ZnS Filters radiation test report

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Sommario

Acronyms

Ab	beam Area	Si	Silicon
Ad	dichroic Area	S/N	Signal to Noise
BTF	Beam Test Facility	UV	UltraViolet
CaF_2	Calcium Fluoride	ZnS	Zinc Sulphide
FP	Filter Position		
InGaAs	Indium-Gallium-Arsenide		
KBr	Potassium Bromide		
LET	Linear Energy Transfer		
LN_2	Liquid Nitrogen		
MCT	Mercury-Cadmium-Telluride		
MIR	Mid-Infra-Red		
MU	Monitor Units		
NIR	Near-Infra-Red		
QTH	Quartz-Tungsten-Halogen Lamp		

Introduction

The present document reports the tests performed on a representative set of dichroic samples of the MAJIS (Moons And Jupiter Imaging Spectrometer) instrument which is part of JUICE (Jupiter Icy Moons Explorer) ESA mission.
The dichroic shall withstands the Jupiter and the icy moons electron radiation environment without any permanent degradation at the end of the mission.
To verify the effect of the electron flux on the optical performances of the dichroic, transmittance and reflectance measurements have been repeated after each irradiation test performed.

1 Propose and scope

The scope of these tests is to study the performance and eventually to identify any possible degradation of the dichroic after the radiation tests. The sample has been exposed at a total electron dose of 100 krad in two steps. The electron dose has been obtained at the e-LINAC, a facility of the Azienda Ospedaliera di Terni" (AOT). The tests have been performed on May 17th 2015 and June 6th 2015.
The optical performances of the dichroic has been measured by using a Fourier Transform InfraRed (FT-IR) spectrometer. The spectral transmittance and reflectance was obtained in the spectral range of interest from 0.3 to 8 μm.

2 Sample Description

The two set of dichroics have been built with a custom coating over a ZnS and ZnSe substrate. Each set is composed by three different samples called *"**L**," **S"* and *"**T**"*. In **Figure 1** , an image of the six samples is shown.
The samples are (**25.0 ± 0.2**) mm in diameter, (**2.0 ± 0.1**) mm in thickness, with specific weight of **5.27** g/cm3 for ZnSe and **4.09** g/cm3 for ZnS.
After a preliminary analysis on the optical performances of the filters, performed according to the procedure described in the next section, and due to the limited time and resources for the irradiation facility, it was decided to select only the **ZnS** substrate for the irradiation test. T**he sample *"T"* is exposed to the electron beam**, while *"L"* and *"S"* are kept as reference.

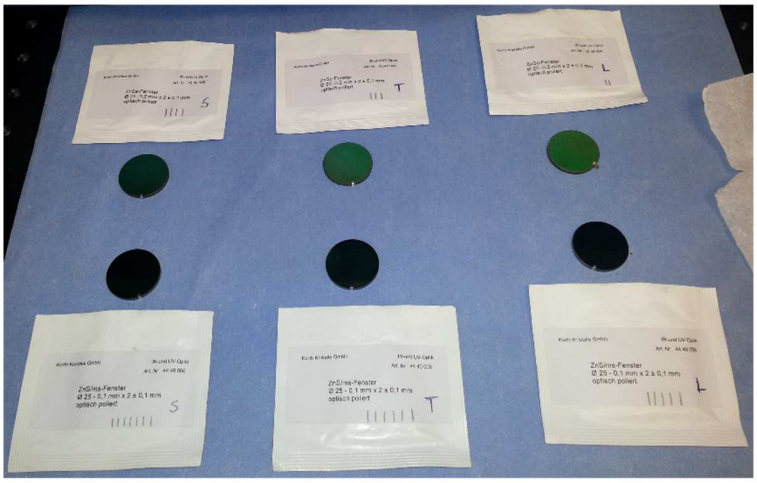


Figure 1: a picture of the ZnSe (on top) and ZnS (on bottom) dichroics filters.

In Table 1, the main features of the dichroics are summarized.

Dichroic	Diameter (mm)	Thickness (mm)	Specific weight (g/cm^3)	Serial number
ZnS	25.0 ± 0.2	2.0 ± 0.1	4.09	44 40 006
ZnSe	25.0 ± 0.2	2.0 ± 0.1	**5.27**	45 40 006

Table 1: physical parameters of the dichroics

3 Optical performance of the dichroics

To verify the effect of the electron flux on the optical performance of the dichroic, transmittance and reflectance measurements before the irradiation tests have been performed. The coating side of the dichroic is placed toward the incident beam.

3.1 Transmittance measurements

A Fourier Transform InfraRed (FT-IR) spectrometer and an optical setup which allows to obtain a parallel beam (see **Figure 2** on the right) have been used for the transmittance measurements.
For the spectral range from 0.3 to 0.9 μm a Si detector, a CaF_2 beam splitter and a QTH NIR lamp have been used; from 0.9 to 1.8 μm, the Si detector was replaced with an InGaAs. Finally, from 1.8 to 8 μm a MIR source, a KBr beam splitter and a MCT detector have been employed.

Figure 2: Fourier Transform InfraRed (FT-IR) spectrometer used to characterize the dichroic filter (on the left); optical setup used to record the transmittance with parallel beams (on the right).

In Table 2, the optical parameters used to acquire the transmittance of the dichroic have been summarized.

Parallel Beam								
Detector	**Beam Splitter**	**Source**	**# Scans**	**Resolution (cm^{-1})**	**Gain preamplifier**	**Apt (mm)**	**Spectral Range (cm^{-1})**	**Spectral Range (∝m)**
Si	CaF_2	NIR	150	4	Ref	6	[10960-31000]	[0.3-0.9]
InGaAs	CaF_2	NIR	50	4	Ref	5	[10960-5598]	[0.9-1.79]
MCT	KBr	MIR	50	4	Ref	6	[5598-700]	[1.79-14.3]

Table 2: Optical parameters used to acquire the transmittance spectra

The **figure 3** shows the transmittance of the **ZnS** (*L, S,* and *T*) dichroic obtained using the parallel beam configuration in the spectral range of interest. As it can be seen, the transmittances of the three samples are almost perfectly overlapped. Small but still visible features due to the atmospheric composition in the lab, mainly water vapour, can also be observed.

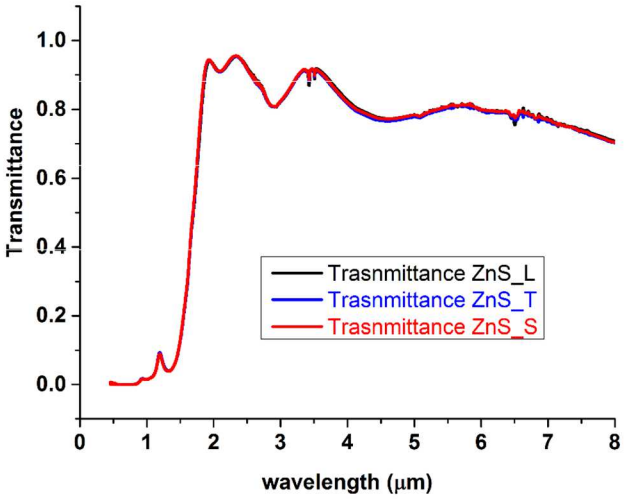


Figure 3: ZnS transmittance recorded using a parallel beam. The blue curve refers to the ''T'' sample, the red and black to the ''S'' and ''L'' respectively.

3.2 Reflectance measurement performed by the FT-IR

For the reflectance of the ZnS dichroic, the FT-IR has been coupled with an optical setup (see **FIGURE** 4 on the right) which allows to obtain the measurements at different incident and emission angles. For this characterization, it was decided to use an incident and emission angle of 14° with respect to the normal direction.
Similarly to the transmittance case, for the spectral range from 0.5 to 1 μm a Si detector, a CaF_2 beam splitter and a QTH NIR lamp have been used; from 0.9 to 1.8 μm the Si detector was replaced with an InGaAs; finally from 1.9 up to 8 μm a MIR source, a KBr beam splitter and a MCT detector have been employed.
In Table 3, the optical parameters used to acquire the reflectance of the filter have been summarized.

Figure 4: FT-IR spectrometer (on the left) and the optical setup used to recorded the reflectance

Reflectance								
Detector	**Beam Splitter**	**Source**	**# Scans**	**Resolution (cm^{-1})**	**Gain preamplifier**	**Apt (mm)**	**Spectral Range (cm^{-1})**	**Spectral Range (∝m)**
Si	CaF_2	NIR	50	4	A	2	[11000-20000]	[0.5-0.9]
InGaAs	CaF_2	NIR	50	4	A	2	[12000-5550]	[0.8-1.8]
MCT	KBr	MIR	50	4	A	2	[6060-1250]	[1.65-8]

Table 3: Optical parameters used to acquire the reflectance

The overall spectra acquired with a resolution of 4 cm^{-1}, combining the different parameters used for the FT-IR, are shown in **Figure 5** . For a direct comparison unbiased for the different parameters, the reflectance in the three separate regions are shown in **Figure 6**. The blue curve refers to the sample ''*T*'' while the red and black to the ''*S*'' and ''*L*'' respectively. As it can be seen, the three curves overlap almost exactly, with a maximum difference smaller than 1% for the ZnS T in the region from 0.9 to 1.6 μm, due to the repeatability of the experimental set up.

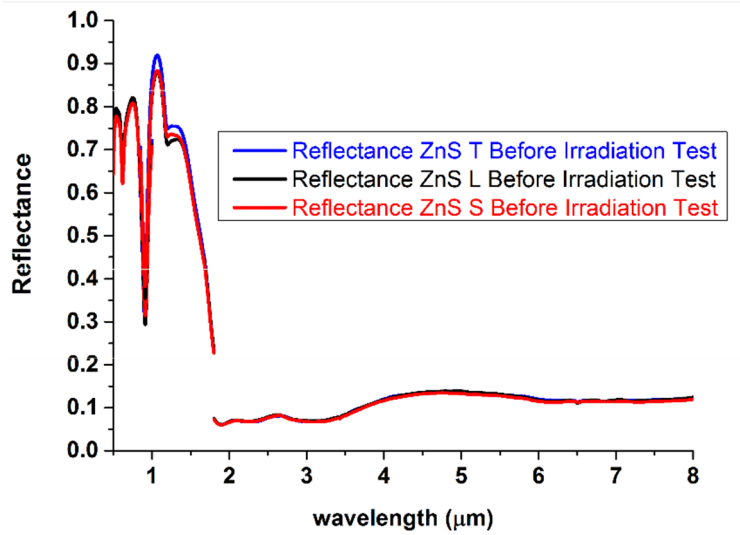


Figure 5 : **ZnS overall reflectance obtained with an incident angle of 14° and an emission angle of 14°. The blue curve refers to the sample T, the black and red to the sample L and S respectively.**

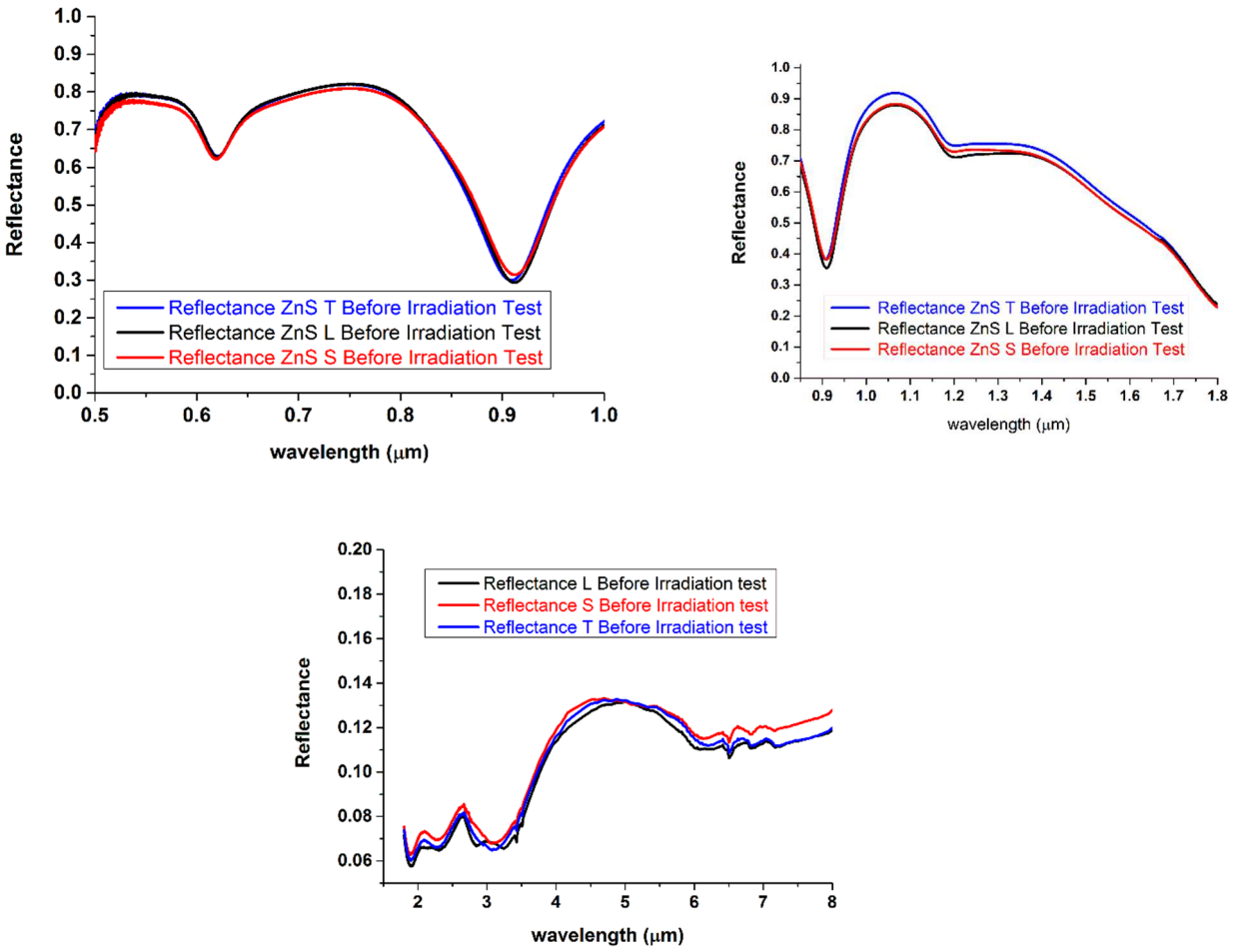


Figure 6: ZnS reflectance recorded before the irradiation test in three different spectral range. The blue curve refers to the sample ''T'', the red and black to the ''S'' and ''L'' respectively.

In **Figure 7** the reflectance and the transmittance of the sample ZnS T are shown before the irradiation test. The gap in the spectral region at about 1.9 μm is due to a bad responsivity of the relevant detectors, being in the boundary between the two.

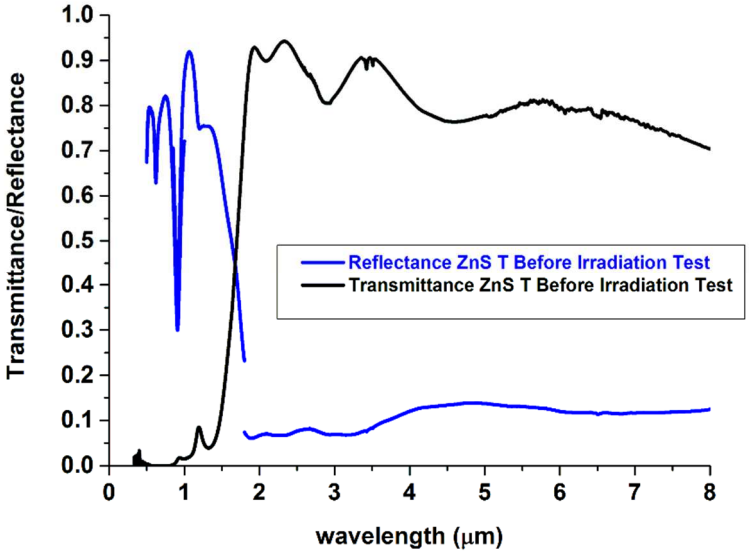


Figure 7: ZnS T reflectance (blue curve) and transmittance (black curve).

4 Cryostat and Irradiation set up

The dichroic is mounted inside a cryostat as shown in **Figure** 8.

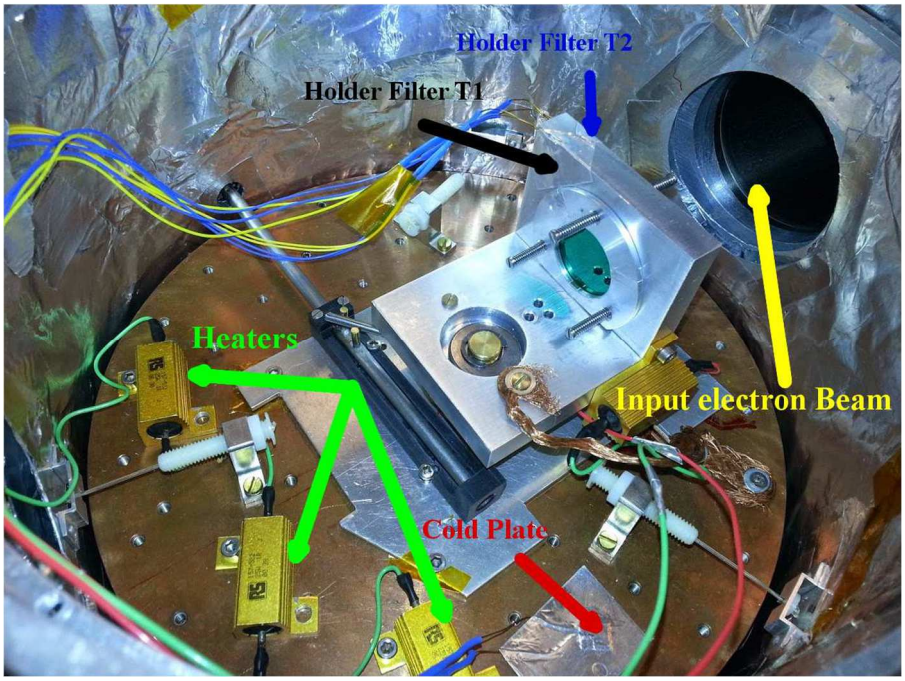
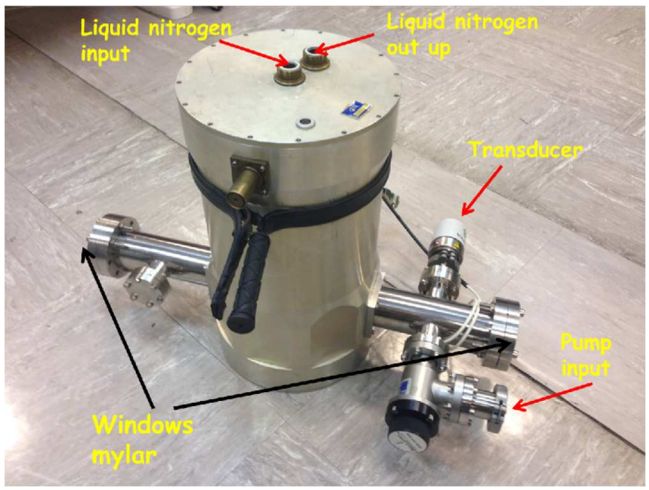


Figure 8: Assembly configuration of the rotating holder filters inside the cryostat.

The system consists of two tanks containing liquid nitrogen (see **Figure 9**), a cold plate where the rotating holder filter has been assembled, two windows of mylar of **50 μm** in thickness and **6.3 cm** in diameter and a tee junction to connect the pump.
The cryostat, filled with LN_2, can reach a temperature well down 150 K with a working pressure at about $1.0*10^{-7}$ mbar. **The system was thermally controlled by a dedicated electronics at 150 K.**



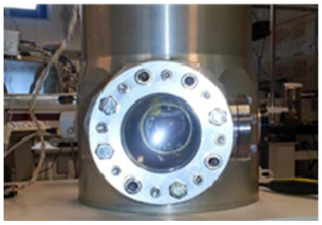


Figure 9: Cryostat picture where the LN_2 input and output, the transducer and the pump input are shown. An image of the mylar window (on right)

The **ZnS T** sample has been assembled on a rotating holder filter and was placed in front of the beam input as shown in **Figure** 10. The dichroic is mounted with the coating side toward the input beam.

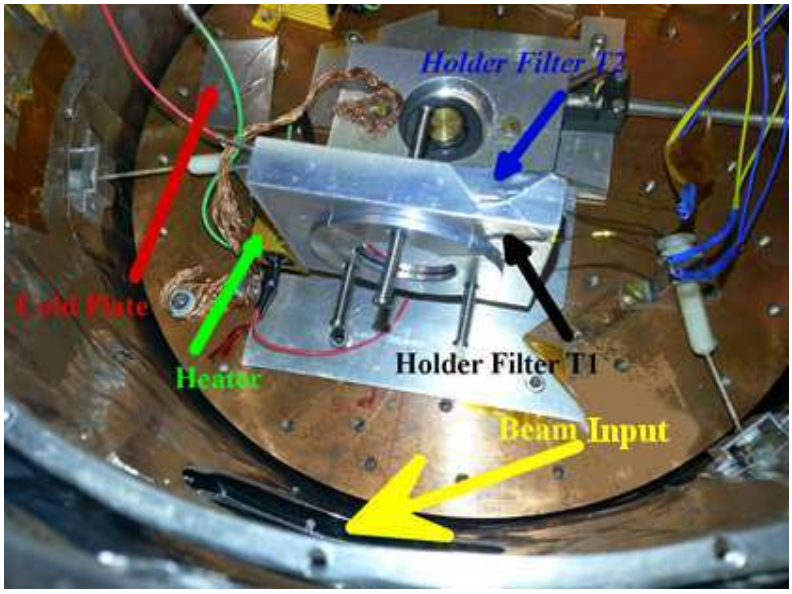


Figure 10: Image of the rotating holder filters. Three Pt100 and four heaters were mounted to control the temperature. The filter was assembled with the coting side toward the input beam.

4.1 Irradiation Facility

The irradiation tests were performed at e-LINAC, a facility of "Azienda Ospedaliera di Terni" (AOT). The accelerator is an ELEKTA Model PRECISE that produce electron beam for clinical use with nominal energies from 4 to 18 MeV. For this tests, electrons of **15 MeV** and **3cm x 3cm** beam area collimator have been used. In **Figure** 11, a sketch of e-LINAC indicating the details of electrons path from the e-LINAC head to the target is shown. Note in particular the definition of the Source to Surface Distance (SSD).

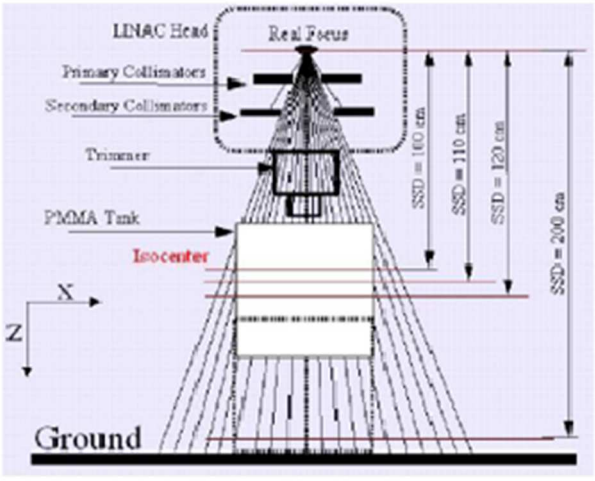


Figure 11: A sketch of the facility indicating the electrons path from the e-LINAC head to the target.

To perform dosimetry measurements, an Advanced Markus Chamber (AMC [1]), PTW type 34045 has been used. The AMC, represented in **figure 12**, is a parallel plate ionization chamber and has a small sensitive volume, 0.02 cm^3, with a thin entrance window. The small sensitive volume of the chamber allows dose distribution measurements in air and water, with good spatial resolution

Figure 12: Advanced Markus Chamber

The dewar, containing the dichroic, placed on the patient's table, the laser system used to align the dewar to mm precision and the AMC mounted on the dewar exit have been shown in **figure 13.**

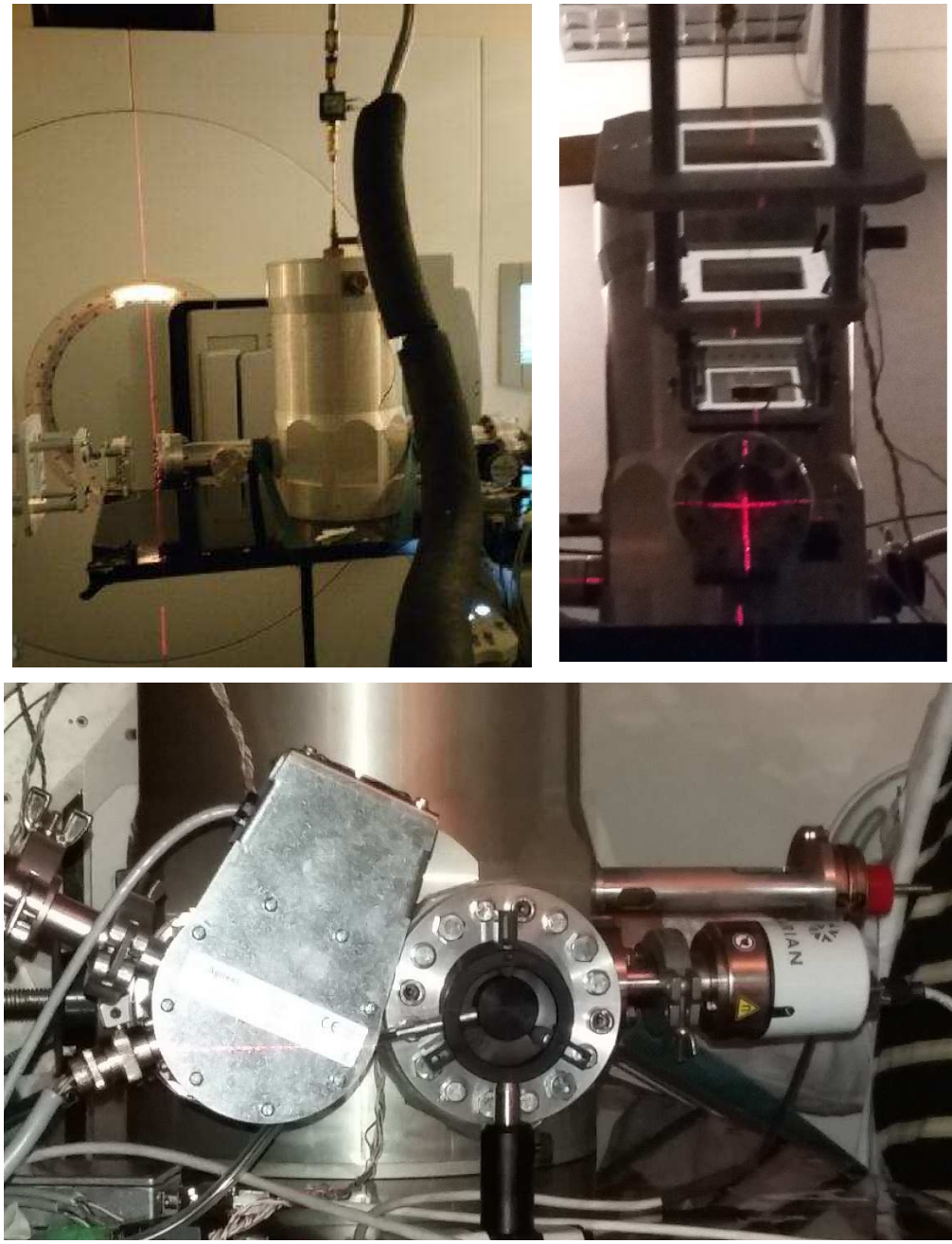


Figure 13: The position of the dewar at the electron beam exit (top left) with laser alignment system of the facility in beam direction, (beam is from left to right). On top right the exit of the beam and its laser centering. The black circle mounted in front of the flange window is the AMC.

4.2 Pre-Irradiation calibration measurements

Pre-irradiation calibration measurements have been executed prior the real test. As it can be seen in **figure 14**, in order to study the beam profile and dose distribution, three different distances from e-Linac head have been selected. The beam profile and the dose distribution data have been taken at 100 cm which corresponds at the window's input of the dewar (Step 1), at 130.5 cm which represents the Filter Position (FP) (Step 2) and finally at 170 cm which represents the window's output (Step 3). All the data were recorded in air.

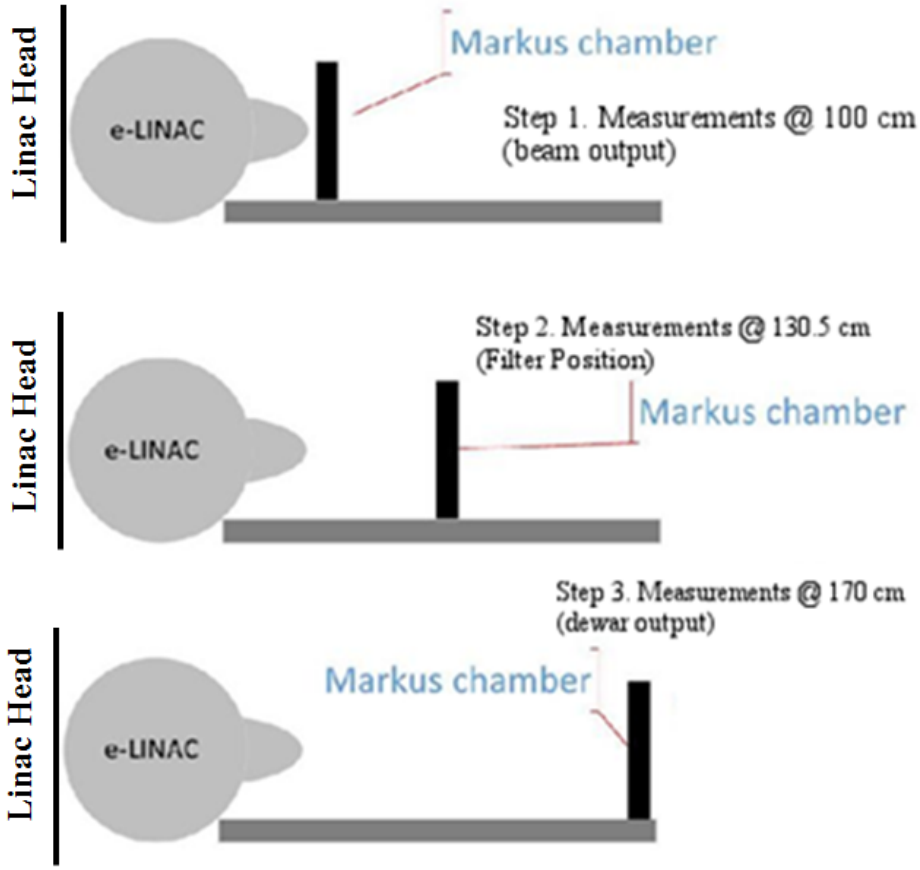


Figure 14: A layout showing the e-LINAC position and three different key positions where the beam profile, the absolute (the first one) and relative doses (for SSD different from 100 cm) have been measured.

The beam profile measured at 100 cm (black curve) and at 130.5 cm (blue curve) is shown in **figure 15**. The profile corresponds to the direction perpendicular to the beam axis. As it can be seen, the dose profile is uniform within 10% in the zone of ± 1.27 mm, which corresponds to a 1-inch diameter of the filter to be tested.

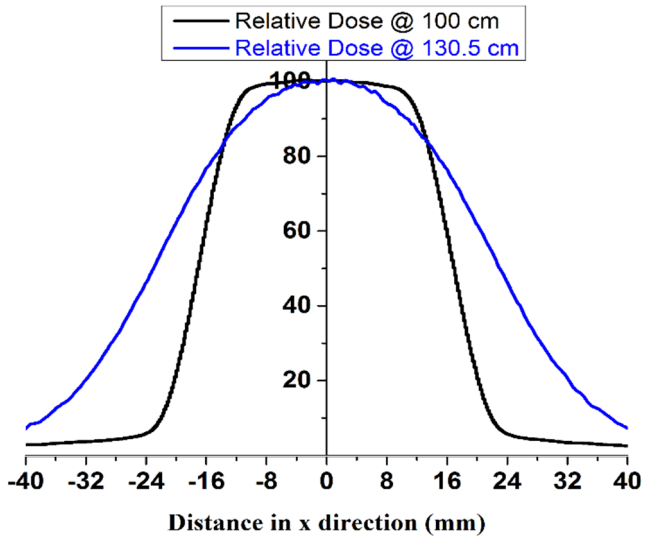


Figure 15: Dose profile measured in air at two different distances, 100 cm (black curve) and 130.5 cm (blue curve).

The e-LINAC machine setting requires to enter the dose to be delivered to the FP in Monitor Units (MU). In order to convert the absolute dose to MU, the followings equations have been used:

$$\frac{\text{Relative Dose}}{MU} = 0.93640^{[1]} \times 10^{-2} Gy^{[2]} / MU\ (@\ 100 cm)$$

$$\frac{\text{Relative Dose}}{MU} = 0.4250^{[1]} \times 10^{-2} Gy^{[2]} / MU\ (@\ 130.5 cm)$$

It should be kept in mind however that the preliminary measurements with the AMC measurements are taken in air for an energy of 15 MeV and a two different distance, 100 and 130.5 cm respectively.

[1] These values were extrapolated by a characterization of the electron beam of the e-LINAC accelerator
[2] 1 Gy=100 rad

In order to provide correct MU to set the machine and to estimate the duration for single step and of total session, the fluence and the energy available at the filter position have been calculated.
The fluence is the measure of how much radiation pass through a given area (electrons/ cm^2) and defined as:

$$Fluence = \frac{Target\ Dose}{1.6*10^{-8}* dE/dX} \qquad (el/cm^{-2})$$

where dE/dX is the stopping power of the material, which for **ZnS** is **2.392 MeVcm²/g**.
The available energy at the FP surface is about:

$$E = E_0 - (\delta_{air}*SSD*dE/dX) \qquad (MeV)$$

Where $\delta_{air} = 0.001223$ (g/cm^3) is the air density and E_0 is the initial value.

In Table 4 the parameters calculated before the irradiation tests are reported. The columns "F" (the MU needed to deliver to FP a given dose) and "G" (the time needed to deliver to FP a given dose) were estimated since we set the dose rate to its maximum value (about 400 MU/min)

A	B	C	D	E	F	G	H	I
# Step	Beam Energy (MeV)	Filter Position (FP) cm	Energy @ Filter surface	Target Dose (krad)	MU needed @ FP (in air)	Time needed in air (minutes)	MU needed @ FP (ZnS)	Time needed @ FP (minutes)
1	15.00	130.5	14.62	10	24027	62.09	24577	64.97
2	15.00	130.5	14.62	10	24027	6209	24577	64.97
3	15.00	130.5	14.62	10	24027	62.09	24577	64.97
4	15.00	130.5	14.62	10	24027	62.09	24577	64.97
5	15.00	130.5	14.62	10	24027	62.09	24577	64.97
				50		310.43	**122885**	**324.83**

L	M	N	O	P
# Step	$\left(\frac{Particles\ Flux}{cm^2 \times sec}\right)\times 10^7$	Fluence $(cm^{-2})x10^{11}$	dE/dX ($MeVcm^2/g$) for ZnS	Measurement @ FP $(Gy/MU)x10^{-3}$	Measured Dose Rate (MU/min)
1	7.112	2.649	2.392	4.162	387
2	7.112	2.649	2.392	4.162	387
3	7.112	2.649	2.392	4.162	387
4	7.112	2.649	2.392	4.162	387
5	7.112	2.649	2.392	4.162	387
		13.25			

Table 4: Parameters estimated before the irradiation test.

5 Irradiation Test

The two sections of irradiation test were done in 17th of May 2015 and 07th of June; the data recorded during the irradiation of the **ZnS T** dichroic, with the Advanced Markus Chamber, are given in table 5 and 6.
Before starting the irradiation test, a preliminary background measurement is acquired.
As it can be seen in **figure 16**, the electron flux coming from the head of the e-LINAC, goes through the mylar's windows and arrives to the Markus chamber.

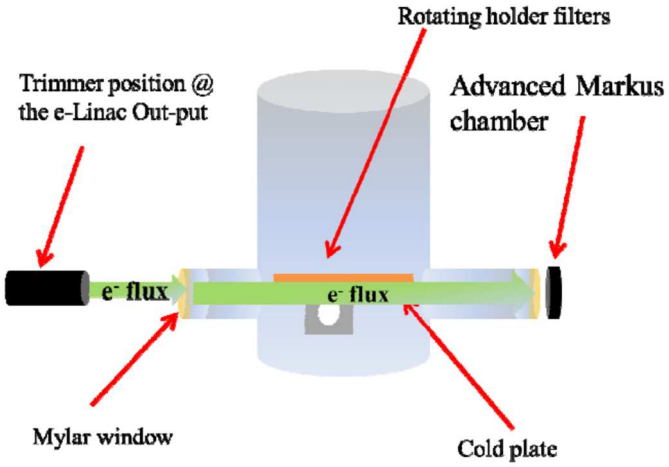


Figure 16: Configuration of the cryostat during the background measurement

After this operation, as it can be seen in **figure 17**, the holder filter is rotated of 90° and the dichroic becomes perpendicular to the e-Linac beam output. This position was maintained constant for the duration of the irradiation test, about 9 h.

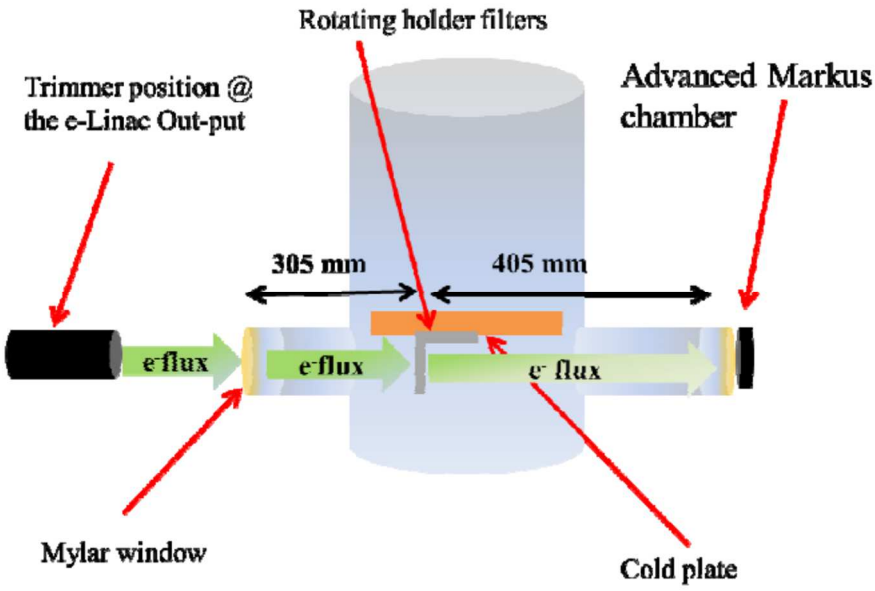


Figure 17: Configuration of the cryostat during the irradiation test.

5.1 First Irradiation section 50 Krad (17/05/2015)

The data acquired during the first irradiation test are reported in Table 4 . The column "D" refers to the Single Step Dose Delivered to the Filter Position (FP) in krad and the "F" to the absorb dose measured with the AMC in mGy.
When the measure was performed as shown in **Figure 17**, the dose measured at the dewar exit was **426.5 mGy** (step 0 column "F" in Table 5). When the filter was rotated in front of the electron beam (see **Figure 17**), the absorbed dose measured was **43 mGy** (step 1 column F in Table 5). One can conclude that the filter reduces the electron flux source at 1/10.

A Step #	B Timeb	C Estimated Cumulative Absorbed Dose by FP (krad)	D Single Step Dose Delivered to FP (krad)	E Single Step Dose Delivered to FP (MU)	F Measured AMC Dose at Dewar Exit (mGy)	G Comments
0	Start	0.10	0.09	200	426.5	Without Filter
1	12:27	0.09	0.09	200	43	With the filter
2		1.71	1.70	4000	881.2	Maybe destroyed some coating on the filter*
3		3.43	1.70	4000	904.8	
4		5.41	1.70	4000	906.2	
5		6.86	1.70	4001	906.6	
6	13:32	8.57	1.70	4000	905.2	
7		10.29	1.70	4000	905.3	
8		12.00	1.70	3998	905.1	
9	14:19	13.71	1.70	4000	904.3	
10	14:31	15.43	1.70	4000	904	
11	++14:45	17.14	1.70	4001		No measurement
12	14:56	18.86	1.70	4001	904.3	
13	15:07	20.57	1.70	4000	902.5	
14	15:21	22.28	1.70	4000	902.9	
15	15:35	24	1.70	4003	904.1	
16		25.71	1.70	3999	903	
17	16:00	27.43	1.70	3999	902.4	
18	16:13	29.14	1.70	3998	902	
19	16:25	30.85	1.70	3999	901.3	
20	16.37	32.57	1.70	3999	900.4	
21		34.28	1.70	4000		No measurement
22		36	1.70	4000	902.1	
23		37.71	1.70	3999	900.3	
24	17:25	39.42	1.70	4002	901.1	
25	17:36	41.14	1.70	3999	901	
26	17:48	42.85	1.70	4003	901.2	
27	18:01	44.57	1.70	4003	902.9	
28		46.28	1.70	4003	901.1	
29	18:29	48	1.70	4001	901.5	
30		49.71	1.70	4002	901.4	
31		51.43	1.70	4000	899.8	
32	19:12	52.57	1.17	2678 (2673+5)	602	
Total		**52.57**	**52.33**	**122884**	**26329.5**	

Table 5: : Data recorded during the first irradiation test (17/05/2015)

During the irradiation test, the temperatures have been acquired and the results are shown in **figure 18**. The blue and black curves refer to the holder (T1) and (T2), placed back and in front of rotating holder filter and the red to the cold plate (see **Figure 8**). As it can be seen, in about 1 hour and half, the system is thermalized and the temperature remains constant for the entire duration of the test.

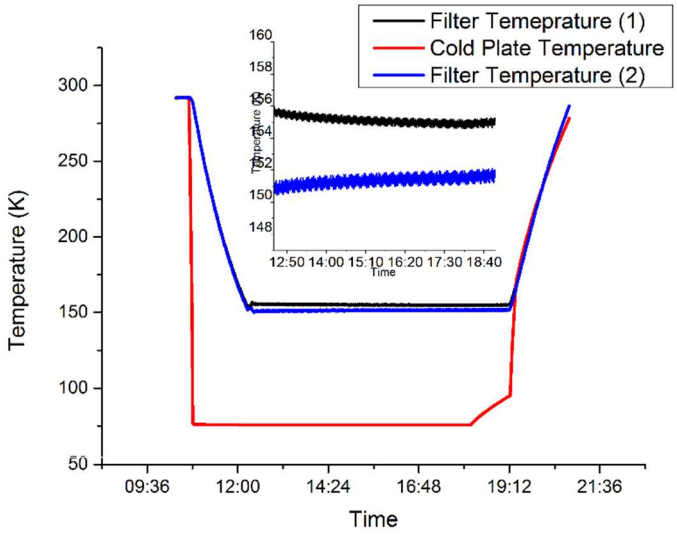


Figure 18 : Temperatures recorded during the irradiation test performed @ AOT. The red curve refers to the cold plate temperature, the blue and the black curves to the holder filter

*The absorbed dose measured during the second run (**904.8 mGy**) is larger than the previous one (**881.2 mGy**). This difference could be interpreted as due to a suspected modification of the coating but, as it can be seen in the seventh column, the value becomes then constant for all irradiation test. A possible sudden modification of the material and then its stable behaviour is considered unlikely. Moreover, the thickness of the coating itself can hardly explain a modification of the total dose in terms of the resulting delta fluxes. This leads us to conclude that the difference is not due to a modification of the coating, but it may be instead due to a slight modification of the electron beam.

5.2 Second irradiation section of additional 50 Krad (07/06/2015)

The same procedure described in section 5 , (see **Figure 16** and **17**), has been applied for the second irradiation test. Even in this case, as it can be seen in **Table 6** (column F step 1), the filter absorbs about **90%** of the radiation coming from the e-LINAC. This result is comparable with that observed in the previous irradiation section.

A Step #	B Time	D Single Step Dose Delivered to FP (krad)	E Single Step Dose Delivered to FP (MU)	F Measured AMC Dose at Dewar Exit (mGy)	G Comments
0	12:00	0.08	200	433.00	Without the filter
1		0.08	200	46.00	With the filter
2		0.08	200	45.4	
3	12:17	1.03	2457.00	576.00	

4		0.36	858.00	201.00	
5		0.15	358.00	201.00	
6		0.53	1259.00	295.00	
7	13:00	0.88	2085.00	485.60	
8		0.43	1034.00	241.20	
9		0.36	864.00	200.90	
10		0.38	915.00	213.3	
11		0.27	652.00	152.8	
12		1.01	2397.00	558.40	
13		0.12	290.60	67.40	
14		0.42	1000.00	233.40	
15		0.86	2047.00	478.90	
16		0.86	2049.00	926.00	
17	15:45	1.67	3978.00	926.00	
18		1.69	4016.00	941.00	
19		1.68	4003.00	939.00	
20	16:27	1.68	4004.00	941.30	
21		1.68	4005.00	943.60	
22		1.68	4006.00	944.50	
23		1.68	4006.00	943.30	
24	17:26	1.68	4005.00	944.40	
25		1.68	4008.00	946.00	
26	17:55	1.68	4004.00	945.50	
27		1.69	4019.00	951.80	
28		1.69	4019.00	952.50	
29		1.69	4020.00	953.70	
30		1.68	4004.00	949.10	
31		1.68	4005.00	950.30	
32		1.68	4005.00	952.30	
33		1.68	4005.00	951.20	
34	19:28	1.68	3991.00	947.30	
35	19:40	1.68	4005.00	950.90	
36	19:53	1.68	4005.00	950.50	
37	20:00	1.69	4020.00	953.50	
38	20:06	1.69	4022.00	952.30	
39	20:30	1.69	4019.00	952.90	
40	20:40	1.69	4018.00	952.90	
41	20:55	1.69	4019.00	953.20	
42		1.24	2959.00	702.10	
Total		**51.23**	**122008.6**	**29743.4**	

Table 6: Data recorded during the second irradiation test (07/06/2015)

The acquired temperatures are shown in **figure 19**. The blue and black curves refer to the holder (T1) and (T2), placed back and in front of the rotating filter holder (see **figure 8**) respectively, and the red curve to the cold plate.

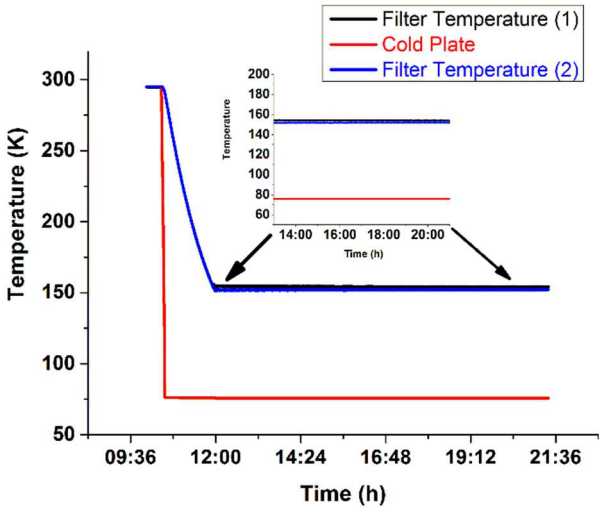


Figure 19: Temperatures recorded during the second irradiation test performed @ AOT.

The mean value and associated standard deviation have been calculated and shown in table 7, in the last column has been indicated the mean pressure indicated.

Section Period	Pt100 (A) Temp (K)	Pt100 (B) Temp (K)	Cold Plate Temp (K)	Pressure (mbar)
17/05/2015	155.1 ± 0.4	151.4± 0.3	75.66 ± 0.03	$(1.2 \pm 0.2)*10^{-6}$
07/06/2015	154.3 ± 0.3	152.1 ± 0.3	75.72 ± 0.02	$(1.7 \pm 0.3)*10^{-6}$

Table 7: Temperatures acquired during the first and second irradiation tests (mean value and standard deviation).

6 Results and discussions

After the first and the second irradiation test performed @ the AOT facility, the transmittance and reflectance of the dichroic, using the same configuration and optical parameters as reported in table 2, 3, have been repeated.
Although only the **ZnS T** dichroic has been exposed to the electron flux, measurements were performed on all samples (ZnS L and ZnS S) for reference.
In order to quantify the effects due to the radiation, the ratio, defined in equation 2, has been calculated:

$$RATIO = \frac{TT\ (after\ ) / TT\ (before\ )}{TL\ (after\ ) / TL\ (before\ )} \qquad Eq.\ 2$$

where TT(after), TT(before) and TL(after) and TL(before) are the transmittance of the sample
''*T* '' and ''*L*" recorded after and before each test performed @ AOT facility. The same equation 2 was used also for the reflectance. For the sample "L" the definition "before" and "after" is purely formal, since the sample has not been exposed to the electronic beam.

6.1 Results after the first irradiation test (50Krad-17/05/2015)

From **figure 20** it results that there are no major differences between the transmittance recorded after and before the first irradiation test. This statement is indeed confirmed by the analysis performed on the ratio calculated according to the equation 2.

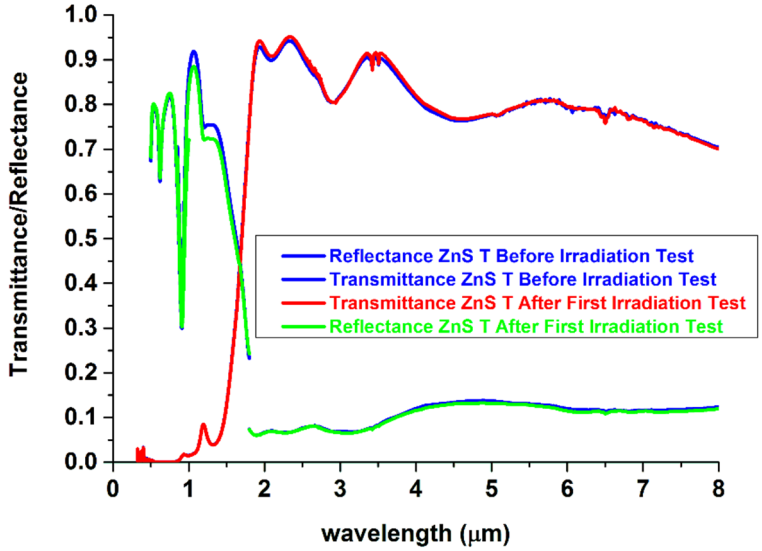


Figure 20 : Transmittance (blue and red curves) and reflectance measured with the FT-IR (blue and green curves) before and after the first test @ AOT facility

For a more accurate analysis of the transmittance, it was decided to estimate the ratio in two different regions, from 0.9 to 1.6 μm and from 1.5 to 8 μm, corresponding to the same parameters used for the FT-IR spectrometer.
In **figure 21**, the ratio vs wavelength has been reported, where the green curve is a reference line while the blue and red curves are the ratio calculated after the first irradiation test for the ZnS T and ZnS S respectively. It has to be emphasized that the analysis on the sample S was made only for comparison, since only sample T has been exposed to the electron flux.
As it can be seen, for the near infrared spectral range (**figure 21** on left) the deviation from the unit is about **0.06** or less and for the InfraRed is about **0.04** such as shown on the right. From the figure, it results that a similar deviation from the unity is observed for both samples "T" and "S", meaning that the effect is intrinsically coupled with the repeatability of the setup rather than on a real effect of degradation due to the radiation for sample "T".

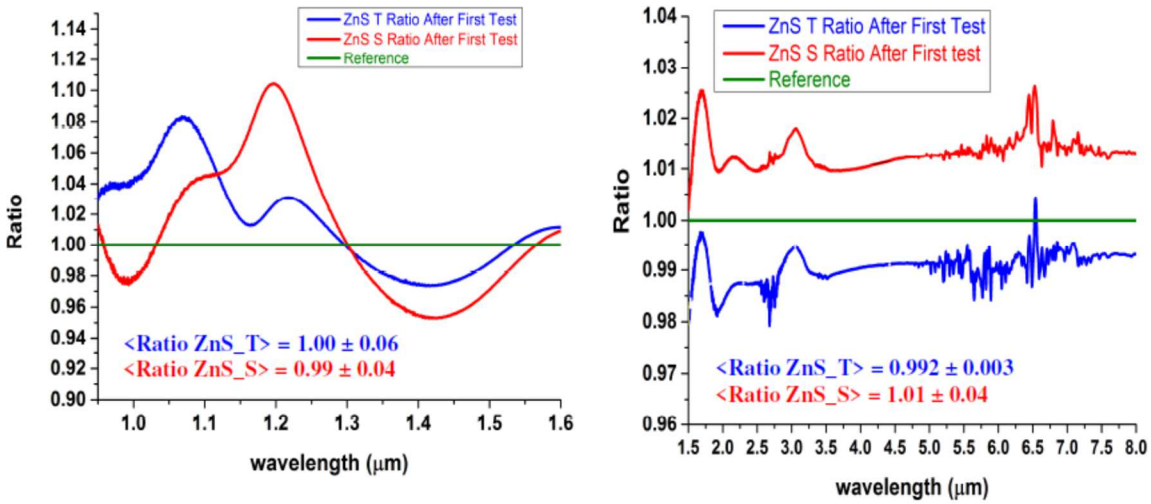


Figure 21: Ratio calculated according to the equation 2. The green curve is a reference while the blue and red curves are the ratio calculated after the first radiation test for the ZnS T and ZnS S respectively.

For the reflectance taken by the FT-IR (see section 3.2), it was decided to estimate the ratio in three different spectral range for the reasons explained above, from 0.5 to 1.0 μm, from 0.9 to 1.6 μm and from 1.5 up to 8 μm respectively. The results are shown in **figure 22**, where the green curve is a reference, while the blue and the red are the ratio calculated according to equation 2 for the ZnS T and ZnS S dichroic. As can be seen, the mean value of the ratio in the spectral range 0.9 - 1.6 μm is smaller of the unit for both the samples (see the **figure 22** on the right). This means that the effect is intrinsically coupled with the repeatability of the setup rather than on a real effect of degradation due to the radiation. For the other region the deviation from the unit is smaller of 1%.

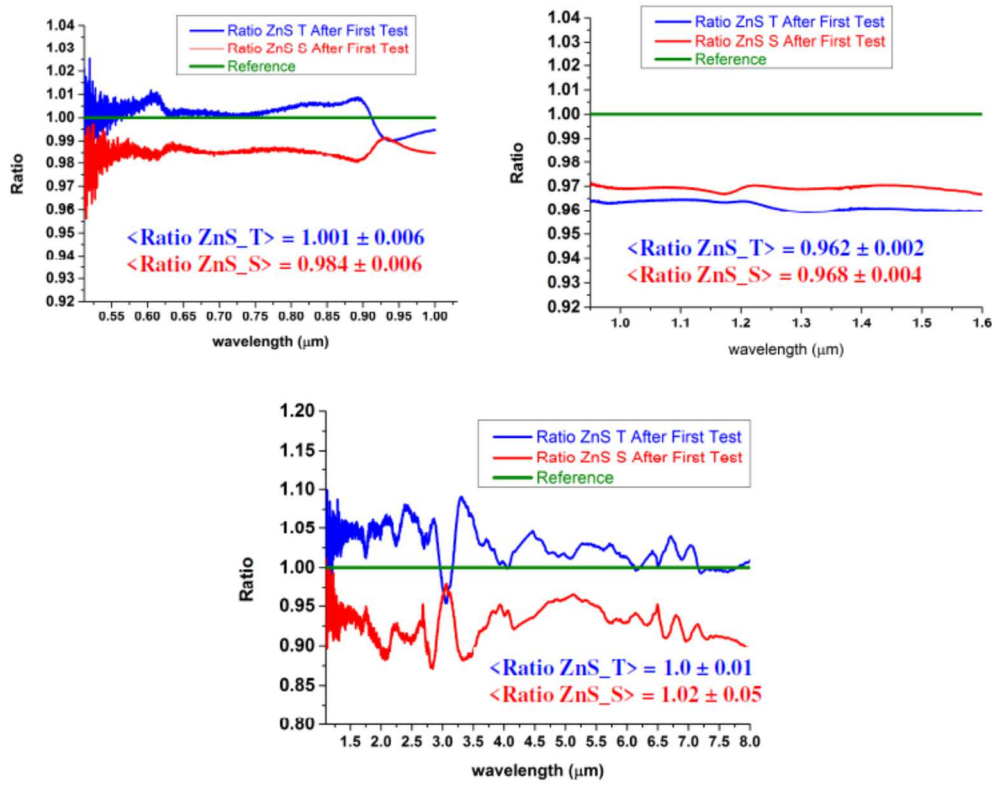


Figure 22: Ratio calculated for the reflectance according to the equation 2. The green curve is a reference while the blue and red curves are the ratio calculated after the first radiation test for the ZnS T and ZnS S respectively.

In this case, the deviation from the unit is less than **7%** along the spectral range of interest. The first evaluation leads to conclude that the deviations are due to the repeatability of the experimental setup and not to the absorbed dose during the irradiation test.
The mean value of the ratio and the standard deviation calculated after the first irradiation test, according to the equation 2, have been summarized in table 8.

Transmittance parallel Beam		
Sample	**Spectral Range (∝m)**	**After I test @ AOT**
ZnS S	0.9-1.6	**0.99 ± 0.04**
	1.5-8	**1.01 ± 0.04**
ZnS T	0.9-1.6	**1.00 ± 0.06**
	1.5-8	**0.992 ± 0.003**
Reflectance		
ZnS S	0.5-1	**0.984 ± 0.006**
	0.9-1.6	**0.968 ± 0.004**

	1.5-8	**1.02 ± 0.05**
ZnS T	0.5-1	**1.001 ± 0.006**
	0.9-1.6	**0.962 ± 0.002**
	1.5-8	**1.0 ± 0.01**

Table 8: Mean value and standard deviation calculated according to the equation 2 after first test performed @ AOT.

6.2 Results after second irradiation test (of additional 50 krad)

After the second irradiation test, during the disassembly procedure, we faced an unexpected problem. When the dewar has been opened, the filter temperature was probably a few degrees colder than usual (about 25°C) and the environment was possibly more wet. As shown in **figure 23** (on right), an apparent condensation formed on the surface of the coating of the ZnS T dichroic.

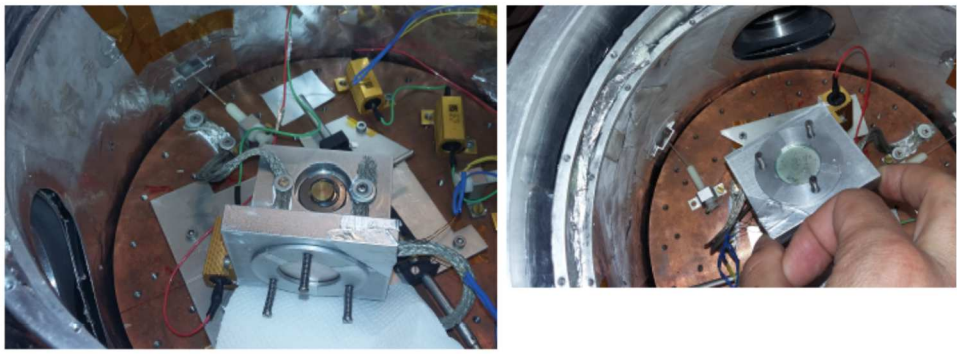


Figure 23: Images of the dewar and the surface of the ZnS T dichroic after the disassembly procedure.

This problem unfortunately resulted in a change of the optical properties of the filter. In fact, as it can be seen in **figure 24**, the surface of the sample ‘’T’’ appeared to be degraded respect to the other samples, probably because the coating has been damaged by the water vapour condensation.

Figure 24: Images of the ZnS T dichroic after the second irradiation test (on left) and a comparison with the other dichroics on the right.

It was decided to perform a visual inspection with a microscope and the results are shown in **figure 25**. The surface of the sample '' T'' seems to be cover by an unidentified opaque and dusty material. Nonetheless, we applied the same procedure used in the previous sessions, and the transmittance and reflectance measurements have been acquired.

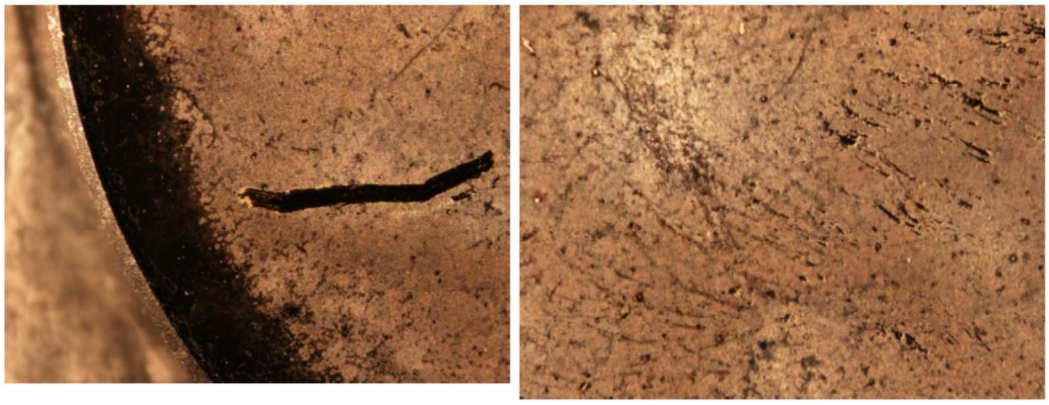


Figure 25: ZnS T images taken by a microscope.

6.3 Transmittance taken by the FT-IR

Using the FT-IR interferometer and the optical configuration described in section 3.1 and 3.2, the following spectra have been recorded. In **figure 26**, a comparison between the transmittance recorded before (dark curve) and after the second irradiation test (dark cyan) is shown. As it can be seen, the shape of the two curves is similar along the spectral range of interest except, among the others, for a strong band at 3 μm and another smaller one around 6 μm. The efficiency of the transmittance is decreased overall by approximately 10% (dark cyan) compared to nominal optical performance. This suggests a deposition of the dusty material which produces a reduction of the transparency.

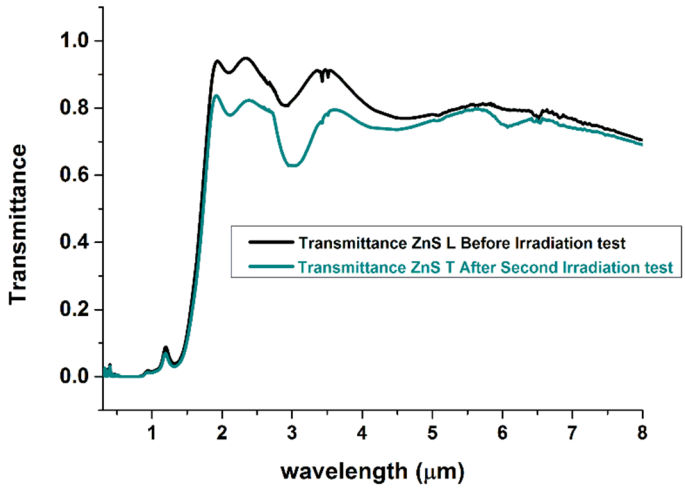


Figure 26: ZnS L (black curve) and ZnS T (dark cyan) transmittance recorded before and after the second test performed @ AOT facility.

Even in this case, according to the equation 2, the ratio has been calculated and the results are shown in **figure 27**. The green curve is a reference while the cyan and blue refer to the ratio calculated after the second and the first irradiation test. As can be seen, the results obtained are very different respect to the previous one. In fact, the standard deviation and the mean value are: **0.77 ± 0.09** for the spectral range from 0.6 to 1.6 µm and **0.88 ± 0.06** from 1.5 to 8 µm respectively.

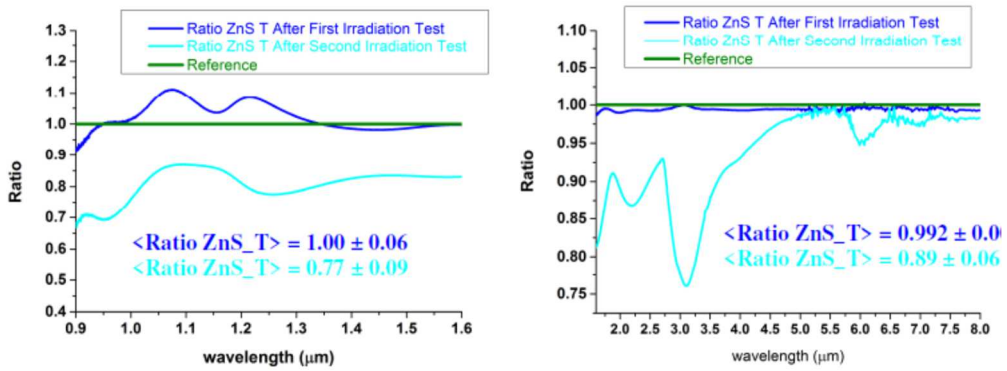


Figure 27: : The ratio of the transmittance calculated according to the equation 2. The green curve is a reference while the cyan and blue refer to the ratio after the second and the first irradiation tests respectively

In **figure 28** all data calculated for the **ZnS T** and **ZnS S** after the first and the second irradiation tests, are reported. The green curve is a reference line, the blue, cyan, red, magenta curves, refer to the ratio calculated for the samples T and S respectively.

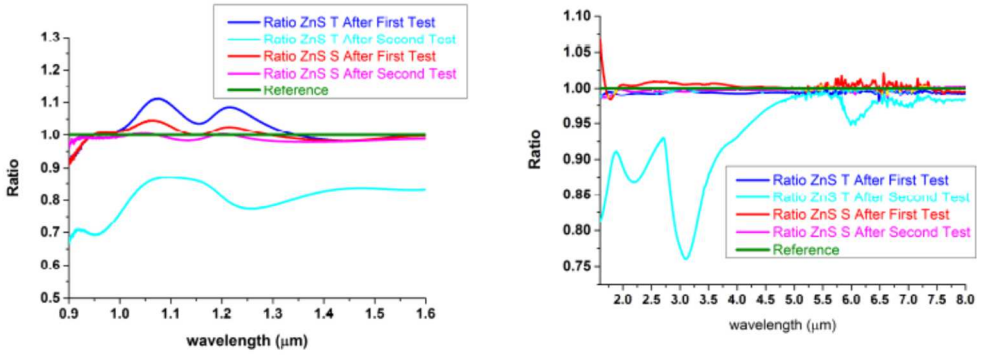


Figure 28: Ratio calculated according to the equation 2 for the ZnS T and ZnS S after the first and the second irradiation test.

6.4 Reflectance taken by the FT-IR

For what concerns the reflectance, using the same parameters summarized in table 3, the following spectra have been recorded. As it can be seen in **figure 29**, the shape of the two curves are similar along the spectral range of interest but not the intensity. The overall efficiency of the reflectance is decreased by approximately 50% (dark cyan) compared to nominal optical performance. To comparison the transmittance and reflectance acquired before (black curves) and after the second irradiation test (dark cyan) are shown in **figure 30**.

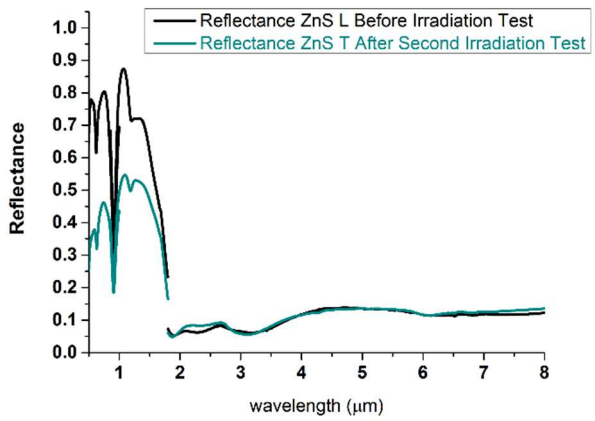


Figure 29: ZnS L (black curve) and ZnS T (dark cyan) reflectance recorded before and after the second test performed @ AOT facility.

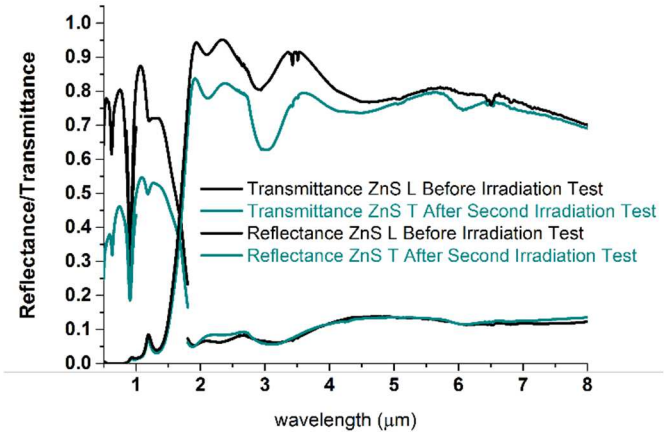


Figure 30: ZnS L (black curve) and ZnS T (dark cyan) reflectance and transmittance recorded before and after the second test performed @ AOT facility.

As in the previous case, the study was performed on three different regions and the results are shown in **figure 31**.

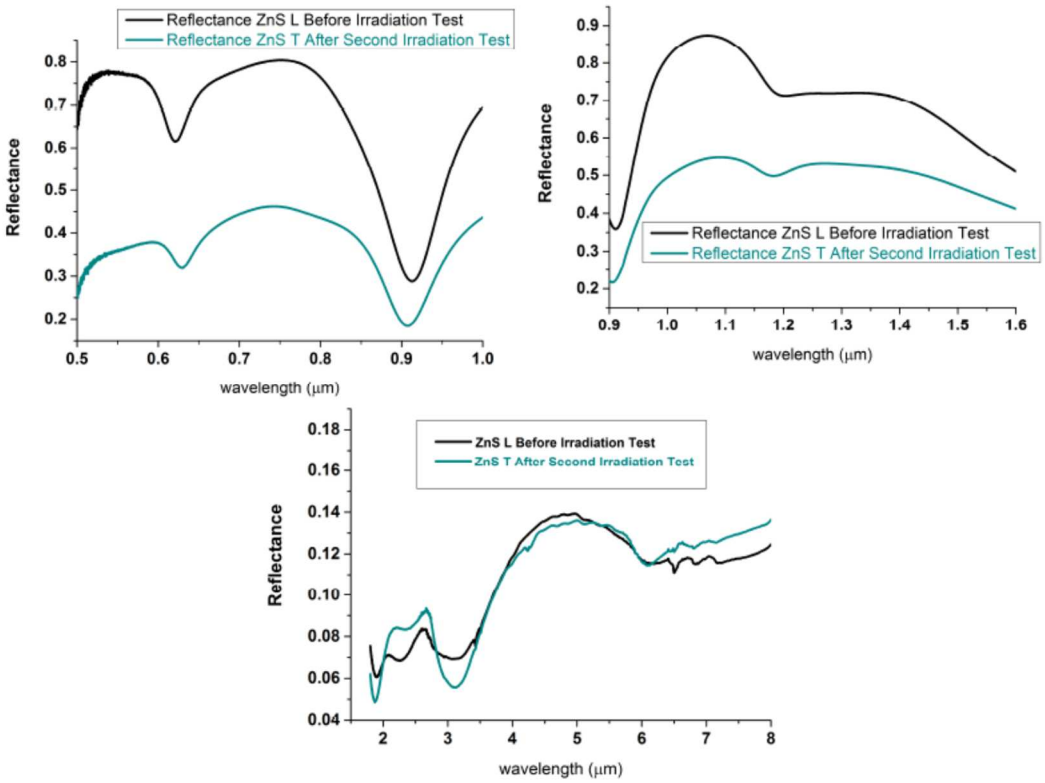


Figure 31: ZnS L (black curve) and ZnS T (dark cyan) reflectance recorded, in three different spectral range, before and after the second test performed @ AOT facility.

Even in this case, according to the equation 2, the ratio has been calculated and the results are shown in **figure 32**. The green curve is a reference while the cyan and blue refer to the ratio after the second irradiation test. As it can be seen, the value calculated is very different respect to the previous one. In fact, the standard deviation and the mean value are: **0.54 ± 0.07** for the spectral range from 0.5 to 1.0 μm, **0.64 ± 0.06** from 0.9 to 1.6 μm and **0.90 ± 0.05** from 1.5 to 8 μm.

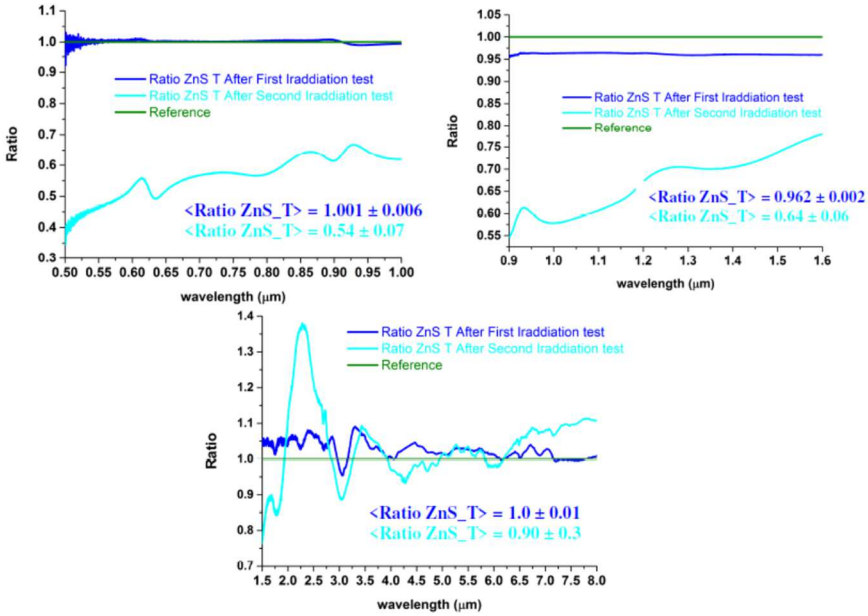


Figure 32: The ratio of the reflectance calculated according to the equation 2. The green curve is a reference while the cyan and blue refer to the ratio after the second and the first irradiation tests respectively.

For comparison, the results obtained after the second and the first irradiation test have been reported in **figure 33**.

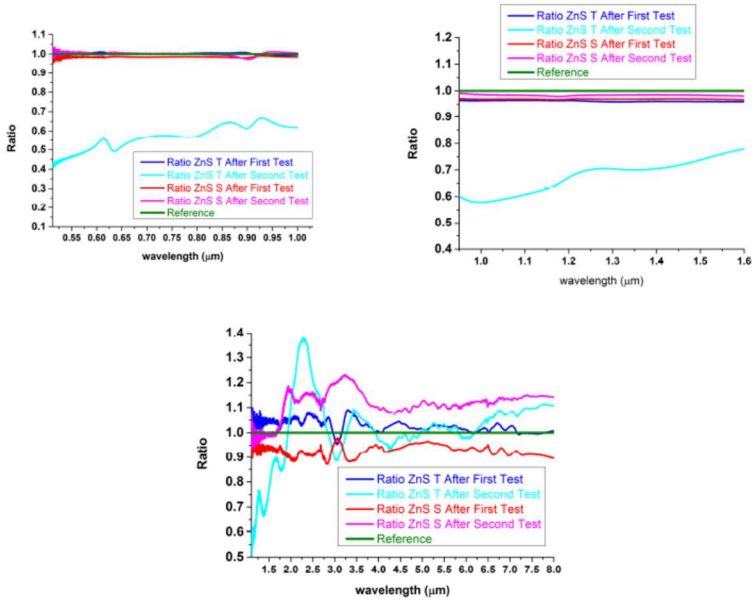


Figure 33: Ratio calculated for the reflectance according to the equation 2. The green curve is a reference while the blue and red curves are the ratio calculated after the first radiation test for the ZnS T and ZnS S respectively.

The values evaluated according to the equation 2 after the first and the second irradiation test, are summarized in table 9.

Transmittance parallel Beam			
Sample	**Spectral Range (μm)**	**After I test @ AOT**	**After II test @ AOT**
ZnS_S	0.9-1.6	**0.99 ± 0.04**	**0.99 ± 0.02**
	1.5-8	**1.02 ± 0.04**	**0.995 ± 0.05**
ZnS_T	0.9-1.6	**1.00 ± 0.06**	**0.77 ± 0.09**
	1.5-8	**0.993 ± 0.003**	**0.89 ± 0.06**
Reflectance			
ZnS_S	0.5-1	**0.984 ± 0.006**	**1.002 ± 0.009**
	0.9-1.6	**0.968 ± 0.004**	**0.983 ± 0.004**
	1.5-8	**1.02 ± 0.05**	**1.07 ± 0.06**
ZnS_T	0.5-1	**1.002 ± 0.006**	**0.54 ± 0.07**
	0.9-1.6	**0.962 ± 0.002**	**0.64 ± 0.06**
	1.5-8	**1.0 ± 0.01**	**0.90 ± 0.03**

Table 9: Mean value and standard deviation calculated according to the equation 2 after the second and the first irradiation test performed @ AOT.

7 CONCLUSIONS

Results of the radiation test performed at AOT (''Azienda Ospedaliera di Terni'') concluded that the delivered dose to the **ZnS T** dichroic is about **104 krad** such as reported in tables 5 and 6. The transmittance and reflectance measurements taken after the first irradiation test (first **50 krad**), do not show measurable changes in the optical performance in the whole spectral range considered. The ratio calculated for the ZnS T, the sample that was exposed to the electron flux, shows that the deviation is about **5% or smaller after the first test**. These fluctuations are comparable or smaller than the accuracy and repeatability of the characterization setup at which the spectra have been acquired. This conclusion
is supported by further analysis on the sample S, which has not been processed with an electron beam. For what concern the results after the second irradiation test, it can be said that the changes observed in the spectral range of interest are attributed to a thermal shock rather than to effects due to the radiation. In fact, after a discussion with the manufacturer of the dichroics, it was found that one of the layers of the coating is hygroscopic. The unfortunate fast change from cold to warm environment in a relatively wet ambient was the cause of the condensation on the substrate. The surface of the sample ''T'' was covered by dusty material which causes a significant reduction of the transmittance for approximately
10% overall and of the reflectance of about **50%**. This problem unfortunately invalidated the second test, so that we have presently a conclusion for a radiation dose of 50 krad only. Future investigation has to be addressed possibly with samples of dichroic closer to the final configuration and with layers as much as possible robust against the condensation of water vapour.

8 REFERENCES

1. *The characterization of the Advanced Markus ionization chamber for use in reference electron dosimetry in the UK.* **Julia Pearce, Russell Thomas and Alan DuSautoy.** 3, s.l. : Physics in Medicine and Biology, January 2006, Vol. 51.