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Irradiation test of mirror samples for the LHCb SciFi tracker

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Abstract

The optical mirrors at the inner ends of the SciFi fibre modules in the upgraded LHCb detector will be exposed to an ionising dose reaching 35 kGy for an integrated luminosity of 50 /fb.

This note describes a campaign at the cyclotron at KIT where 7 different samples were irradiated with 23 MeV protons. The samples consisted of plastic scintillator tiles, on which two different mirror foils – aluminised mylar and 3M ESR - were attached with two different glues – Epotek H301-2FL and Dow Corning RTV 3145. The transmission and/or reflectivity of the samples were measured before and after irradiation.

The measurements reveal the combination of 3M ESR foil and Epotek H301-2FL to give the highest reflectivity, before and also after irradiation. In all cases, the irradiation leads only to a small, i.e. less than 10%, degradation of the transmission or reflectivity.

From a radiation hardness point of view, all investigated mirror samples qualify for use in the SciFi detector.

1 Introduction

The LHCb SciFi detector which is currently under development for installation during the long shutdown 2, is equipped with mirror foils attached to the inner ends of the scintillating fibres. Their role is to increase the signal detectable in the SiPM detectors at the outer fibre ends. At the upgraded LHCb, the ionising radiation levels in the inner part of SciFi, particularly close to the beam pipe, will reach a dose of 35 kGy, integrated for a luminosity of 50 /fb.

Earlier irradiation tests[1] performed at the CERN PS Irrad facility with 24 GeV protons showed that the mirrors or the glue used to attach them to the fibre ends may be affected by such ionising dose values. However, these tests were performed with BC-600 glue from Saint Gobain, which is not the type foreseen for the SciFi detector.

In the following we describe an irradiation test performed at the cyclotron facility of the KIT in Karlsruhe. Seven samples, including the combinations of two different glues and two different mirror foils were irradiated with 23 MeV protons to a dose of approximately 35 kGy. Transmission or reflectivity of the different samples were measured with a commercial spectrometer at CERN.

2 Test samples

A total of seven samples with an area of 40 x 40 mm^2 and approximately 2 mm thickness were prepared. The samples were designed to allow distinguishing between radiation effects of the scintillating tile, the glues and the mirror foils themselves.

The plastic scintillator was of type Eljen EJ-200. The investigated glue types were optically transparent Epotek H301-2FL epoxy glue[2] and Dow Corning RTV 3145, a transparent silicone glue[3]. The mirror foils consisted of mylar foil (60 μm thickness) vacuum coated at CERN with an Al/MgF_2 pair (90 nm / 20 nm thickness) and the commercial Enhanced Specular Reflector (ESR) film produced by 3M.

Scintillator tiles of 1 or 2 mm thickness were prepared. The 1 mm thick tiles served as inner and outer support, in between which a layer of 100 μm thick glue was applied. The 2 mm thick tiles were used as substrates on which the mirror foils were attached with the glues. The thickness of the glue layers was controlled by adhesive tapes in the peripheral region of the samples.

The chosen sample configuration is similar to the one in the SciFi detector, where the mirror foils will be attached to the fibre ends, which after diamond cutting will have a smooth end face.

As the Epotek H301-2FL glue is very fluid and therefore difficult to apply, it was heated to 40°C for 20 minutes prior to applying it to the samples. Both glues were cured at room temperature.

[1] C. Joram and T. Schneider, Mirroring of fibre ends for the LHCb SciFi project. LHCb-PUB-2014-020

[2] The Epotek H301-2FL glue is also used in the SciFi project to bond the fibres to fibre mats.

[3] Dow Corning RTV 3145 has been successfully used in previous experiments like CMS ECAL or AX-PET.

The samples have the following structure and composition:

no.	sample structure
1	bare scintillator tile, 2 mm thick
2	100 μm RTV glue between two 1 mm thick scintillator tiles
3	100 μm H301-2FL glue between two 1 mm thick scintillator tiles
4	Alum. Mylar mirror glued with 100 μm RTV to a 2 mm scintillator tile
5	3M ESR mirror glued with 100 μm RTV to a 2 mm scintillator tile
6	Alum. Mylar mirror glued with 100 μm H301-2FL to a 2 mm scintillator tile
7	3M ESR mirror glued with 100 μm H301-2FL to a 2 mm scintillator tile

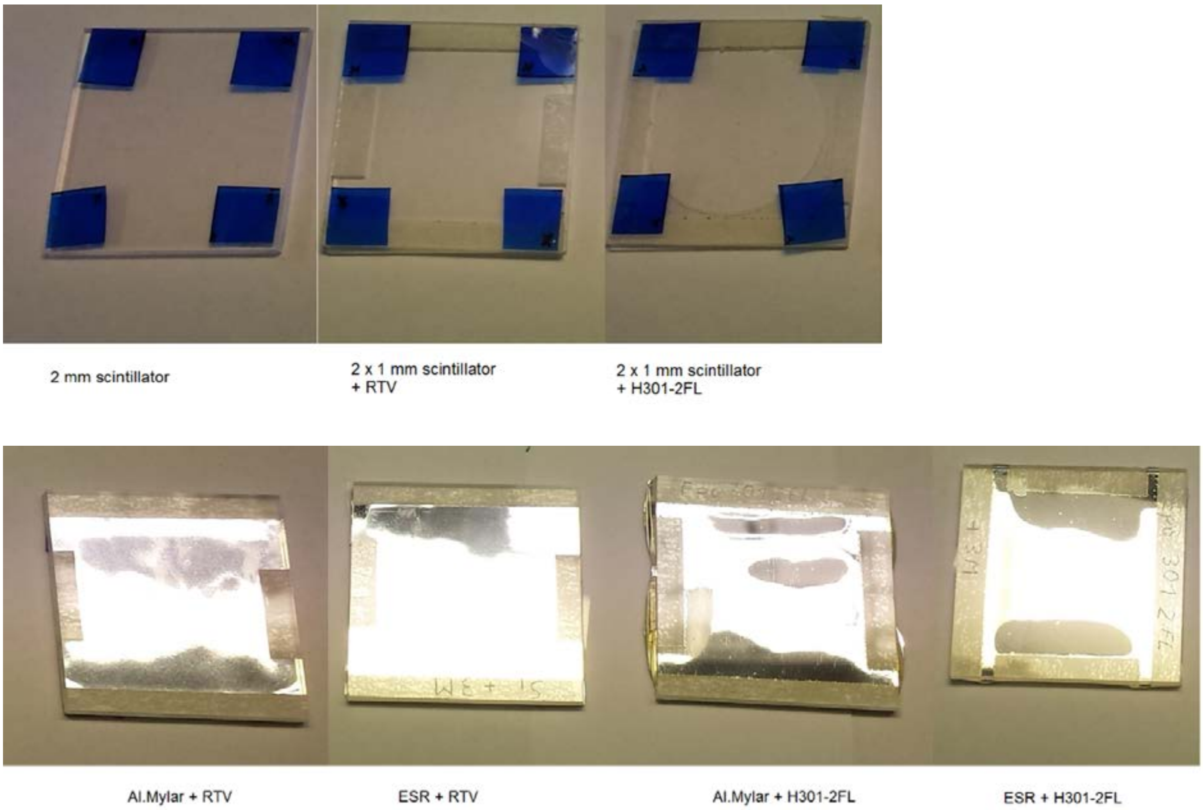

Figure 1: Photos of the seven samples, taken after the irradiation. The blue squares on the photos in the top row are remainders of the dosimetry film, which was used for an independent check of the dose and its uniformity (see sec. 4).

3 Transmission and reflectivity measurements before irradiation

Transmission and reflection measurements were performed with the commercial UV-Visible (190 – 900 nm) spectrometer Perkin Elmer Lambda 650. It provides sub-nm wavelength resolution and is regularly serviced and calibrated by the producer. For the measurements below we used a Ø150 mm integrating sphere from Perkin Elmer which allows to distinguish angular (specular), diffusive and total reflection. The diffusive part is generally small (<5%). In this note we show therefore only results of the specular transmission and reflectance.

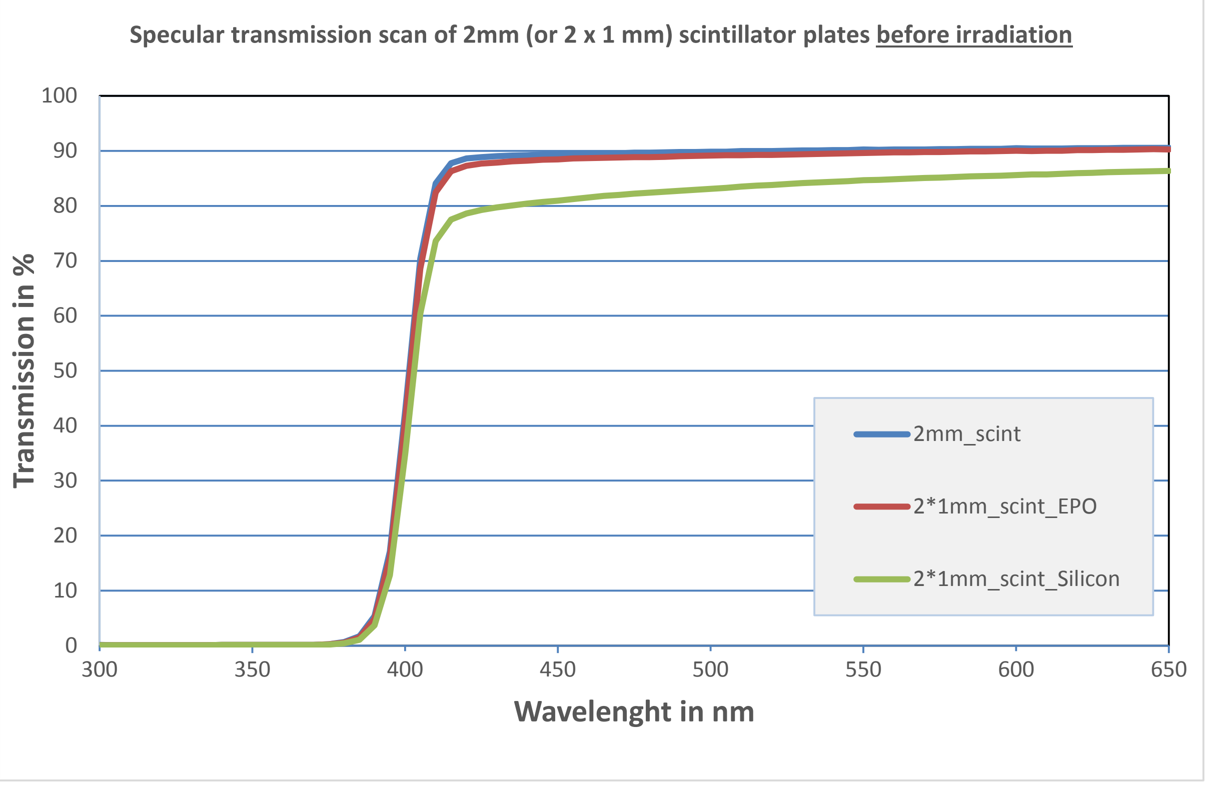

Figure 2: Specular transmission of the samples 1 – 3 versus wavelength, prior to the irradiation. The 5 – 10 % lower specular transmission of the RTV silicone glue is mainly due to the more diffuse aspect of this glue.

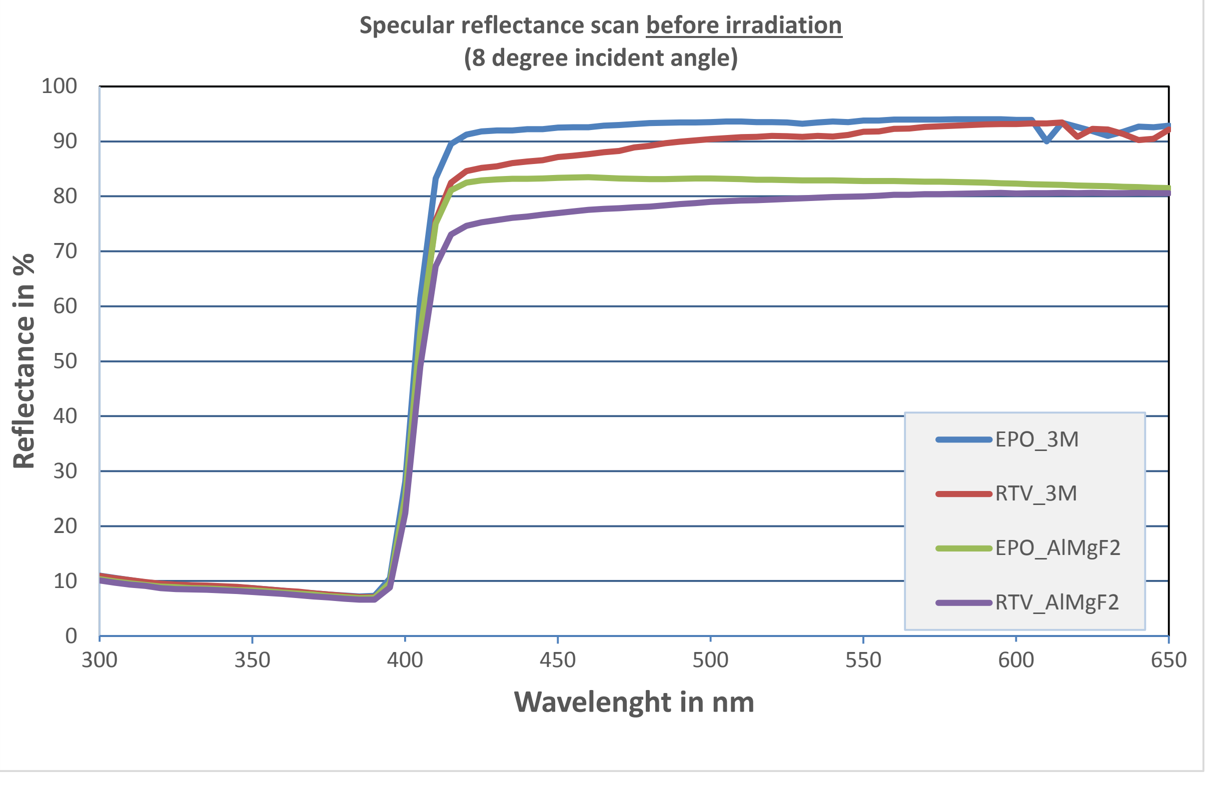

Figure 3: Specular reflectance of the samples 4 – 7 for an angle of incidence of 8°, prior to the irradiation.

All measurements were performed in the central region (within 2 x 2 cm^2) of the samples. The samples were placed manually. Therefore, measurements before and after irradiation do not exactly correspond to the same position on the sample. The samples show good visual uniformity. A few small air bubbles were present.

The transmission of the samples 1 - 3 was measured at normal incidence, while the reflection of the samples 4 - 7 was measured under an angle of incidence of 8° (w.r.t. the mirror normal). No corrections were applied for the Fresnel reflections which occur at the air – scintillator interfaces. Due to the high refractive index of polystyrene of n = 1.59, the Fresnel reflection amounts to $R_F = ((n-1)/(n+1))^2 \approx 5.2\%$ per interface.

Figure 2 shows the specular transmission of the samples 1 – 3 versus wavelength. All samples show the expected behaviour, namely nearly constant transmission down to the cut-off wavelength of the scintillator.

Figure 3 summarises the results of the reflectance measurements for an angle of incidence of 8°. The 3M ESR film shows about 10% higher reflectance than the aluminised Mylar samples (90% vs 80%).

Thanks to its higher clarity, combinations with the Epotek epoxy glue result in higher specular reflectance than combinations with the RTV silicone glue. The apparent reflectance below 400 nm is an artefact which is caused by the Fresnel reflection at the scintillator entrance surface and by UV - excitation of the wavelength shifting dye in the scintillator plate.

4 Irradiation and dosimetry

Following the above described measurements, the samples were sent to KIT Karlsruhe for irradiation with 23 MeV protons from the cyclotron facility[4]. The relatively low energy leads to a high ionisation loss of 22.9 MeV/cm in polystyrene. To achieve an ionising dose of 35 kGy, the required proton fluence is $9.5 \cdot 10^{12}$ p/cm^2. The beam spot has a diameter of 4 – 8 mm. The object to be irradiated is placed in a box which can be scanned w.r.t. the beam to generate the desired dose distribution. The turning points of the scan can be placed such that good uniformity is achieved in a defined target region. For an independent dose and uniformity check, dosimeter films of type FWT-60[5] of 4 x 4 cm^2 size were attached to the samples (behind the mirror foil). The samples were oriented such that the incident beam traverses first the dosimeter film.

The irradiation was performed during the week 25-29 January 2016. KIT guarantees the proton fluence and hence the ionising dose with an uncertainty of ±20%. The analysis of the optical density of the dosimeter films at CERN resulted in an average dose of 26.9 kGy in the central 2 x 2 cm^2 region with a non-uniformity of 1.1 kGy. In the peripheral region, where the scan turning points are located, between 24 and 45 kGy were measured. From previous experience, the uncertainty of the film based dose measurements are known to be about ±15%. Weighted averaging of the KIT and CERN results lead to a dose of 30.6 ± 4.0 kGy.

[4] http://www.ekp.kit.edu/english/irradiation_center.php
[5] Far West Technology, Inc.

Following transport to CERN and radiological checks, the optical measurements described in the following chapter were performed on 12 February 2016.

5 Transmission and reflectivity results after irradiation

The samples showed no signs of mechanical or geometrical degradation which could be attributed to the irradiation or transport. Attempts to peel off the mirror film in a corner of the samples showed that the adherence of the films to the scintillator substrate was high for all glue/film combinations. Only sample 2, Epotek H301-2FL between 2 x 100 μm scintillator, shows a slightly brownish discolouration, particular in the outer zone, where the dose reached up to 45 kGy.

Figure 4 and Figure 5 show the transmission of samples 1 -3 and the resulting transmission loss after irradiation. While the scintillator tile alone and the sample with the RTV glue show only a very small reaction to the ionising dose (1-2%), the Epotek H301-2FL glue leads to an additional absorption, rising from about 1% to 7% close to the cut-off wavelength. The wavelength dependence of this effect is similar to what was observed on the before mentioned BC-600 epoxy glue sample irradiated in 2015 at the CERN PS.

Figure 6 and Figure 7 show the reflectance of samples 4 – 7 and the loss due to the irradiation. The two samples glued with Epotek H301 glue show maximum losses of 3 and 7%. Considering that the light has to pass the 100 μm thick glue layer two times, the transmission loss observed on the Epotek H301 sample (see Figure 5) would let us expect an effective reflectance loss in the 10-15% region. The mismatch is not due to a radiation related increase of the diffuse component, which remained also after irradiation on the small level of <5%.

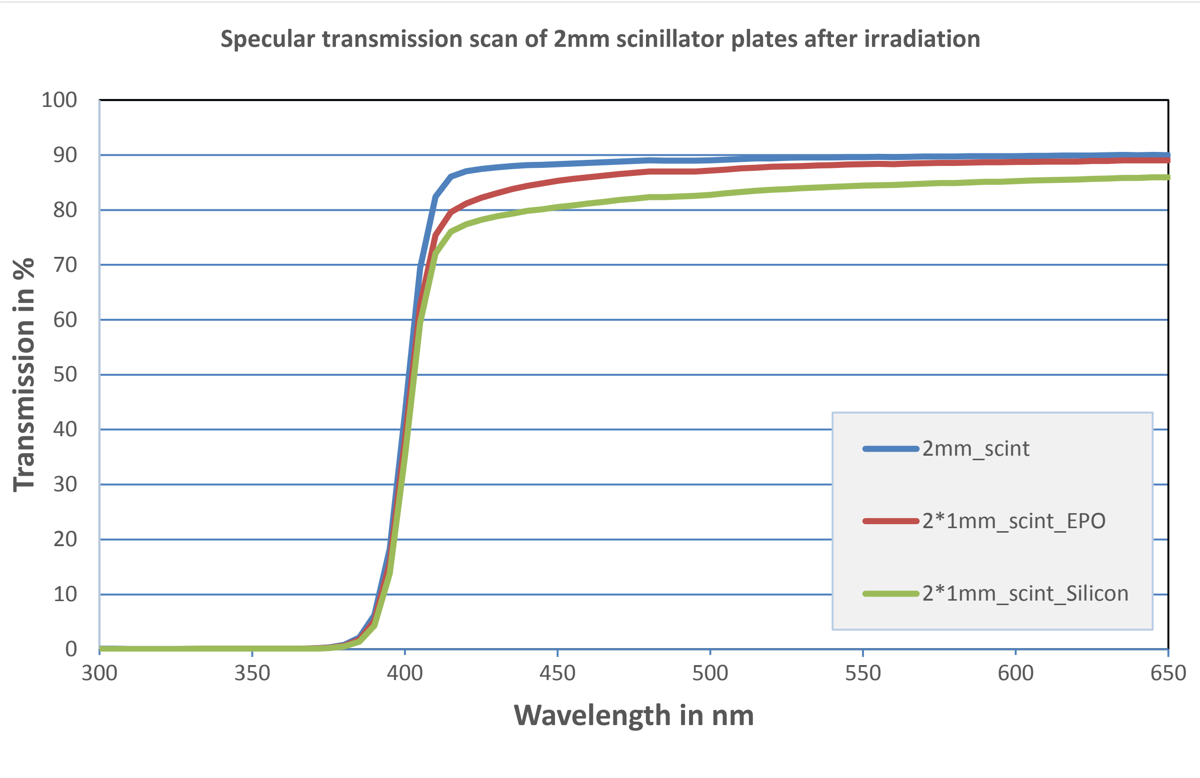

Figure 4: Post-irradiation measurement of the specular transmission of samples 1 – 3. Compared to Figure 2, one can note a slight reduction of the transmission of the Epotek glue sample.

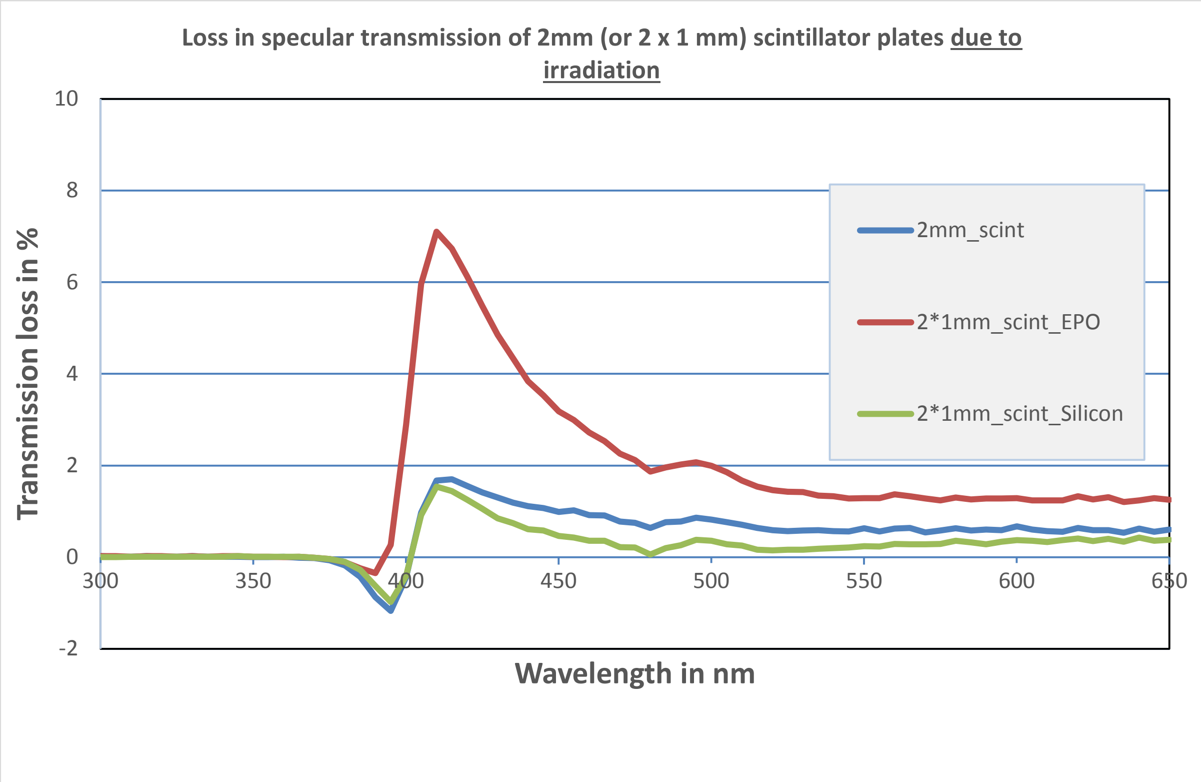

Figure 5: Loss of fransmission due to the irradiation. The scintillator sample shows a very small loss of 1-2% close to the cut-off wavelength. The RTV glue does not lead to any additional transmission loss. The H301 glue shows a transmission loss of about 1% increasing to 7% close to the cut-off wavelength.

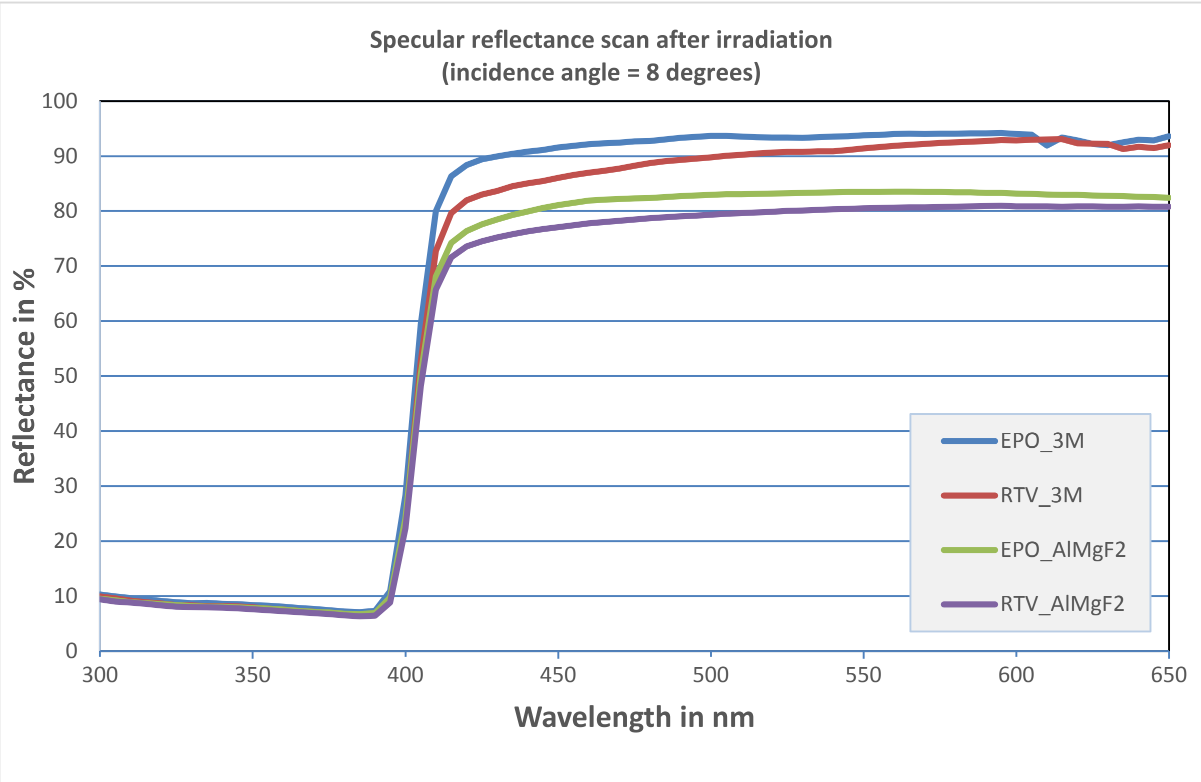

Figure 6: Specular reflectance of samples 1 – 4 after irradiation.

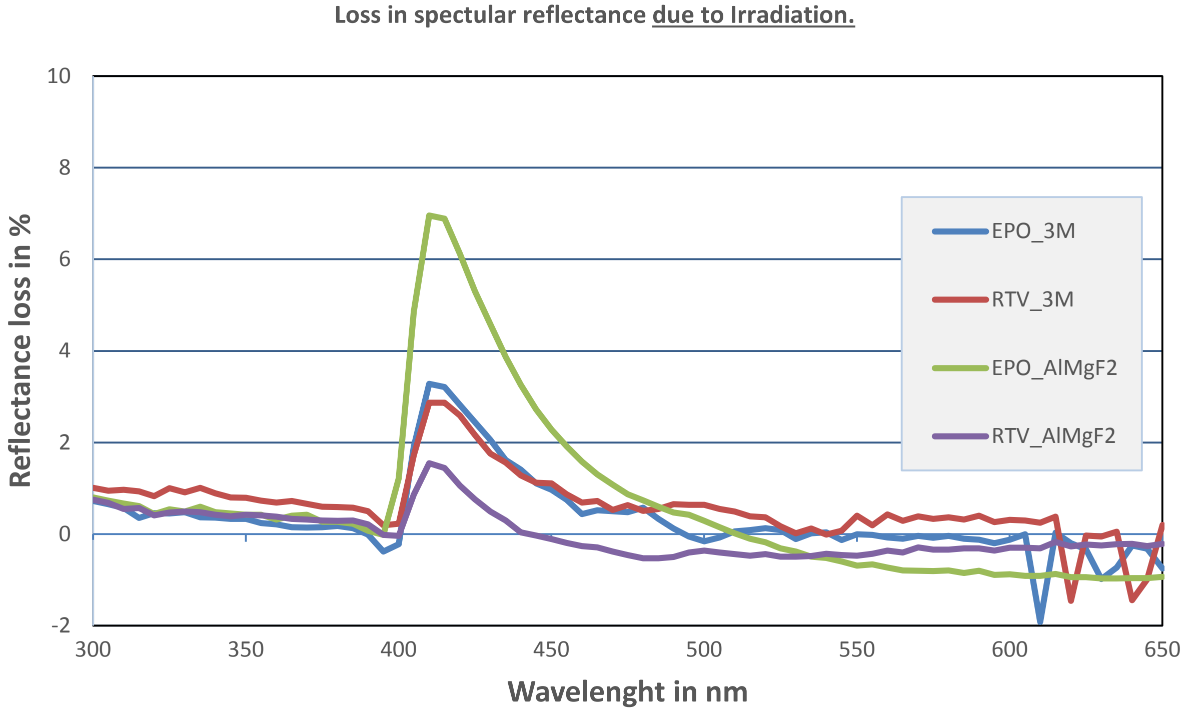

Figure 7: Loss in specular reflectance of samples 4 – 7 due to irradiation. The two samples glued with Epotek H301 glue show maximum losses of 3 and 7%. The RTV glued samples show losses of 1.5 – 3%.

The RTV glued samples show losses in the reflectance of only 1.5 – 3% which are practically insignificant.

The data suggest that the observed small but non-zero losses in the effective reflectance can be attributed to additional absorption in the 100 μm thick glue layers.

6 Summary and conclusions

A set of seven samples for transmission and reflectance measurements were irradiated with 23 MeV protons to an ionising dose of approximately 30 kGy.

The 2 mm thick scintillator substrate showed a very small loss of transparency (1 – 2%). Layers of 100 μm thickness of the Epotek H301-2FL glue showed a transmission loss varying between 1 and 7%. The Dow Corning RTV 3145 glue showed a practically insignificant transmission loss of max. 1%. These losses L can be related to optical absorption lengths, $1 - L = \exp(-d/\Lambda_{abs})$ where d is the thickness of the glue layer, resulting in:

Epotek H301-2FL: Λ_{abs} ~ 5 mm (λ = 500 nm), Λ_{abs} ~ 1.4 mm (λ = 410 nm)

Dow Corning RTV 3145: Λ_{abs} > 5 mm (λ = 400 - 600 nm)

The four investigated mirror samples showed reflectance values in the 75 – 95% range before irradiation and only modest losses due to irradiation. The combination of 3M ESR foil and Epotek H301 glue gives the best reflectance (~94% at 500 nm) before and after irradiation.

The results suggest that the reflectance losses of 3-7% shown by the samples glued with Epotek H301-2FL can be explained by the reduced transmission of the glue layer. The reflectance losses of the sampled glued with RTV 3145 glued samples are only 1.5-3% and hence practically insignificant.

From a radiation hardness point of view, all four mirror samples qualify for use in the SciFi detector.

Acknowledgements

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