# Preliminary Evaluation of Radiation Total Ionization Dose Influence on the Optical Transmittance of CBERS 3&4 Multispectral Camera (MUX) Subsystem

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**Abstract.** This paper is result of a preliminary work that has been carried out to evaluate the influence of space radiation total ionization dose on the optical transmittance of the CBERS 3&4 Multispectral Camera (MUX) Subsystem. The exposure of optical glasses used in the lens system to ionizing radiation generates color centers which decrease the total optical transmittance of the optics and, consequently, reduce the signal-to-noise ratio. The experimental transmittance of optical glass samples was determined for different dose values, yielding the dose coefficient curve and allowing the extrapolation of the transmission loss due to radiation at any dose level. The results were used to have a first estimative of the system total transmittance after the three years of mission.

**Keywords:** total ionization dose, color centers, radiation effects, optical glass, imaging systems.
**Palavras-chave:** dose total ionizante, centros de cor, efeitos de radiação, vidros ópticos, sistemas de imageamento.

## 1. Introduction

One of the most important issues concerning the use of satellite imaging systems based on a refractive Optics is related to the effects of the space radiation on the transmittance of the optical glasses used in the lenses' fabrication. The exposure of such materials to ionizing radiation induces the formation of color centers, which give rise to absorption bands in the visible region of the spectrum, mainly in the blue region. The transmission loss of the collecting lens system causes the decrease in the image signal and, consequently, the signal-to-noise ratio, which is one main importance in the imaging system operability. Depending on the space radiation vulnerability, the optical system can become completely useless during the orbit time. Hence, it is of extreme importance to have a realistic estimate of the radiation dose which the system will be exposed and, if necessary, to increase the shielding in order to minimize the degradation effects on the optical system.

Although the operating orbit of CBERS 3&4 (polar orbit, 778 km altitude) is characterized by relatively low space radiation levels, the radiation effects on the optical components can no longer be neglected. For this reason, it is necessary to consider the composition, the fluence and the spectrum of each type of radiation, as well as the effective shielding characteristics used to estimate the total accumulated dose during the three years lifetime of the satellite.

The MUX camera will operate in an environment composed, basically, of: i) Trapped radiation, composed by a wide spectrum of charged particles (mainly protons and electrons) trapped in the Earth magnetic field; ii) Cosmic rays: low fluxes of highly energetic atomic nuclei and iii) Solar radiation: composed mainly by protons and electrons emanated from the Sun. Additionally, there is the occurrence of electromagnetic radiation from the breaking (bremmstralung) of charged particles (electrons, mainly) in the spacecraft shielding. For the considered orbit, and taking into account the shielding characteristics at the subsystem level (at least 7 mm of Alluminum in any direction), the major contribution is due to high energy electrons and protons and the expected total ionizing dose is lower than 10 krad.

## 2. Optical System

The optical system proposed for the CBERS 3&4 MUX camera is based on a refractive design composed by 11 lenses and 8 types of optical glasses, as showed in Figure 1. The main optical characteristics of the imaging system are presented in Table 1. A 7 mm thick Aluminum barrel is used to provide the lateral radiation shielding whereas a 20 mm thick fused silica (SUPRASIL ®) window is used to protect the lens from frontal space radiation.

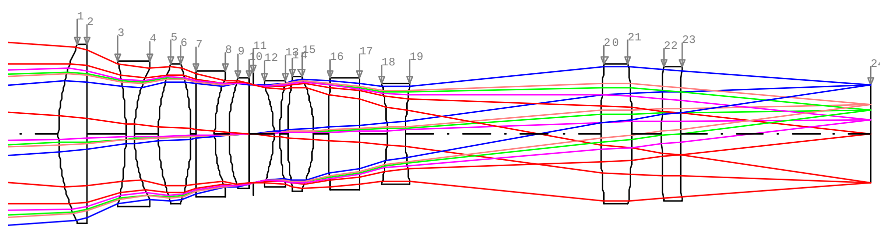

Figure 1: Optical Design of the MUX Camera.

Table 1: Main Characteristics of the Optical System of the MUX Camera.

| Parameter | Value |
|---|---|
| Effective Focal Length (EFL) | 505.80 mm |
| Angular Field of View (FOV) | 8.8 º |
| F-number (F#) | 4.5 |
| Number of surfaces | 22 |
| Number of elements | 11 |
| Optical Transmittance (with AR coating) | > 76.6 % (B05); > 87.0 % (B06); > 84.5 % (B07); > 86.0 % (B08); |

## 3. Experimental Results

The preliminar analysis used to evaluate the radiation effects on the transmittance of the optical glasses was done using na uniform gamma radiation source of Cobalt 60 (Gamma Cell Co-60), maintained by Centro de Tecnologia das Radiações do Instituto de Pesquisas Nucleares (CTR/IPEN/CNEN – SP). This kind of ionizing radiation has been chosen for this purpose because it is highly penetrating and relatively easy to be handled, ideal to simulate accumulative effects of different kind of space radiation which the optical system will be exposed in orbit. Glass samples of 10 mm in thick of two different glass kinds: one “flint” glass (SF11) and a “crown” type glass (PSK3), both from Schott, were exposed to total dose varying from 10 to 100 krad at a dose rate of 355 krad/h. These preliminary experiments have shown that the transmittance effectively decreases (between 8% and 12% at 485 nm wavelength), even for relatively low doses values like 10 krad. Moreover, different variations in the transmittance curve were observed for the different kinds of glass, as can be viewed in Figure 2.

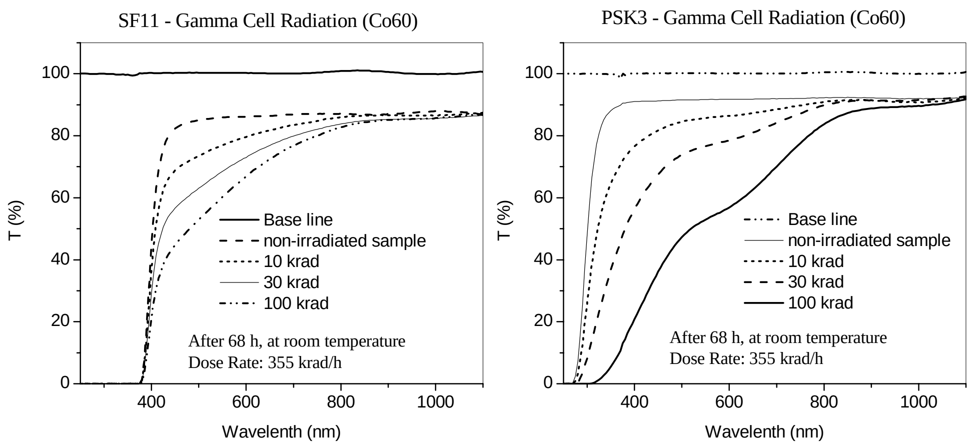


Figure 2: Total dose effect of gamma radiation (Co-60) on the optical transmittance of two optical glasses. Sample thickness: 10 mm.

The results have shown that, despite the initially lower transmittance of SF11 in comparison to the PSK3, it presents a less accentuated transmission loss with radiation, meaning that it is more resistant to ionizing radiation. Such effect can be well quantifyed considering the displacement of the glass half-transmittance wavelength (Table 2). Although this wavelength, before irradiation, is much higher for the SF11 than for the PSK3 (403 nm against 302 nm, respectively), the flint glass hás shown a displacement of at about 80 nm for a 100 krad dose whereas the crown glass presented a 217 nm displacement for the same radiation dose.

Another observed effect was the decrease, with time, of the “darkening” observed immediately after sample irradiation. Figure 3 compares the displacement of the half-transmittance wavelength for samples measured 3 days after the irradiation and 2 months after the irradiation. The results are evidence that a fraction of the radiation-induced effects are metastables, recovering part of the optical transmittance after long times after irradiation.

Table 2: Displacement of half-transmittance wavelength with Co60 radiation exposure.

| | 3 days after irradiation | | 2 months after irradiation | |
|---|---|---|---|---|
| | SF11 | PSK3 | SF11 | PSK3 |
| Dose (krad) | $\lambda_{0.5}$ (nm) | $\lambda_{0.5}$ (nm) | $\lambda_{0.5}$ (nm) | $\lambda_{0.5}$ (nm) |
| 0 | 402.7 | 301.6 | 402.7 | 301.6 |
| 10 | 408.8 | 322.9 | 406.6 | 317.7 |
| 30 | 424.5 | 381.2 | 409.1 | 369.9 |
| 100 | 482.5 | 519.1 | 413.9 | 464.7 |

From such results, one observes that the flint glass (SF11) presents only a small transmittance loss in comparison to the crown glass (PSK3) if one considers a resting time of 2 months, even for total doses of 100 krad. On the other hand, although PSK3 also shows the diminution of the darkening effect with time, the total transmission variation is still accentuated. Such analysis shows that the transmission loss cannot always be considered solely dependent on on the total dose value, being necessary to consider also the dynamic relaxation of the generated defects.

Although the in orbit imaging optics is constantly under the radiation effect, the dose rate is several orders of magnitude lower than the actually used in the experiments, which makes it hard to infer about the effective result to be considered in the transmittance evaluation of a determined kind of glass. A more detailed study will be undertaken in a near future to check if such variation is related to a longer relaxation time of the generated defects or if it is simply related to a larger number of radiation-generated species.

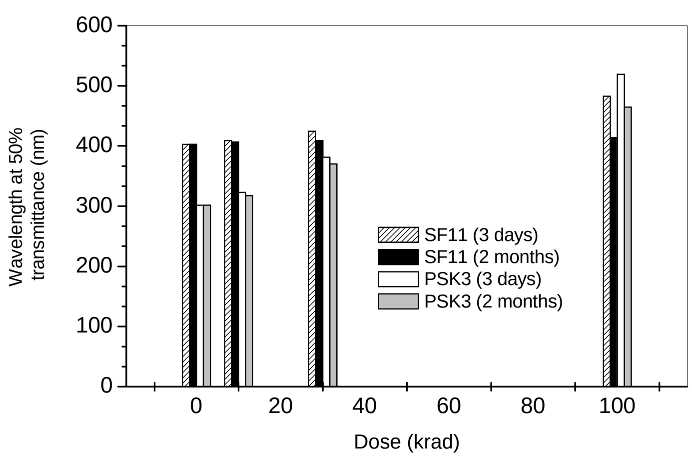


Figure 3: Displacement of half-transmittance wavelength with the resting time after Co60 radiation exposure.

The higher sensibility of PSK3 with radiation can also be checked by the analysis of the transmission loss at the center of each one of the spectral bands of interest, as can be observed in Table 3, where one observes that the "blue" band ($\lambda_m$ = 485 nm) and the "green" band ($\lambda_m$ = 555 nm) are the most affected by the radiation. The transmission loss in the near infra-red band can be considered acceptable even for relatively high doses of 100 krad.

Table 3: Optical transmittance at the center wavelength for each spectral band.

| | SF11 | | | | PSK3 | | | |
|---|---|---|---|---|---|---|---|---|
| Dose (krad) | $T_{485\ nm}$ (%) | $T_{555\ nm}$ (%) | $T_{660\ nm}$ (%) | $T_{830\ nm}$ (%) | $T_{485\ nm}$ (%) | $T_{555\ nm}$ (%) | $T_{660\ nm}$ (%) | $T_{830\ nm}$ (%) |
| 0 | 84.5 | 86.1 | 86.3 | 87.0 | 91.5 | 91.7 | 91.9 | 92.4 |
| 10 | 72.5 | 77.3 | 81.1 | 86.5 | 83.9 | 85.8 | 87.7 | 91.5 |
| 30 | 61.3 | 69.0 | 75.5 | 84.5 | 72.5 | 76.9 | 81.5 | 90.7 |
| 100 | 50.7 | 61.3 | 70.3 | 83.8 | 44.8 | 53.4 | 64.2 | 86.3 |

To estimate the radiation dose effects as a whole, it is necessary to have information about the effects each kind of radiation on each kind of optical glass used in the system as well as the geometry of each lens. For this reason, the procedure proposed by Fruit *et al.* [2] to calculate the dose coefficient to determine the transmission loss for any kind of radiation at a certain total dose is quite reasonable. Such procedure allowed the calculation of the dose coefficients for both analyzed glasses, as can be observed in Figure 4. As can be observed in Figure 4, it is not always that is possible to achieve a universal curve for the dose coefficient for a given king of optical glass, appearing a certain dose dependence on the dose coefficient curve, as can be observed for SF11 (Figure 4-a). Morever, it could not be observed a unique pattern of behavior for the dose coefficient curve with the total dose value, differing even for glasses which belong to the same family. However, despite its lower resistance to ionizing radiation previously shown, the PSK3 glass presented a behavior which converges to an universal dose coefficient curve (Figure 4-b).

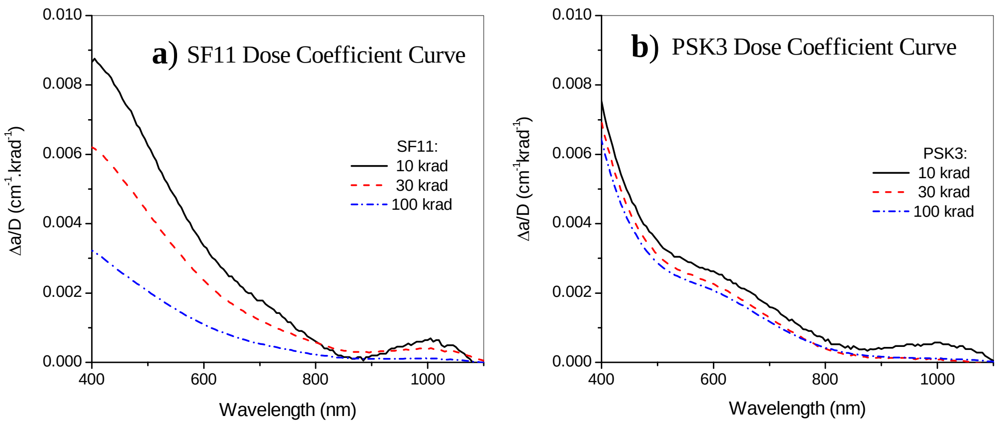


Figure 4: Dose coefficient curves measured after Co60 radiation exposure.

## 4. Analysis

After the calculation of the dose coefficient curves, the following procedure was used to estimate the radiation effects on the whole optical system: i) the dose coefficient obtained for a dose of 10 krad (which was the nearest value used in the experiments to the real values at which the system will be exposed) was used to calculate the SF11 transmitance and we have used such data to create new glasses in the optical design software ZEMAX ® with the same optical properties than SF11, but with lower values of transmittance due to the attenuation caused by 1.5 and 5 krad irradiation; ii) the dose coefficient calculated for 10 krad for the PSK3 glass (which presented the universal behavior) was used to create glasses which are equivalent to the ones used in the final optical project, corresponding to transmittance losses due to 1.5 and 5 krad irradiations. The worst case, the coefficient dose calculated for the transmittance curve obtained in the shortest time after the irradiation, has been adopted in the calculations, for margin safety.

Using such private glass catalog generated in ZEMAX ®, the total transmittance of the optical system, for different accumulated radiation doses, were calculated, allowing the evaluation of the total transmission of the whole system, as shown in Figure 5. One observes that, considering a 7 mm thick Aluminum shielding and no margin design ($D$ = 1.5 krad), the system would experience a loss of 19% and 17% in the blue and green bands, respectively, after three years of orbit. Considering a total dose of 5 krad, the system would experience a transmission loss of 47% in the blue band and 44% in the green band, what becomes to be problematic in terms of signal-to-noise ratio.

Table 4: Estimative of the optical system transmission loss for each spectral band em total accumulated dose.

| Spectral Band | Optical Transmittance | | | |
|---|---|---|---|---|
| | D = 0 krad | D = 1.5 krad | D = 5 krad | D = 10 krad |
| B05 | 76.6 % | 57.4 % | 29.2 % | 11.1 % |
| B06 | 87.0 % | 70.1 % | 42.5 % | 21.1% |
| B07 | 84.5 % | 74.0 % | 53.5 % | 33.8 % |
| B08 | 86.0 % | 83.6 % | 76.9 % | 68.4 % |

One deficiency of such used procedure of analysis is that it considers that all the other glasses used in the optical system, except to SF11 (for which the specific coefficient dose has been calculated), present the same dose coefficient, which is not exactly true. However, for a first estimative, the considerations used in the system modeling can be considered quite reasonable. A more detailed study is presently being carried out in order to obtain the dose coefficients for all optical glasses used in the optical system of the MUX camera, as well as to have a library containing such information for the highest number of available glasses in stock.

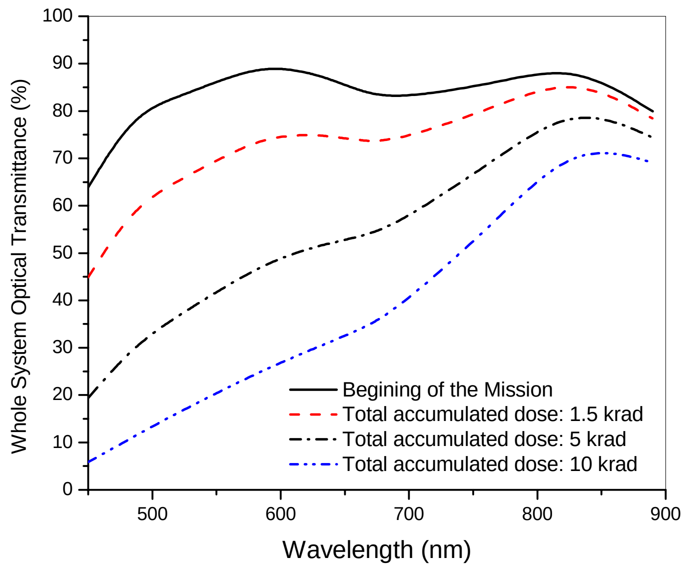


Figure 5: Total transmission curve and estimated transmission loss due to radiation exposure. The estimated total dose, considering a 7 mm Aluminum shielding, is about 1.5 krad after 3 years in orbit.

Figure 5 shows the total optical transmittance of the MUX camera, simulated using ZEMAX ® optical design software and the estimated curves considering accumulated doses of 1.5, 5 and 10 krad. The highest acceptable transmittance loss would be for an estimative of 5 krad (which is a little bit more than the estimative for three years of orbit and considering a design margin of 300%). For a total accumulated dose of 10 krad, the system would become useless in terms of signal-to-noise ratio.

## 5. Conclusions

The presented results show a reasonable method to evaluate the optical transmission loss in the objective of the MUX camera aboard the CBERS 3&4 satellite due to the glass degradation by space ionizing radiation. Future work will be done in order to study the effect of the radiation dose rate on the transmission results, since the dose rate values in orbit are several orders of magnitude higher than the values used in the experiments. Additionally, transmittance variations due to "recovering" of the glass coloration for longer periods after the irradiation will also be a issue to be addressed.

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