ITK – Qualification of new materials for radiation hardness

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Motivation

This document describes the proposed procedures for the thermal and mechanical characterization of new candidate materials for the ITK pixel upgrade after exposure to ionizing doses comparable to the ones expected in the ITK

Background

According to ATL-UPGRADE-PUB-2014-003, the expected radiation dose for the innermost regions of the ITK pixel barrel is expected to be $7.7 \cdot 10^{6}$ Gy, at an integrated luminosity of 3000 fb^{-1} .

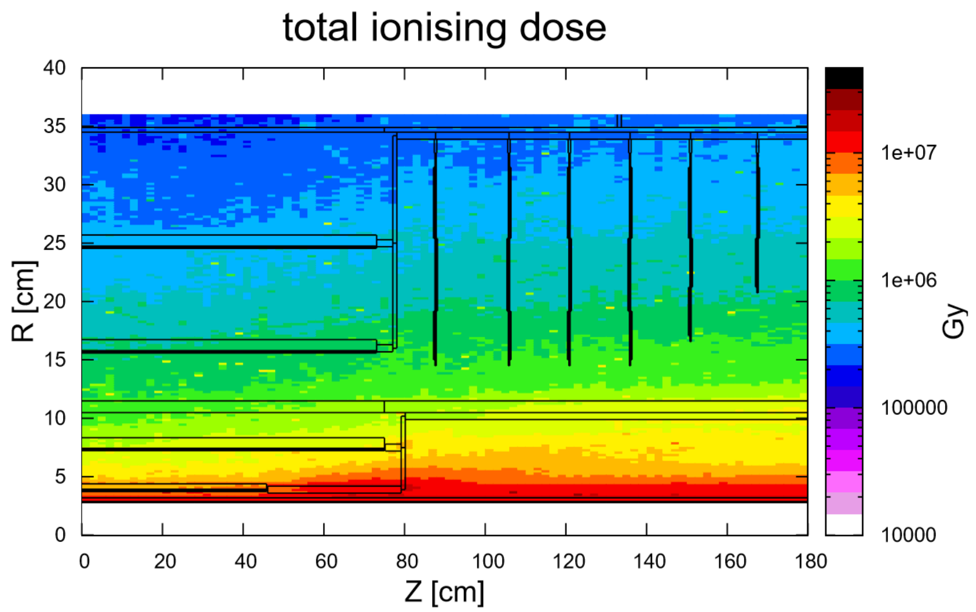

Figure 1: Total ionizing dose for the ITK pixel barrel [ATL-UPGRADE-PUB-22014-003]

We expect to employ a wide range of new glues and interface materials in the ITK, for which there is no radiation hardness qualification so far performed. Some classes of materials of interests are:

- Glues / conductive and insulating
- Thermal gap fillers
- Phase change materials
- Pre-impregnation resins
- Etc.

A preliminary list of materials candidate for characterization is accessible through a Google Docs spreadsheet:

https://docs.google.com/spreadsheets/d/1Xd1SWfz0UO2caJr1HirvmpbHe4plTNXs9grWGGTxaAM/edit?usp=sharing

Material Chemical Characterization

For these materials for which the user license allows it, X-ray fluorescence spectroscopy (XFS) shall be performed at CERN. The technique allows to detect discrete concentrations (>0.5%) of elements with a Z higher than the one of Mg. This will allow to perform a first skimming of the samples containing elements with high neutron activation cross sections.

Neutron irradiation

Samples of small size will be irradiated at a neutron facility (e.g. the TRIGA reactor in Ljubljana, part of the AIDA network). This will allow to test the material with gamma spectroscopy, to assess the presence of residual (traces) heavy elements not detected by the XFS.

Gamma irradiation

Following the results obtained with XFS and neutron irradiation, we'll proceed to irradiated only the samples that showed no presence of elements with high neutron activation cross sections. The samples will be prepared, using custom jigs, in assemblies ready for mechanical and thermal testing (see section "Sample Preparation").

Of the investigated facilities, a gamma facility in Germany allows doses of 67.5 kGy/h (Air). Assuming a target final dose of $2 \cdot 10^7$ Gy, the irradiation can be completed in 2 weeks. However the high dose rate facility imposes limitation on the size of irradiated volume. The dimensions of a mock-up box simulating the dimensions of the irradiation chamber is provided in Figure 2 (dimensions are in mm).

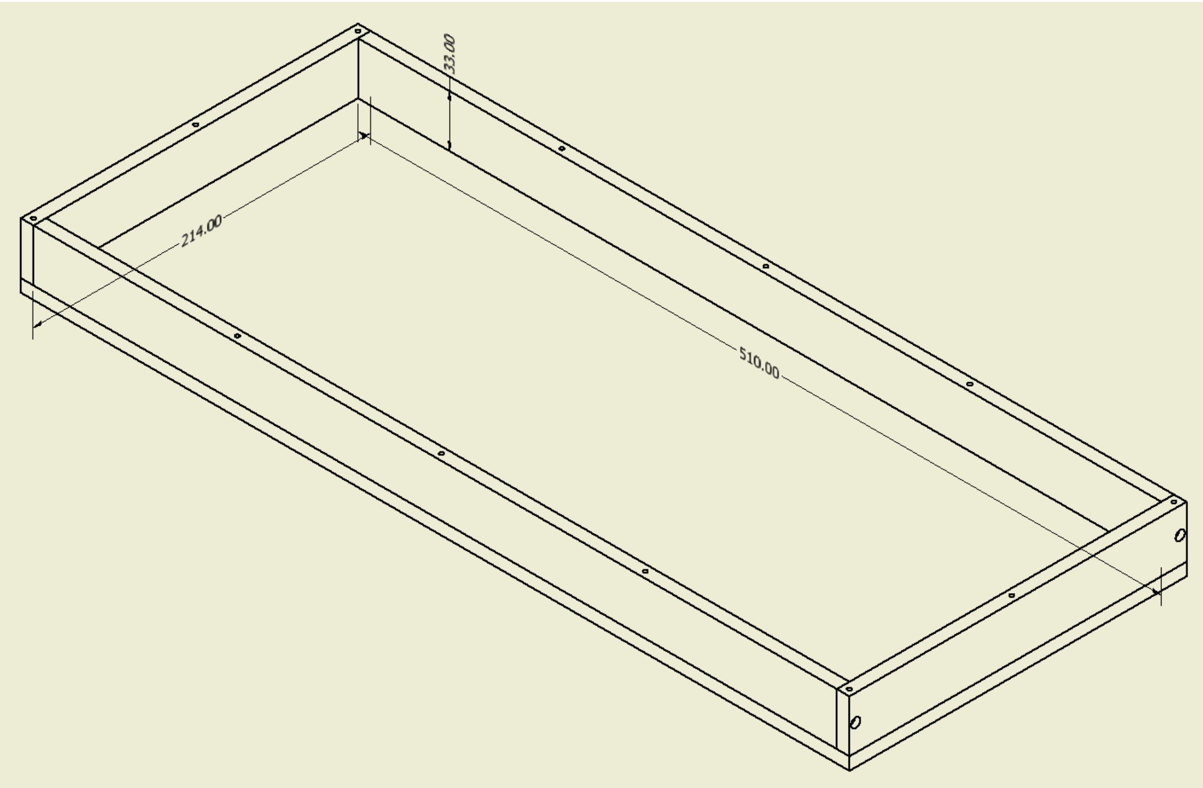

Figure 2: Mock-up drawing of rradiation box at Fraunhofer irradiation facility

Gamma Dosimetry

TBC

Sample preparation

Chemical analysis

For the chemical analysis with XFS, samples should be produced with a size sufficient to allow absorption of the X-rays. Recommendation from the chemistry lab at CERN point towards samples prepared in the shape of cubes with 2cm side. Smaller samples can be measured as well, but this of course will decrease the measurement sensitivity.

Thermal and mechanical testing

For the thermal and mechanical testing, we propose a single form factor for the sample preparation: a lap joint derived from slightly modifying the ISO4587 standard, with the dimensions shown in Figure 3.

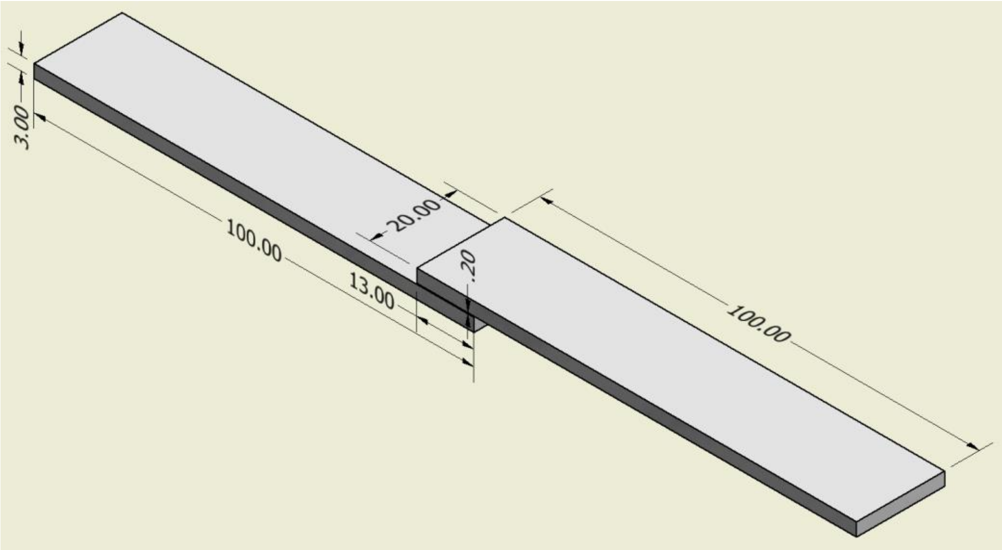

Figure 3: Lap-joint for thermal/mechanical testing.

The lap-joint shall be assembled using a dedicated jig [TBC]. The thickness of the adhesive shall be controlled by using predefined spacers to a thickness of 200 um (?).

Sample marking

The samples shall be identifiable by a specific code (TBD). As the gamma irradiation at such high doses can be expected to degrade the ink from markers, the sample ID shall be engraved in the aluminium of the lap joint, in a region non conflicting with thermal tests (heater/temperature sensors).

Sample multiplicities

For the XFS, considering the size of the sample, a single sample per material is sufficient. For the neutron activation studies, 2 samples per material are recommended, to have consistency checks.

For gamma irradiation, at least three target doses should be foreseen, e.g. 7, 13, 20 MGy. This would allow to swap part of the samples during the irradiation at the reach of e.g. the 7 MGy dose, to optimize the space utilization in the box.

For thermal testing, 2 samples per material, per dose, should be foreseen for consistency checks, for a total of 6 samples per material. The same amount of samples should be foreseen for the mechanical tests, for 12 total samples per material. Of the two thermal samples per dose, after successful testing of the first one, the second should further be dedicated to mechanical tests, for a total of three mechanical samples per dose.

Assuming a regular envelope for the lap-joint samples of 6.2 x 187 x 20 mm, the irradiation box can accommodate (an underestimated number of) 125 samples, for a total of 10 materials per irradiation run.

Thermal testing

Thermal testing shall be performed in a vacuum chamber, to avoid thermal losses due to air convection movements. Optionally, the adoption of multi-layer insulation (MLI) can be envisaged to increase the accuracy of the measurements. The conductivity of the sample shall be tested by applying a heater to one arm of the lap joint and a heat sink (cooling block) to the other arm. Two temperature sensors shall be placed in close proximity of the joint (one per arm), in order to measure the ΔT.

[To be continued with procedure for calculating TFM, wattages, temperature of sink, etc.]

Mechanical testing

Mechanical testing shall be performed following the ISO4587 standard and using a tensile strength machine.

Timeline

The following list covers the expected duration for every single step of the testing campaign.

- XFS characterization: 2 weeks from sample delivery
- Neutron irradiation and spectroscopy: 1 month from sample delivery (can proceedi in parallel with XFS)
- Gamma irradiation: irradiation usually starts within 2 weeks from the contractual agreement
- Mechanical testing: several samples / day (??) /institute
- Thermal testing: 1 sample/day/institute

Please note that the duration of each single step was assessed through personal discussions with the involved entities and should be regarded as indicative.