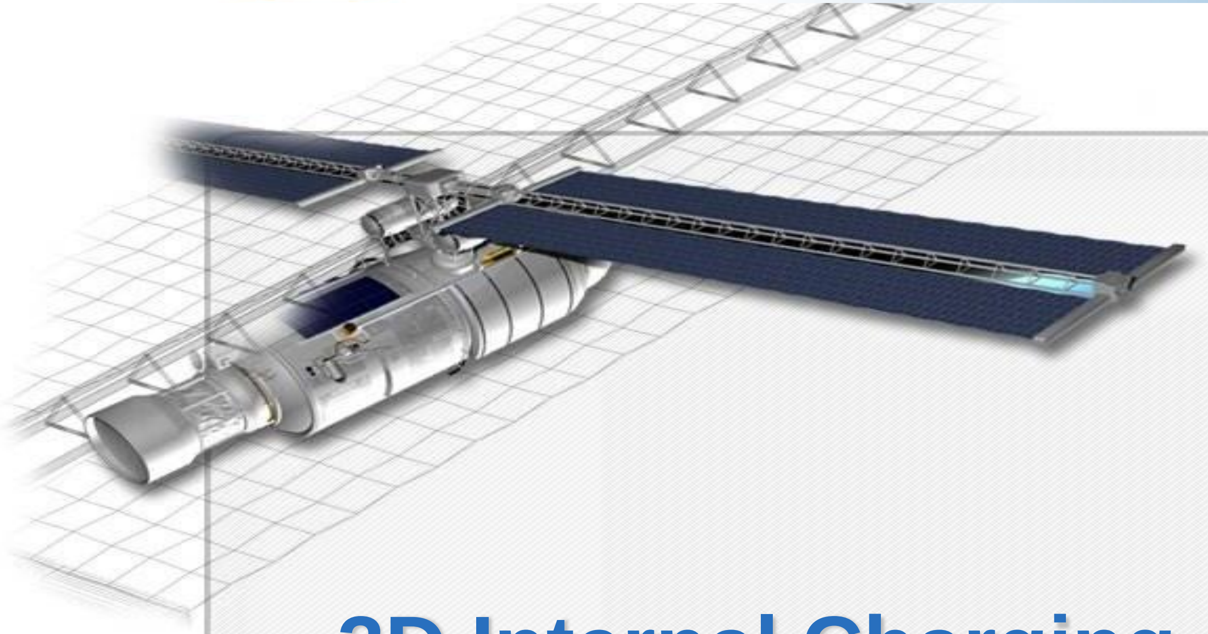

3D Internal Charging Analysis in FASTRAD®

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28th SPINE meeting: 8th-10th of June 2021, ESA/ESTEC, The Netherlands

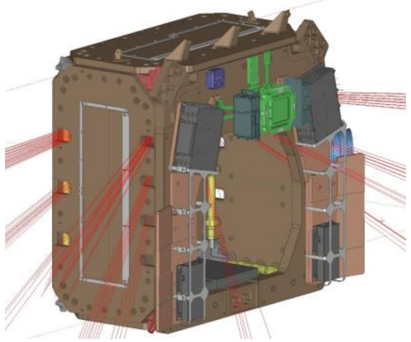
Outline

- Introduction to FASTRAD
  - A radiation analysis tool
- First level analysis: current density
  - Identify the critical parts
- Second level analysis: electric field
  - Example on a 25-pins connector
- 3D comparison
  - Coaxial cable
- Conclusion

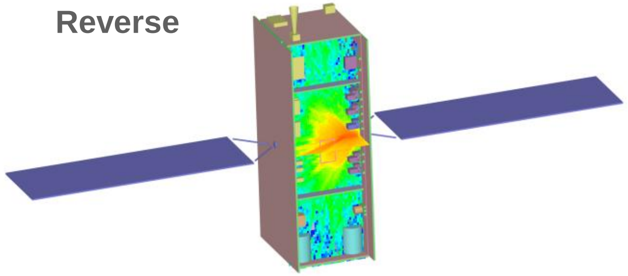
FASTRAD: a radiation analysis tool

Dose calculation (TID & TNID) based on two methods:

- **Sector analysis**
  Ray-Tracing

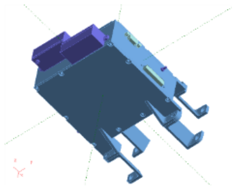


- **Particle transport based on GEANT4: Monte Carlo**
  Forward
  Reverse



Analysis process:

Import geometry from CAD softwares
(.STEP, .IGES)



FASTRAD

MODELING

Graphical user interface, material, components

Environment
(Dose curve, flux)

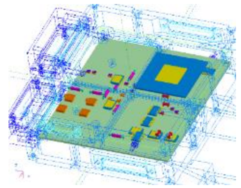
CALCULATIONS

Sector analysis

Monte Carlo
- Forward
- Reverse

POST PROCESSING

Shielding, comparison to specifications

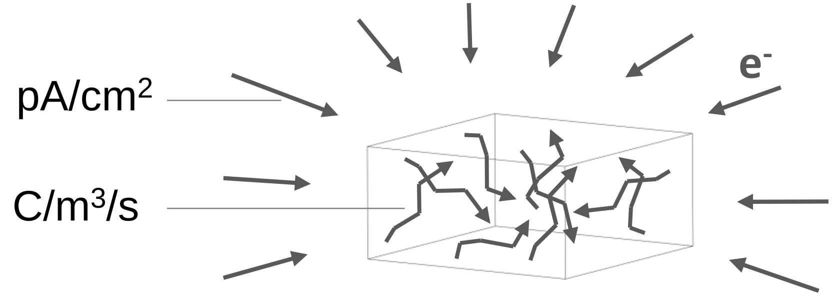


x Specifications not achieved

✓ Specifications achieved

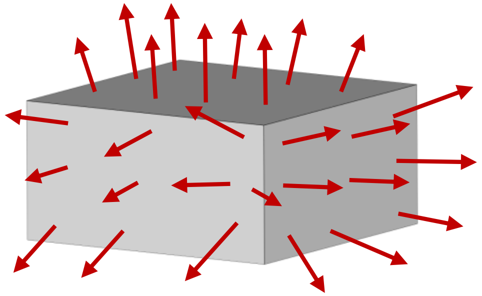
First level analysis: current density

- Inputs
  - Worst case electron flux (short term average).
  - Select a sensitive volume in the 3D model.

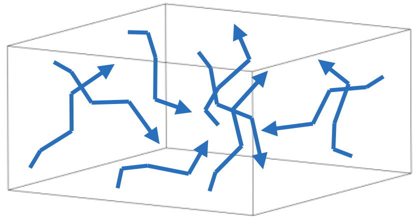


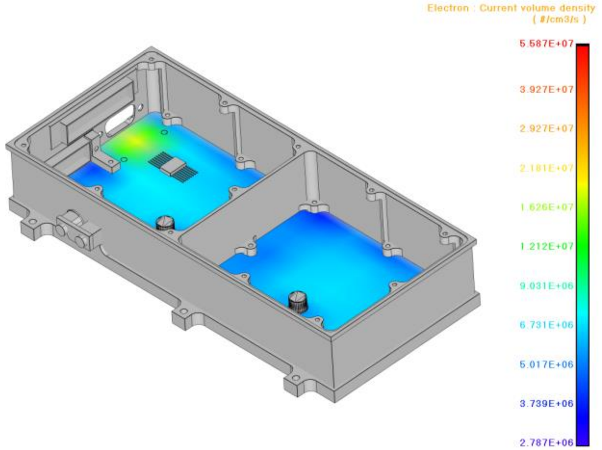
- Calculation method

From the surface to the outside:
Reverse Monte-Carlo



From the surface to the interior:
Forward Monte-Carlo



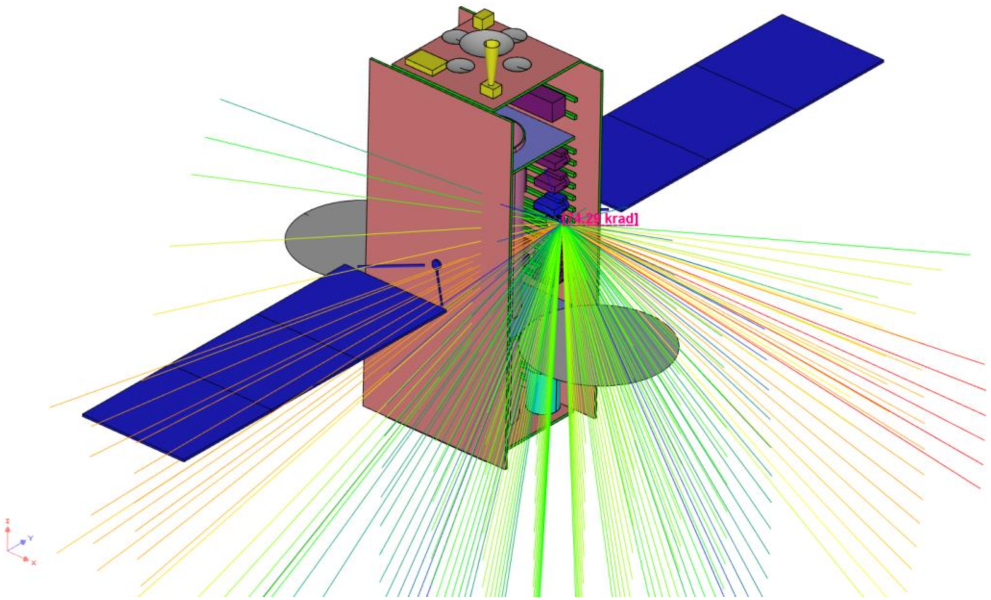


- Outputs
  - Current density (pA/cm^2) of the incident electrons at the surface of the sensitive volume.
  - Charge deposition rate ($C/m^3/s$) inside the sensitive volume.

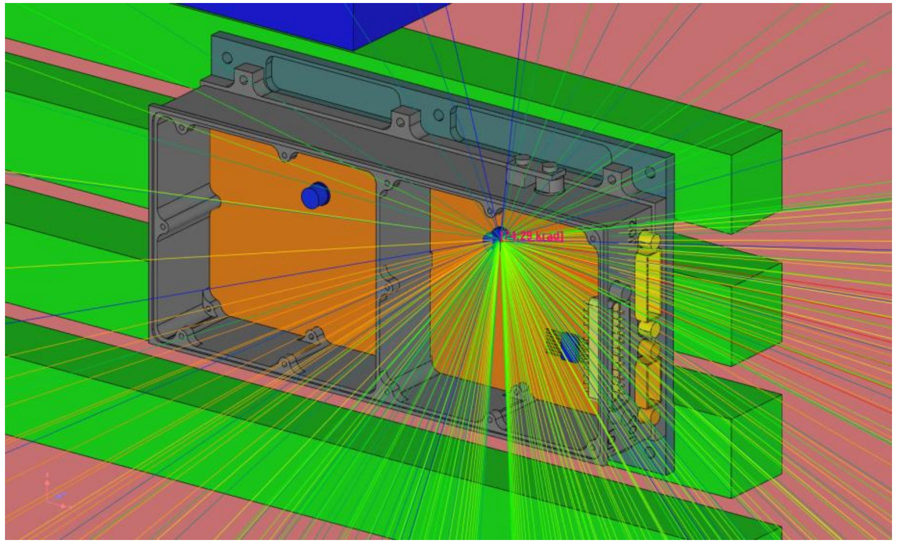
First level analysis: current density

Geometry model

- Use the same geometry model as for the TID/TNID analysis.
- Example: geometry from the ray tracing analysis.



Ray tracing view

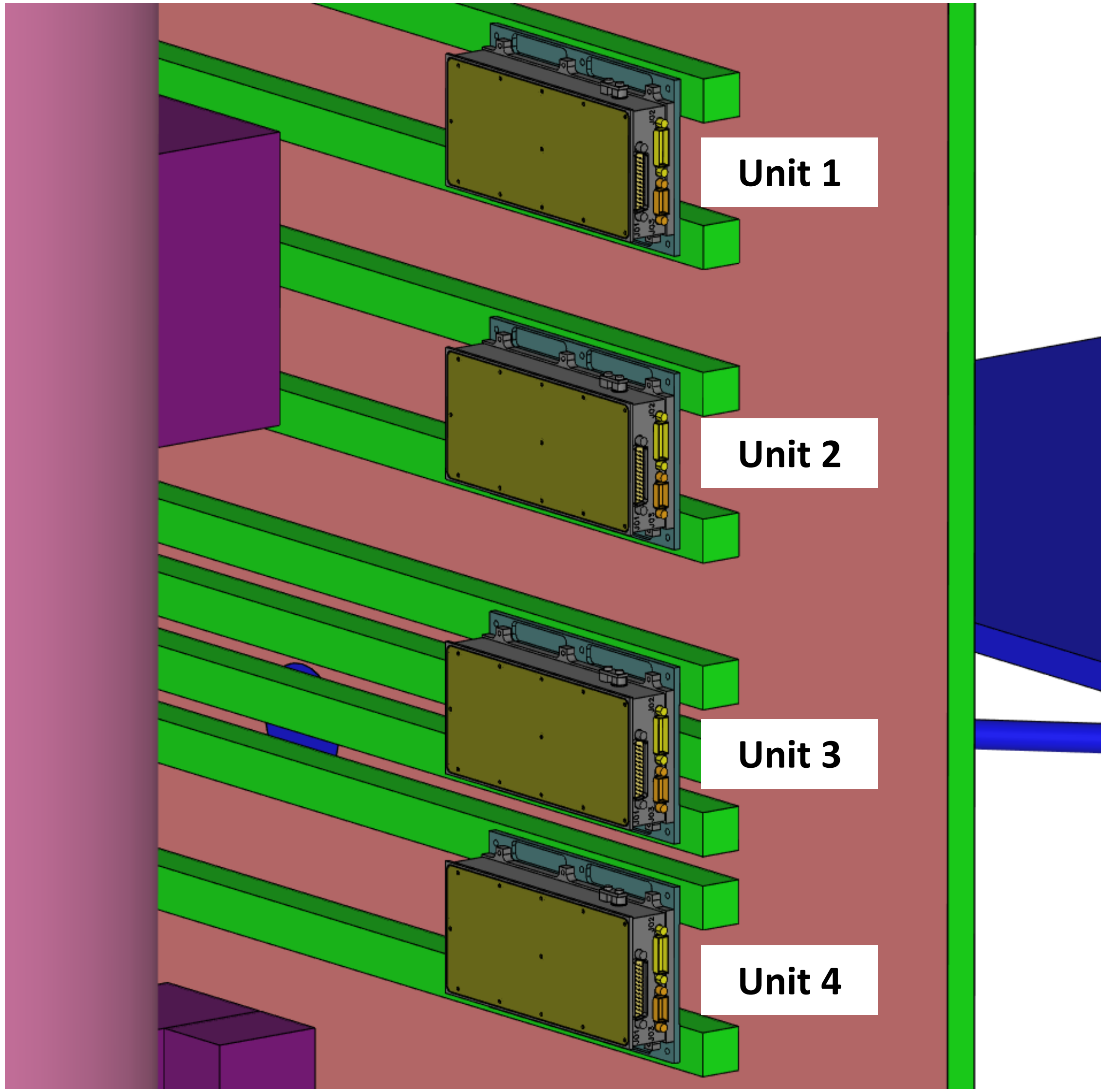


Ray tracing view

First level analysis: current density

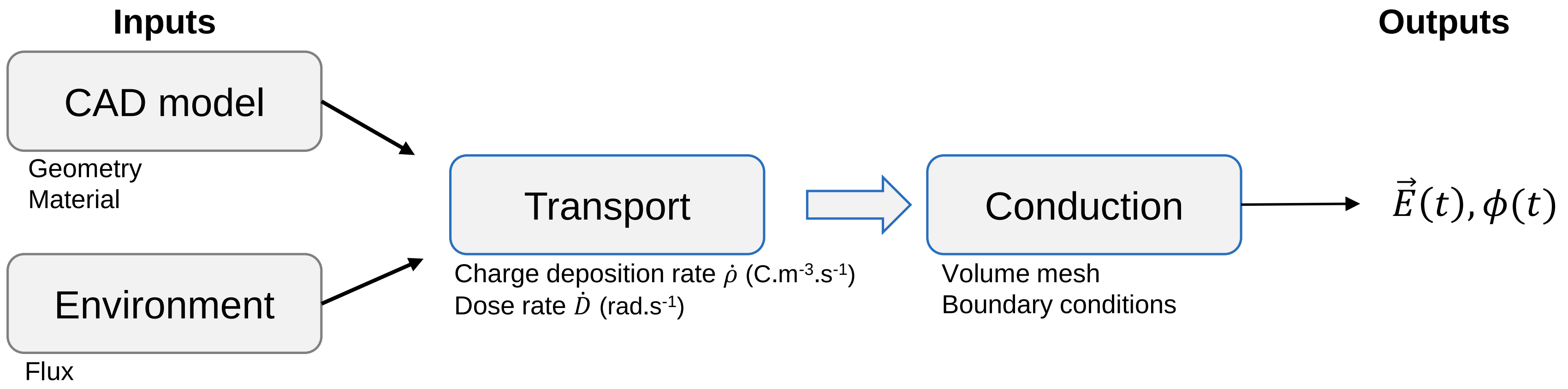
- Identify the critical parts: Reverse Monte Carlo method
  - Run a Reverse Monte Carlo transport calculation on every critical part among connectors, PCBs, cables.
  - Calculation of the incident current density
  - Display the current density and compare to the ECSS threshold [ECSS-E-ST-20-06_0070118]
    - If T > 25°C : $J_{max} = 0.10$ pA/cm^2
    - If T < 25°C : $J_{max} = 0.02$ pA/cm^2

Unit	Part	Current density	Calculate Electric Field ?
1	Connector	J > 0.02 pA/cm^2	YES
1	PCB	J < 0.02 pA/cm^2	NO
2	Connector	J < 0.02 pA/cm^2	NO
2	PCB	J < 0.02 pA/cm^2	NO
3	Connector	J < 0.02 pA/cm^2	NO
3	PCB	J < 0.02 pA/cm^2	NO
4	Connector	J > 0.02 pA/cm^2	YES
4	PCB	J > 0.02 pA/cm^2	YES



Second level analysis: electric field

- General approach for the ESD risk assessment:



- Starting from the charge deposition $\dot{\rho}$ and the dose rate $\dot{D}$, the potential is solved in 3D.

Gauss equation

$$-\nabla \varepsilon \nabla \phi = \rho$$

Continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla \vec{J} = \dot{\rho}$$

Ohm's law

$$\vec{J} = -\sigma \nabla \phi$$

Differential equation for the potential

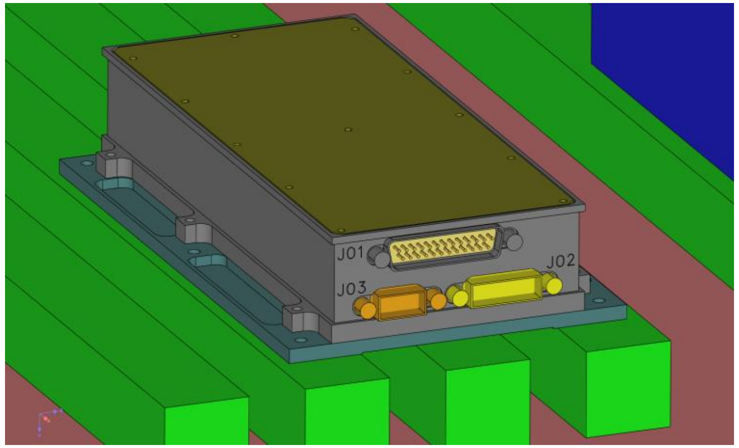
$$-\nabla \varepsilon \nabla \frac{d\phi}{dt} - \nabla \sigma \nabla \phi = \dot{\rho}$$

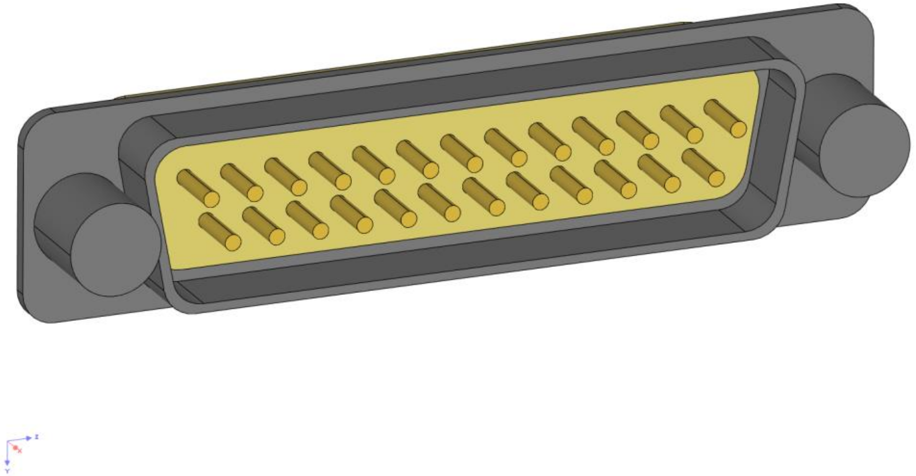
Outputs

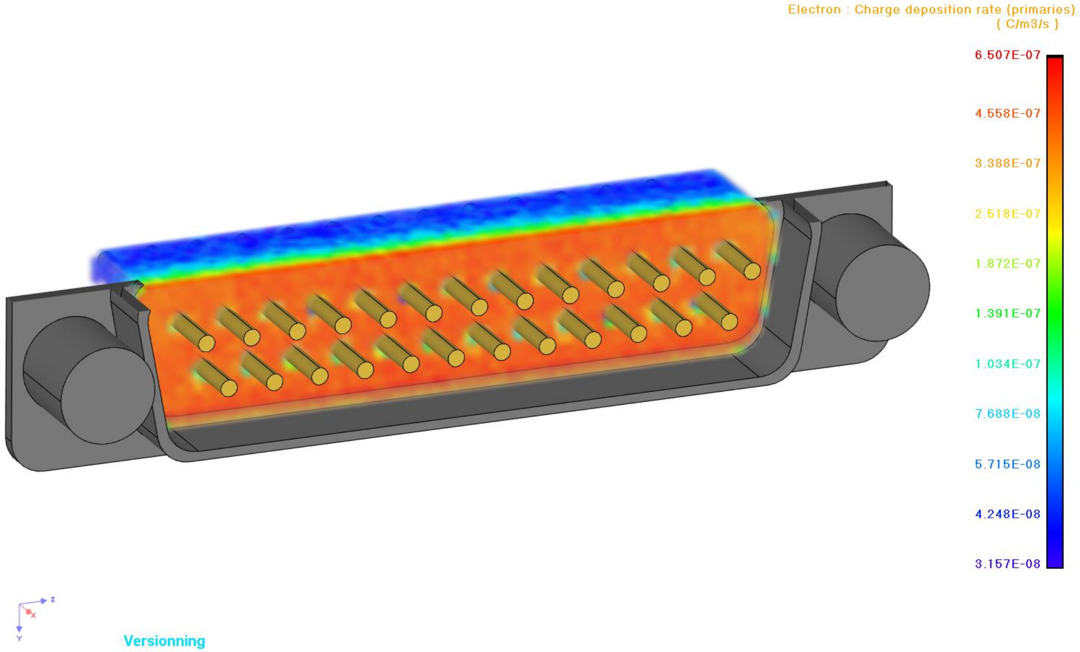
- $\phi(\vec{r}, t)$
- $\vec{E}(\vec{r}, t) = -\nabla \phi$

Second level analysis: electric field

- Step 1: charge and energy deposition
  - Both Forward and Reverse Monte Carlo methods can be used.
- Example:
  - Connector: 25 pins
  - Complete geometry model: satelite geometry + unit geometry
  - Particle transport method: Reverse Monte Carlo

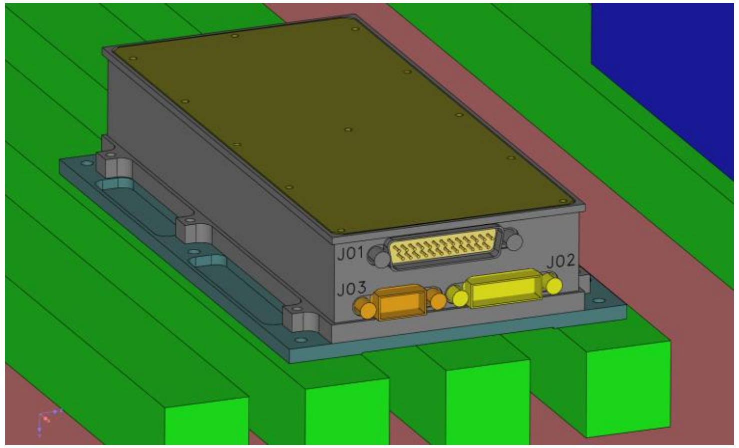


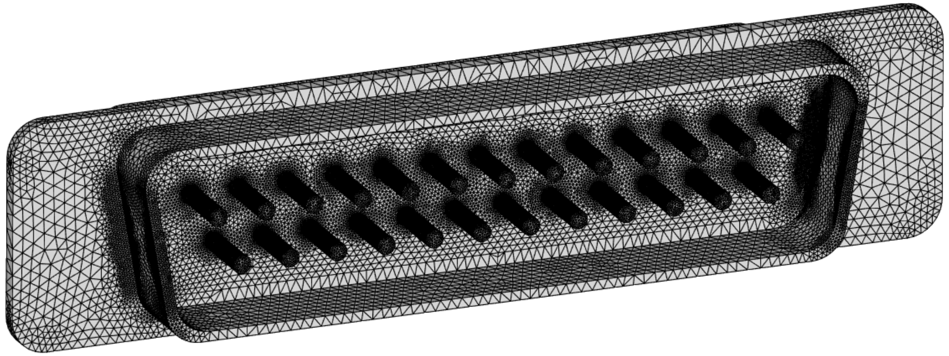


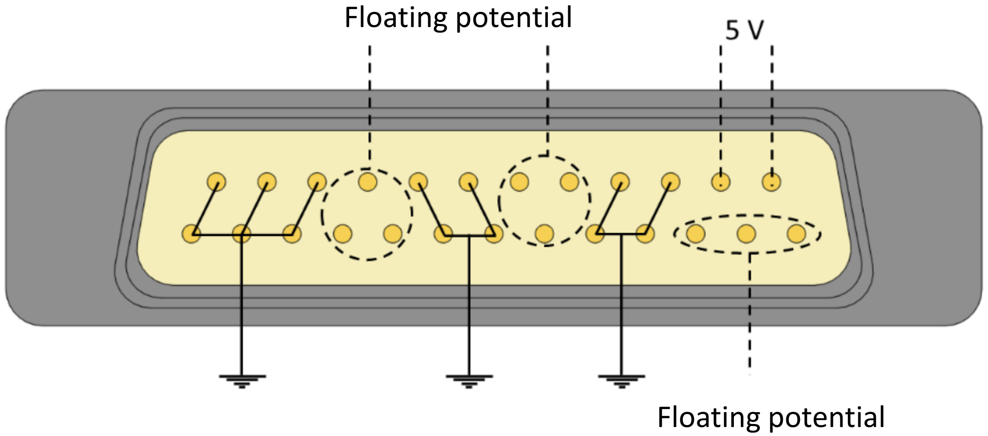


Second level analysis: electric field

- Step 2: mesh and boundary conditions
  - Create the volume mesh
  - Display and refine the volume mesh
  - Assign boundary conditions

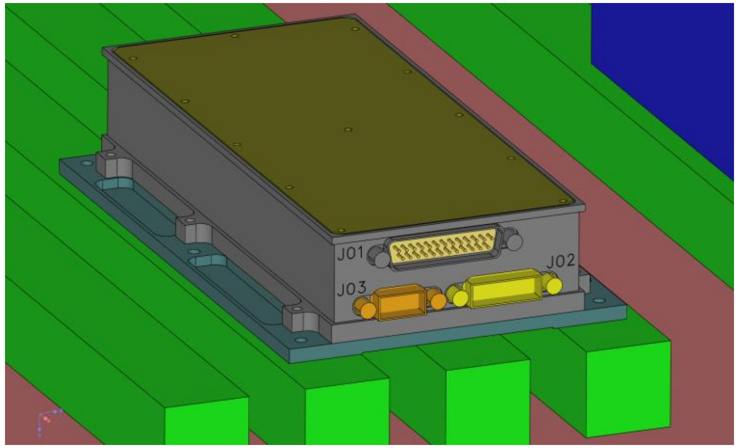


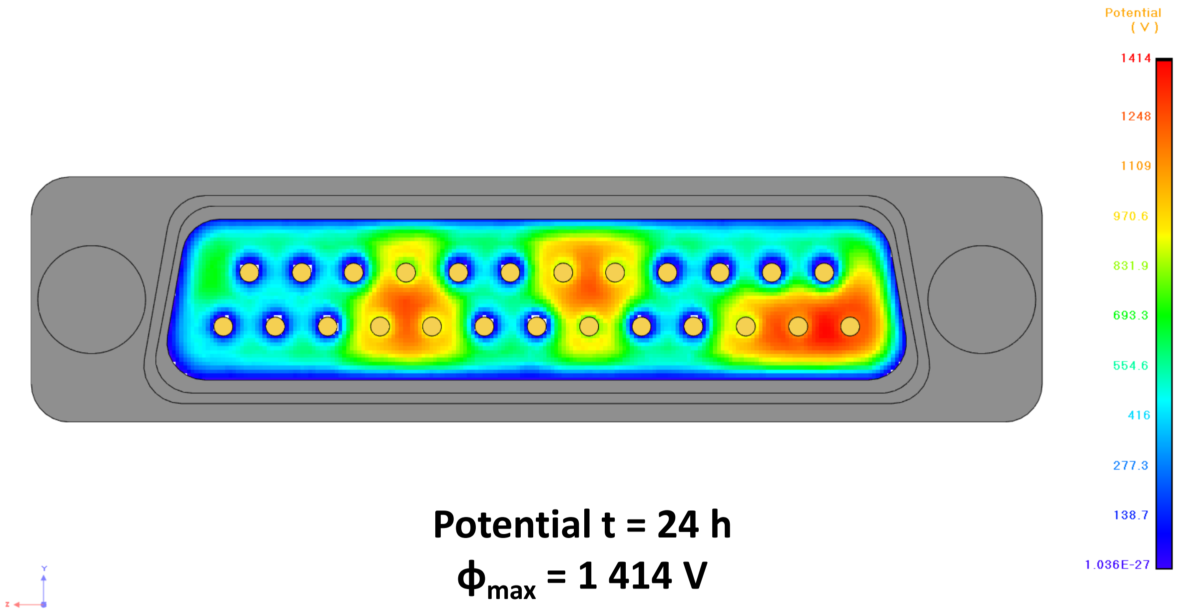




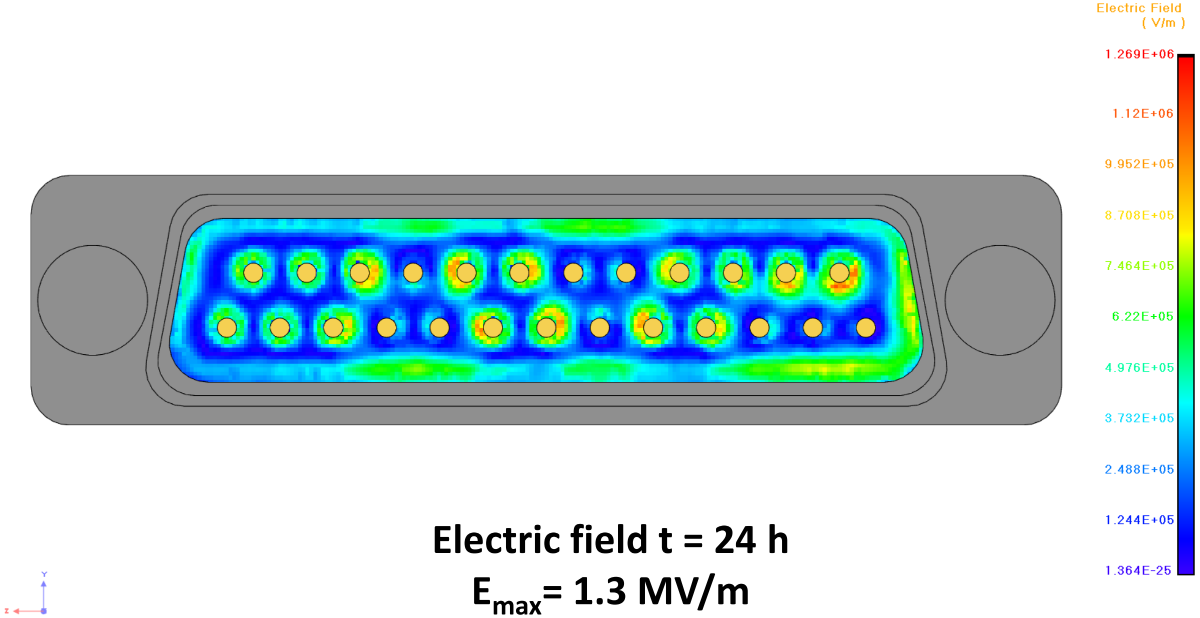
Second level analysis: electric field

- Step 3: electric field calculation
  - Define the duration of irradiation, e.g. 24h
  - Define the time step
  - Run the electric field calculation
  - Display the potential and electric field evolution





Potential t = 24 h
ϕ_{max} = 1 414 V



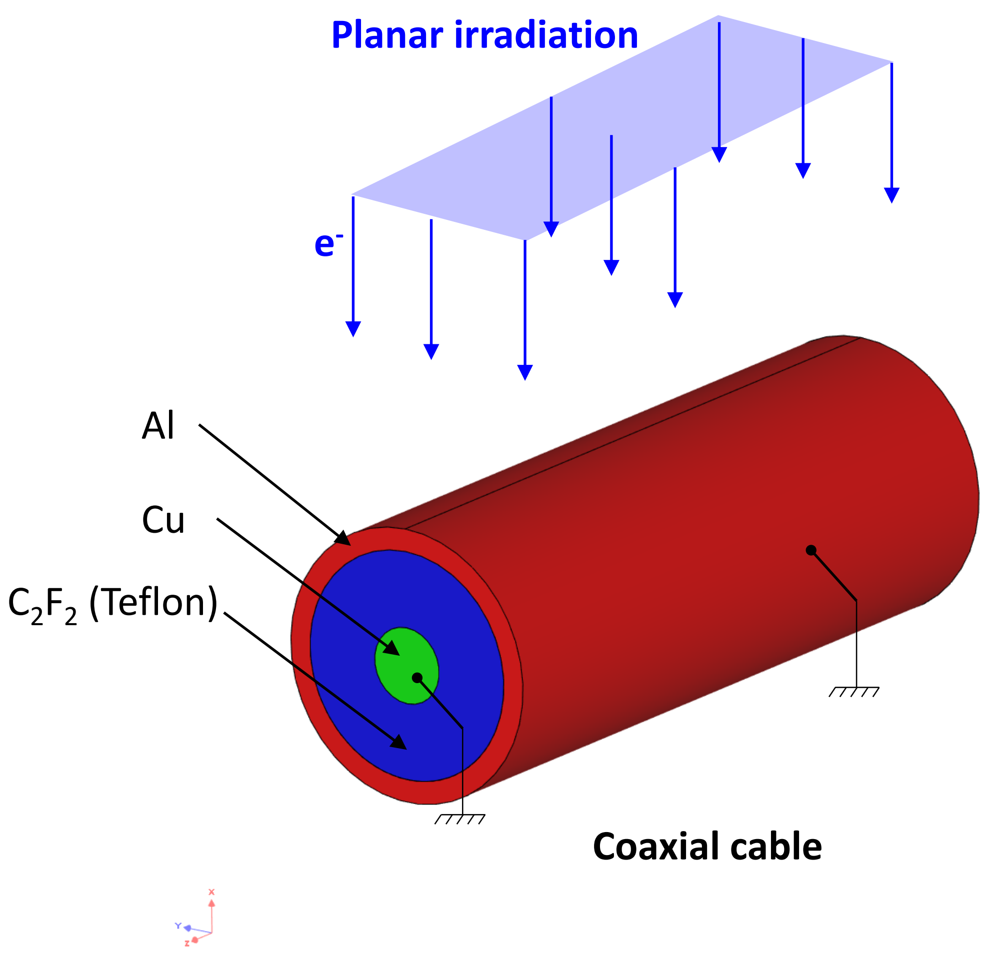
Electric field t = 24 h
E_{max}= 1.3 MV/m

3D Comparison

- 3D comparison by using a coaxial cable.
- The comparison is made with 3DNUMIT [1].
  - Coaxial cable: Al, Cu and Teflon
  - Planar irradiation for 400 h
  - Inner conductor and shielding are grounded

Dielectric properties	Teflon
Relative permittivity	2.15
Bulk conductivity ($\Omega^{-1}.m^{-1}$)	2.60×10^{-19}
Radiation induced conductivity ($\Omega^{-1}.m^{-1}.rad^{-\Delta}.s^{\Delta}$)	6.10×10^{-16}
Δ	1

[1] "Benchmarking internal dielectric charging simulation platforms" Likar et al. , ASEC 2019

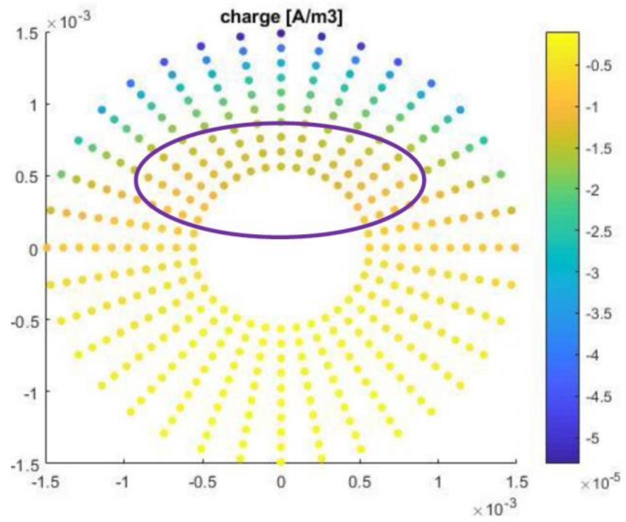


3D Comparison

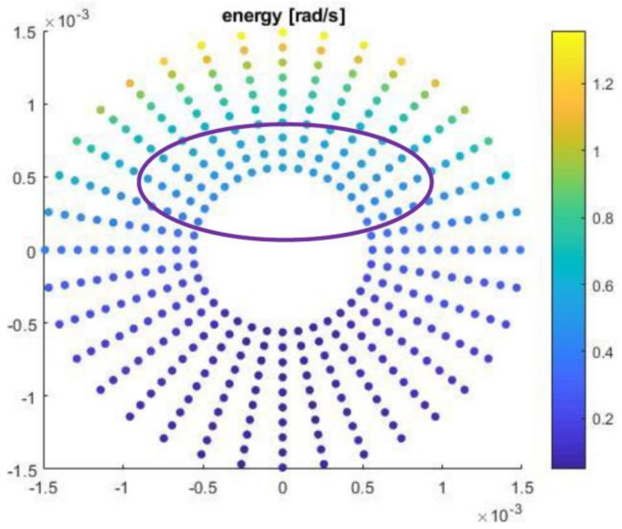
- Charge & Energy deposition
  - Good agreement with distribution and magnitudes.
  - Subtle differences in magnitudes (different particle transport codes, different meshing)

3DNUMIT

Max: 5.2×10^{-5} A/m^3

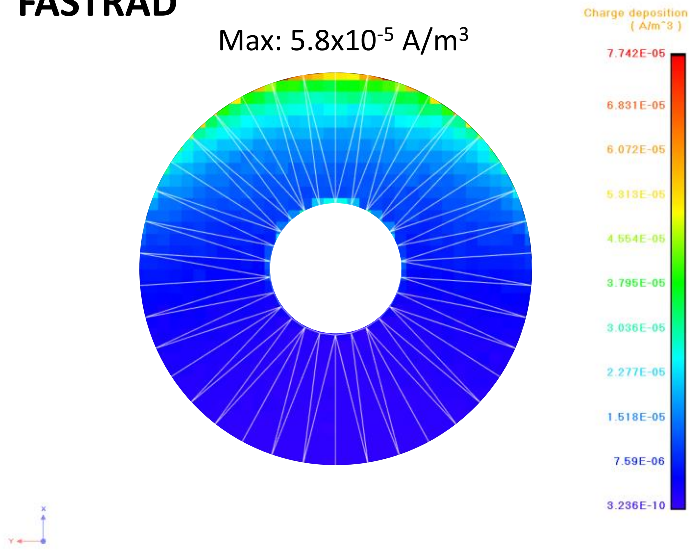


Max: 1.30 rad/s

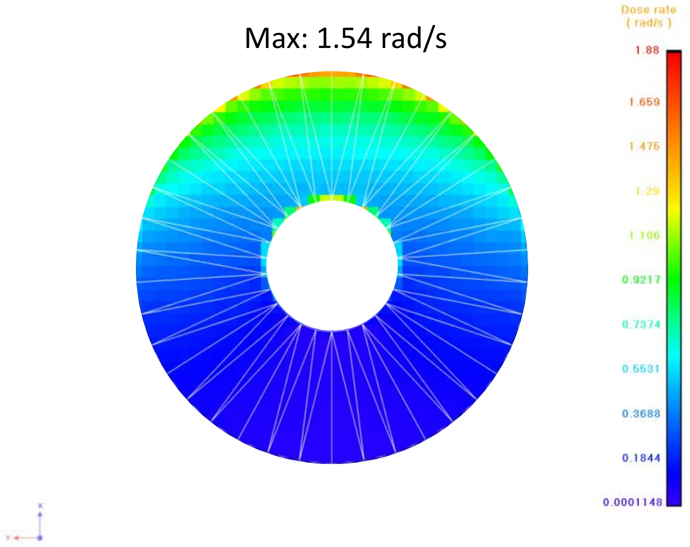


FASTRAD

Max: 5.8×10^{-5} A/m^3



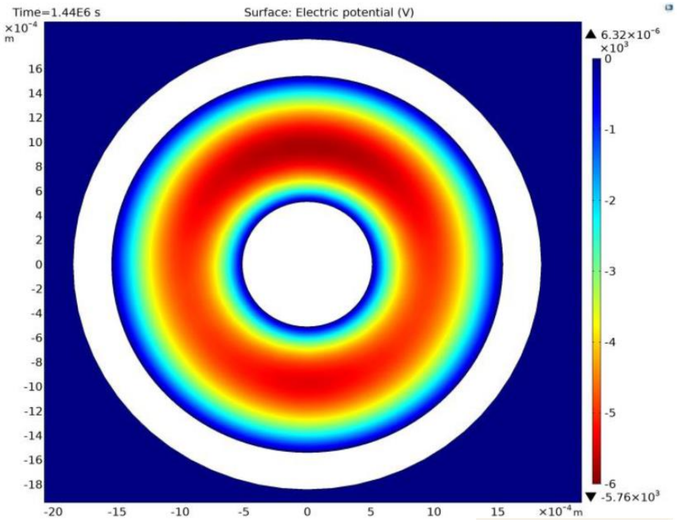
Max: 1.54 rad/s



3D Comparison

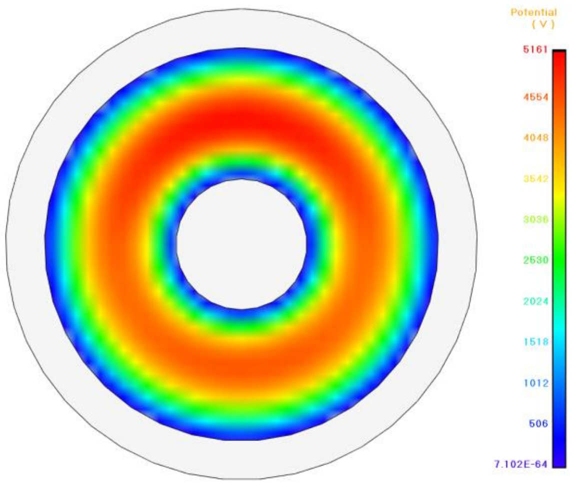
- Potential after 400 h irradiation
  - Good agreement of potential for space distribution and value
  - The maximum potential is -15% lower than 3DNUMIT

Potential



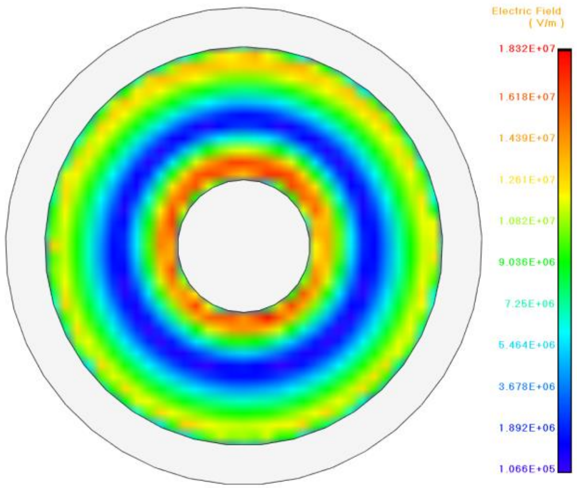
3DNUMIT
ϕ_{max} = -6 000 V

Potential



FASTRAD®
ϕ_{max} = -5 161 V

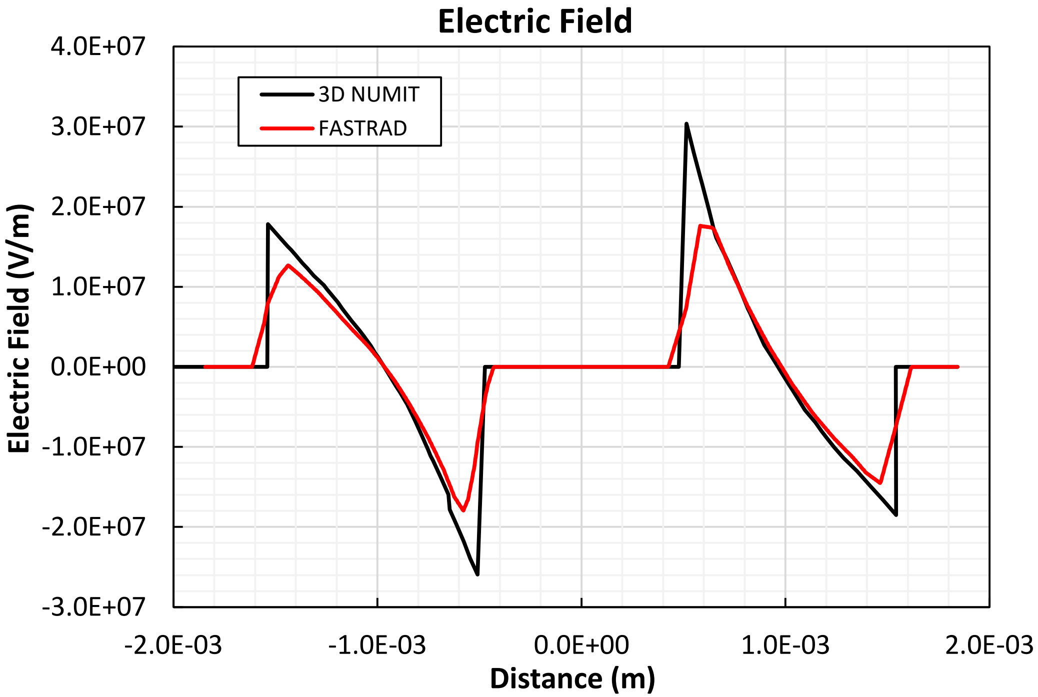
Electric Field

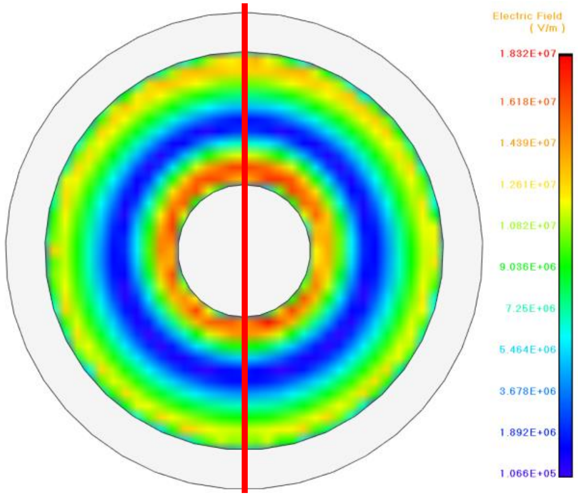


FASTRAD®
E_{max}= 18 MV/m

3D Comparison

- Electric field after 400 h irradiation
  - Good agreement of electric field for space distribution.
  - The maximum electric field at the interfaces is lower than 3DNUMIT.
  - Maybe due to different interface behavior for the electric field solver in the finite element method.





FASTRAD®
E_{max}= 18 MV/m

Conclusion

- Internal charging analysis with geometry coming from the TID analysis.

- Two levels of internal charging analysis in FASTRAD, allowing save time:
  - First level: electron current density
    - particle transport method: Reverse Monte Carlo can be used
    - comparison to ECSS thresholds
    - identification of critical parts
  - Second level analysis: electric field calculation
    - Only on critical parts
    - Display potential and electric field evolution

- Validation
  - Particle transport code, based on Geant4 physics, validated and published [RADECS 2016]
  - 1D cases have already been used for validation (not shown here)
  - 3D validation with one case
  - Additional 3D validations with other tools and experimental data are in progress

- Beta version available June 2021
  - Official FASTRAD release September 2021

Thank you for your attention