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RADIATION SHIELDING OF COMPOSITE SPACE ENCLOSURES

2nd FP7 Space Research Conference
15-16 November, Larnaca, Cyprus

NEED

The main components of the space environment are energetic electrons and protons

The standard practice in space hardware is the use of aluminium as both a radiation shield and structural enclosure

To reduce weight => **composite materials** which have higher strength-to-weight ratios than aluminium.

- Conventional graphite epoxy composites are not as efficient shielding materials as aluminium because of their lower density
  - for the same mass, composites provide 30 to 40% less radiation attenuation than aluminium
  - for the same radiation attenuation, the composites tend to be 30 to 40% thicker than aluminium.
- Key aspects in the understanding of the transport phenomenon and the nature of interactions between space radiation and shielding material are:
  - Material to be incorporated to the composite enclosure to obtain the required level of radiation shielding with minimum mass
  - Amount to be incorporated;
  - Position in the composite enclosure
- Testing development is necessary to check the validity of the modelling and the analysis. With a very good understanding of the phenomena it will be possible to predict the level of radiation only by using simulation software and avoid expensive testing costs and time consuming tests

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SEVENTH FRAMEWORK PROGRAMME

Development of the technologies and tools required to obtain lightweight, safe, robust and reliable composite structures.

Technological objectives:

- Development of analytical tools and models for radiation design of composite structures
- Assessment of material technologies for providing improved radiation shielding behaviour
  - Nanotechnology: Two different strategies will be followed: Doping of the bulk resin with nanofillers and buckypaper
  - Integration of foils
- Skilled handling and manufacturing of complex shapes components with brittle high thermal conductivity fibres.
- Study of manufacturability and handling of openings and joints
- Development of a test set-up and testing of a composite enclosure
- Validation of the developed technologies and analytical models by means of testing.

BENEFITS

- Understanding of radiation influence in composite materials.
- Validation of the tools used for mission requirements definition and radiation behaviour.
- Composite structures design phase optimization by means of the development and validation of specific analytical tools.
- Definition of specific test procedures and test set-up for composite structures.
- Important mass savings in the spacecraft mass as a consequence of using reliable composite structures instead of aluminium.

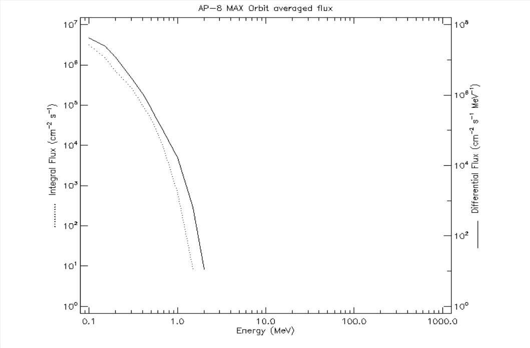
SPECIFICATIONS

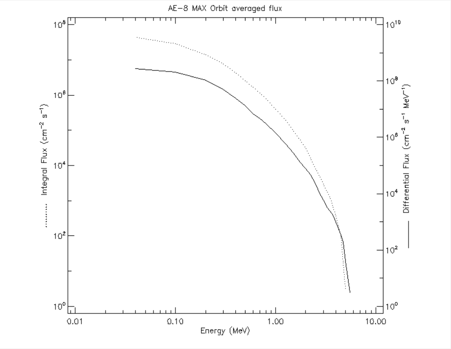
Orbit	Duration [years]	Altitude [km]	Inclination i [°]	Longitude λ [°]
LEO	7	1,600	60	$\lambda(t)$
GEO	18	35,794	0	36

Protons

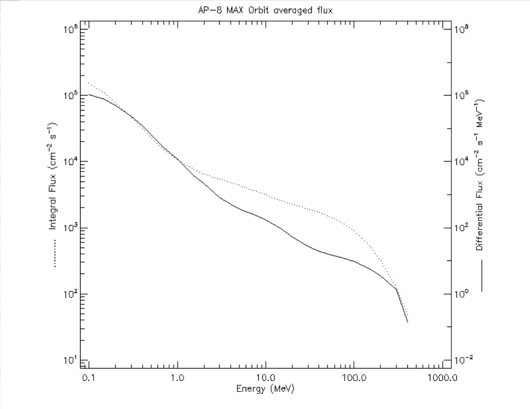
Electrons

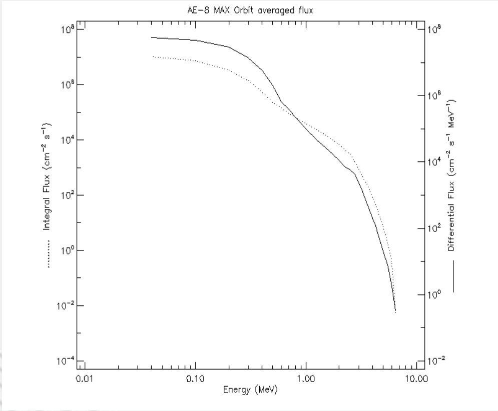
GEO orbit





LEO orbit



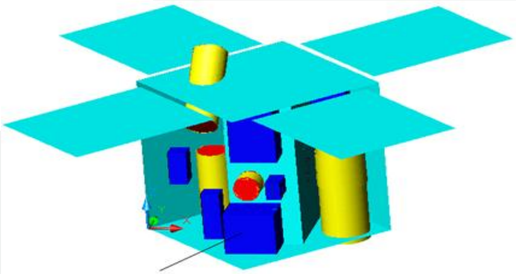


Altitude, [km]	Integral density of protons fluence (earth trapped radiation belt)[$cm^{-2}s^{-1}$]	protons fluence (from sun),[cm^{-2}/year][1]	Integral density of electrons fluence (earth trapped radiation belt)[$cm^{-2}s^{-1}$]
1600	10^5 (E=0.1-400MeV)	$4\cdot10^{10}$	$9\cdot10^5$
35794	$9\cdot10^5$ (E=0.1-3 MeV)	$4\cdot10^{11}$	$4\cdot10^5$

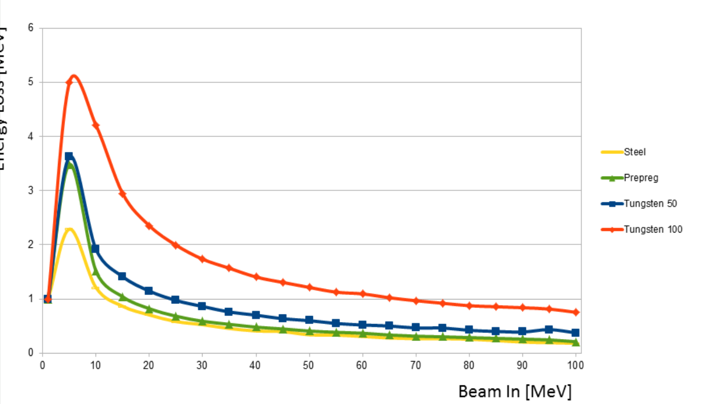
ANALYSIS OF THE EFFECTS OF RADIATION IN COMPOSITE STRUCTURES

Interaction of protons, electrons, secondary radiations (interaction of proton stream with material)

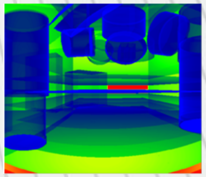
Tool for optimal arrangement of satelitte materials

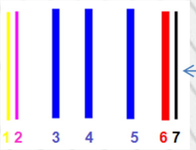


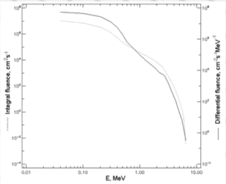
Block of onboard radioelectronic equipment been used for example of calculations

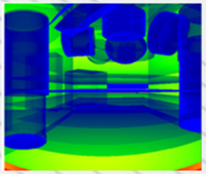


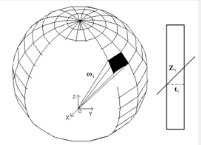
Sector analysis to find place for additional shielding → MULASSIS macro generation → Calculation of ionizing and nonionizing doses with MULASSIS tool → Replacement of dose values in arrays → Calculation of total ionizing and nonionizing doses at the defined point











$$D^{ion} = \frac{1}{4\pi}\sum_{i=1}^{N} D_i^{ion} \cdot \omega_i$$

$$D^{non-ion} = \frac{1}{4\pi}\sum_{i=1}^{N} D_i^{non-ion} \cdot \omega_i$$

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SEVENTH FRAMEWORK PROGRAMME

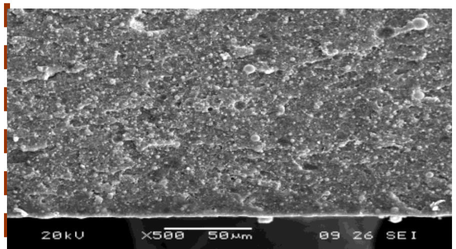
Technologies to improve radiation behaviour of composite structures

– MTM44 epoxy resin from ACG and the M40J fibre have been selected

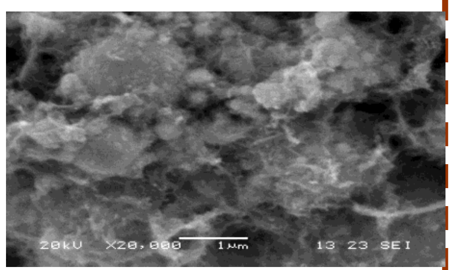
Nanomaterials

Doped resin

Buckypaper



Tec4 (30% wt nW/0.5% wt CNT)

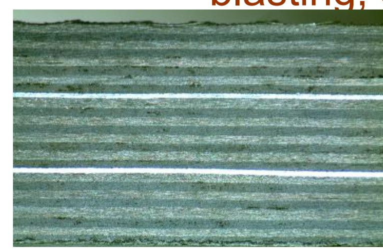


CNT/W 6/94

Integration of Foils

Different foils (steel, W)

Various surface treatments (grit blasting, etching…)



Doping strategy:

- W particle size. The SkySpring W nanopowder does not present an homogenous particle size. From nanometric size (30 nm) up to micrometric particles (5 microns) have been found. Decantation of larger size particles has been observed in some samples.
- The epoxy resin can be doped with high percentage of W particles keeping manufacturability parameters (viscosity around 4000-5000cp).
- Maximum content of 0,5% CNT and 30% W can be achieved when combining both fillers to dope the epoxy resin

Buckypaper strategy:

- High CNT loading can be obtained with BPs
- Buckypapers are porous materials. Therefore, a good impregnation with epoxy resin is assured.
- High contents of CNT in combination of W nanoparticles can be obtained (50 % CNT/50 % W)
- W particles decantation has not been produced due to the CNT network

Integration of metallic foil:

- W foils have been integrated.
- Integrity of laminates with metallic foils is secured with proper surface treatment foils.
- Grit embedment and warping of laminate due to asymmetric lay-up and internal residual stresses have been found.

SAMPLES DETAILS

Reference	Details
TEC1	Doped resin with 2,21%CNT
TEC2	Doped resin with 88%W
TEC3	Doped resin with 63%W
TEC4	Doped resin with 30%W/0,5%CNT
TEC9	Buckypaper 100%CNT
TEC8	Buckypaper 76,60%CNT/23,4%W
TEC7	Buckypaper 50%CNT/50%W
TEC6	Buckypaper 24%CNT/76%W
TEC5	Buckypaper 6%CNT/94%W
TEC11	0,Buckypaper 76,60%CNT/23,4%W,90,Buckypaper 76,60%CNT/23,4%W,0
TEC10	Impregnated Buckypaper 30%W
Aalto-1 & Aalto-6	2 prepreg layers + 0.05 mm Tungsten + 4 prepreg layers
Aalto-2 & Aalto-7	3 prepreg layers + 0.05 mm Tungsten + 3 prepreg layers
Aalto-3 & Aalto-8	4 prepreg layers + 0.05 mm Tungsten + 2 prepreg layers
Aalto-4 & Aalto-9	5 prepreg layers + 0.05 mm Tungsten + 1 prepreg layer
Aalto-10:	3 prepreg layers + 0.05 mm Tungsten + 1 prepreg layer + 0.05 mm Tungsten + 2 prepreg layers
Aalto-11:	4 prepreg layers + 0.05 mm Tungsten + 1 prepreg layer + 0.05 mm Tungsten + 1 prepreg layer
Aalto-12:	3 prepreg layers + 0.05 mm steel + 1 prepreg layer + 0.05 mm Tungsten + 2 prepreg layers
Aalto-13:	4 prepreg layers + 0.05 mm steel + 1 prepreg layer + 0.05 mm Tungsten + 1 prepreg layer
Aalto-14:	2 prepreg layers + 0.05 mm steel + 2 prepreg layers + 0.05 mm Tungsten + 2 prepreg layers
Aalto-15:	3 prepreg layers + 0.05 mm steel + 2 prepreg layers + 0.05 mm Tungsten + 1 prepreg layers
Aalto-18:	8 prepreg layers + Gadolinium paint
Aalto-19:	4 prepreg layers + 0.05 mm Tungsten + 4 prepreg layers
Aalto-20:	6 prepreg layers + 0.05 mm Tungsten + 2 prepreg layers
Aalto-21:	7 prepreg layers + 0.05 mm Tungsten + 1 prepreg layer
Aalto-16:	6 prepreg layers (reference)
Aalto-17:	8 prepreg layers (reference)
Aalto-22:	2 mm Al-2024-T3 (reference)

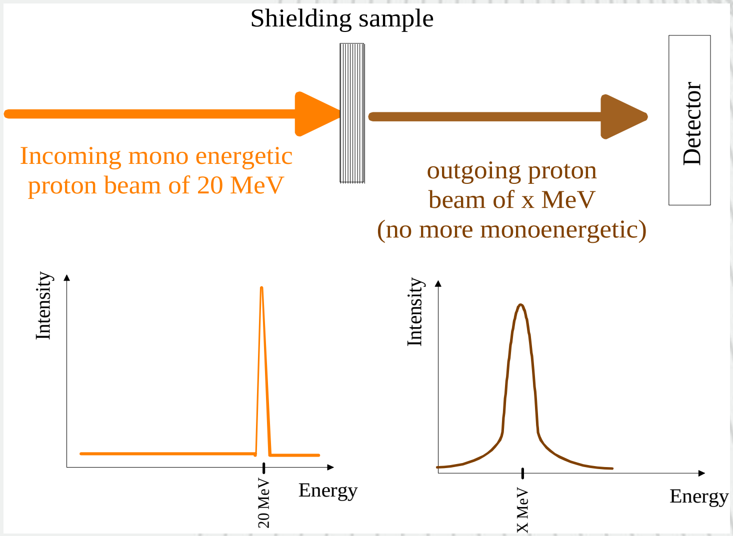
TEST CAMPAIGN

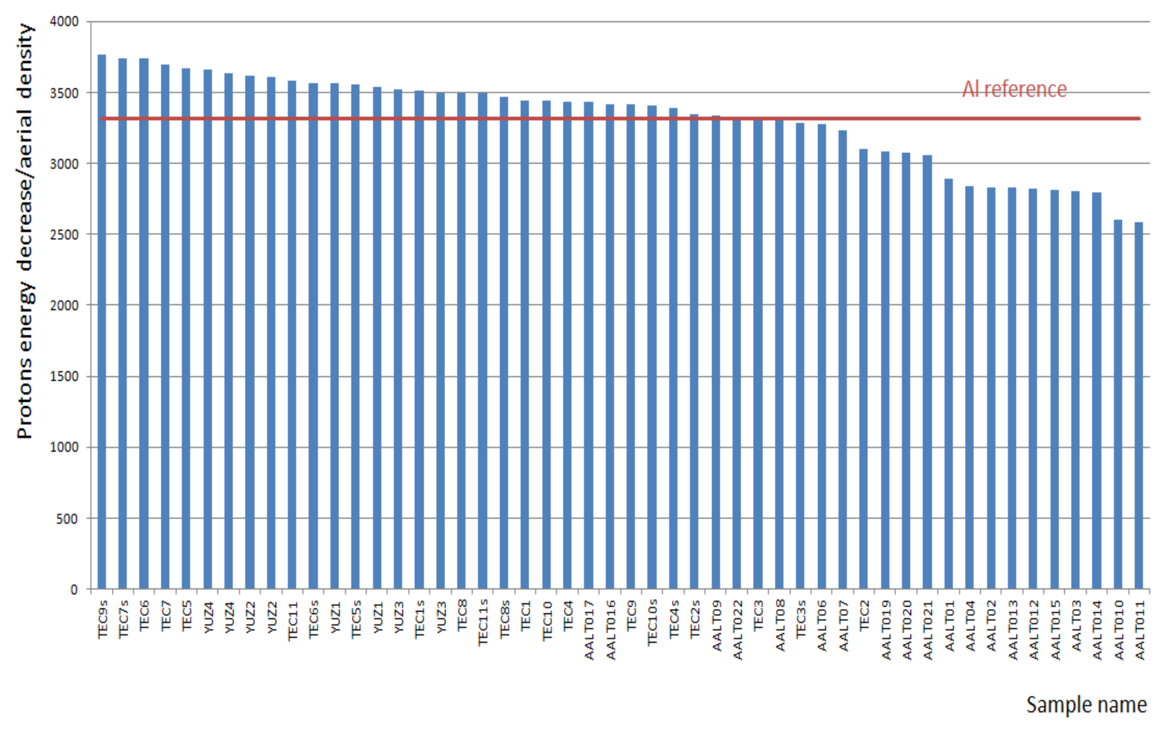
First Test campaign

– Proton irradiation:
  - The incident proton beam will have an energy of 20 MeV
  - One energy spectrum of the protons after each sample will be recorded
– Electron irradiation:
  - 6 MeV electrons
  - One energy spectrum of the electrons after each sample will be recorded
– Gamma irradiation:

Proton irradiation

PROTON TESTS (20 MeV)

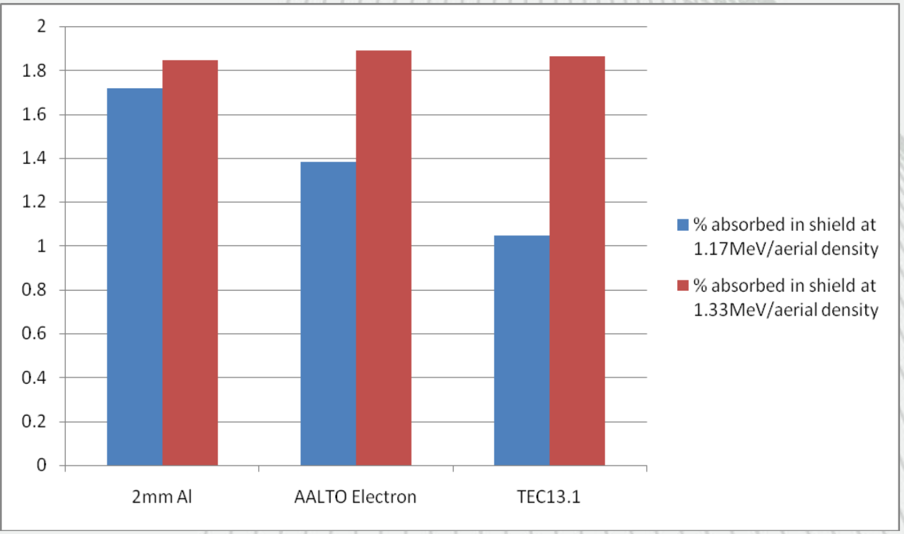




TEST CAMPAIGN

Gamma Irradiation

Source : ^{60}Co,measurement of photons spectrum after shielding



Gamma peak at 1.33 MeV the composite sample is more efficient shielding than Al. However, it is less efficient for the 1.17 MeV peak

Electrons Irradiation

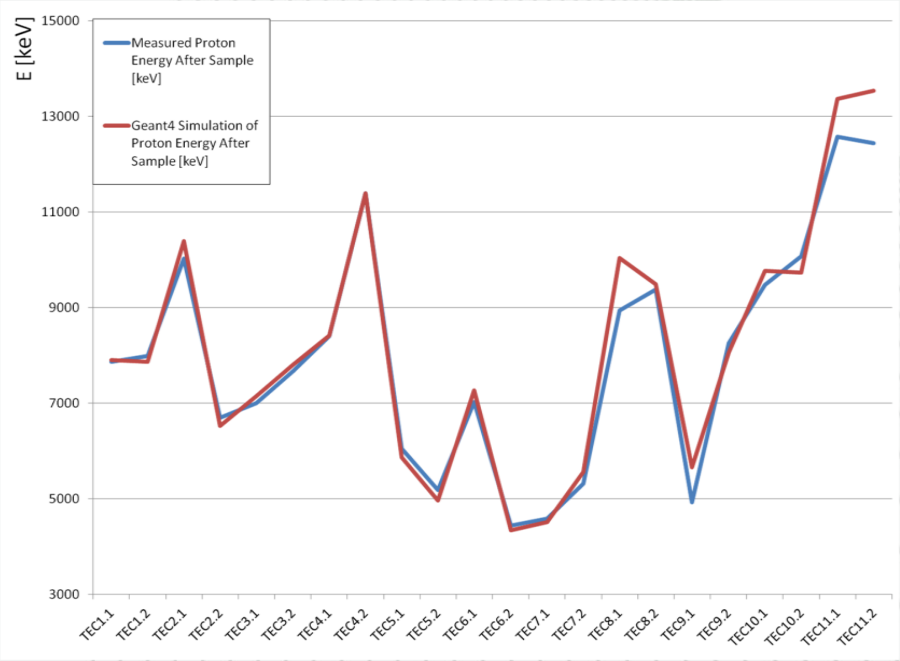
Medical electron accelerator was used to irradiate samples with 6 MeV electrons beam.

	No shield	Al 2mm shield	AALTO shield	TEC13_1 shield
Calculated dose Radfet 1 (cGy)	78.92	18.34	75.74	78.13
Calculated dose Radfet 2 (cGy)	80.52	23.92	74.94	82.91

No more efficient than aluminium. New combinations will be tested in the next phases of the project

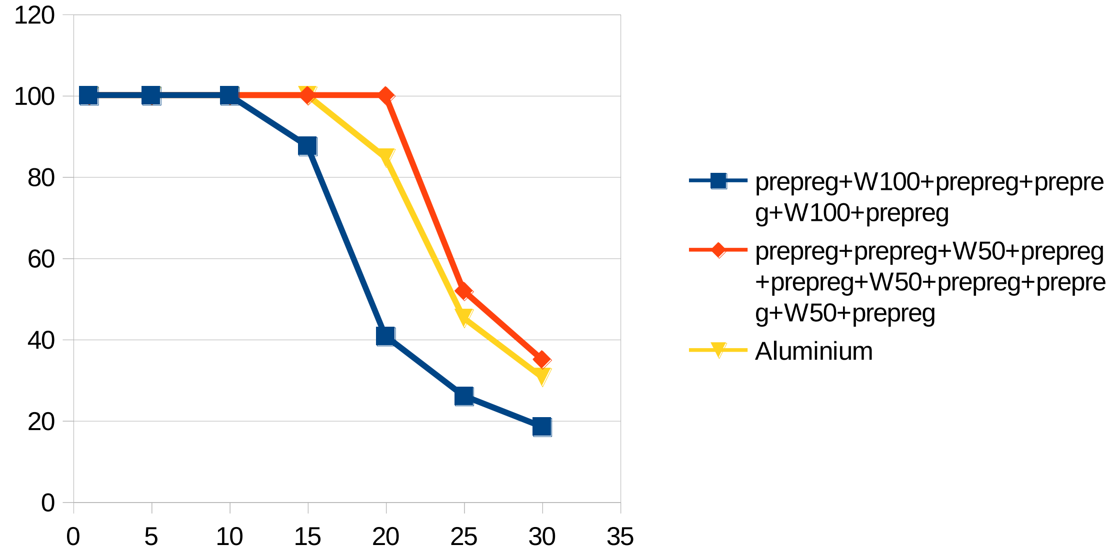
Correlation Simulations vs Experimental

Simulation model follows closely with test results (protons – 20MeV) obtained in the test campaign



SIMULATIONS – Optimization (for 2nd test campaign)

Performance of the samples in comparison with 2 mm layer of Al.



Performance of the selected compositions in comparison with 2 mm layer of Aluminium. The X-axis is the energy of the incoming protons in MeV and the Y-axis the relative energy loss in per-cents.

CONCLUSIONS

- The use of nanotechnologies and the integration of W foils has been considered to improve the radiation shielding behaviour of composite materials.
- Manufacturing approaches to incorporate the nanofillers into the laminates have been developed: doping of the resin and buckypapers.
- Simultations and tests at sample level have been carried out.
- A correlation of the results obtained indicates simulation models can predict composite behavior. Secondaries influence will be considered in further steps of the study.
- An analytical tool to identify locations where radiation shielding is critical or required is being developed.
- Promising results have been obtained with the nanomaterials in the Proton Irradiation test (20 MeV). However, the strategy to shield against electrons will have to be further studied in the next steps of the project.
- Results presented correspond to the first stage of SIDER project. In further steps, simulations in the whole energy spectra in order to select the most promising material and a detailed Second Test campaign will be carried out.

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