Radiation Experiments and New Materials

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Close Out Meeting, Cambridge, UK, 23 March 2017

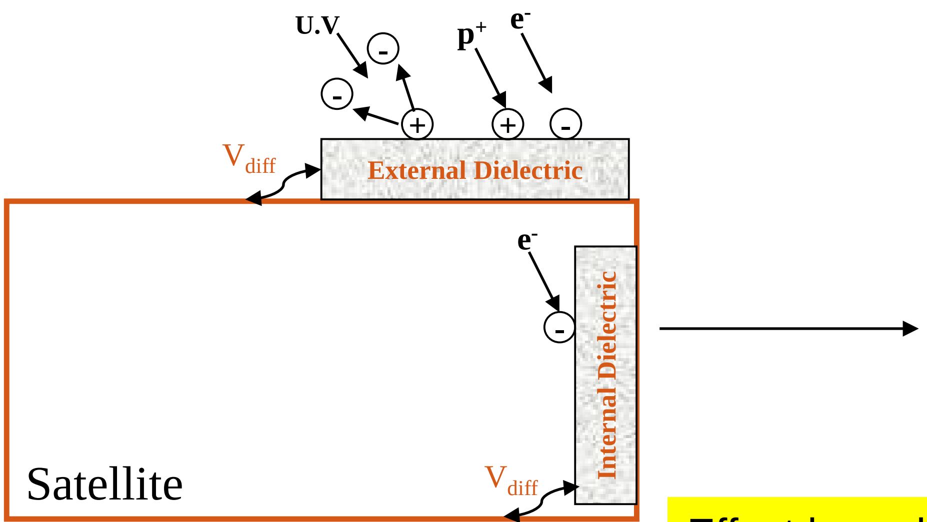
Outline

- Motivations
- Physics of internal charging
- Objectives of the current project
- Experimental facilities and measurement set-up
- Characterisation of materials used on internal parts
- Characterisation of components in representative electron environment
- Conclusion

Motivations

- Harsh radiation environment in MEO
  - High fluxes at high energy levels : irradiation on inner elements

  ⇒ important effect on internal charging with potentially high charging kinetics



- Thick dielectric support
- Insulated wires
- Circuit board

With low conductivity (low charge decay)
⇒ Charge accumulation

Effect brought into evidence by on-board experiments : SCATHA, CRRES, DSP

- ⇒ Consequence : generation of high electric field
  - Initiation of disruptive ESD → high risks on metallic floating parts
  - Dielectric breakdown
  - Damages on electronics
  - EMC issues
  - Degradation of physical properties

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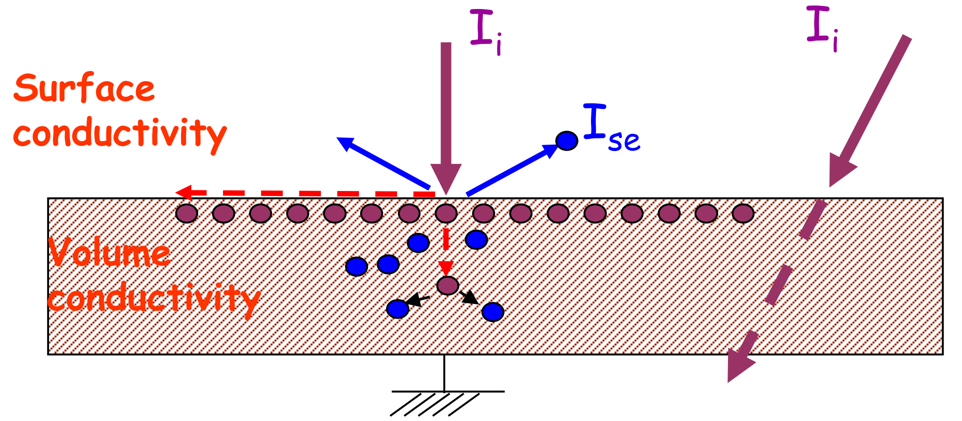
Physics steering internal charging

- Physical mechanims steering charging potential

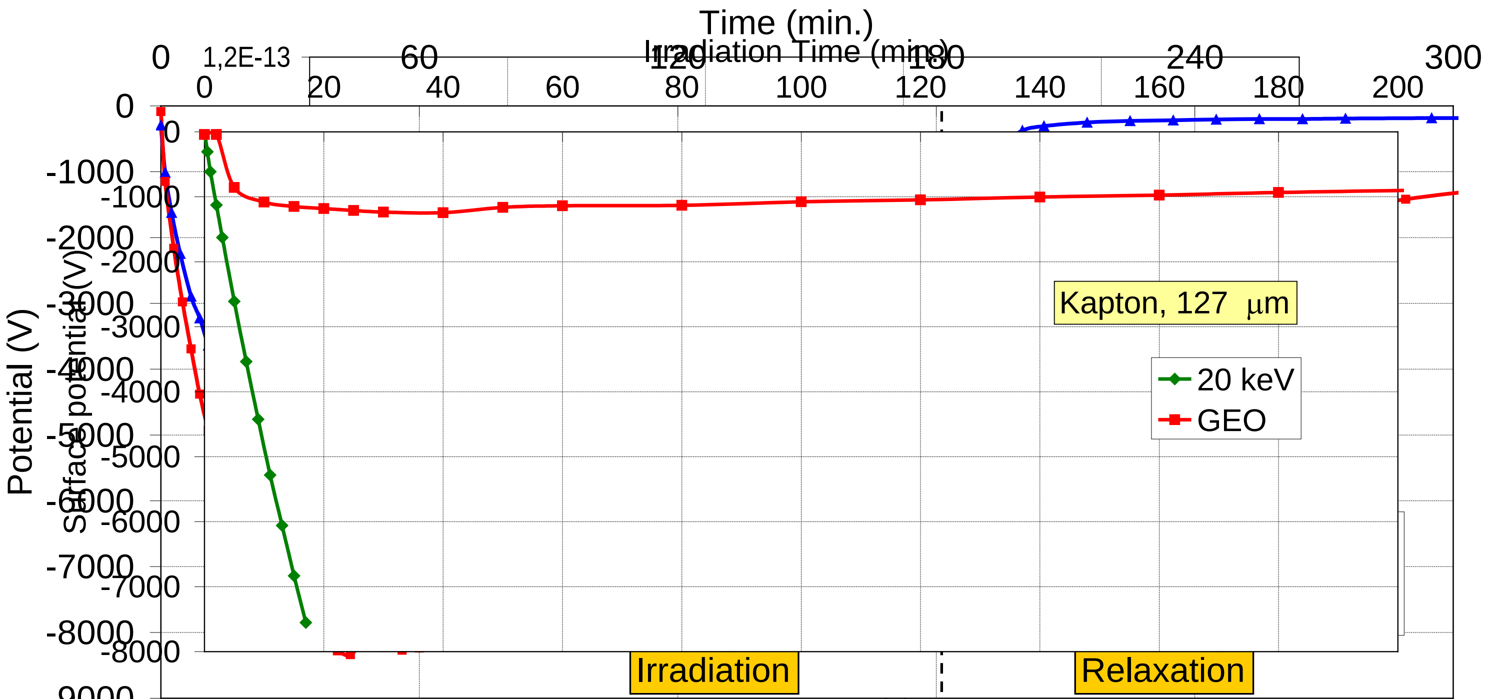


Effect on charging kinetics and decay

- Bulk conductivity
- Surface conductivity
- Secondary electron emission
- Polarisation effect
- Radiation induced conductivity

Physics steering internal charging

- Charging behaviour of materials in space



Effect of radiation dose

- Radiation induced conductivity ▪ RIC (instantaneous effect)

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

- Effect of radiation dose : $\sigma_{RIC}=f(D)$
- Permanent effect : Physical and chemical ageing

Objectives

• Assess impact of extreme space weather and events on internal charging

- Improve our knowledge of phenomenology and physics of internal charging at material level
    - Charging kinetics and charge decay assessment
    - Effect of ionising dose : acts on radiation induced conductivity (RIC)
    - Radiation history and recovery effect : radiation affect charging properties (delayed RIC)
    - Ageing effect

      ⇒ **Characterisation of electric and charging properties of defined materials and systems**
- Prediction of charging levels and kinetics and risk of ESD for specific space weather events and Determine situation especially at risk due to materials or sub-systems design (geometry, specific wiring,…)

  ⇒ **Characterisation of charging behaviour in representative irradiation conditions and geometries**
- Definition of a test procedure for internal charging evaluation

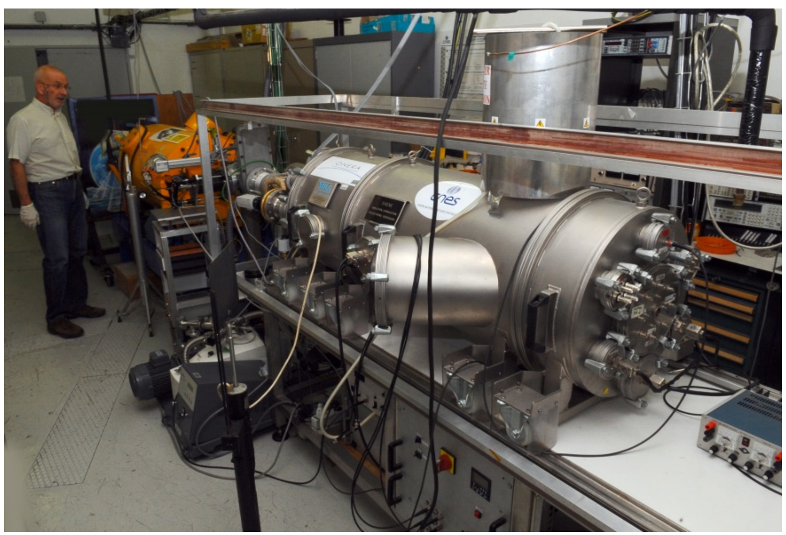
  ⇒ **Test under different irradiation conditions**

Test facilities for material characterisation

SIRENE facility

SIRENE functions

- **Charging of space materials under representatiive electron beam spectrum in energy range [0-400 keV]**
- **Assessment of intrinsic and radiation induced conductivities (bulk and surface)**
- **Ageing through electron radiation (400 keV)**

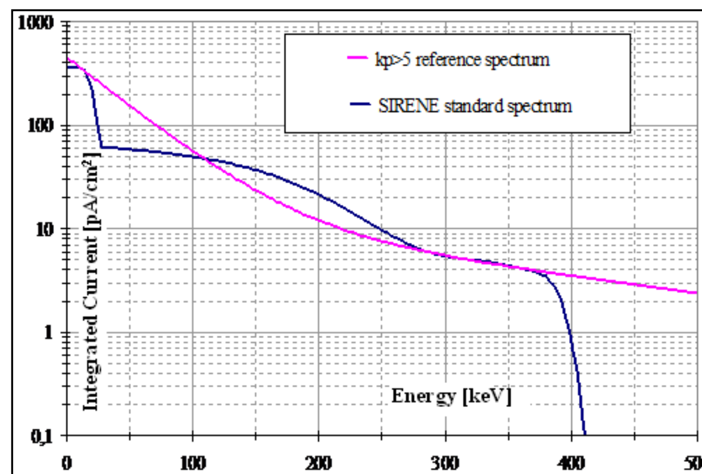


SIRENE Facility Characteristics :

✓Two monoenergetic electron beams:
Electron gun : energy of 7 to 100 keV, fluxes 0-5 nA/cm2
Van de Graaff accelerator: 400 keV, 1 pA.cm^{-2} – 5 nA.cm^{-2}

✓ Instrumentation : Kelvin probe, PEA in situ, current

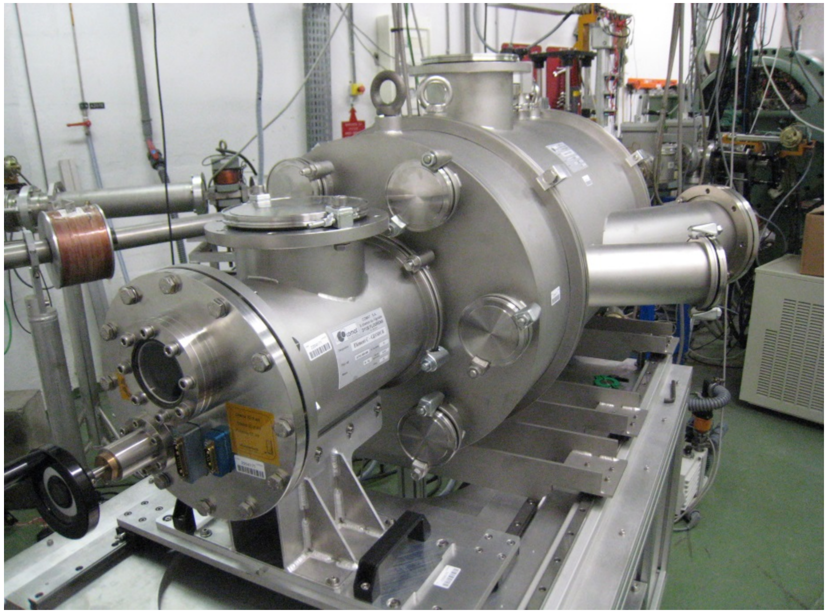
✓Operating conditions :
Vaccum : 10^{-6} torr
Temperature : -150°C/+250°C

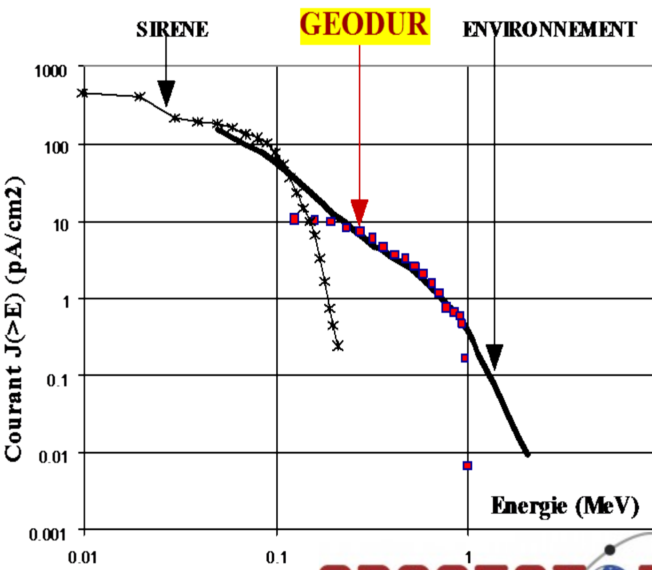


Test facilities for internal charging

GEODUR facility

Equipped with a 2.5 MeV Van de Graaff accelarator + 35 keV electron gun
Spot size = ∅ 160mm
Temperature range [-150°C, +250°C]
Electron Flux ranging from 0.1 $pA.cm^{-2}$ to 40 $nA.cm^{-2}$
Surface potential (KP method – vertical axis scan) and electric current measurements
Dosimetry and current measurements with Faraday cups
Possible transfer of charged sample under vacuum to storage facility (SPIDER)
Vacuum : 10^{-6} hPa





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Characterisation of electric and charging properties

Phase 1: Characterisation of electric and charging properties of the defined materials and systems

- ✓ Seven tested materials :
  - ✓ Insulating and conformal parts : PEEK, PEI, Silicone varnish MAP 213, Solithane (polyurethane based resin)
  - ✓ Cable application - insulating sheath : Kapton, ETFE
  - ✓ Paint : Polyurethane based paint (PU1)
- ✓ Extraction of electric conductivities + analysis of main trends (dose rate effect, electric field effect, …)
- ✓ Analysis of cumulative effect (long term ionisation effect + ageing)

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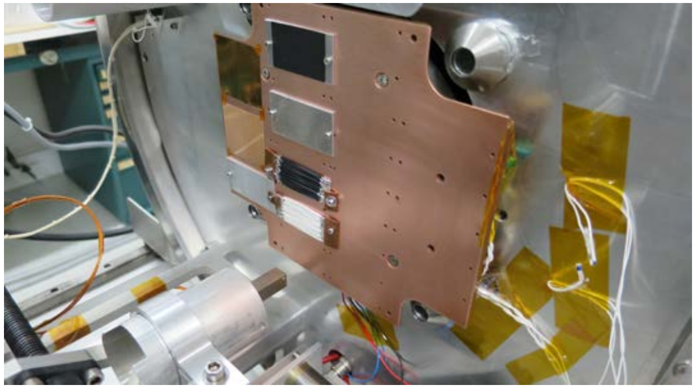
Characterisation of electric and charging properties

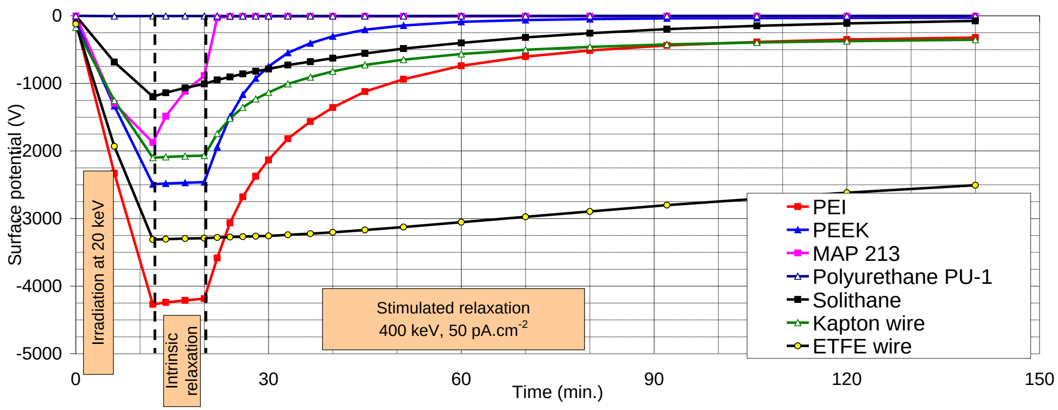
Analysis of conduction processes

- Charging at 20 keV
- Intrinsic relaxation
- Irradiation at 400 keV with four different fluxes : 0.1, 1, 10 and 50 pA/cm2

$$\sigma = \varepsilon_o \varepsilon \frac{dVs/dt}{Vs}$$

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





RIC

	PEI	PEEK	MAP 213	Kapton wire
k	$2.3\ 10^{-13}$	$7.3\ 10^{-13}$	10^{-12}	$1.58\ 10^{-13}$
Δ	0.84	1	0.51	0.68

Bulk conductivity

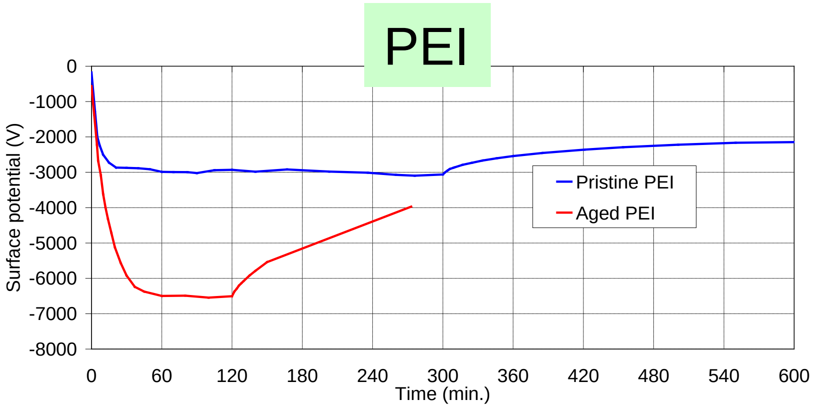
PEI, PEEK, Kapton, ETFE : $\rho > 10^{15}\ \Omega$.m

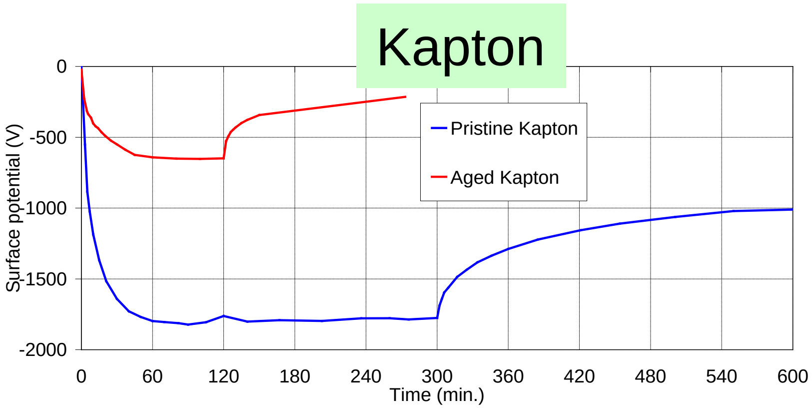
MAP 213 : $\rho = 3.5\ 10^{13}\ \Omega$.m
Solithane : $\rho = 8\ 10^{13}\ \Omega$.m

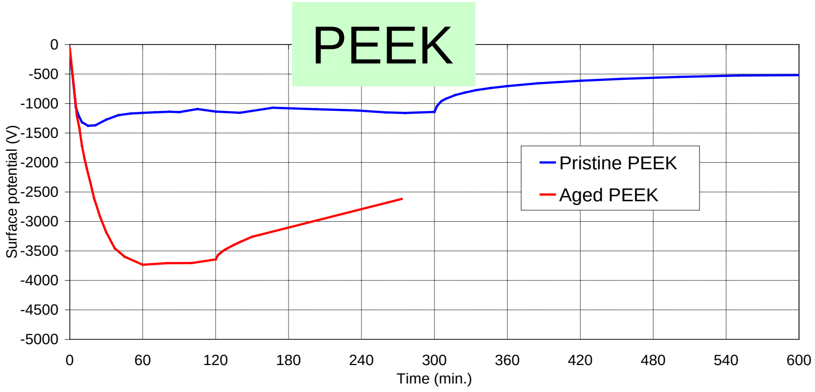
Characterisation of electric and charging properties

Effect of dose

- Successive irradiation (low dose)
- Ageing (doses > 10^5 Gy $\rightarrow$ 5-6 years close to the surface behind 1 mm shielding)







- Radiation history : delayed effect
- Different behaviours in regard of high dose
  - Degradation of conductivity for PEEK and PEI
  - Higher conductivity for Kapton
- Data used for model parameter extraction

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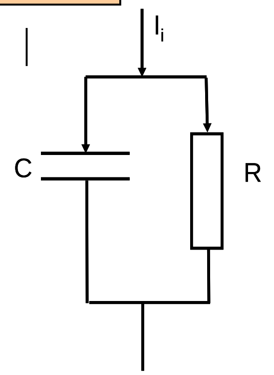
Characterisation of electric and charging properties

Numerical simulation

Circuit model



$I_i = I_Q + I_{SE} + I_{surf} + I_R$

$I_Q + I_R = I_i.(1-\eta-\beta)$

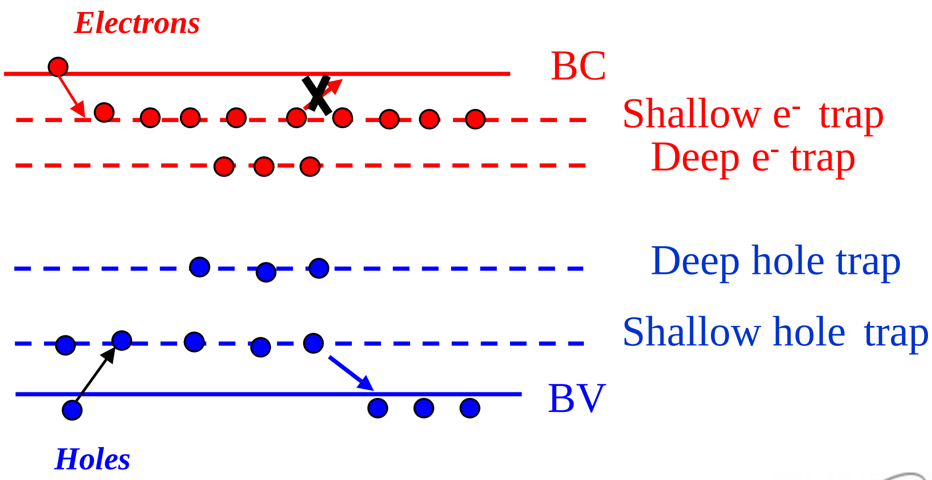
$C.dV/dt + V/R = I_i.(1-\eta-\beta)$

$dV/dt = (Ji.L.(1-\eta-\beta) - \sigma.V)/\varepsilon$

$\sigma = e.(n_-.\mu_- + n_+.\mu_+)$

Two traps model

$$\begin{pmatrix} \dfrac{dn}{dt} = g(E) - \alpha_1 n(p_{t1} + p_{t2}) - \dfrac{n}{\tau_n} - \dfrac{n}{\tau_{n2}} + \dfrac{n_{t1}}{\tau_{nt1}} + \dfrac{n_{t2}}{\tau_{nt2}} \\ \dfrac{dn_{t1}}{dt} = \dfrac{n}{\tau_n} + \dfrac{n}{\tau_{n2}} - \dfrac{n_{t1}}{\tau_{nt1}} - \alpha_2 p n_{t1} \\ \dfrac{dn_{t2}}{dt} = \dfrac{n}{\tau_n} + \dfrac{n}{\tau_{n2}} - \dfrac{n_{t2}}{\tau_{nt2}} - \alpha_2 p n_{t2} \\ \dfrac{dp}{dt} = g(E) - \alpha_2 (n_{t1} + n_{t2}) p - \dfrac{p}{\tau_p} - \dfrac{p}{\tau_{p2}} + \dfrac{p_{t1}}{\tau_{pt1}} + \dfrac{p_{t2}}{\tau_{pt2}} \\ \dfrac{dp_{t1}}{dt} = \dfrac{p}{\tau_p} + \dfrac{p}{\tau_{p2}} - \dfrac{p_{t1}}{\tau_{pt1}} - \alpha_1 n p_{t1} \\ \dfrac{dp_{t2}}{dt} = \dfrac{p}{\tau_p} + \dfrac{p}{\tau_{p2}} - \dfrac{p_{t2}}{\tau_{pt2}} - \alpha_1 n p_{t2} \end{pmatrix}$$



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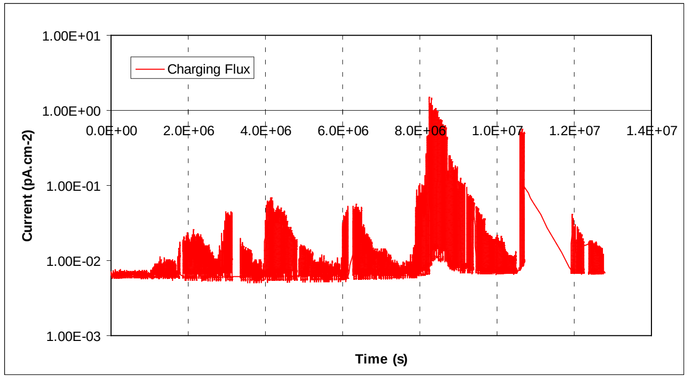
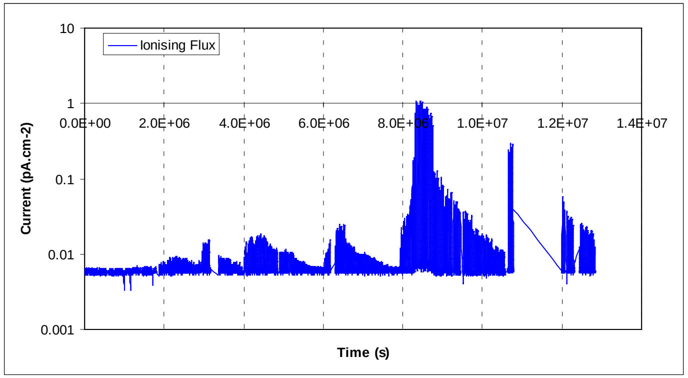
Characterisation of electric and charging properties

Numerical simulation

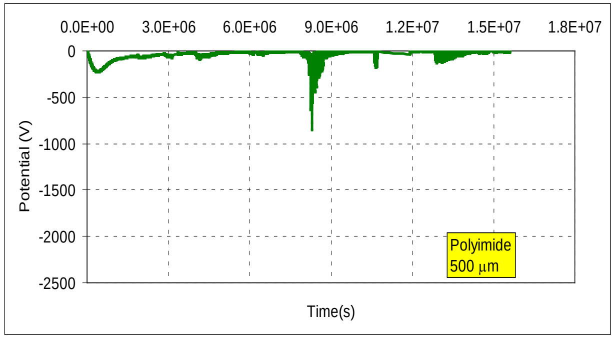
SURF data

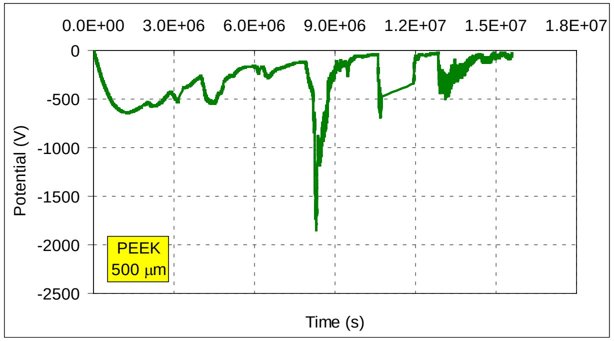
From 01/01/2010 to 30/06/2010
Shielding : 0,5 mm

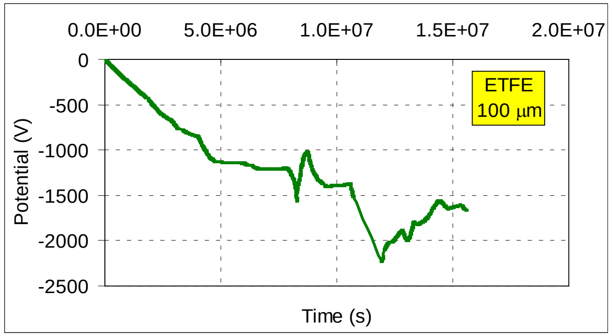




With ONERA model (RIC = f(D))







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Characterisation of electric and charging properties

Numerical simulation

SURF data

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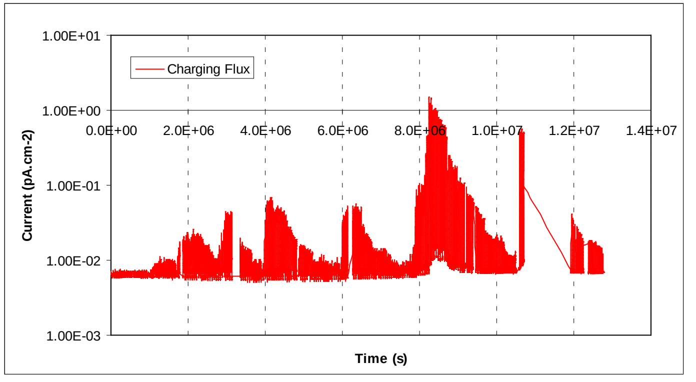
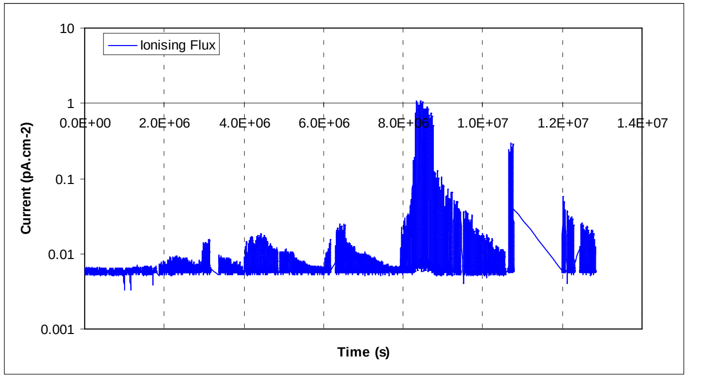
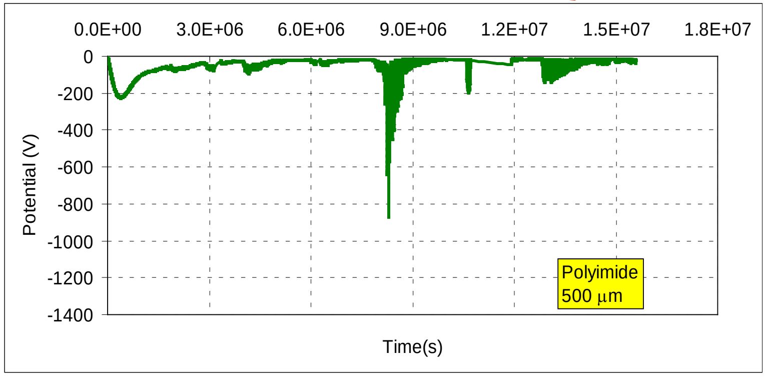
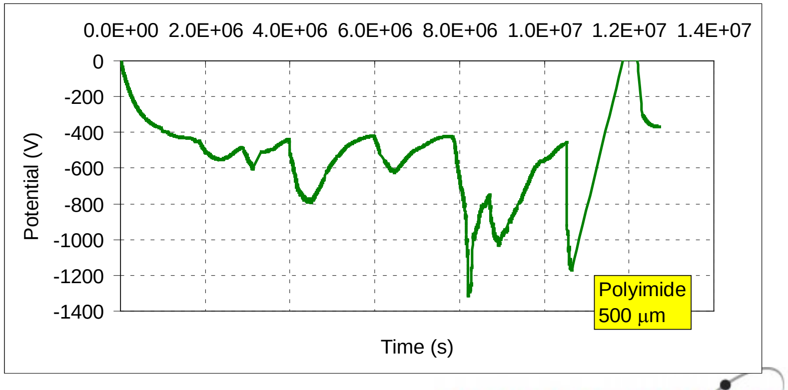




Comparison between ONERA model (RIC = f(D)) and conventional model (RIC = constant)





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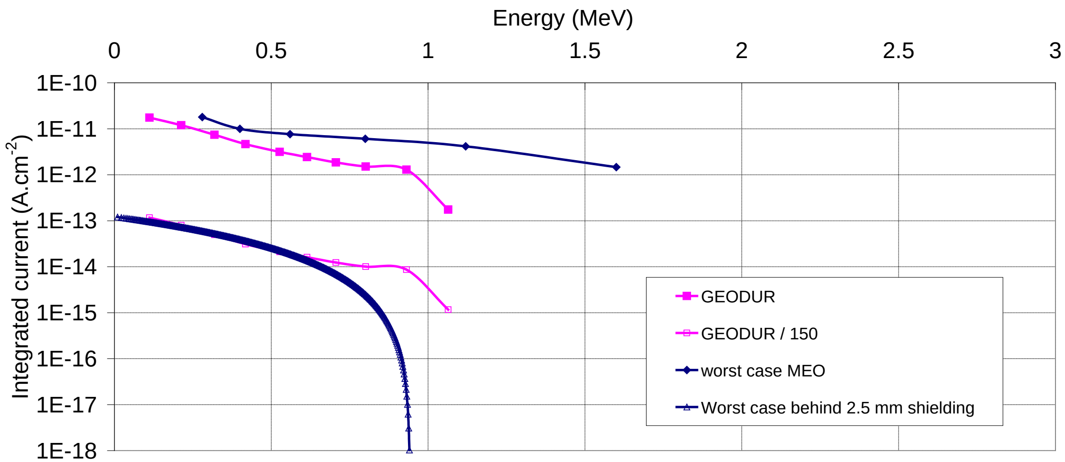
Characterisation of materials in real representative spectrum

- **Phase 2**: Characterisation of charging behaviour in representative irradiation conditions and geometries
  - ✓ Irradiation of PCB (polyimide based PCB) under representative worst case MEO conditions with and without grounded tracks and detection of any electrostatic discharge
  - ✓ Irradiation of space used materials under representative MEO conditions to study charging kinetics

1. Assessment of electron spectrum behind 2.5 mm shielding

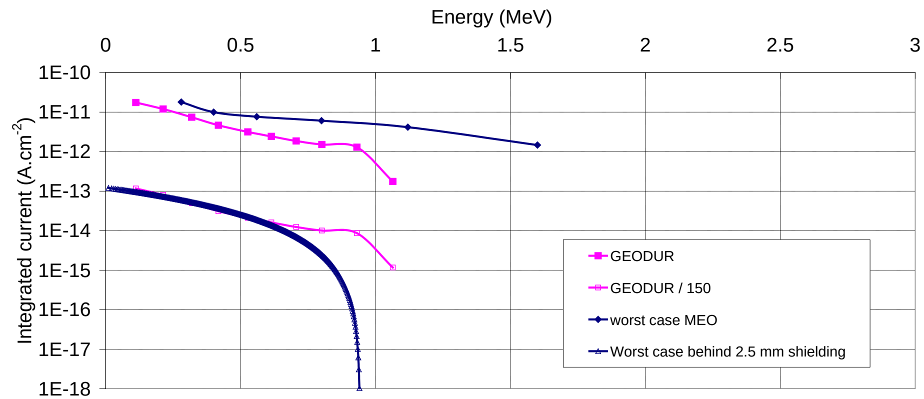


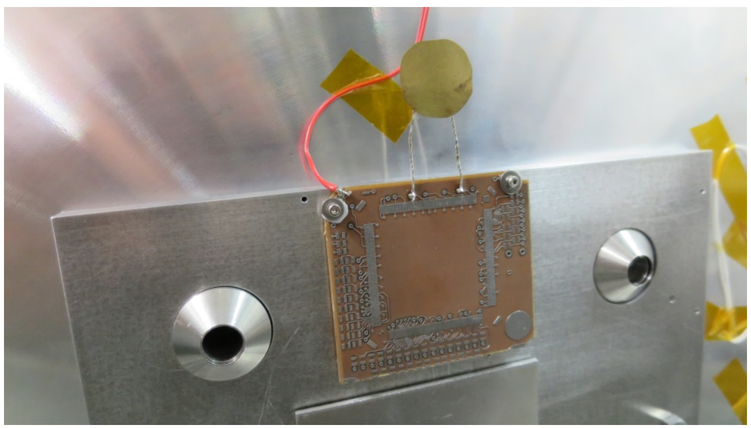
- The GEODUR spectrum can be fitted to get close to the MEO worst case spectrum behind shielding
- Materials tested with spectrum behind 2.5 mm shielding

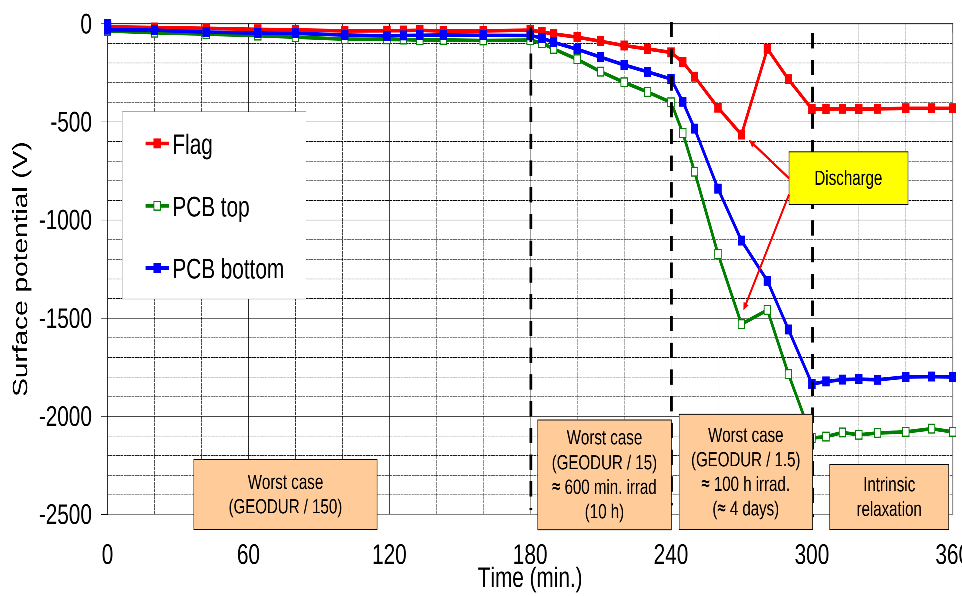
C. Inguimbert, S. Bourdarie, "Etude de l'environnement électronique en orbite MEO et GEO", ONERA Report RTS 1/07608 DESP - Mars 2003

Characterisation of materials in real representative spectrum

2. Irradiation of PCB (polyimide based)





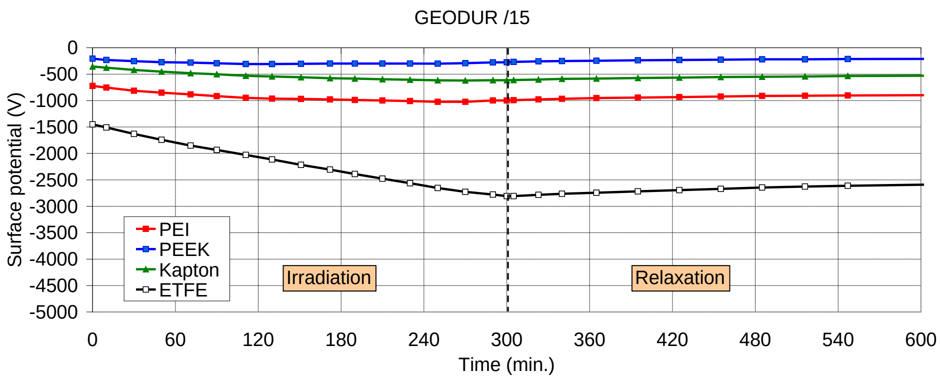


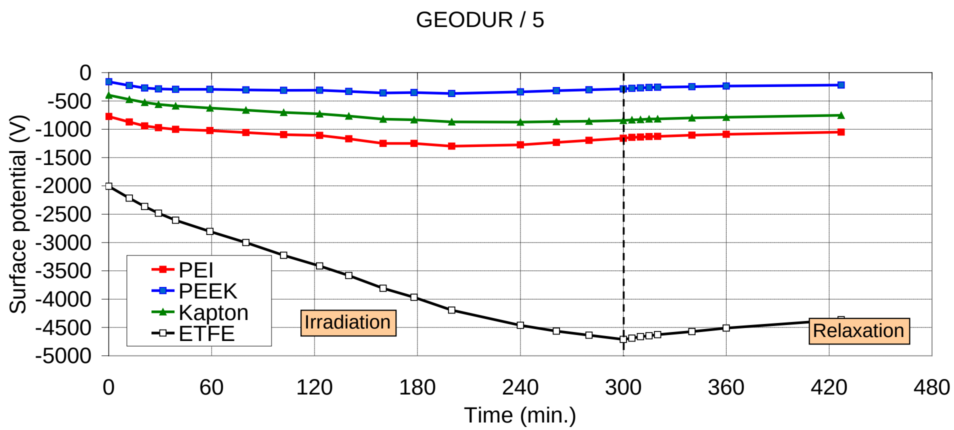
- **Initiation of discharge (at 10^6 V.m^{-1}) far below the dielectric breakdown threshold (> 10^8 V.m^{-1})**
- **Process confirmed through different experiments**

Characterisation of materials in real representative spectrum

3 : Studying combined effect of charge implantation and RIC

- What is the charging behaviour when shifting the overall electron flux to higher values ?
- Can we think about a procedure for the reduction of test duration ?





- No strong evolution of charging level on PEEK → RIC increase by the same factor as charging current
- Higher potential for higher flux for PEI, Kapton wire → RIC increase lower than charging current
- Steady increase of charging kinetics for ETFE wires → no RIC

⇒ Different behaviour for the materials in regard of spectrum variation

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Characterisation of materials in real representative spectrum

Knowing the electric properties of the material (RIC), we can apply an acceleration factor for internal charging assessment

No RIC (like ETFE)

With accelerattion factor, we increase the charging kinetics and reach more quickly the threshold for discharge initiation

$$\frac{dV}{dt} = I/C$$

Δ = 1 (like PEEK or Kapton HN)

Applying an accelerattion factor does not change the equilibrium surface potential but allows reaching more quickly this equilibrium

$$V = \frac{1}{\sigma}\frac{L}{S}.I$$

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

$$V_2 = \frac{1}{\sigma_2}\frac{L}{S}.I_2 = \frac{1}{10.\sigma_1}\frac{L}{S}.10.I_1 = V_1$$

Δ < 1 (like PEI, silicon, Wires)

Applying an accelerattion factor change the equilibrium surface potential but extrapolation is feasible knowing the conductivity parameters

$$V_2 = \frac{I_2}{\sigma_2}.\frac{L}{S} = \Gamma^{1-\Delta}\frac{I_1}{\sigma_1}.\frac{L}{S}$$

$$V_2 = \Gamma^{1-\Delta}.V_1$$

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Conclusion

- Development of representative electron spectrum

- Electric Characterisation of new space used insulating material in representative space environment $\rightarrow$ extraction of the key parameters for charge prediction and risk assessment

- Advancement on internal charging :
  - Irradiation under representative spectrum behind shielding : effect of this spectrum on charging behaviour
  - High charging risks in MEO environment
  - Key point : Radiation Induced conductivity
  - Material ageing effect
  - Use of acceleration factor for assessment with long duration

- Evidence of electrostatic discharge occurrence on critical elements : PCB with floating parts

- Definition of a test procedure for internal charging evaluation

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