

# STUDY OF THE NEUTRON SHIELDING CAPACITY OF DIFFERENT CARBON MATERIALS FOR SPACE APPLICATIONS

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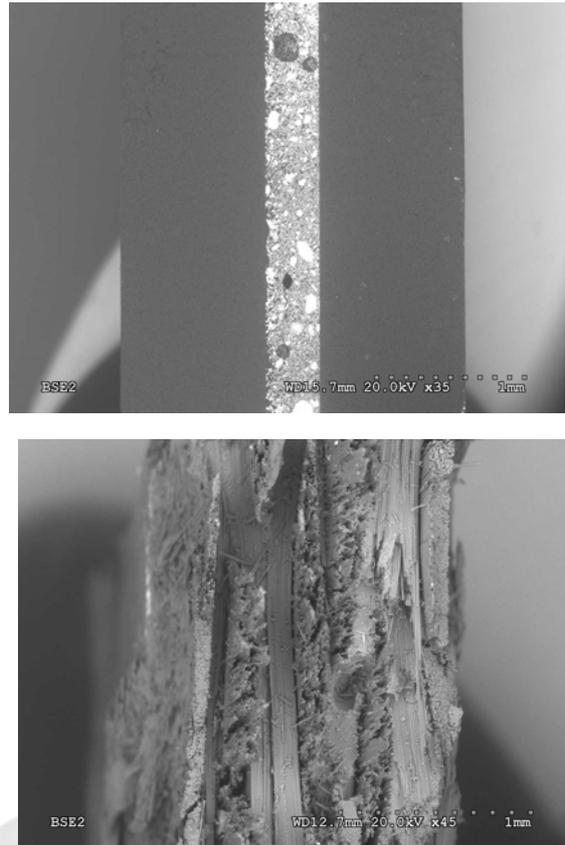
## Introduction

The space radiation mainly consists of electrons, protons and ions with a wide range of energies. The impact of this radiation to artificial satellites damage the on board electronic devices, which must be properly protected [1]. The satellite structure provides a certain protection against radiation, and when a particular device requires additional protection is placed within a heavy metal box. Usually, aluminum is the preferred material for satellite structures, but currently, carbon materials are becoming of interest due to their lower weight. This has motivated an increasing effort in order to develop carbon composites that fulfill the requirements of space applications [2] and is also promoting the study of the radiation effects on carbon materials [3-5].

The aim of this study is to compare the proton shielding capacity of aluminum foils with that of several pure carbon materials and carbon-resin-tungsten composites.

## Experimental

2x2 cm square samples of different thickness have been prepared with a carbon material, tungsten and/or epoxy or phenol formaldehyde resin. Different commercial carbon materials were tested: graphite foils, powder graphite, carbon black, and carbon fibers. The samples were characterized by SEM-EDS, XRF and Raman Spectroscopy. The proton shielding capacity was tested with monoenergetic proton beams at the National Accelerators Center (Seville, Spain) and at the Paul Scherrer Institute (PSI, Villigen, Switzerland) with proton beams with energies in the range of relevance for space applications (10-21 MeV). Commercial aluminum foils of different thickness were also tested.



**Fig. 1** SEM images of two of the carbon materials prepared and tested. Top: Epoxi resin layer loaded with tungsten powder between two graphite layers. Bottom: Carbon fibers and phenol-formaldehyde resin composite.

## Results and Discussion

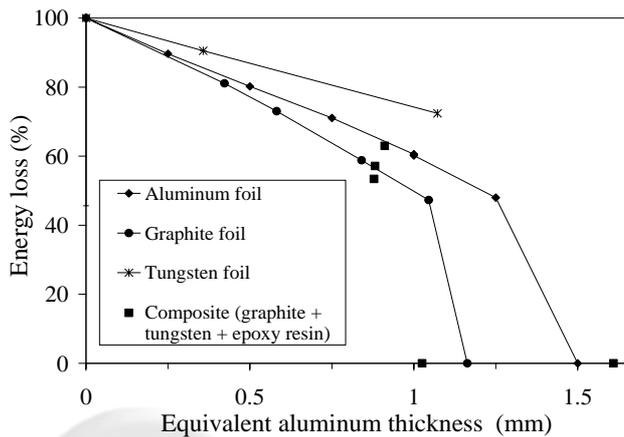
As an example, Figure 1 shows SEM images of two of the carbon materials prepared and tested. Figure 1 (top) shows a few micrometers epoxy resin layer, loaded with tungsten powder, between two graphite layers and Figure 1 (bottom) shows a carbon fibers and phenol-formaldehyde resin composite.

Figure 2 shows the loss of energy of an 18 MeV proton beam when it travels through foils of different thickness and composition. The proton shielding capacity of the pure materials irradiated (graphite, aluminum and tungsten) is inverse to the atomic weight of the material, graphite reaching the highest proton shielding capacity if foils of similar weight are compared. There are not significant differences among the carbon materials tested, the proton shielding capacity only depends on the carbon material density.

The carbon-tungsten-resin composite behavior is in between or even better in some cases, than that of the parent

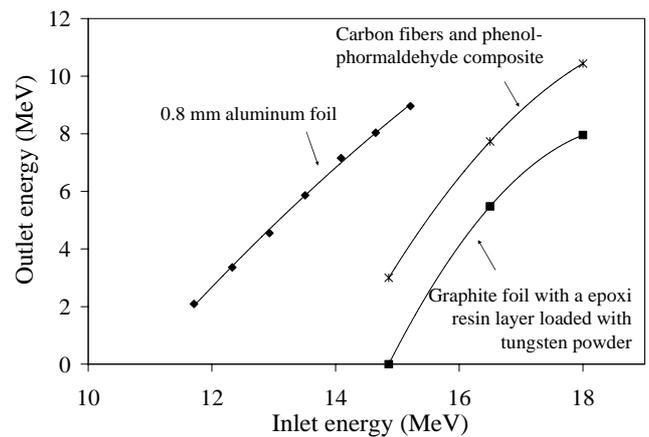
materials. The improved proton shielding capacity showed by several composites is attributed to the contribution of the hydrogen on the resin.

The proton shielding capacity of all materials increases with thickness, as expected, and above a threshold value between 1 and 1.75 mm (aluminum equivalent), which depends on the material, the energy of the proton beam is totally depleted.



**Fig. 2** Irradiation with an 18 MeV proton beam of samples with different thickness. (The equivalent aluminium thickness of a sample is defined as the thickness that would have an aluminium foil with the same weight than this sample).

The conclusions reached with the 18 MeV proton beam can be extended to all the range of energies studied. In Figure 3, the energy of the outlet proton beam is plotted against the inlet energy. The samples selected are an aluminum foil of 0.8 mm, a graphite foil coated with a thin layer of epoxy resin loaded with tungsten particles, and a carbon fiber-phenol-formaldehyde resin composite, all of them with similar equivalent aluminum thickness (~ 0.8 mm). As it is deduced from Figure 3, the proton shielding capacity of the carbon materials tested is superior to that of aluminum within all the range of energies with interest for space applications.



**Fig. 3** Irradiation with proton beams of different inlet energies of samples with equivalent aluminum thickness of about 0.8 mm.

### Conclusions

The carbon materials studied outperform the proton shielding capacity, for proton beams with 10-21 MeV, of aluminum foils with similar weight. This has practical relevance in the design of future satellites since carbon-based materials are able to provide the same protection against proton radiation than aluminum saving about 10% of the material weight.

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