ICSO 2016

International Conference on Space Optics

Biarritz, France

18–21 October 2016

Edited by Bruno Cugny, Nikos Karafolas and Zoran Sodnik

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esa icso proceedings cnes

International Conference on Space Optics — ICSO 2016, edited by Bruno Cugny, Nikos Karafolas, Zoran Sodnik, Proc. of SPIE Vol. 10562, 1056214 · © 2016 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2296084

THE ESA RADGLASS ACTIVITY: A RADIATION STUDY OF NON RAD-HARD GLASSES

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I. INTRODUCTION

Optical instrumentation on space platforms, typically needs to adhere to high quality standards, in particular as far as robustness to the applicable environment is concerned. The term 'environment' typically encompasses all types of loads that a system or component might encounter and is required to survive during its lifetime in space without loss of performance. For example this might be the thermal, mechanical, electromagnetic, but also the radiation environment. Depending on the mission profile, the latter can sometimes be particularly harsh, thus necessitating special precautions already at the very early design phases.

As far as dioptric optical systems are concerned, it is well known that high energy radiation can cause alteration of the glasses transmission properties through ionization and displacement and the creation of coloration centers [1],[2]. Typically, reduction in the transmission is observed both in the visible and ultraviolet regions. The presence of impurities in interstitial positions greatly amplifies the effect of radiation; vacant ion sites behave as electron traps giving rise to new or enhanced absorption bands in the bulk of the glass material. From an instrument design point of view, this would mean loss of optical throughput, which, depending on the instrument specification might not be acceptable.

Optical glass can be stabilized against transmittance loss caused by ionizing radiation by adding cerium (Ce) or other types of dopants to the composition [2],[3]. While doping with cerium can add a slight yellowish coloration to the glass and also shift the UV transmission edge towards longer wavelengths, it has been shown to provide good stabilization to ionizing radiation and it is the main method used nowadays to produce radiation hard (rad-hard) glasses.

Unfortunately, only a handful of radiation hardened glasses are accessible in the market today (see for example [4]). Moreover, their stock availability cannot always be easily guaranteed. Therefore, the use of such rad-hard glasses in space systems, while it comes as a first natural choice, is not always trouble free. Most notably, even if their availability can be indeed secured in the timeframe of the system development, the choice, which is left for the optical designer, is rather poor, leading to either complex designs or to limitations in the performance. On the other hand, and for some mission scenarios, the radiation levels are not particularly high (e.g. Low Earth Observation orbits) and therefore, the deployment of conventional, non-radiation hard, glasses could be in principle tolerated depending on the instrument concept (e.g. variable integration time could be introduced to counterbalance the loss of throughput). However, lacking direct experimental evidence, their incorporation or not into the design of an optical instrument is always the subject of lengthy discussions during the early feasibility studies.

Despite increasing demand, an approach, which would allow one to accurately predict the loss of transmission of glass materials during their lifetime in space and under the applicable radiation environment, has not been elaborated yet. While some attempts towards this direction have been made using phenomenological methods [5][6], the actual models thus developed depend very much on the availability of experimental results from the specific glasses under consideration, which still remain very sparse.

We have conducted irradiation campaigns on several different types of conventional, non-radiation hard glasses, selected from the wider pool of the Schott latest arsenic and lead free series (N-*) and characterized their spectral transmission properties before and after ionizing dose deposition. Some findings have been already reported here [7]. In this paper, some additional results are reported.

II. EXPERIMETAL SETUP

A. Glass Samples

For each of the identified materials, a set of samples was procured to facilitate the tests. These were cylindrical, flat window samples (see Fig. 1), with a typical thickness of 5 mm and no anti-reflection coating.

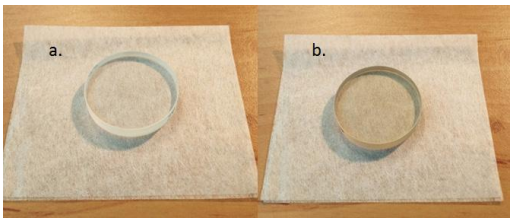

Fig. 1. A glass sample (the material is Schott N-SF2) before (a) and after (b) irradiation. Coloration and darkening of the sample after irradiation is clearly visible.

B. Irradiation Facility

We irradiate the samples with ionizing gamma irradiation using a dedicated ESTEC facility. At this stage, we do not irradiate with protons, neutron or heavy ions. Our facility features a Cobalt-60 source, which produces energetic photons (gamma rays) with energies of 1.173MeV and 1.332 MeV. Dose rate is regulated by controlling the samples' distances from the Co60 source. Calibrated dosimetry is implemented in the facility. The ESTEC Co60 facility is accredited by RvA (Dutch Accreditation Council) according to ISO/IEC 17025.2005. The uncertainty budgets are: 4.2 % (k=2) for absorbed dose to water and 4.4% (k=2) for absorbed dose rate to water. More info about the facility can be found here [8]. Fig. 2 provides a schematic of the ESTEC Co60 facility.

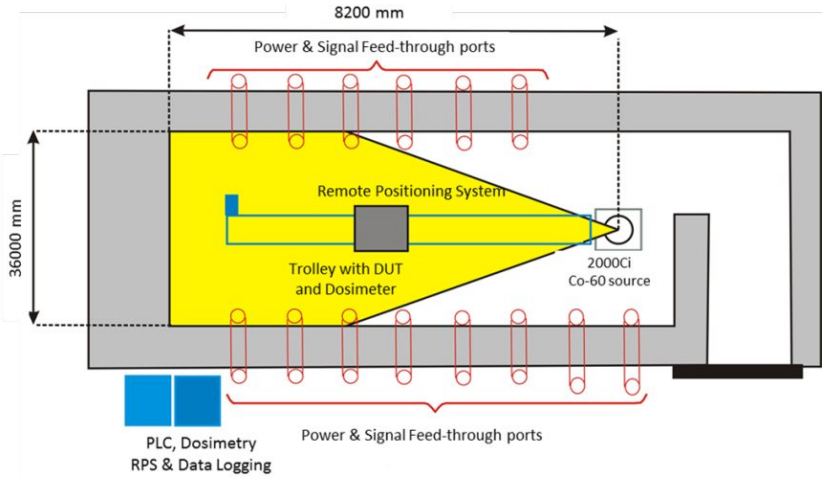

Fig. 2. A view of the ESTEC Co-60 irradiation facility

C. Optical Measurement Setup

We use a commercial spectrophotometer (Agilent Cary 5000) to measure the transmission of the samples before and after each irradiation step. The *total transmission* of each sample is measured from 250 nm up to 2500 nm with a spectral resolution of 2nm and a spectral sampling interval of 1nm. The measurement concept is shown in Fig. 3. The reference beam is used to monitor and compensate for temporal instabilities of the sources or the environment. In order to cover the full spectral range of measurement, two different sources as well as two different detector units are used.

First, a scan is performed with no sample placed in the sample beam. This is necessary to calibrate the reference gain of the instrument. Then the sample is inserted at normal incidence to the sample beam and the scan is repeated. Several measurements are obtained for each spectral position to reduce temporal sources of noise. Tests with calibrated neutral density filters have indicated an error of our setup in the order of 0.5% - 1%. However, a safer assumption according to our estimations will be more in the range of 1% - 1.5% to account for

non-optimum alignment of the sample during measurements, small residual wedge on the sample window, non-perfectly collimated beam, as well as scattering or polarisation effects.

Using the setup of Fig.3, one measures the *total transmission T* of the samples, which therefore includes any reflections on the front and back surfaces of the sample. Given that there is no anti-reflection coating, such reflections can become significant, depending on the refractive index of the material.

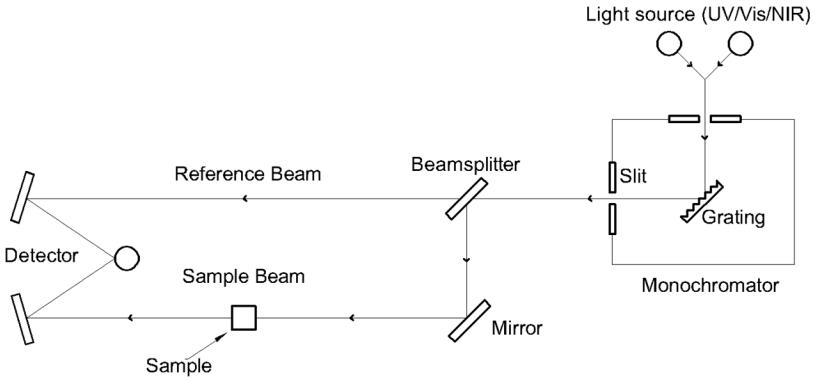

Fig. 3. Measurement concept of the spectral transmission of the RADGLASS samples.

Assuming that the refractive index value of the material is known however, (depending on the target accuracies, catalogue values will normally suffice), the *internal transmission Ti* and thus the *absorption coefficient a* of the material can be subsequently derived using the following formulas (d is the thickness of the sample and n its refractive index):

$$T = \frac{t^2 T_i}{1 - r^2 T_i^2} \quad \text{with} \quad T_i = e^{-ad}, \quad r = \left(\frac{n-1}{n+1}\right)^2 \quad \text{and} \quad t = 1 - r \tag{1}$$

D. Sequence of the Tests

Tests are performed in rounds / irradiation campaigns. In each irradiation, the samples are arranged in a matrix perpendicular to the gamma beam. The residual beam non-uniformity is in the order of ±1% of the average value quoted in the graphs provided below.

We start by measuring the transmission of the samples in a given group before these are exposed to irradiation. We call the transmission curve thus recorded, Ts0. We then subject the samples to the first irradiation step, remove the samples from the facility and repeat the transmission measurement. The curve recorded is similarly called Ts1 (i.e. transmission-step-1). We then repeat with the same group of samples the last two steps (i.e. irradiation + transmission measurement) several times until the desired total accumulated dose is reached (about 500 krad). Typically, seven steps of irradiation are performed for each group of samples. The curves recorded are named Ts2, Ts3, etc. respectively.

In an attempt to minimize relaxation effects between measurements, we perform mostly, for each step, the irradiation during the night and the transmission measurements during the following day, thus allowing only for one day (or a couple of days) in between consecutive measurements. In order to achieve this timing we regulate the dose rate by changing the distance of the sample holder from the source (see Fig. 2), thus adjusting the dose rate. For the results shown here, depending on the irradiation step, the dose rate was varied between 0.2 krad/h and 2.2 krad/h. A typical timing, which is nevertheless valid for all results presented in this paper, is shown in Table 1 below (t0 is used to denote the start of the irradiation campaign). Finally, some transmission measurements are repeated several days or weeks after the completion of the campaign to assess relaxation (annealing) phenomena (these measurements are denoted with TRx in the following). Typically, we perform those, one week, one month or six months after the end of the campaign.

Table 1. Typical dose levels and timing of the RADGLASS transmission measurements

Step	Ts0	Ts1	Ts2	Ts3	Ts4	Ts5	Ts6	Ts7
Time (days)		t0	t0+1	t0+2	t0+3	t0+6	t0+9	t0+15
Accumulated dose (krad)	0	5	10	25	50	100	200	500

III. RESULTS

In the following figures, we report some of our measurements. In total, measurements from eight (8) glass materials are presented here. One chart is given per material, each giving the transmission curves measured for the various accumulated doses shown. The material name appears in the chart. For each dose step, the respective total accumulated ionizing dose in krad is shown in the legend of the charts. All doses quoted are doses in water. In fact, the exact dose deposited will depend on the very material that receives it and its specific chemical structure. For SiO2 for example, this will means that the figures quoted in krad(water) will be approximately 10% more than what is actually deposited.

Were relaxation measurements exist, we also provide those using the dotted lines (TRx). The respective relaxation period since the last transmission measurement of the campaign (i.e. since Ts7) is indicated in the charts for each relaxation measurement separately (in days after the Ts7 measurement). The thickness of the sample used to perform these measurements is also provided. This is needed if one needs to derive dthe respective internal transmission curves.

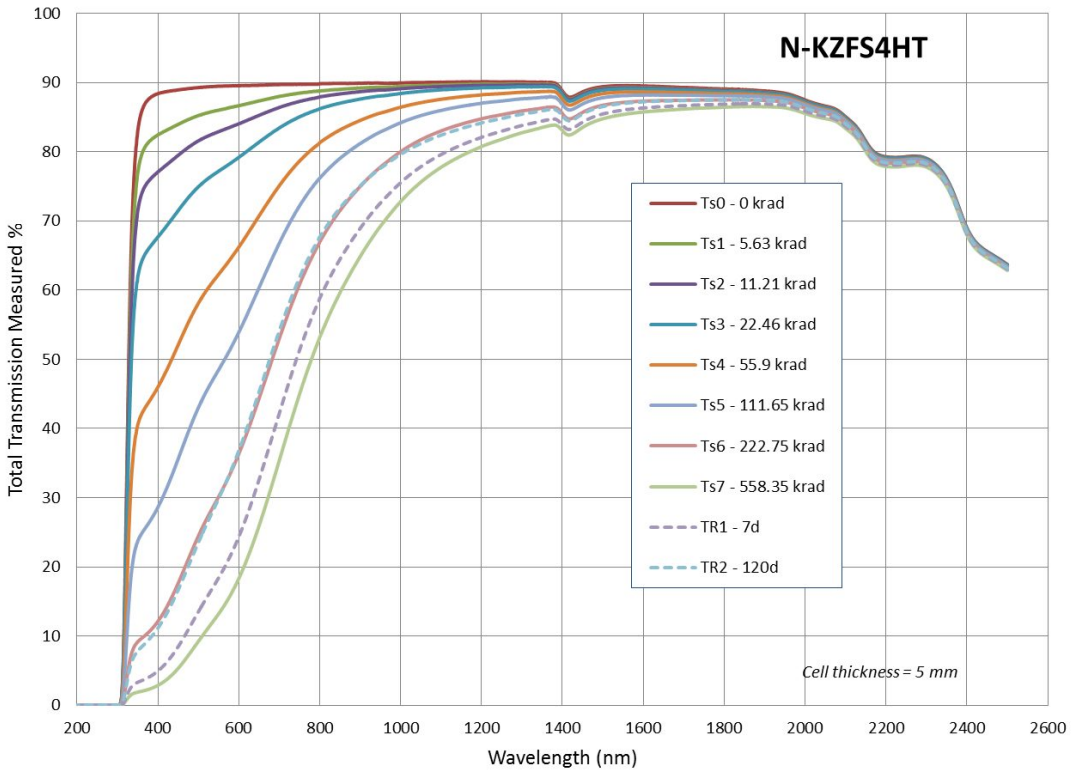

Fig. 4. ESA RADGLASS total transmission plots for Schott N-KZFS4HT. All doses in krad(water).

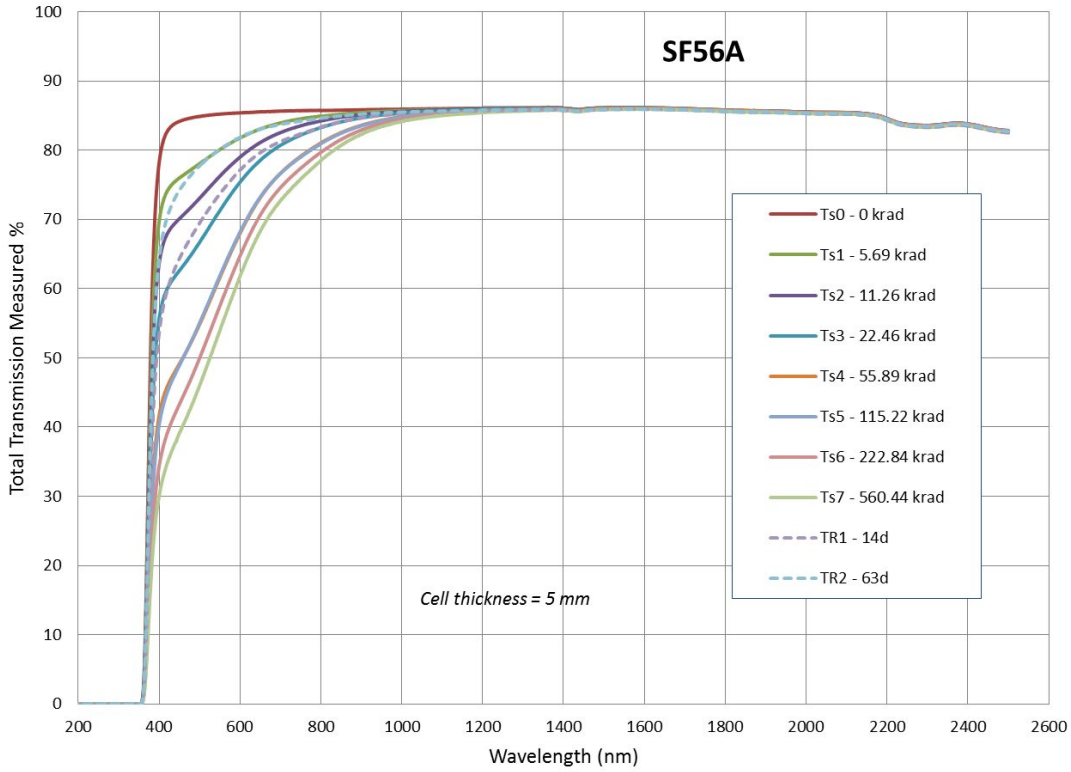

Fig. 5. ESA RADGLASS total transmission plots for Schott SF56A. All doses in krad(water).

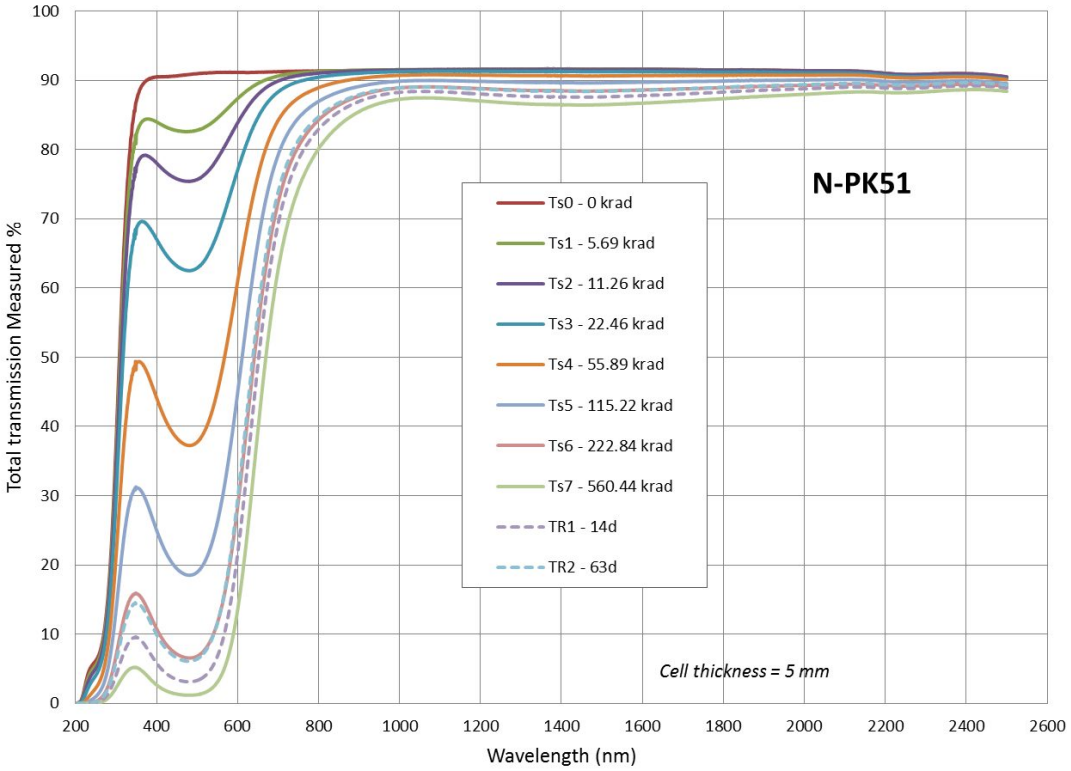

Fig. 6. ESA RADGLASS total transmission plots for Schott N-PK51. All doses in krad(water).

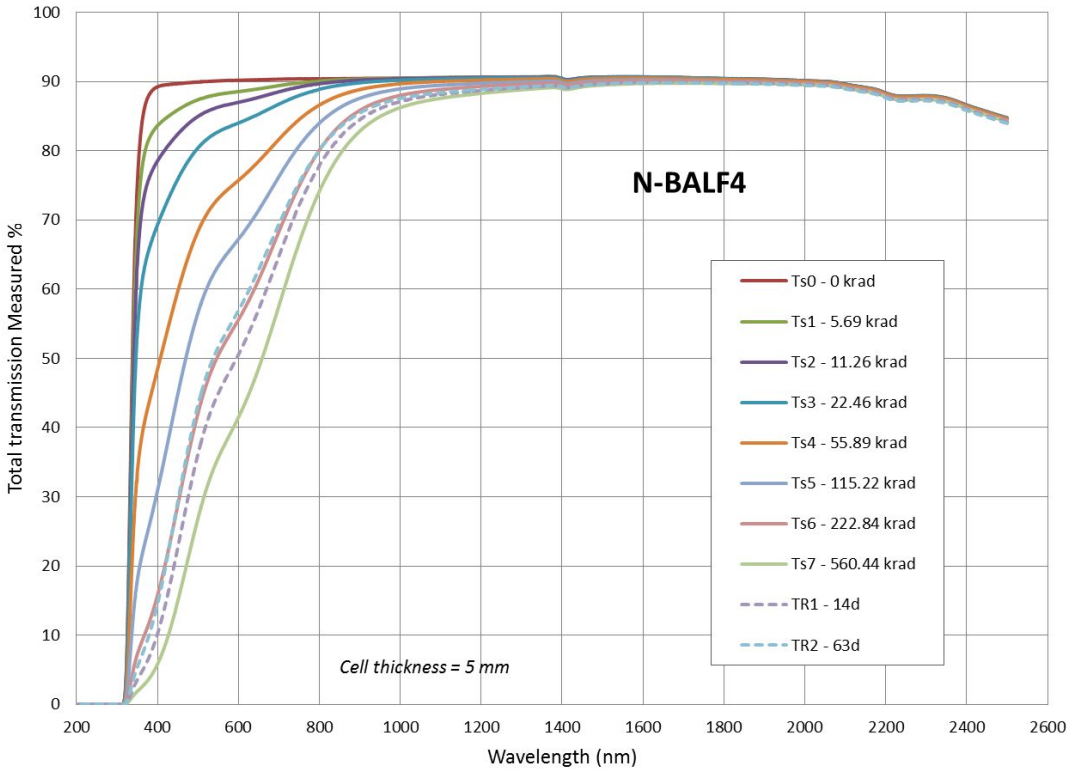

Fig. 7. ESA RADGLASS total transmission plots for Schott N-BALF4. All doses in krad(water).

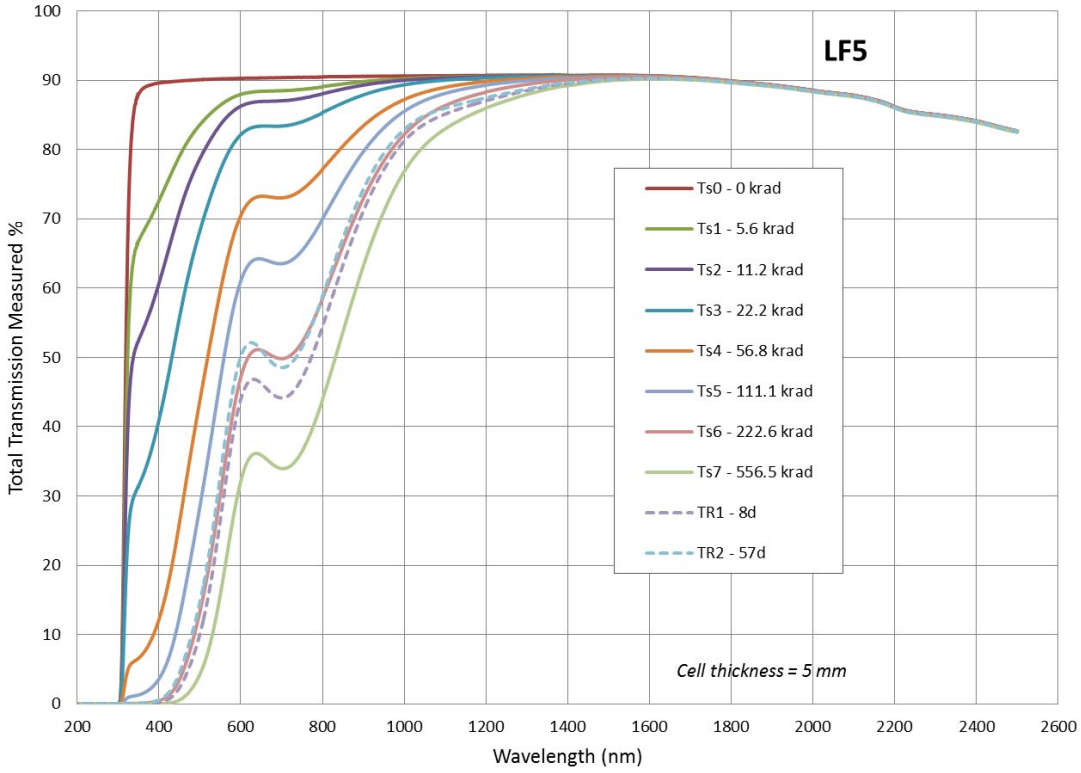

Fig. 8. ESA RADGLASS total transmission plots for Schott LF5. All doses in krad(water).

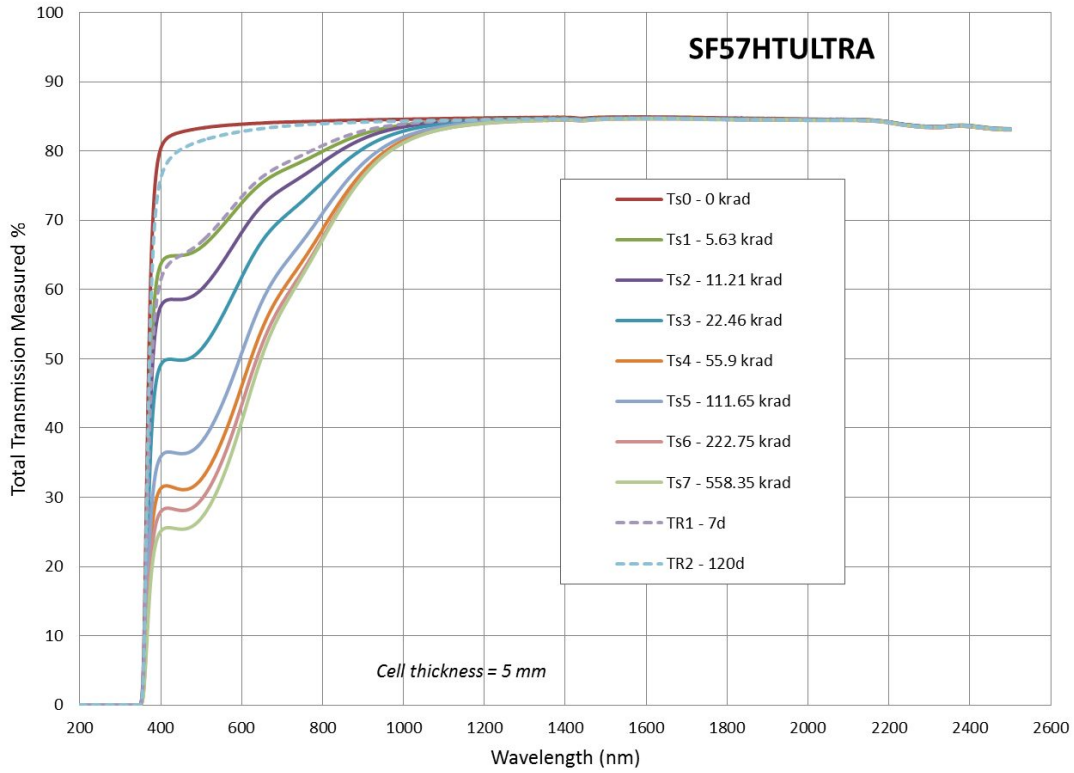

Fig. 9. ESA RADGLASS total transmission plots for Schott SF57ULTRA. All doses in krad(water).

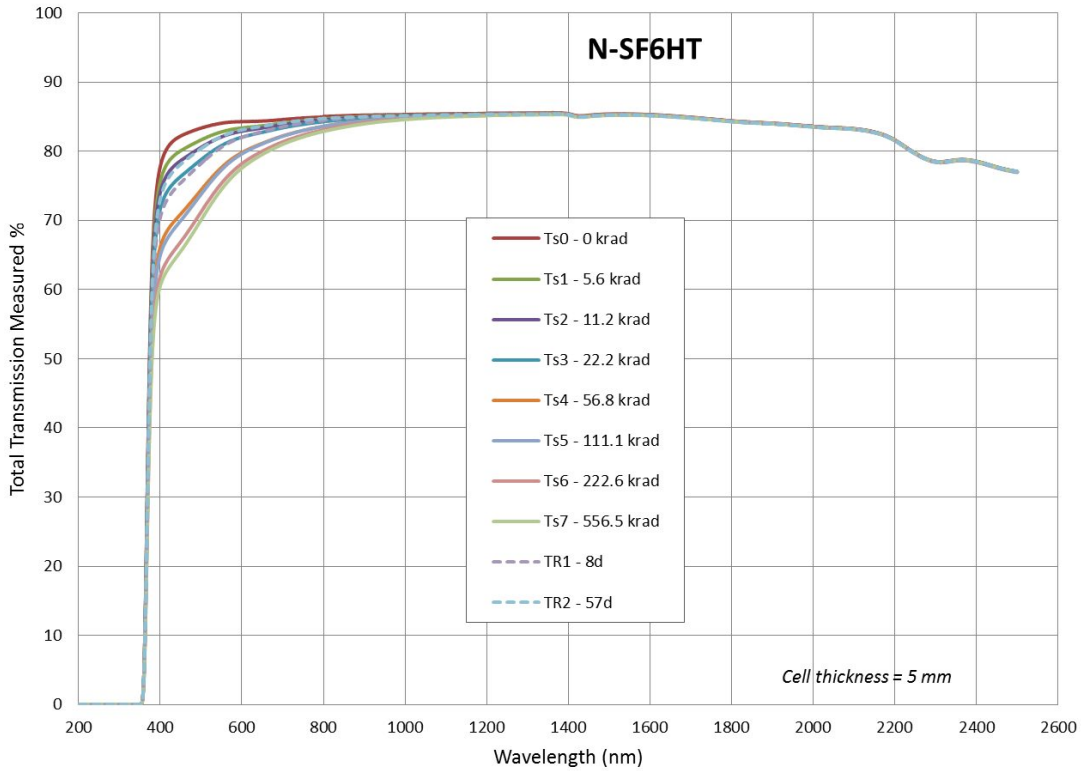

Fig. 10. ESA RADGLASS total transmission plots for Schott N-SF6HT. All doses in krad(water).

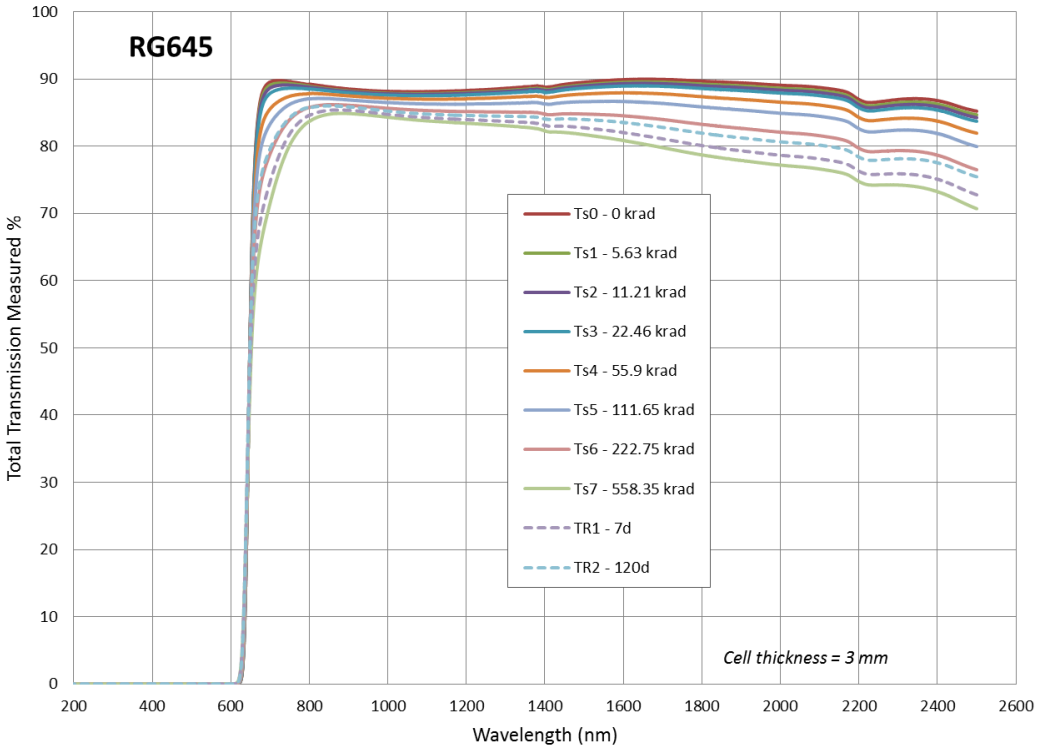

Fig. 11. ESA RADGLASS total transmission plots for Schott RG645. All doses in krad(water).

IV. CONCLUSIONS

We have presented some of the results of the ESA RADGLASS activity. These include total transmission measurements on several different glass materials from Schott for several doses of ionising irradiation. It is obvious that not all materials react the same way to ionising radiation. Loss of transmission is much faster for some and slower for some others. It appears that absorption increases faster with radiation for the shortest wavelengths (i.e. closer to the UV) and much slower for wavelengths above 800 nm. The rate of transmission loss with dose is not linear, however. In several examples, specific spectral absorption bands are clearly discernible. Furthermore, some materials seem to anneal much faster than others. Taking into consideration mission profiles with relatively benign radiation environments (e.g. Low Earth orbit mission), it is evident that for some of the materials, depending on the wavelength of interest, the degradation of transmission due to ionising radiation, while clearly measurable, might not necessarily be a showstopper as far as its deployment in an optical instrument goes. Of course this shall always be the subject of a detailed qualification campaign for any given mission under consideration.

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