SPIS-DC activity in the frame of ELSHIELD project

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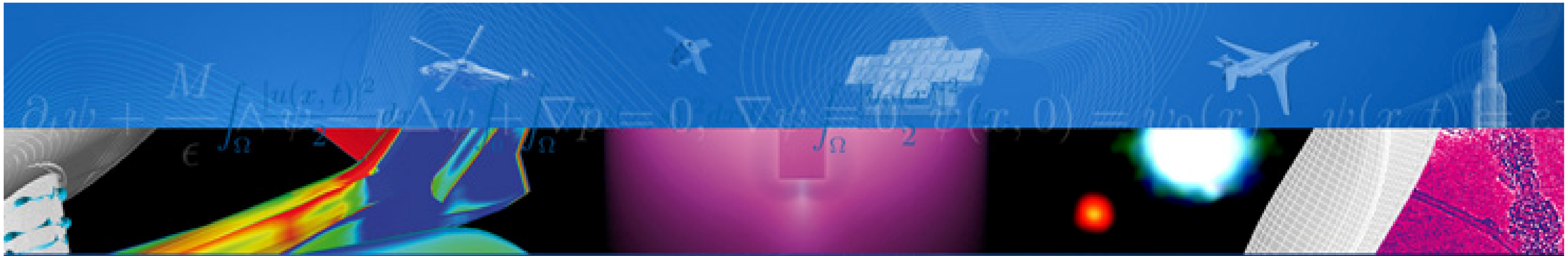
outline

- Context and motivation
- Global workflow and data exchange between tools
- The SPIS solvers dedicated to internal charging
  - Implementation details
  - Solver testing simulations
- Conclusion and perspectives



The ELSHIELD project

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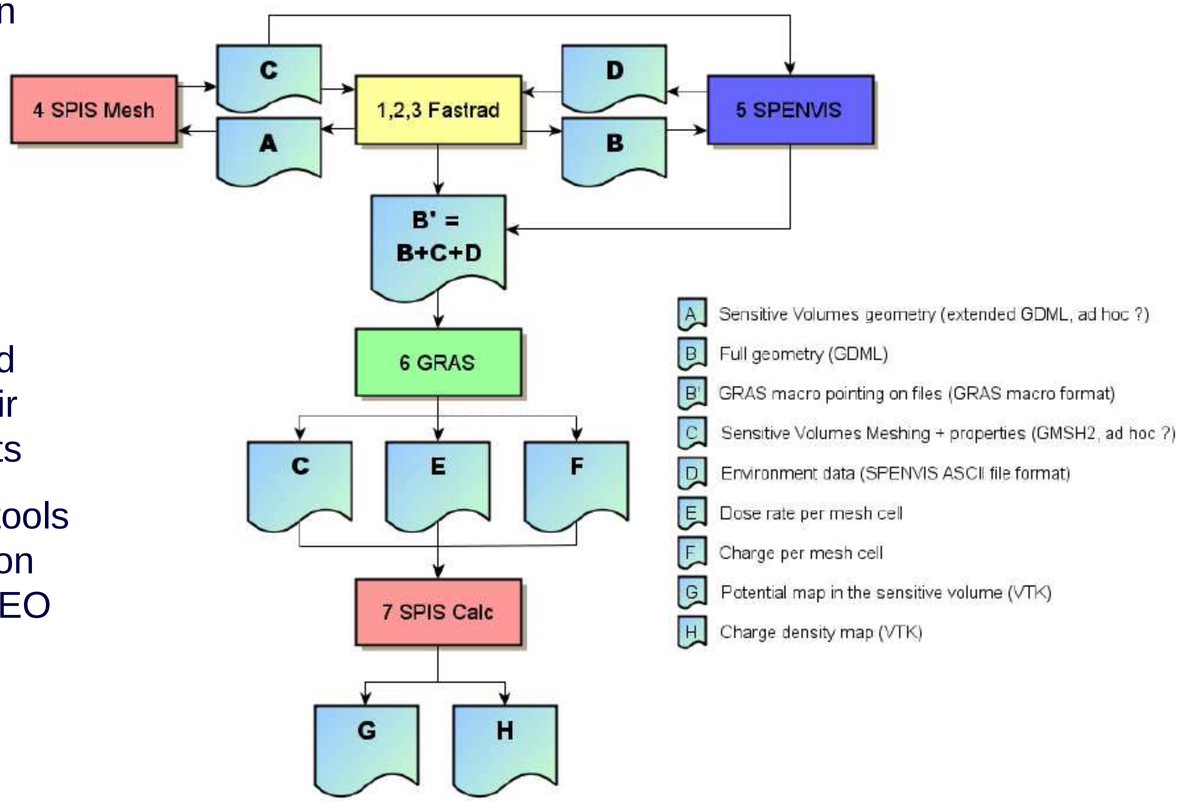
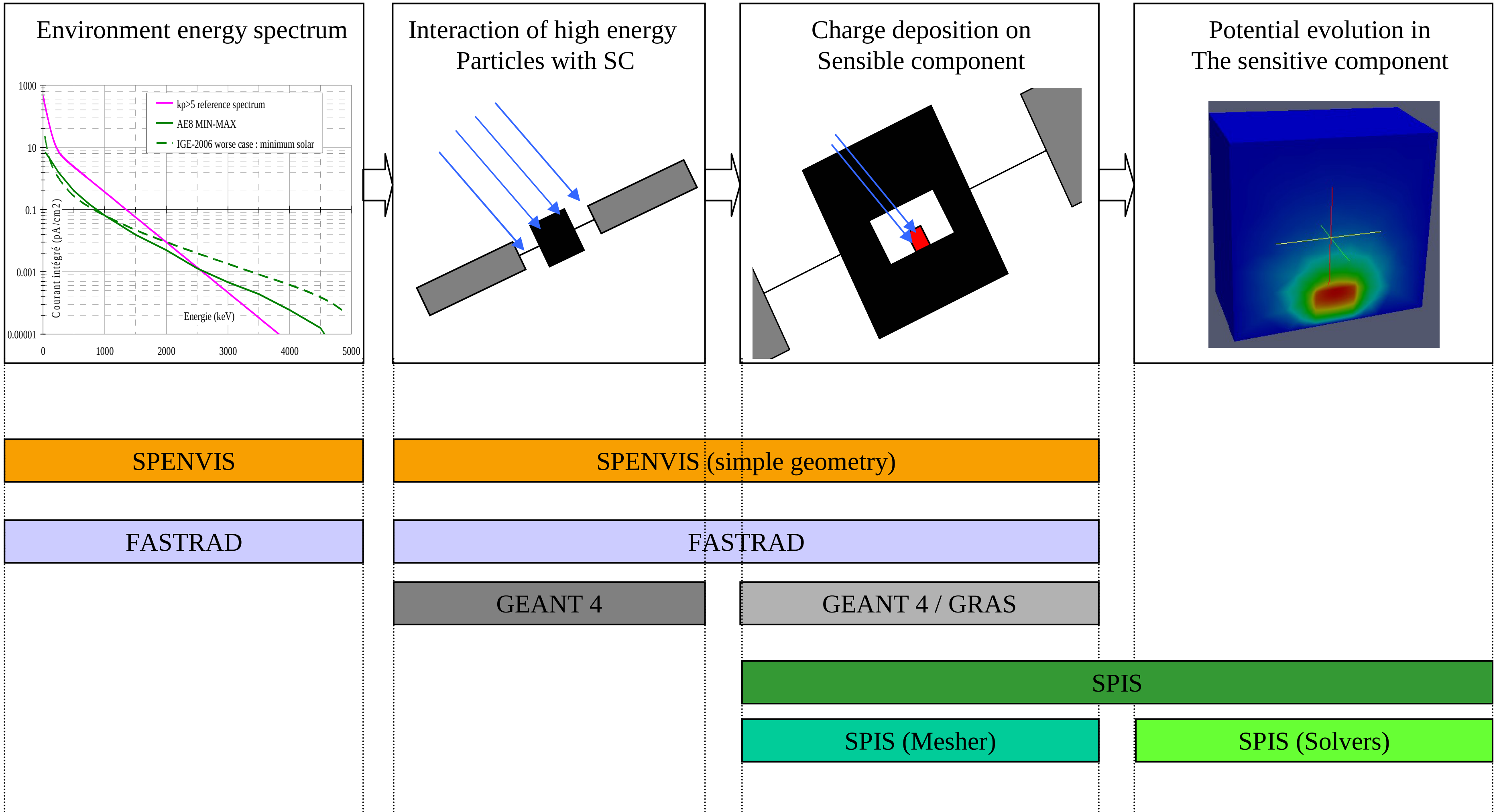
Introduction

- Scope
  - ESA/ESTEC contract
    - Technical Officer: Giovani Santin
    - Partners: G4AI (Geant4 Associates International Ltd, UK), TRAD (Tests and Radiations, FR), DH Consultancy (BE), ARTENUM (FR), ONERA (FR), TAS-F(F), INTA (SP) ,TAS-E (SP) (Prime).
  - ELSHIELD = Energetic Electron Shielding, Charging and Radiation Effects and Margins

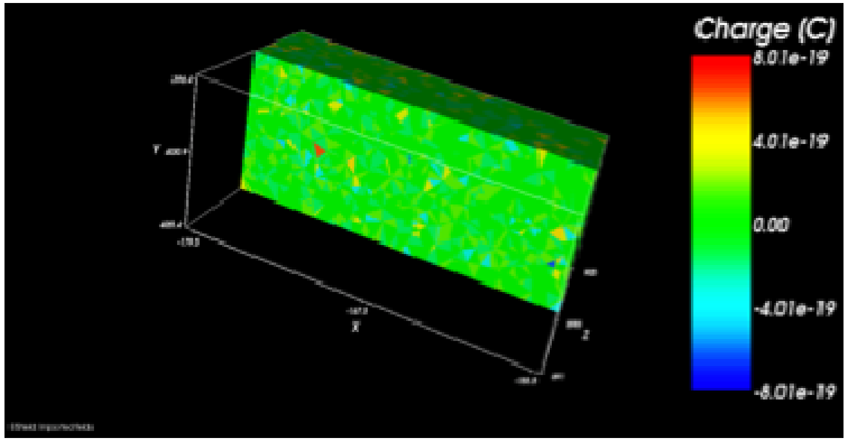


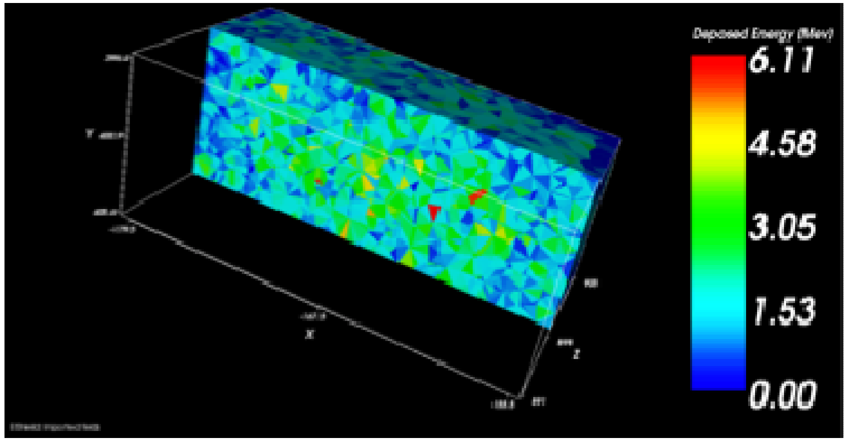
- Objectives
  - Analyse problems with respect to energetic electron penetration and interactions in spacecraft and their payloads in high flux environments
  - updated and improved industrial tools capabilities supporting the radiation analysis needed to cover GEO/MEO mission requirements

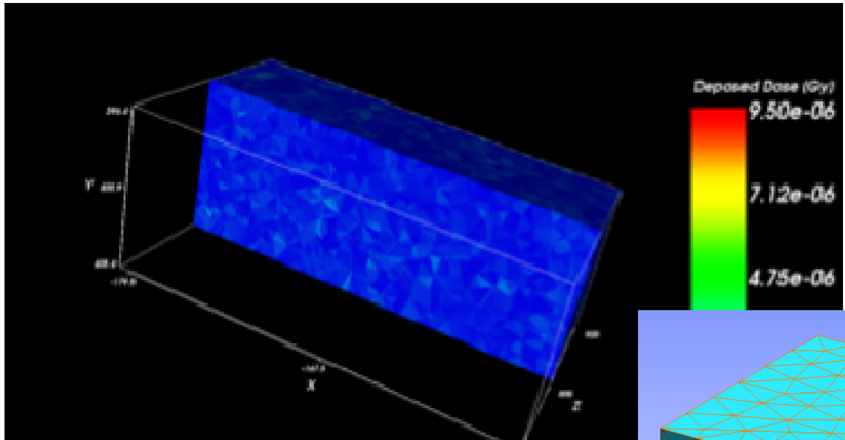
ELSHIELD tool ovreview

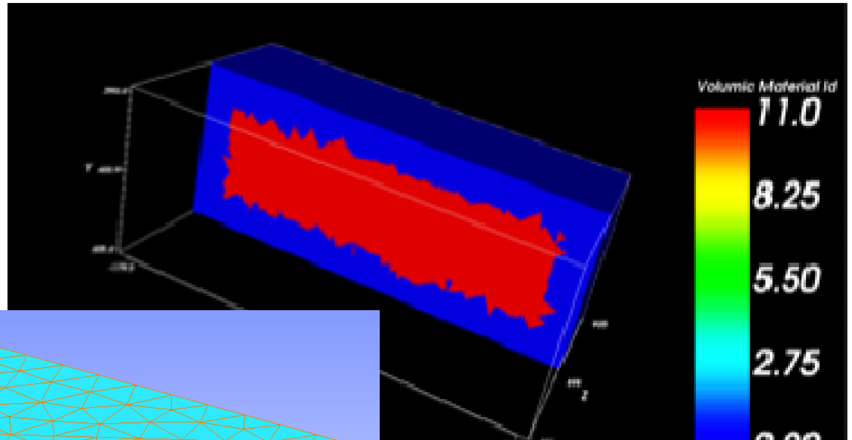


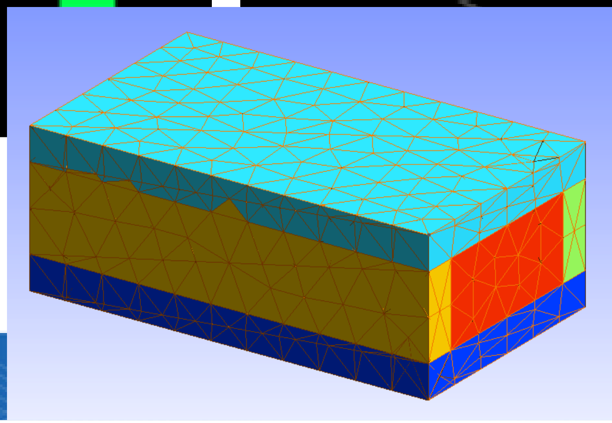
Tools Interfaces











Internal charging modules in SPIS-NUM

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Internal charging solvers in SPIS

- Internal charge transport =>
  Three modes of resolution:
  1. The time scheme solver

$$\begin{cases} -\nabla\cdot(\varepsilon_r\varepsilon_0\nabla V)=\rho \\ \dfrac{\partial\rho}{\partial t}+\nabla\cdot J=\dot{\rho} \\ J=\sigma E \end{cases}$$

  2. The steady state solver

$$\begin{cases} \nabla.(\sigma E)=\dot{\rho} \\ \rho=-\dfrac{\nabla(\varepsilon_0\varepsilon_r\sigma).E}{\sigma}-\dfrac{\varepsilon_0\varepsilon_r\dot{\rho}}{\sigma} \end{cases}$$

  3. Automatic selection mode

- Conductivity model (=> Based on DICTAT):

$$\sigma(T,E,D)=\sigma(T,E)+\sigma(D)$$

  - Bulk conductivity: $\sigma(T)=\sigma_\infty\exp\left(-\dfrac{\varepsilon_A}{kT}\right)$
  - Field induced conductivity (Adamec and Calderwood):

$$\sigma(T,E)=\sigma(T)\frac{\left(2+\cosh\left(\beta_F\dfrac{\sqrt{E}}{2kT}\right)\right)}{3}\frac{2kT}{eE\delta}\sinh\left(\frac{eE\delta}{2kT}\right)$$

  - Radiation induced conductivity: $\sigma(D)=k_p D^\Delta$

- Material properties needed:
  - Activation energy ε_A
  - Maximum conductivity σ_∞
  - Jump distance δ (fixed at 10Å)
  - Dielectric relative permittivity ε_r
  - Radiation induced conductivity parameters k_p and Δ

The materials

- XML database dedicated to internal charging simulations:

Material	Density (g/cm^3)	Dark conductivity $(\Omega^{-1}m^{-1})$	Dielectric constant	kp $(\Omega^{-1}m^{-1} rads^{-\Delta} s^{\Delta})$	Δ	E_A (eV)	Charging hazard
Betacloth	1.05	1.46E-15	3.2	n/s	n/s	2.5	Low
CFRP	1.1	3.11E-13	-	-	-	-	V low
Delrin	1.41	4.41E-14	4	n/s	n/s	1.26	Low
FEP	2.15	2.78E-16	2.91	3.91E-15	0.36	0.25	High
FR-4	2.06	8.48E-16	5.59	1.73E-20	1.07	2.44	High
LDPE	0.92	6.94E-15	4.26	6.97E-14	1.08	1.16	Low
PMMA	1.19	3.05E-17	3.95	n/s	n/s	0.47	High
Polyimide	1.42	1.49E-16	3.01	n/s	n/s	1.75	High
POM	1.41	1.54E-14	3.72	2.07E-13	1.57	1.11	Low
Solithane	0.91	3.56E-14	12.47	1.73E-15	0.57	1.33	Low

SPIS materials defined as a NASCAP like property (i.e. existing in the previous version)

SPIS extended property (must be define in the XML form of material definition – not possible in the previous format)

1D testing cases

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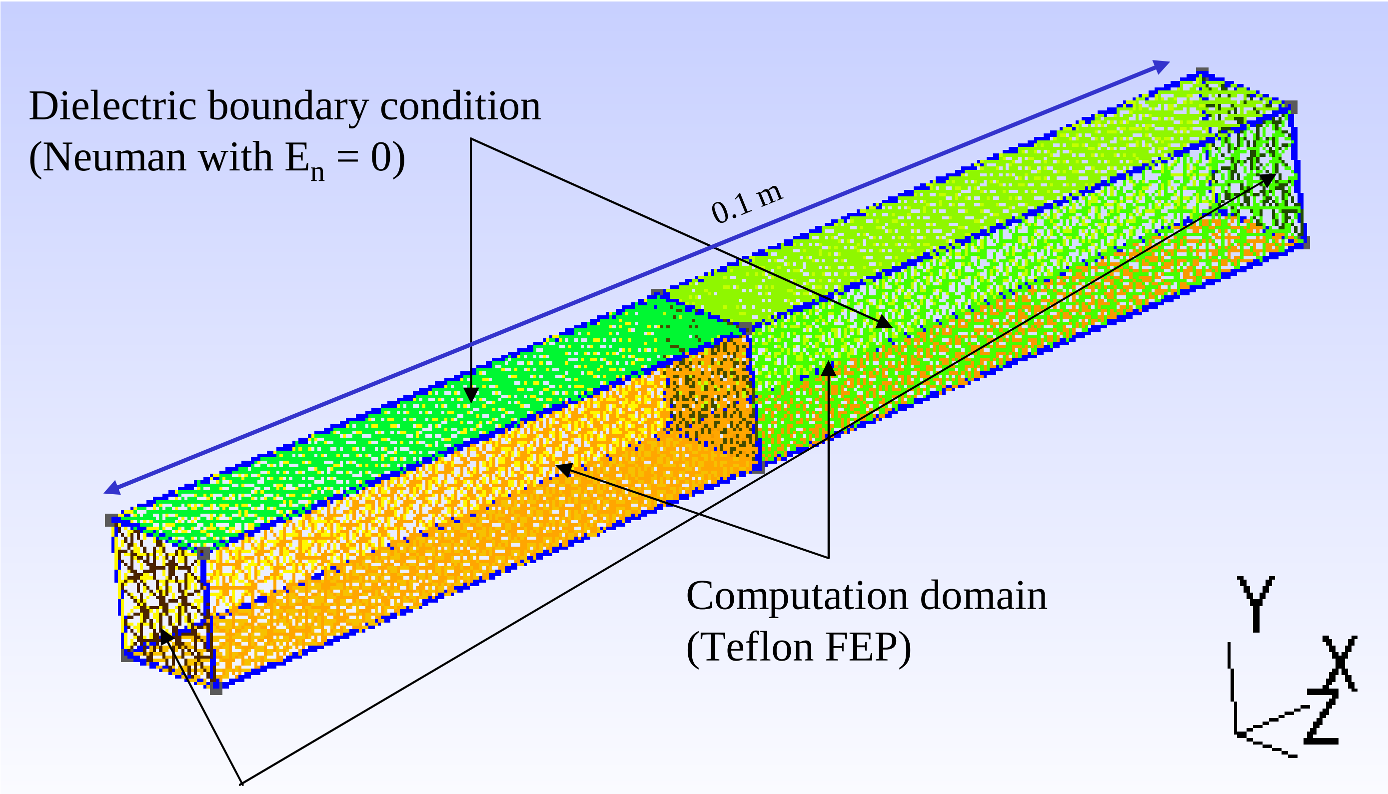
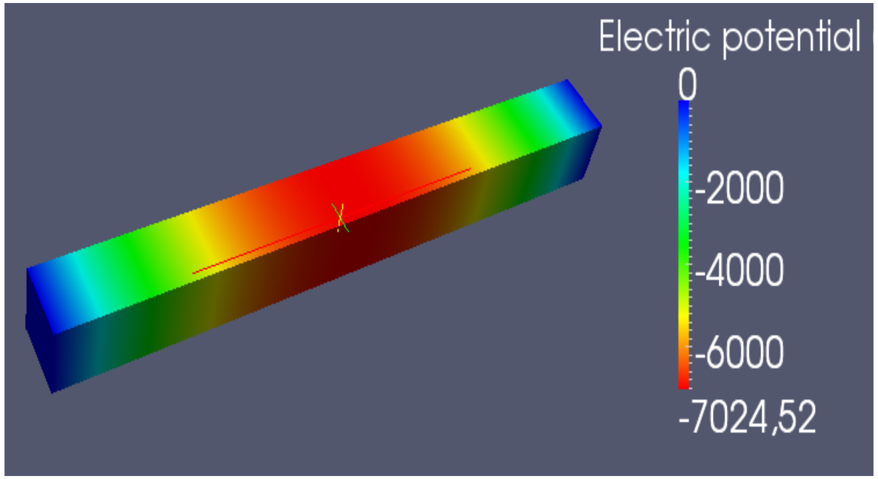
Case 1 : 1D with uniform dielectric

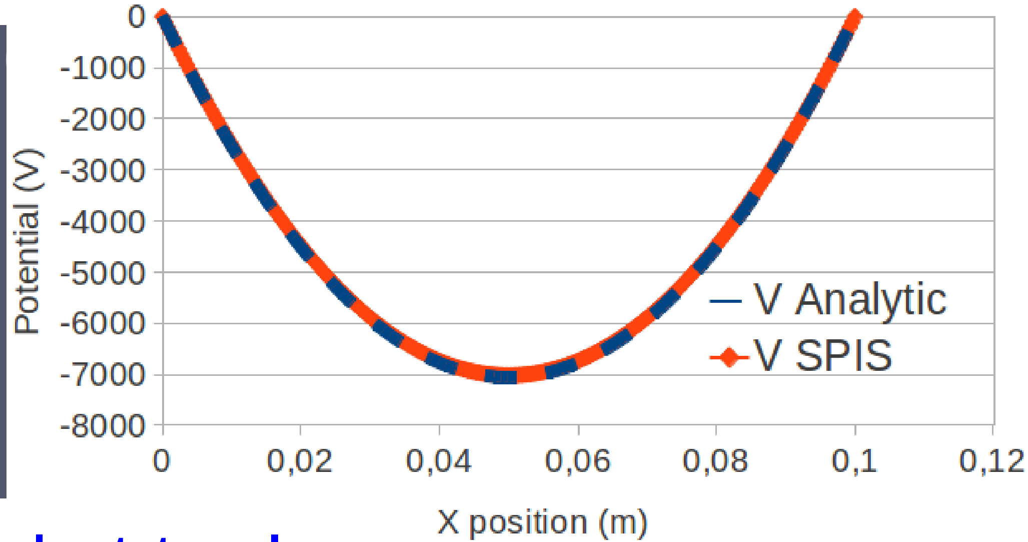
- Simulation on teflon FEP material between two plates on aluminum.
  - Charge deposition rate: 10^{-13} A/m^3
  - material temperature: 300 K
  - Conductivity (including RIC): $1.77 \times 10^{-20}\ \Omega^{-1}.m^{-1}$



Metal boundary (V = 0, Aluminum)

The electric potential at the steady state





Results from the **steady state solver**

- Charging characteristics:
  - Time characteristic of charging: 1.46×10^{9} s (about 46 years)
  - Maximum charge density : -1.46×10^{-4} C/m^3
  - Maximum potential corresponding is 7060 V
- To compare to 7025 V in the simulation.

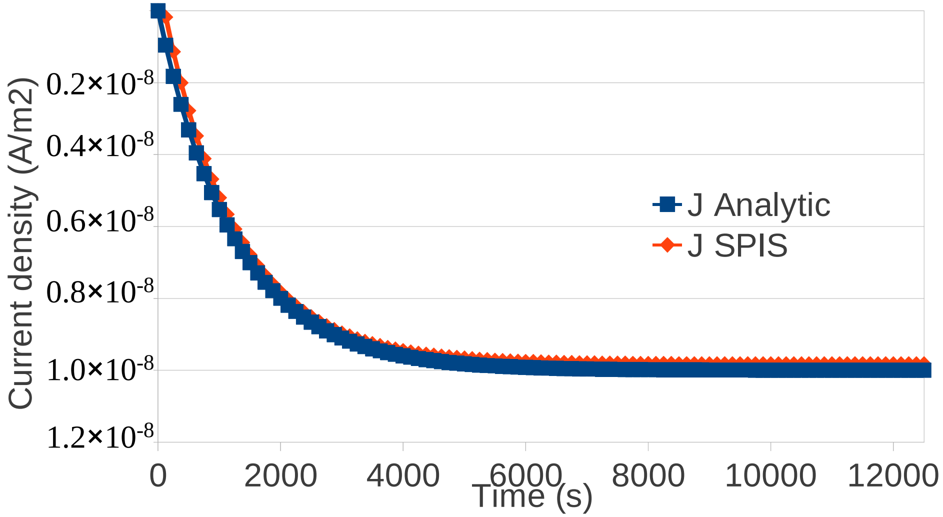
→ the result error is less than 0.5 % which is quite good for a mesh with only 20 000 tetrahedra (100 points along x)

Comparison of the current collected

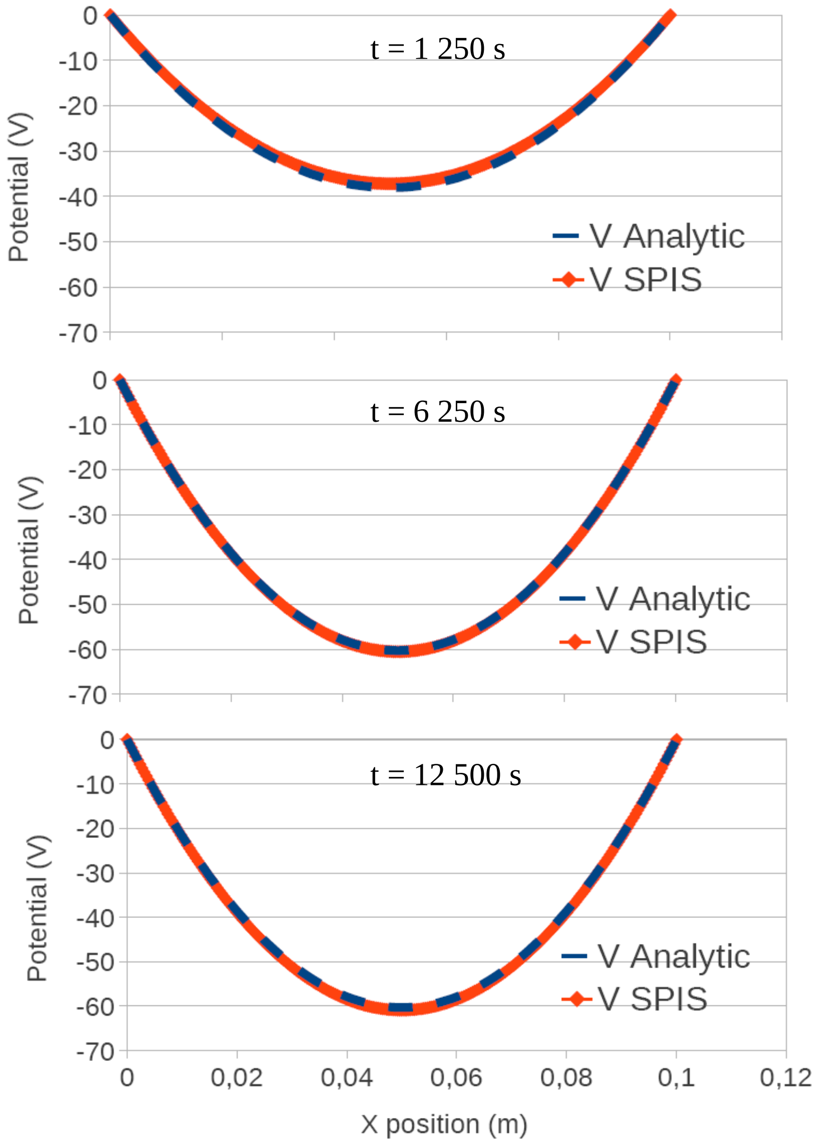
Simulation on teflon FEP material between two plates on aluminum :

- Charge deposition rate: 10^{-9} A/m³
- Dose deposition rate: 1 Gy/s
- material temperature: 300 K
- the conductivity: $2.07\times10^{-14}\ \Omega^{-1}.m^{-1}$

Results from the **time scheme solver**



$$J_{tot} = \sigma E(x=l,t) - \sigma E(x=0,t) = \left[\dot{\rho} + \left(\frac{\rho_0 \sigma}{\varepsilon_r \varepsilon_0} - \dot{\rho}\right)\exp\left(-\frac{\sigma t}{\varepsilon_r \varepsilon_0}\right)\right]\times l$$



3D demonstration case with the time solver

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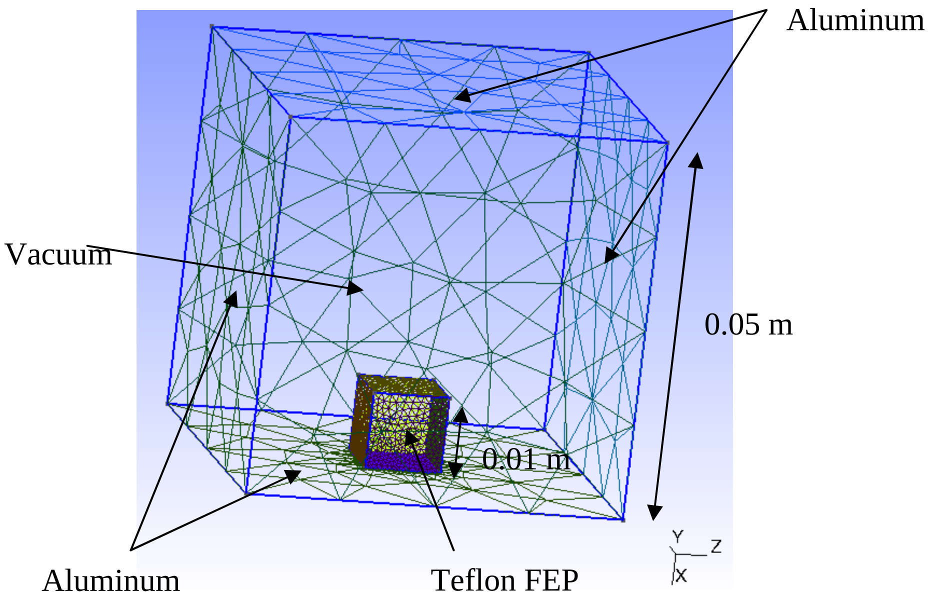
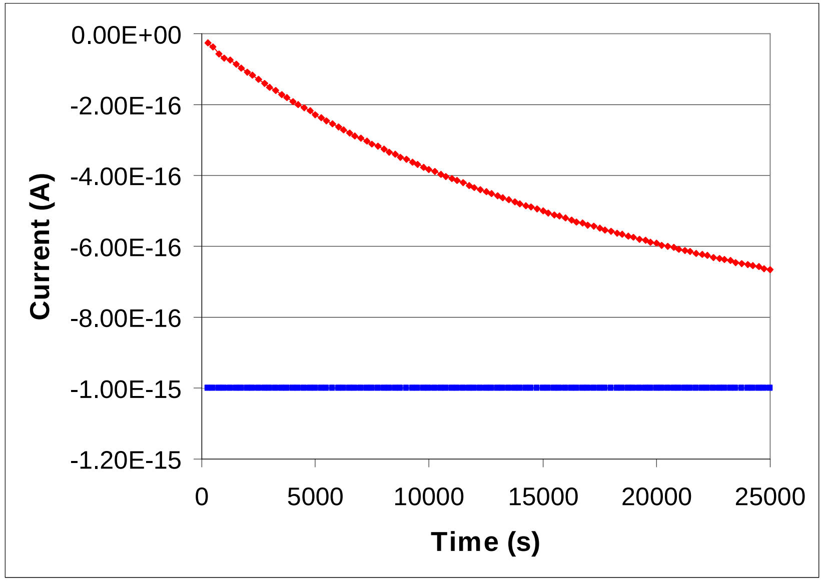
Case 3 : three dimensional test case

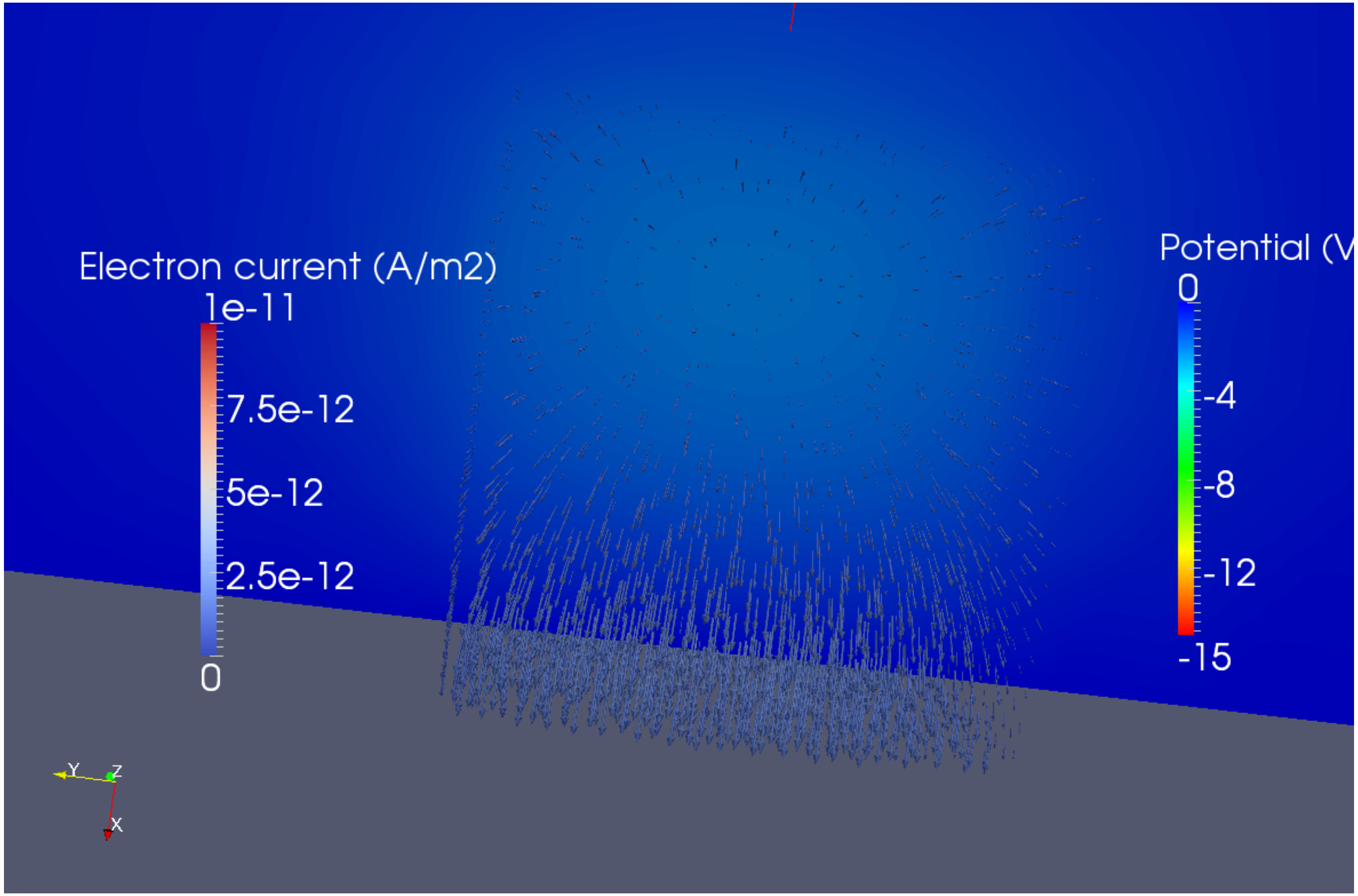
- The simulation condition are as follow:
  - Charge deposition rate: 10^{-9} A/m^3
  - Dose deposition rate: 0.01 Gy/s
  - material temperature: 300 K
  - Conductivity (including RIC): for FEP $3.91 \times 10^{-15}\ \Omega^{-1}.m^{-1}$





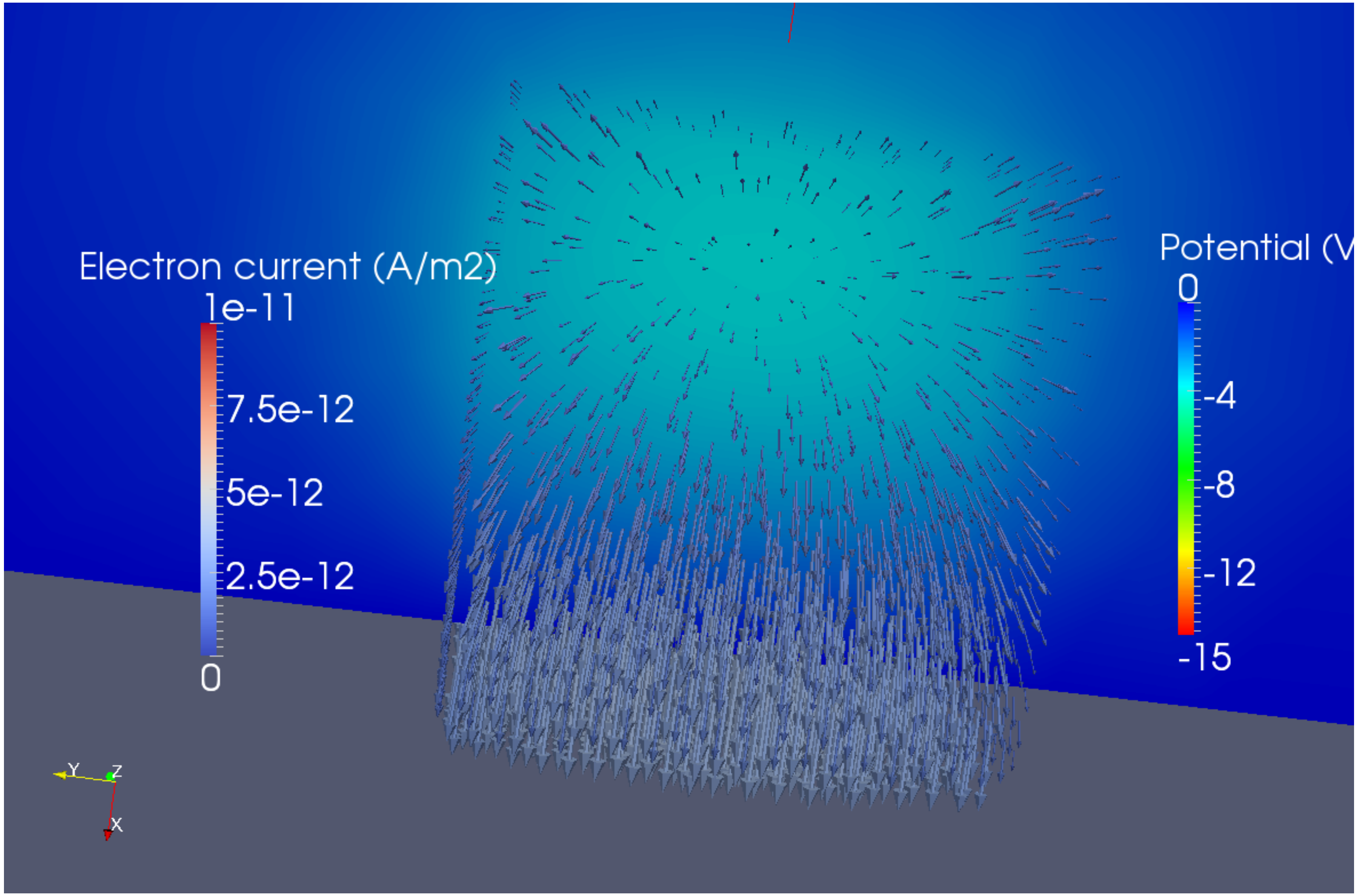
Electrical potential and current evolution

Results from the **time scheme solver t = 5000 s**



Electrical potential and current evolution

Results from the **time scheme solver at t = 10000 s**



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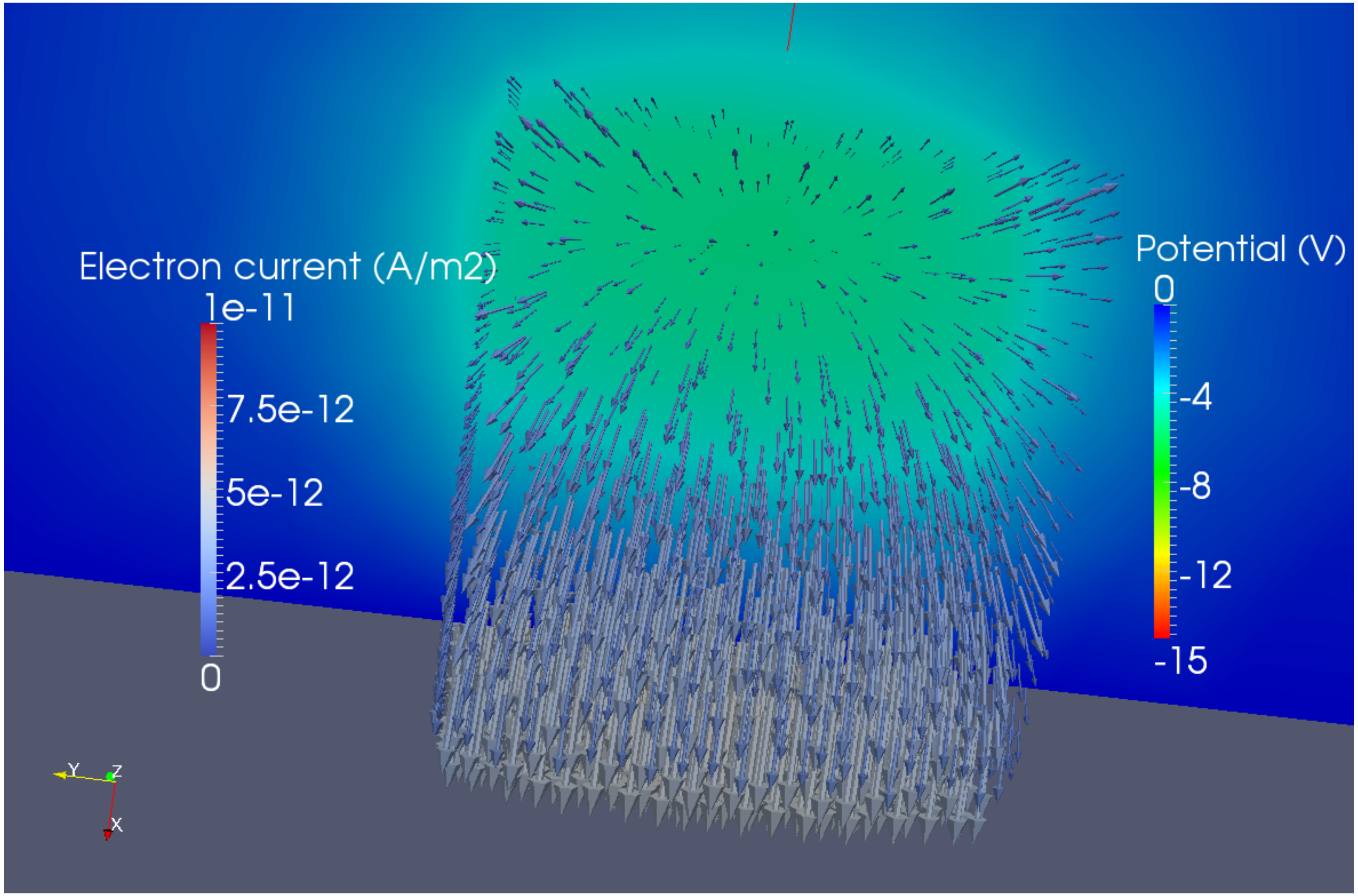
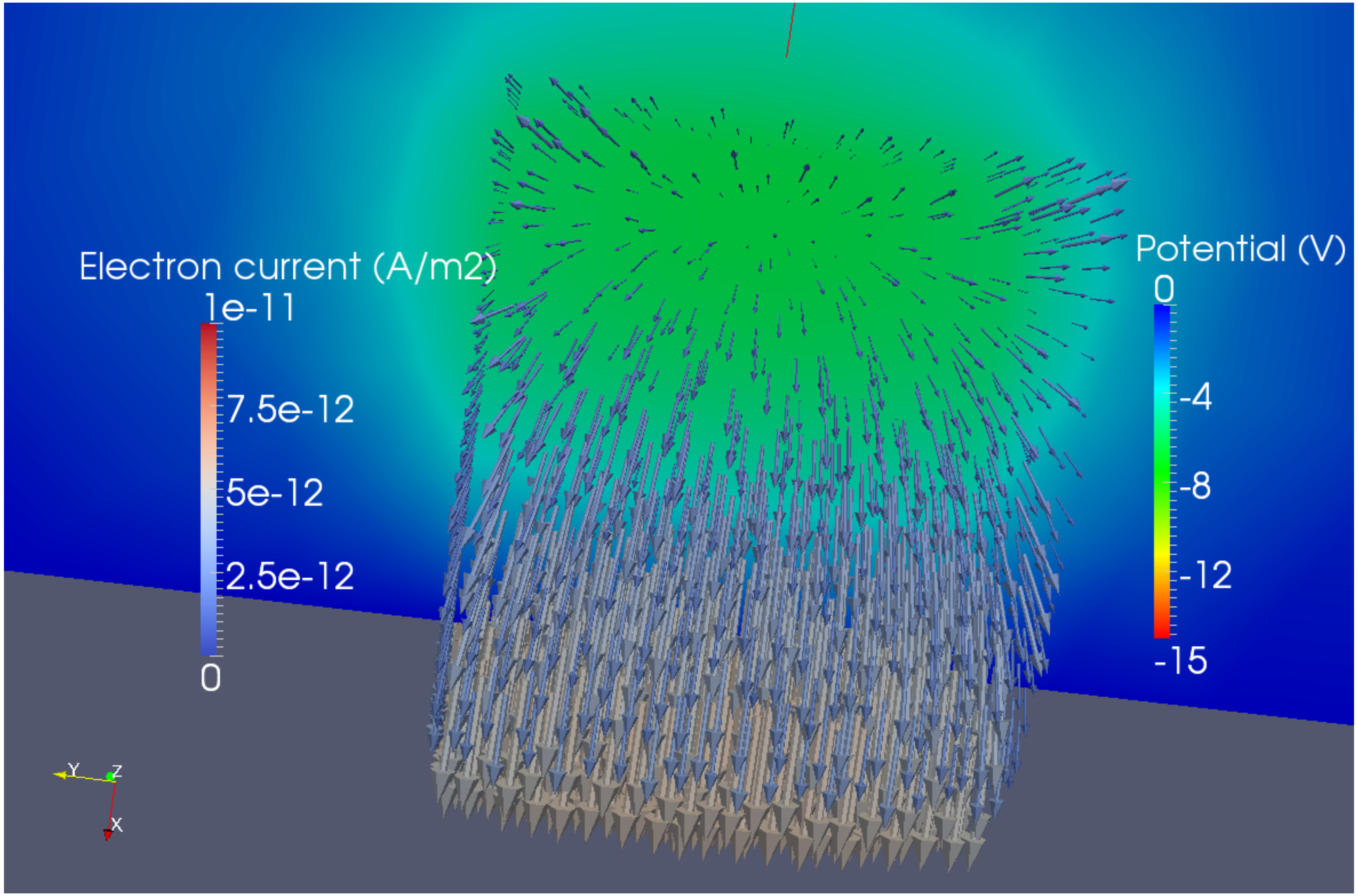
Electrical potential and current evolution

Results from the **time scheme solver at t = 15000 s**



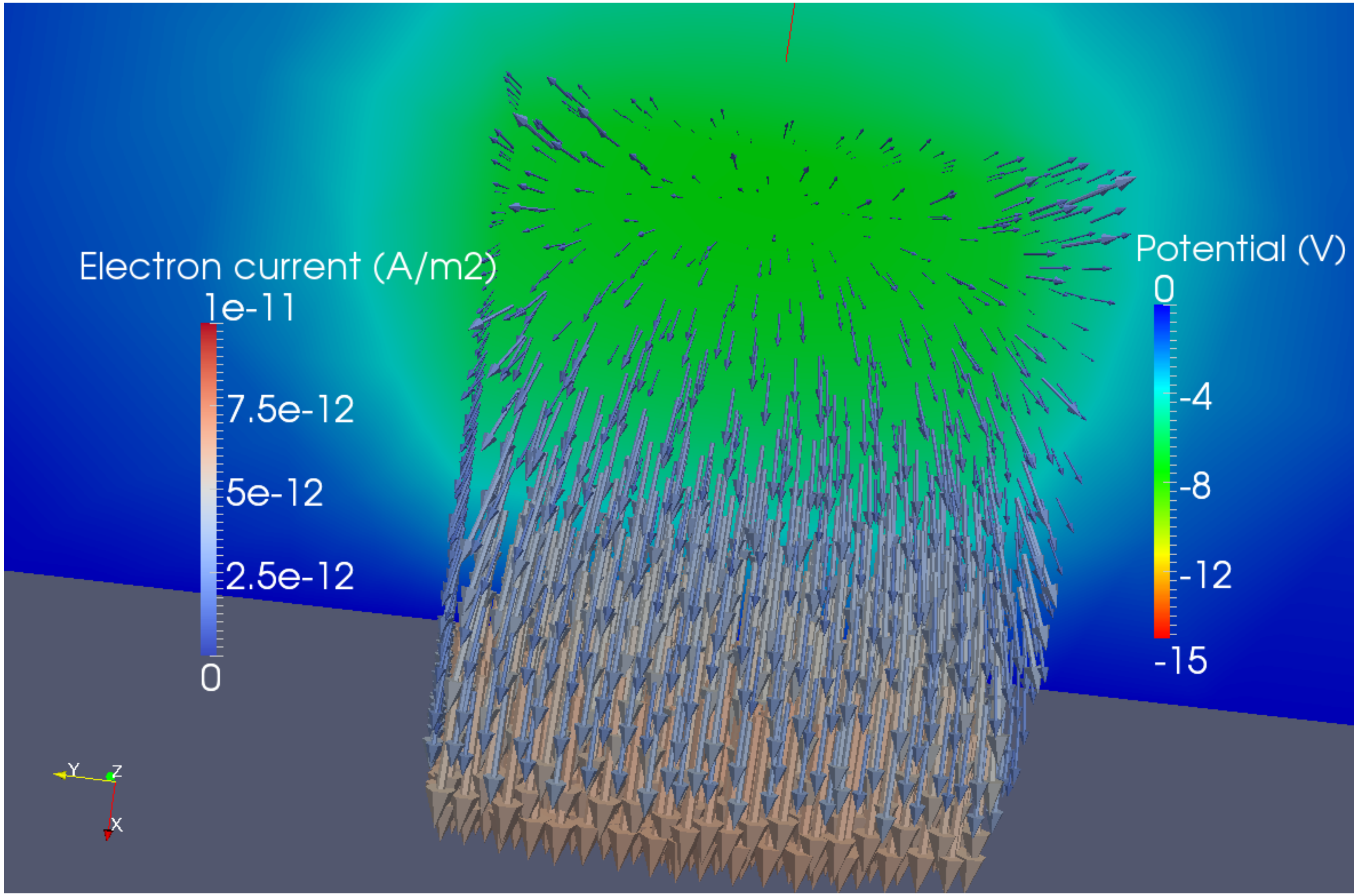
Electrical potential and current evolution

Results from the **time scheme solver at t = 20000 s**



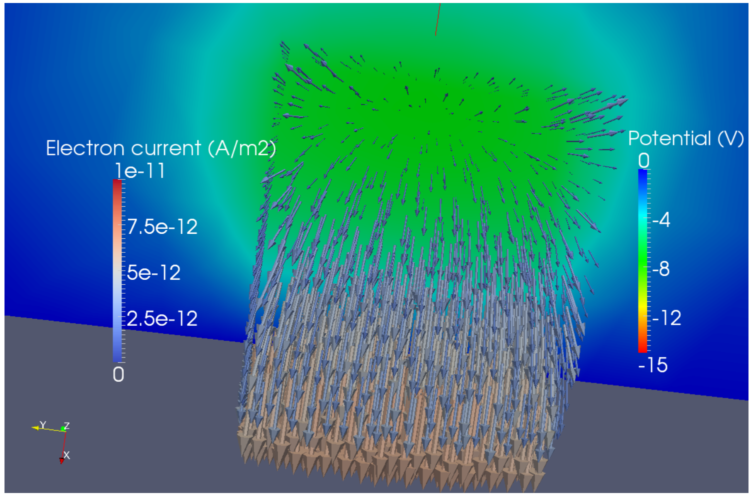
Electrical potential and current evolution

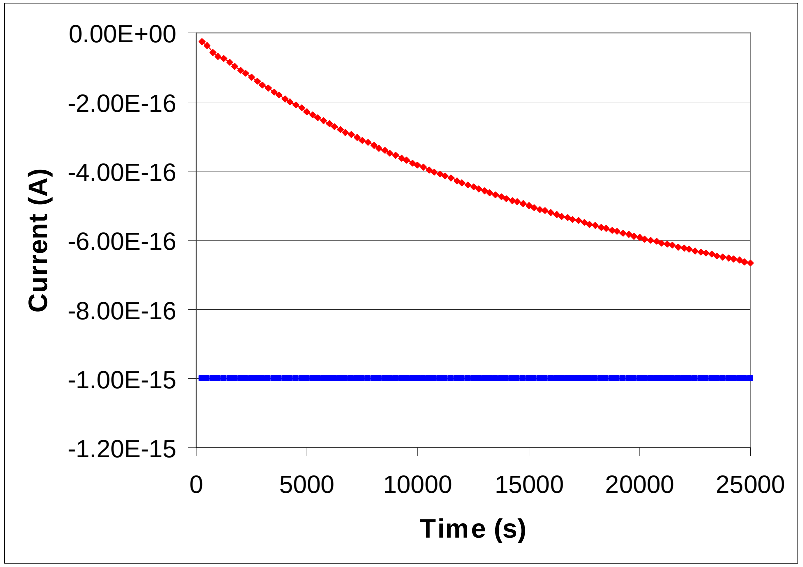
Results from the **time scheme solver at t = 25000 s**



Simulation results at the end of simulation

Results from the **time scheme solver at t = 25000 s**



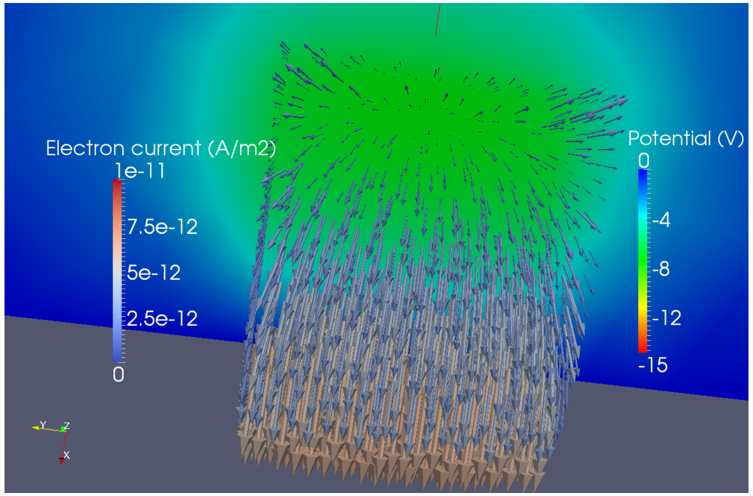


- The current are not completly directed toward the conductor
- The current collected by the conductor does not correspond to the charging current

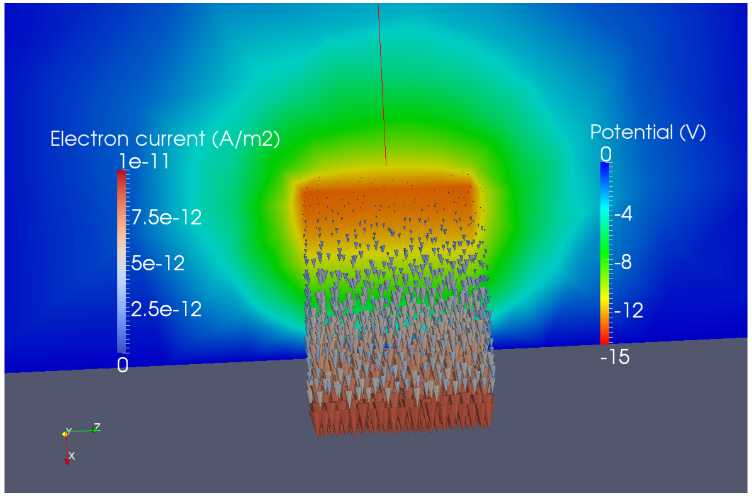
→ the steady state is not reached

Solver mode comparison

Results from the **time scheme solver at t = 25000 s**



Results from the **steady state solver**



- The current are not completly directed toward the conductor
- The current collected by the conductor does not correspond to the charging current

→ the steady state is not reached

- The potential obtained is far to be the maximum potential at the steady state

Conclusion

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Conclusion

- 3D Internal charging tool implemented in SPIS:
  - Charge and dose deposition map as input
  - Poisson equation + continuity + Ohm Law
  - Conductivity mode with temperature, E field and RIC
  - XML list of internal charging material

- Testing wrt analytic case done

- A 3D demonstration case shown using the steady state solver and the time scheme sover

Questions

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