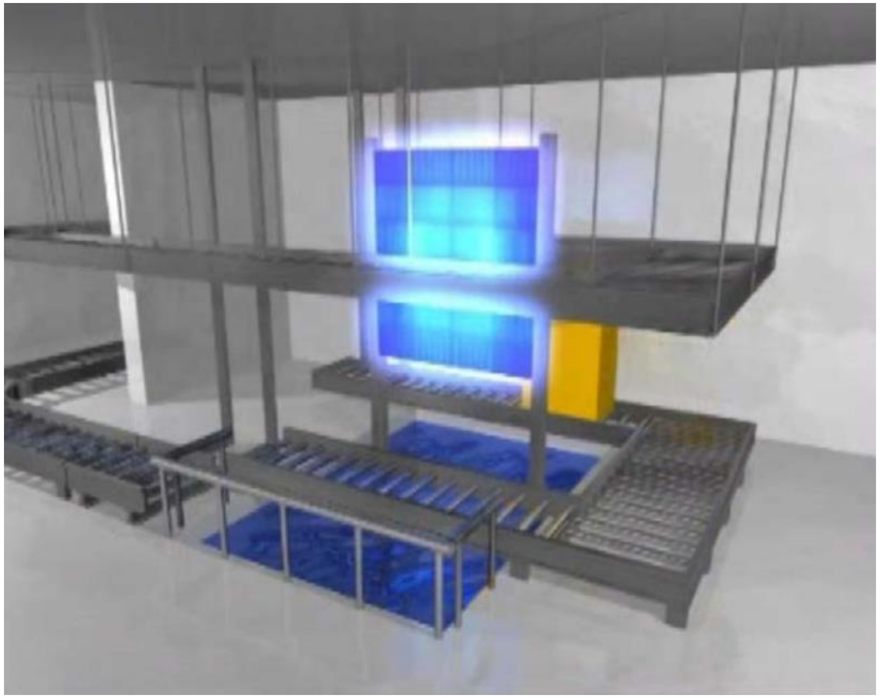
- Assembly through dedicated jig
  - Glue thickness control (where needed) through ~100 um fishing wire
  - Curing of full jig in the oven at the required temperature
  - Pressure on top plate to be applied either with calibrated weights or autoclave (if available)
  - Due to good manufacturing quality of the aluminium plates, acetone cleaning is enough.
- First samples have been successfully assembled at CERN – preliminary mechanical and thermal testing in progress
- 650 aluminium pieces (for 325 lap joints) already received. – assembly ongoing.
- Offsite lap joints assembly at CPPM and Lancaster/RAL





Irradiation facility

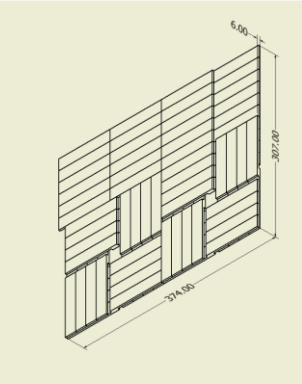
- Industrial irradiation facility, access through Fraunhofer Institut
- Co60 source, maximum activity $2 \cdot 10^{17}$ Bq
- Two irradiation options:
  - Conveyor belt (Europallet, ~10 kGy/h), suitable for irradiation of large samples
  - Dedicated fixed position sample box, 33x10x40 cm, ~40 kGy/h
- Dosimetry uncertainty: 5.5~6%



Gamma Irradiation

Irradiation at industrial facility with Co60 source, dose rate up to 30 kGy/h

- Maximum target dose: 15 MGy (3 intermediate dose steps, 0.5, 2 and 7 MGy)
  - Testing through one standardized structure (there might be space allowance for other non-standard samples for different tests)
- Irradiation at an industrial facility (dose rates up to 30 kGy/h) equipped with a Co60 source



Option 1: Irradiation box

- Samples stacked into one box 33x40x10 cm, up to 54 samples per layer
- ~200 Lap-joints, 3 layers (First 1.5 layers stay for the remaining layer gets swapped between 2 and 7 Mgy), max 15% attenuation for the last layer.
- Residual space for smaller test structures around the lap-joints block
- Earliest availability: September

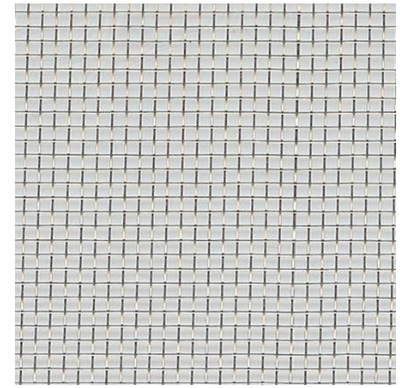
Option 2: (under discussion) Pallet irradiation

- Sharing of pallet with other users
- Next availability: September
- Discussions in progress concerning space availability, uniformity, dosimetry and costing.

Layer	Depth (cm)	Dose (MGy)
1	0.3	9.71
2	0.9	9.15
3	1.5	8.62
4	2.1	8.12
5	2.7	7.65
6	3.3	7.21
7	3.9	6.79
8	4.5	6.40
9	5.1	6.03
10	5.7	5.68
11	6.3	5.35
12	6.9	5.04
13	7.5	4.75
14	8.1	4.47
15	8.7	4.22

Sample packaging and precautions

- Detailed definition of the irradiation procedure (also basis for the quote)
- No direct access to the facility, samples have to be loaded by an operator of the facility
  - Simple packaging in batches in order to avoid mishandling
- Samples are expected to reach 60C due to the high dose rate in the irradiation box. Irradiation on pallet is recommended for these (lower dose rate = lower temperature)
- Ozone is formed in important quantities: possible chemical aggression of the samples
  - Packaging of batches through metallic mesh to allow ventilation
- Dosimetry performed on site – CERN will also provide own film dosimeters (Far West Technologies) to cross check the dose rate – no total dosimetry is possible (no dosimeters surviving the foreseen total dose)
  - Contextual verification of self-attenuation of gamma flux



Call for interest

- Effort started at CERN EP-DT for the ATLAS ITK tracker, could have potential interest from other experiments
- Learning from the lessons from this first irradiation campaign we could arrange other campaigns, targeting other structural glues and materials
- Pooling of materials helps distributing the fixed costs related to the irradiation at an industrial facility
- Results are expected to be published in a report complementing the existing yellow reports
- Constitution of a pool of collaborating institutes with complementary testing capabilities

Summary

- An irradiation campaign is ongoing to qualify materials, started for ATLAS ITK, could gather the interest of other institutes
- Activation study completed, final results in the next week.
- Assembly of lap joints ongoing, expected completion end of August.
- At present we are identifying other “custom” samples that might fit into the irradiation volume.
- Negotiation with gamma irradiation facilities ongoing, irradiation foreseen September-October.
- First results of mechanical and thermal characterization of irradiated samples expected Mid-late fall.
- Further irradiation campaigns can be foreseen in the future with sufficient demand.