Electric ageing process of space used materials under high radiation dose in geostationary orbit

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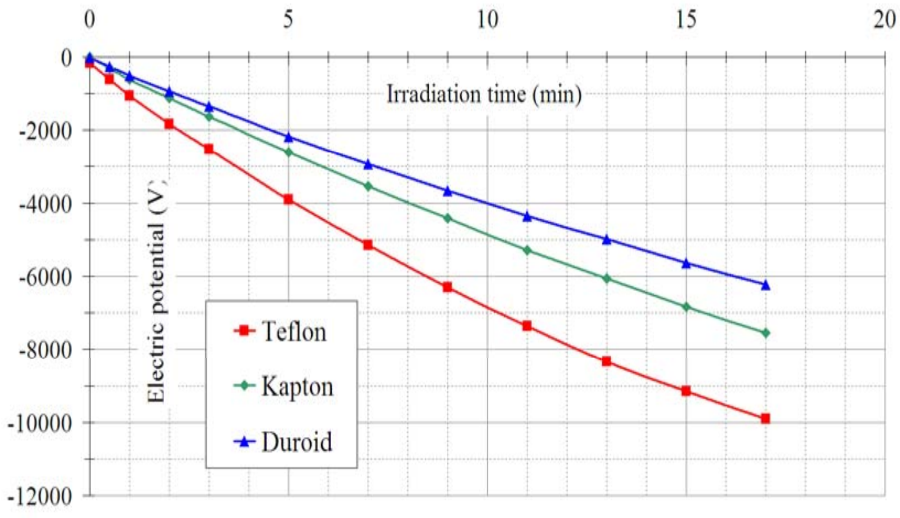
Presentation Plan

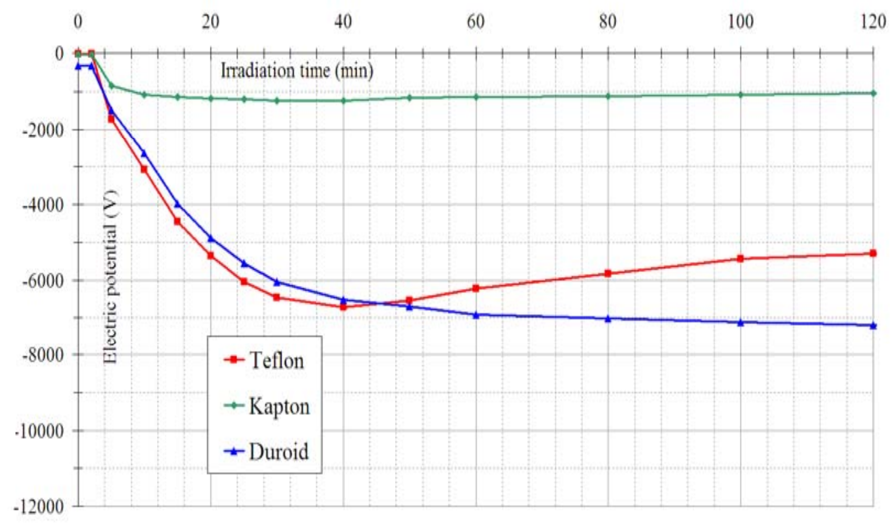
1. Overall issues and Objectives
2. The experimental irradiation facility (SIRENE)
3. Description of the tested samples
4. Experimental protocol
5. Experimental results
6. Conclusion

Overall Issues (1/2)

Charging kinetics of dielectric materials (127 µm thick) under monoenergetic 20 keV electron beam (250 pA.cm^{-2})



Charging kinetics of dielectric materials (127 µm thick) under GEO electron environment ([20 keV, 250 pA.cm^{-2}]+ [0-400 keV, 50 pA.cm^{-2}])



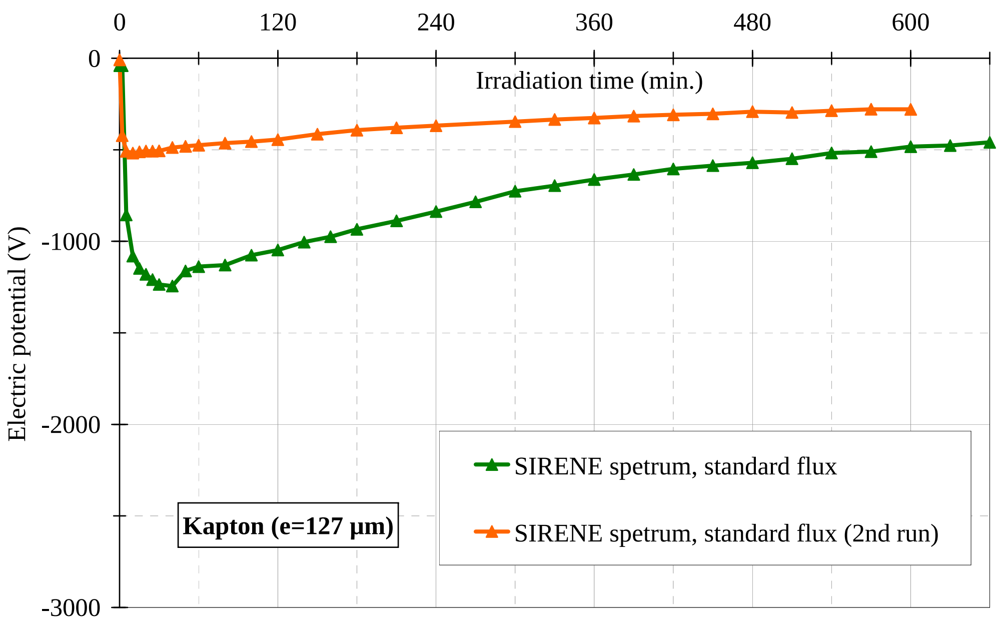
High sensitivity to radiation dose rate

Effect of radiation induced conductivity (Instantaneous effect)

$$\sigma_{ric} = k\left(\frac{dD}{dt}\right)^{\Delta}$$

Overall Issue (2/2)

Charging kinetics of dielectric materials after consecutive SIRENE irradiation SIRENE electron environment ([20 keV, 250 pA.cm^{-2}]+ [0-400 keV, 50 pA.cm^{-2}])



LOW RADIATION DOSE

	Kapton®	Cumulated GEO equivalent days
1st run	1.33 10^4 Gy	13
2nd run	2.21 10^4 Gy	21

- Effect of radiation dose on the charging level and material conductivity

⇒Ageing process

⇒ Behaviour for high radiation dose ?

Objective and experimental approach

Objective of this study

Effect of high radiation dose injection (high equivalent flight duration : up to 6 months) on charging behaviours of space materials

Experimental Approach

1. Ageing of materials with the monoenergetic (400 keV, 2.5nA.cm^{-2}) electron beam

2. Charging with the GEO like electron spectrum (standard Kp>5 flux with SIRENE facility)

SIRENE facility (1/3)

Irradiation facility for the study of surface and internal charging by means of an electron source with a "space like" energy distribution in the 0-400 keV range

- **Objectives** :
- Study of voltage building up on spacecraft dielectric materials and equipment samples for geostationary orbit application
- Characterization of electrostatic discharges
- Measurement of intrinsic and radiation induced conductivity of materials
- Characterization of total radiation dose and temperature effects on electric conductivity

- **Features** :

Two electron sources

- Electron gun : E=7-100 keV + simple foil: homogeneous diffusion of the beam
- 400 keV Van de Graaff electron accelerator + complex diffusion foil

→ **spectral energy distribution : 0-400 keV**

- Instrumentation : current probes, voltage probe, in situ camera, contact-less PEA equipment

Temperature range : -180°C/+150°C

Pressure : 10^{-6} hPa

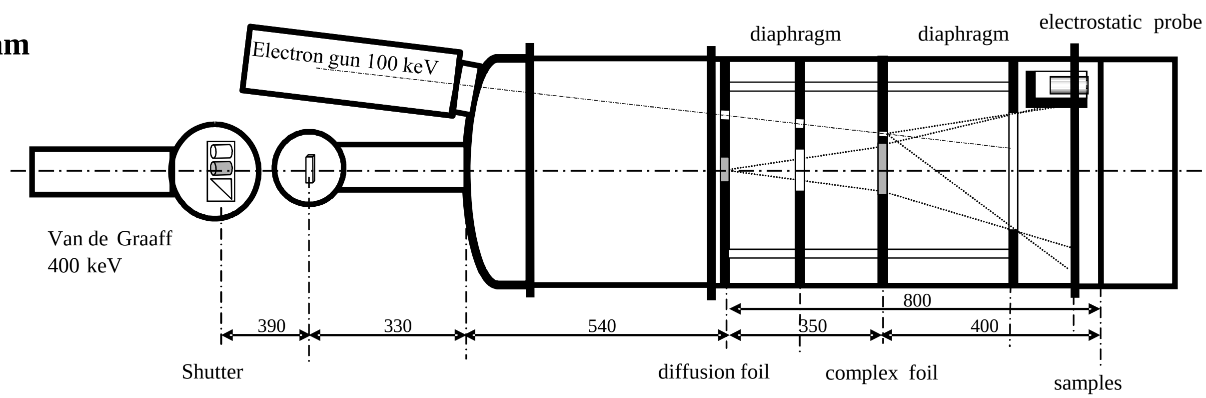
Sample capacity : ∅=160 mm

Current : up to 20 nA/cm^2

SIRENE facility (2/3)

General view of SIRENE

Schematic diagram of SIRENE



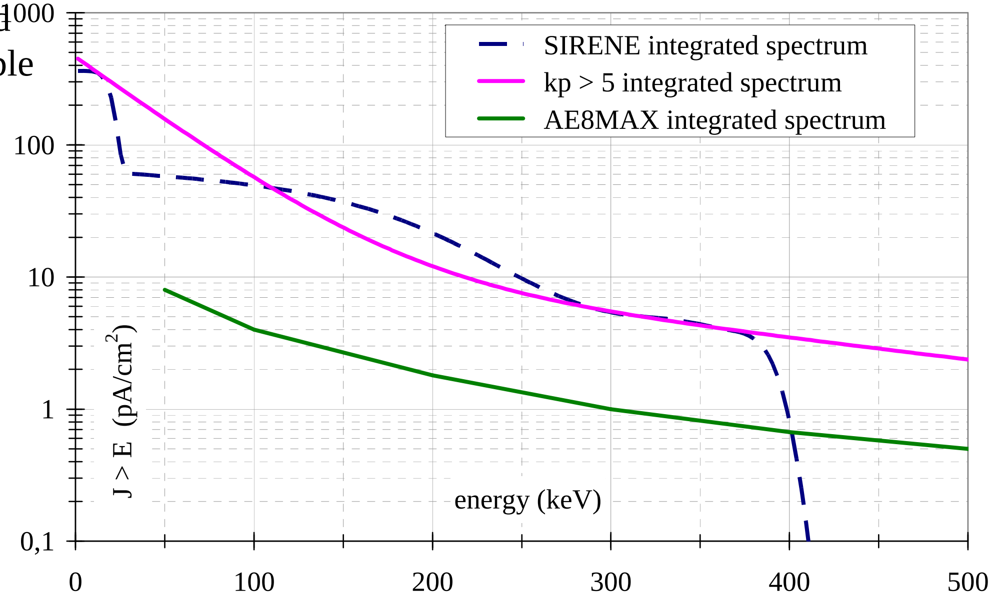
SIRENE facility (3/3)

Reference spectrum for Geostationary orbit

- Geostationary orbit electron fluxes reference spectrum : Kp>5
- Kp>5 (an index for geomagnetic activity linked to high charging risk) is well modelled by a double maxwellian

$$J(>E) = A\,e^{-\frac{E}{E_a}} + C\,e^{-\frac{E}{E_c}}$$

A=9,52*10^7 E_a= 268,64 keV
C=2,8*10^9 E_c =44,16 keV



- AE8MAX spectrum is not fitted for charging studies (for which high fluxes govern the issue)

- **SIRENE spectrum, standard flux :**
  E=20 keV, Φ=250 pA/cm^2 +
  E=0-400 keV, Φ=50 pA/cm^2

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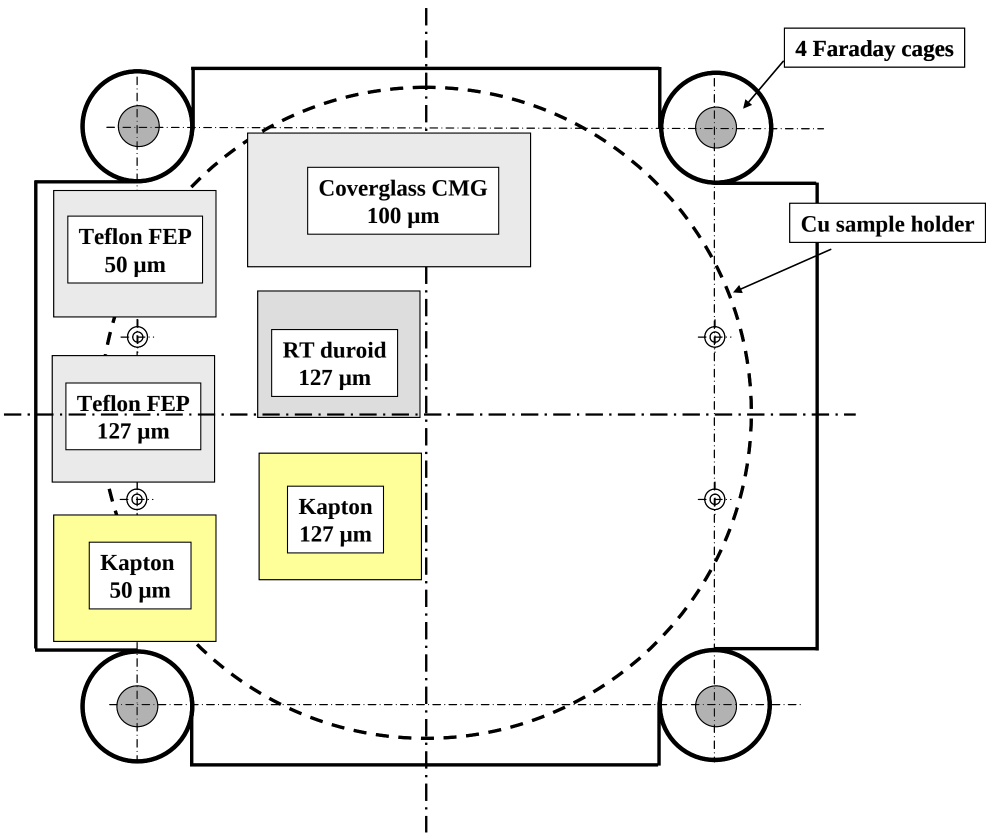
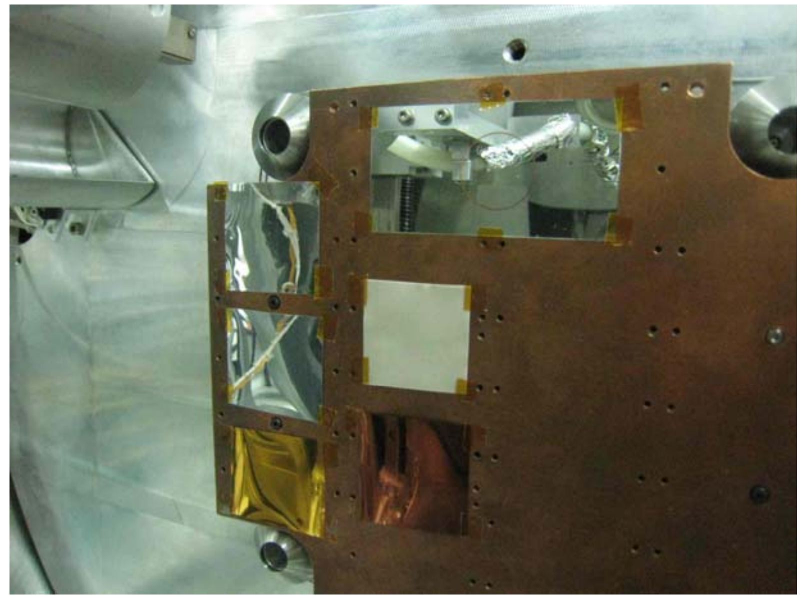
Description of the tested samples





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Experimental protocol

- General objective: Ageing of materials and study of the evolution of conduction process
- Ageing process with (400 keV, 2,5 nA/cm-2) and three increasing radiation dose level
  - Dose 1 : 15 minutes irradiation
  - Dose 2 : 1 hour irradiation
  - Dose 3 : 4 hours irradiation
- Description of the different sequences

Sequence 0 : dose 0	→ Standard SIRENE spectrum	→ potential relaxation (2h)
Sequence 1 : ageing dose 1 = 15 ‘	→ Standard SIRENE spectrum	→ potential relaxation (20h)
Sequence 2 : ageing dose 2 = 1h	→ Standard SIRENE spectrum	→ potential relaxation (40 h)
Sequence 3 : ageing dose 3 = 4h	→ Standard SIRENE spectrum	
Sequence 4 : 120 h after dose 3	→ Standard SIRENE spectrum	recovery effect ?
Sequence 5 : 315 h after dose 3	→ Standard SIRENE spectrum	
Sequence 6 : 960 h after dose 3	→ Standard SIRENE spectrum	

- Performed measurements : Surface electric potential on each samples

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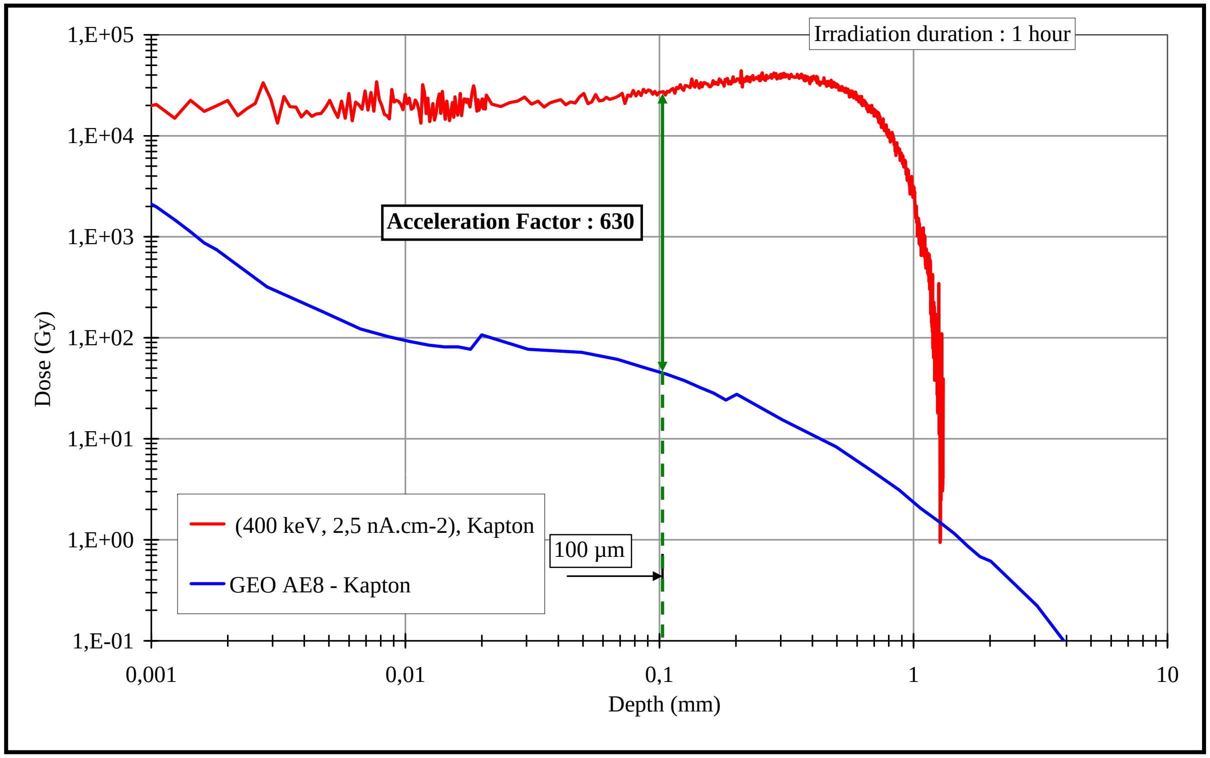
Acceleration factor (1/2)

- ✓ Dose injected in experimental conditions : calculated with **GEANT 4 software**
- ✓ Electron spectrum considered :
  - ✓ Average GEO spectrum : AE8 MIN-MAX
  - ✓ Kp > 5 GEO SIRENE spectrum
  - ✓ 400 keV monoenergetic electron beam
- ✓ Materials : CMG, Teflon FEP, RT/Duroid, Kapton



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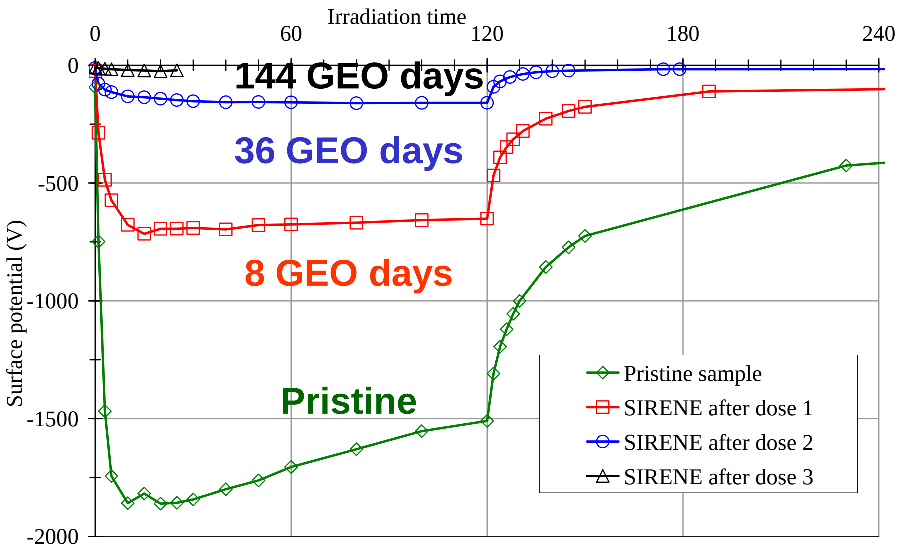
Acceleration factor (2/2)

Ageing dose varying from 8 days to 334 GEO days

	Dose 1 (Gy) Equivalent GEO days	Dose 2 (Gy) Equivalent GEO days	Dose 3 (Gy) Equivalent GEO days
Kapton (127 µm)	$8.71\ 10^3$ Gy **8**	$3.82\ 10^4$ Gy **36**	$1.51\ 10^5$ Gy **144**
Teflon FEP & RT/Duroid (127 µm)	$9.4\ 10^3$ Gy **12**	$4.34\ 10^4$ Gy **56**	$1.75\ 10^5$ Gy **227**
CMG (100 µm)	$1.02\ 10^4$ Gy **18**	$4.71\ 10^4$ Gy **81**	$1.94\ 10^5$ Gy **334**

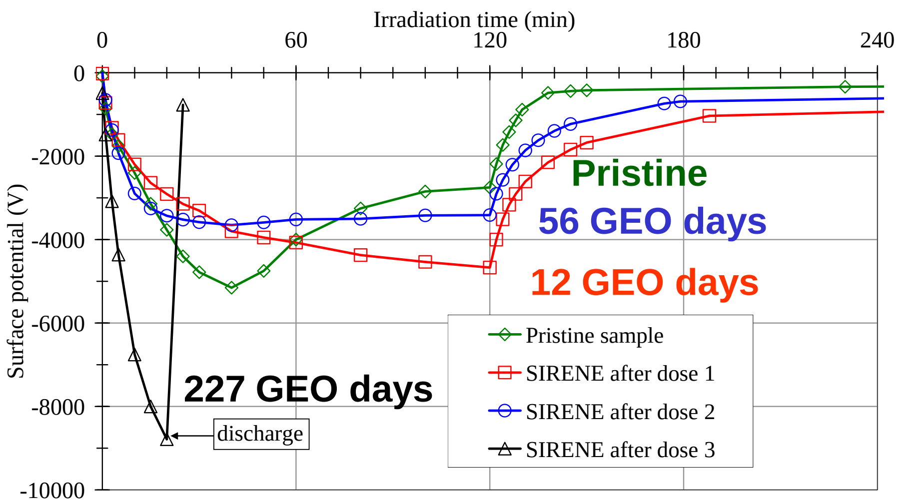
Experimental results
Charging behaviour on aged materials (1/2)



Kapton (127 μm)

• Continuous increase of RIC for pristine sample ⇒ High sensitivity of conductivity for low radiation dose

• Continuous of RIC with increasing dose ⇒ Null charging potential for GEO duration higher than 144 days



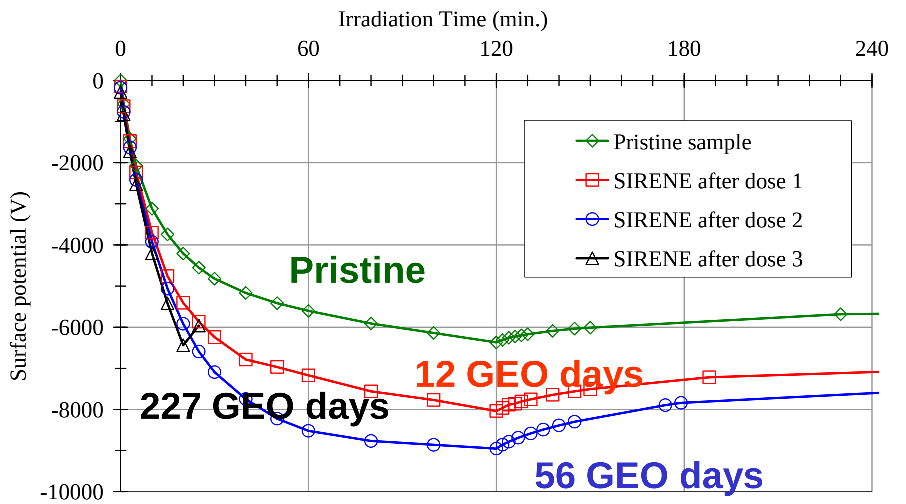
Teflon(127 μm)

• Continuous increase of RIC for pristine sample High sensitivity of conductivity for low radiation dose

• Fluctuation of RIC with increasing radiation dose

• Overall decrease of RIC with increasing dose ⇒ Hazardous charging potential for duration higher than 227 days (or lower)

Experimental results
Charging behaviour on aged materials (2/2)

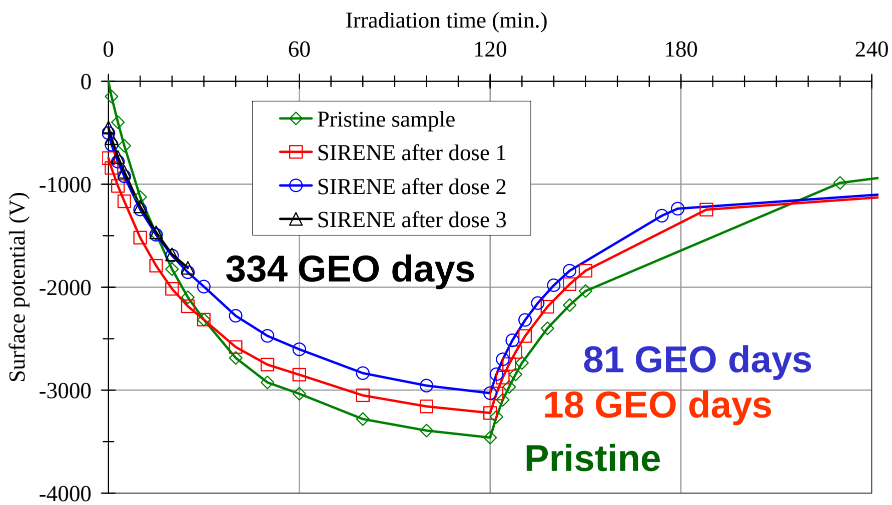


Duroid (127 µm)

- ***Continuous decrease of RIC with increasing dose***

- ***Apparent RIC saturation after 56 days***

⇒ Hazardous charging potential for duration highe than 56 days



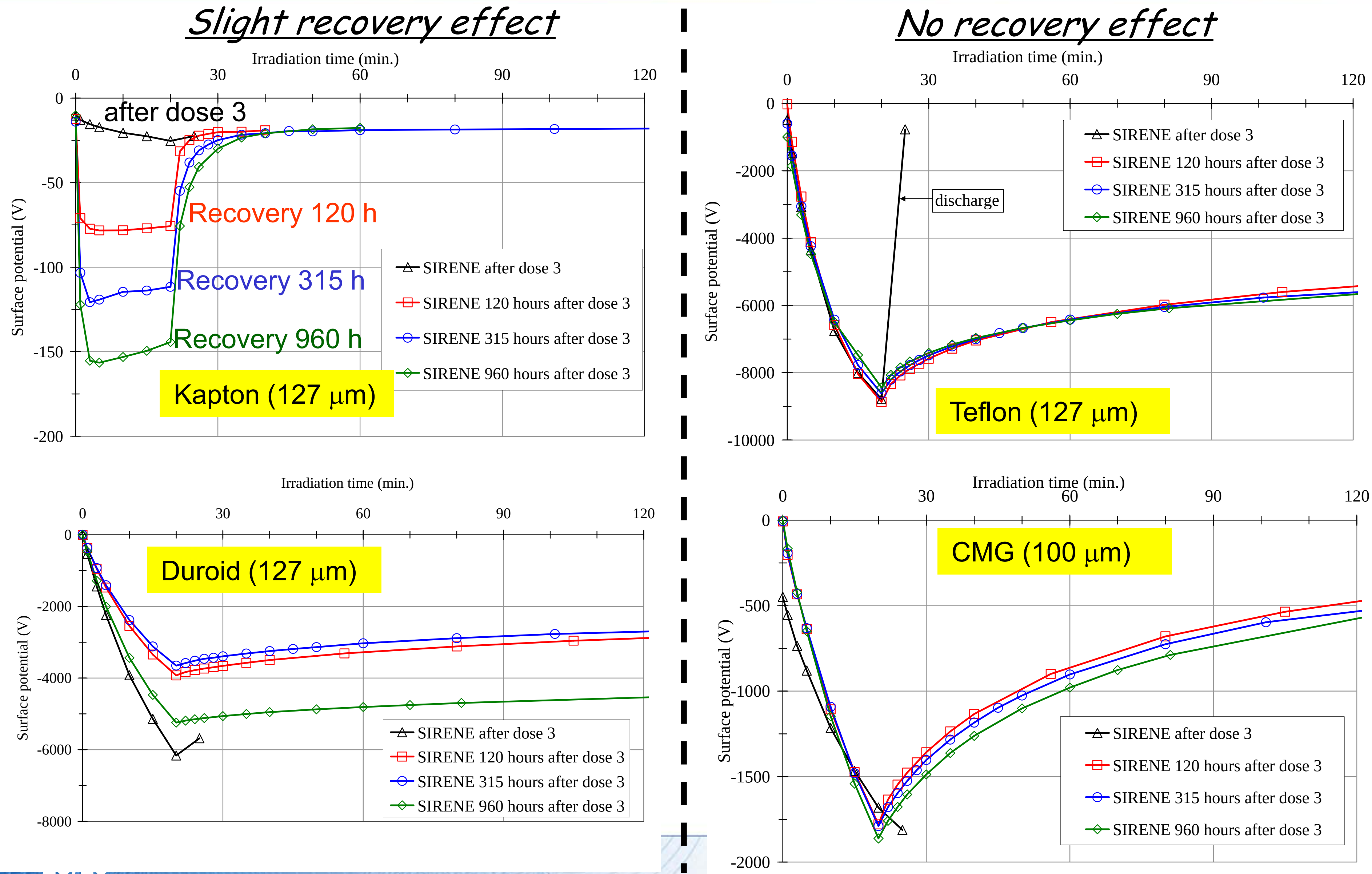
CMG (100 µm)

- ***Continuous but slight increase of RIC with increasing dose***

- ***Apparent RIC saturation after 81 days***

→ very different behaviour for each material

Experimental results
Relaxation processes



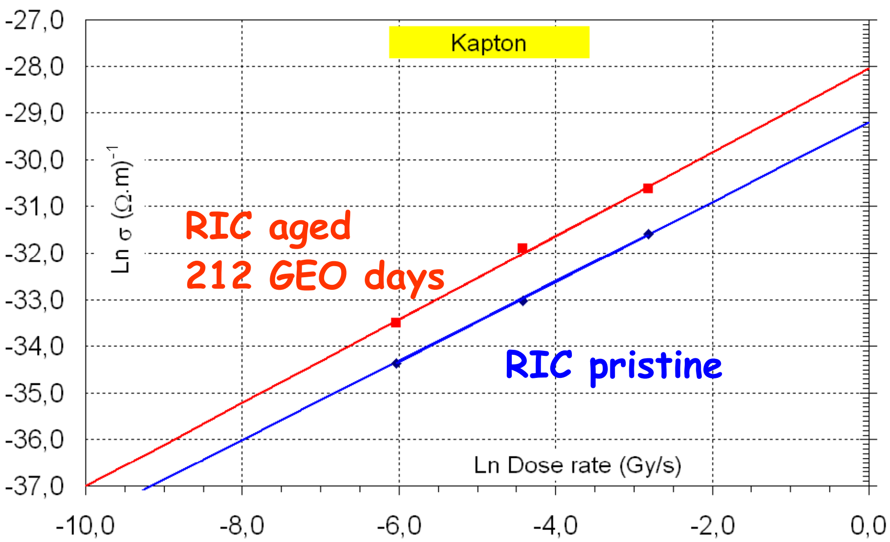
Experimental results
Sensitivity of RIC with injected radiation dose

Extra experimental protocol

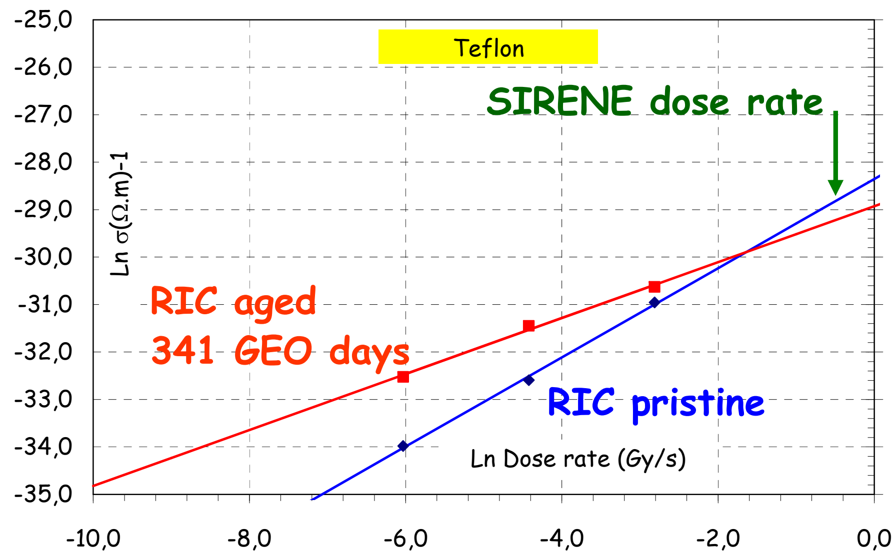
1. Charging with 20 keV monoenergetic e- beam

2. 20 keV irradiation shut-down ⇒ enhanced relaxation of surface potential

   → Stimulated relaxation with 400 keV monoenergetic beam with three different dose fluxes at 2.4, 12, 60 mGy/s (1, 5, 25 $pA.cm^{-2}$)



⇒ Strong evolution of RIC with radiation dose and dose rate



⇒ The RIC-dose rate characteristics evolves with radiation dose

$$\sigma_{ric} = k\left(\frac{dD}{dt}\right)^{\Delta}, \quad k = k(D), \Delta = \Delta(D)$$

Conclusion

1. Radiative ageing through high energy electron irradiation strongly affects the charging behaviour of space materials in GEO orbit

2. Radiation induced conductivity is strongly dependent on the radiation dose rate as well as on the injected radiation dose
   - Polyimide and glass based materials tend to get highly conductive : RIC increases with radiation dose

   - Teflon based materials tends then to get less and less conductive ⇒ RIC decreases with increasing radiation dose

3. Slight or null recovery effect during quiet phases

⇒ Permanent degradation of material structure and electrical properties

⇒ Issues related to material reliability and space mission lifetime

⇒ Material qualification procedure should include ageing effect through electron irradiation to assess the evolution of electrical properties of space materials

Acknowledgments

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for R&T funding and technical support for this study

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- ✓ Dose injected in experimental conditions : calculated with **GEANT 4 software**
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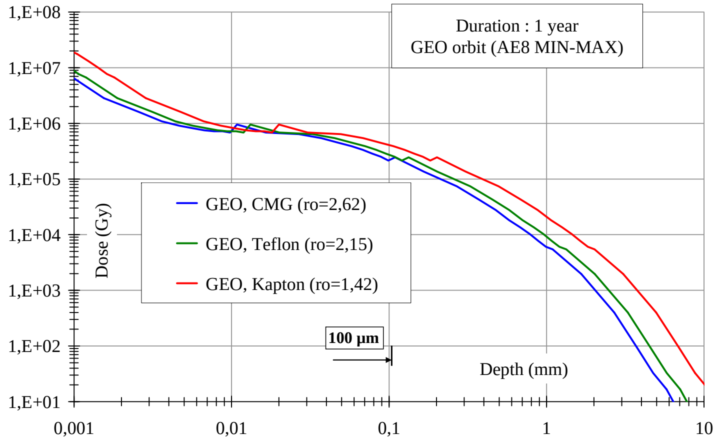
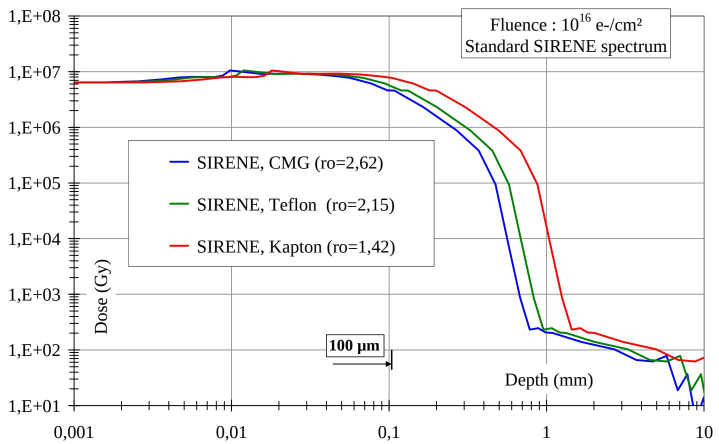
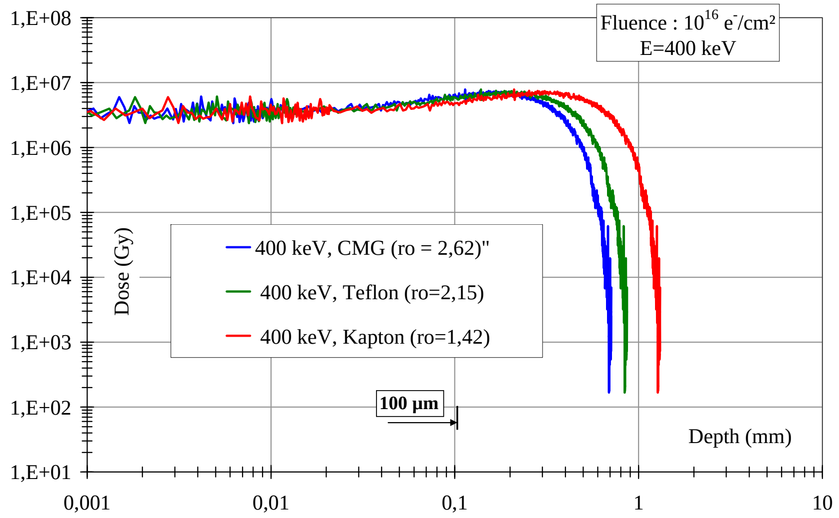
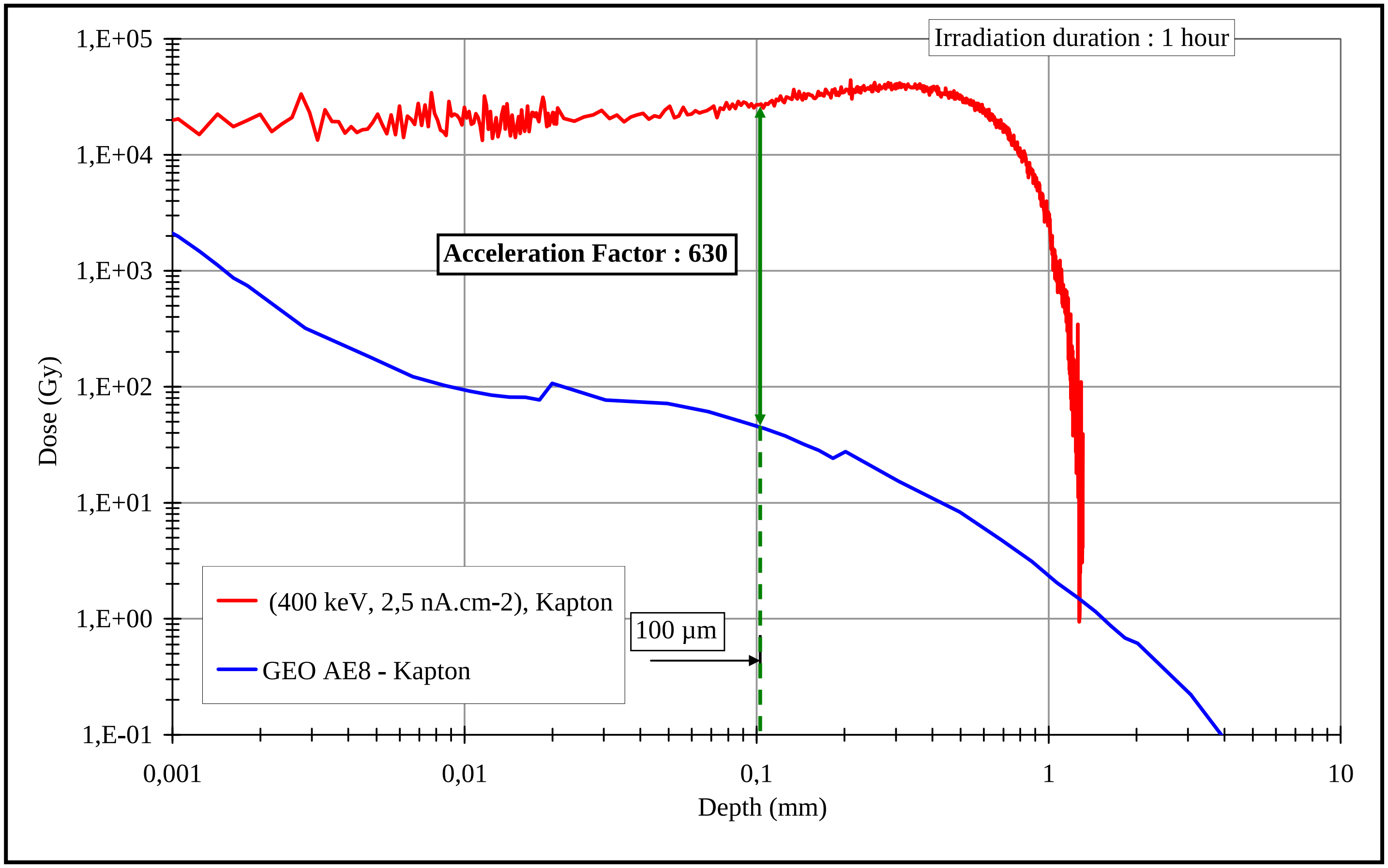






Comparison of radiation dose levels injected at the rear face with 400 keV electron beam and AE8 GEO spectrum (for a given duration)



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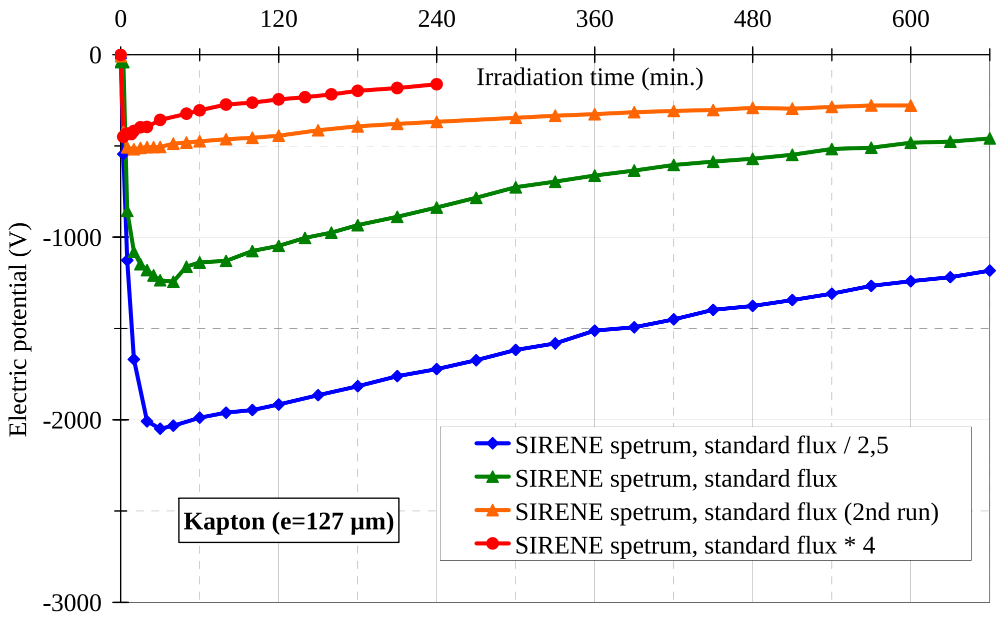

LOW RADIATION DOSE

	Kapton®	*GEO equivalent days*
d_1	3.81 10^3 Gy	4
d_2	1.33 10^4 Gy	13
d_3	2.21 10^4 Gy	21
d_4	3.62 10^4 Gy	34

- Effect of radiation dose on the charging level and material conductivity

⇒Ageing process

⇒ Behaviour for high radiation dose ?