FASTRAD 3.2: Radiation Shielding tool with a new Monte Carlo module

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***Abstract*--FASTRAD® is a complete engineering software developed for 3D radiation shielding analyses. A new Monte Carlo module, including forward and reverse methods, performs particle transport and dosimetry for space environment.**

I. Introduction

FASTRAD® [1], [2] is a complete engineering software developed for 3D radiation shielding analyses. It includes modeling, calculation and visualization tools, combined with a user-friendly interface. A Monte Carlo module has been recently added to improve radiation analysis through a realistic particle transport computation. Results obtained are coherent with existing Monte Carlo methods (forward and reverse).

II. The FASTRAD Software

FASTRAD is a software developed by the TRAD company. It is a valuable tool for radiation engineers allowing to (i) create 3D radiation models (ii) manage radiation analysis in terms of deposited dose calculation and (iii) perform post-processing analysis.

A. Radiation CAD interface

The interface has been developed in order to provide the user with an intuitive and efficient toolset to create a radiation model. The 3D solids can either be created using the CAD toolkit or they can be imported from another CAD tool (CATIA, Pro/Engineer…) through the standard STEP or IGES format.

In order to decrease the computational time due to the complex geometry, FASTRAD provides an interface dedicated to shape reconstruction. The goal is to replace complex curved solids by simple shapes (box, cylinder,…). This reconstruction phase can be easily achieved through “control points”, lines and planes which are created directly in the display window.

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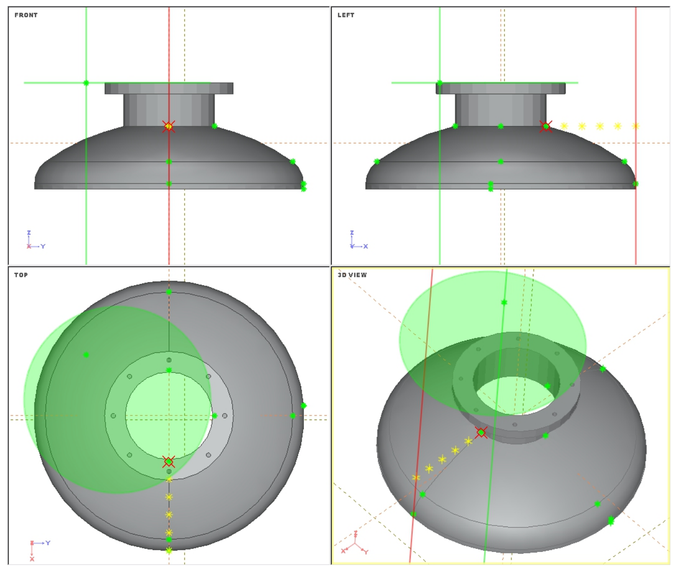

Fig. 1. Example of model simplification using reconstruction tools. Control points are an easy and efficient way to create and to place simple shapes, a cylinder in this case.

The material properties of each element can be defined by the user or they can be selected through a complete material reference table.

Once the modeling phase has been completed, FASTRAD is able to perform the radiation calculation as a stand-alone software or export the complete input data to another calculation software like GEANT4 [3] or NOVICE (http://empc.com/).

B. Dose Calculation

The radiation analysis engine of FASTRAD includes complementary calculation modules:

- a ray-tracing tool for fast radiation calculation (sector analysis),
- a Monte Carlo algorithm for realistic transport computation.

The well-known ray-tracing method is used to obtain dose calculation results rapidly, even on a large number of point detectors.

The Monte Carlo module has been developed in partnership with the CNES. It includes forward and reverse methods. In the forward method, FASTRAD manages the transport of electrons and photons. Sensitive Volumes (SV) are selected by the user and FASTRAD computes the deposited energy and the transmitted flux inside those SV. The reverse Monte Carlo is dedicated to the dose calculation due to an isotropic irradiation of electrons in a complex geometry.

C. *Post-Processing Analysis*

Post-processing tools provide efficient and interactive analysis.

A shielding analysis module allows visualization of the rays/directions according to the shielding mass distribution for each point detector. Moreover it calculates the impact of rays on the deposited dose (Fig.2). This feature is helpful for designing and placing additional shielding for critical parts.

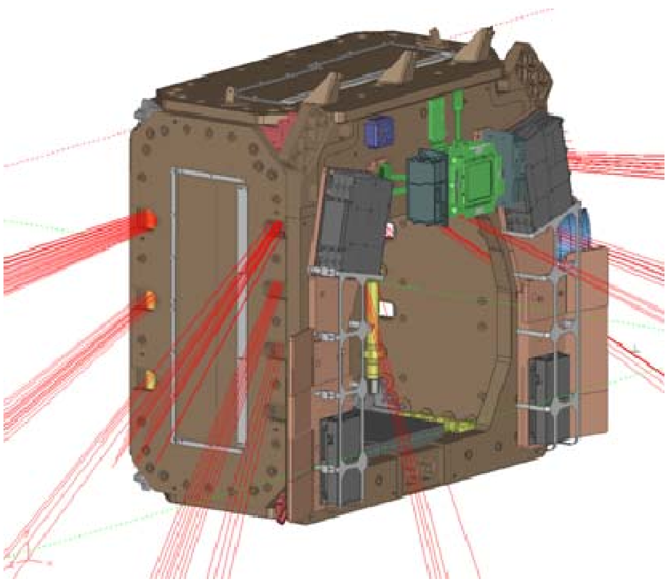

Fig. 2. 3D view of a ray-tracing calculation.
The rays display the location of the thinnest parts of the model.

III. The Monte Carlo Module

Forward and reverse Monte Carlo algorithms for electrons and photons are available in FASTRAD.

The physical interactions taken into account are: multiple scattering, ionization, Bremsstrahlung photon creation, photoelectric effect, Compton diffusion and materialization.

The forward Monte Carlo computes the transport of particles from the source to their total energy loss (inside the model limits). Secondary particles created by physical interaction are also tracked. A large variety of sources can be described:

- an isotropic radiation environment, the “World”,
- a circular beam for which the radius, center and beam direction are set by the user,
- a surface of a virtual sphere or a solid in the 3D model, with isotropic emission.

The drawback of this forward approach appears when the size of the SV is several orders of magnitude smaller than the size of the model. Performing such a calculation leads to huge computational time especially for isotropic electron irradiation. In this case, biasing techniques as the reverse algorithm must be used.

The general principle of the reverse method is to (i) use the forward tracking inside the SV (ii) track back the particles from the SV to the source area. Fig. 3 illustrates the electron tracks during a reverse Monte Carlo calculation. The SV is considered as a point detector.

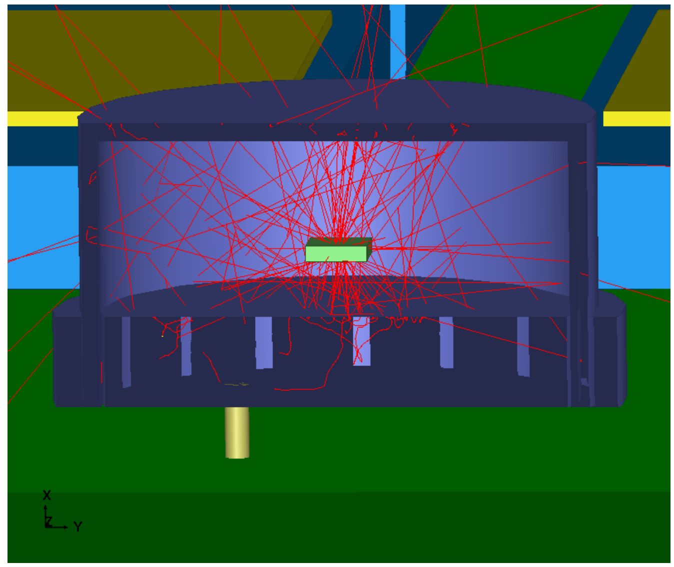

Fig. 3. Screen shot of electron tracks during the reverse Monte Carlo calculation on an electronic equipment.

IV. Results and Validations

The Monte Carlo module has been successfully validated against GEANT4 (CERN) for the forward algorithm and NOVICE (EMPC) for the reverse method.

A. *Forward Monte Carlo validation*

Several test cases were defined to validate the forward algorithm with the GEANT4 software. One test case was the complete modeling of a TRAD Space Dosimeter (TSD) under a Co60 irradiation. TSD is a PMOS specially designed to be used as a dosimeter [4]. The calculation was performed on its oxide layers (thickness: 0.1 μm) and the first silicon layers. The aim of the study was to observe the dose enhancement due to gate material .

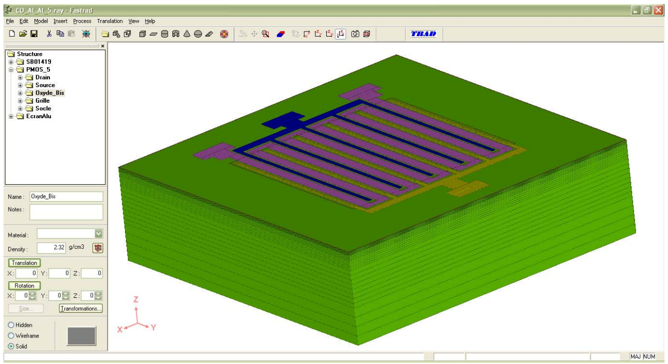

Fig. 4. TSD model.
The study was carried out on the first layers, the darkest ones on this view.

The deposited dose results obtained with FASTRAD (2.09 krd) are coherent with those obtained with GEANT4 (1.91 krd). The dose values are normalized for an incident gamma flux of 1 J*cm^{-2}.

B. *Reverse Monte Carlo validation*

The validation of the reverse Monte Carlo was carried out using different energy spectrum types:

- a geosynchronous orbit electron flux,
- a Jovian environment electron flux (up to 1 GeV),
- a quasi-monoenergetic electron flux.

1) Geosynchronous orbit

The 3D radiation model includes the complete satellite structure, the electronic units and the component packages (Fig. 5).

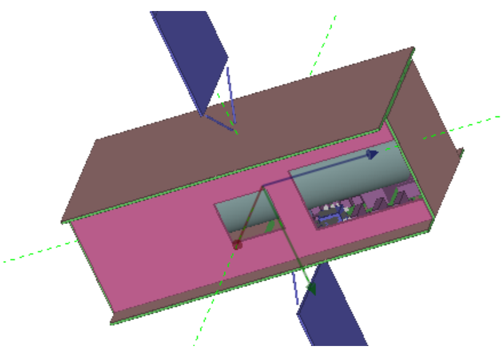

Fig. 5. Complete spacecraft model.

Fig. 6 a) shows the deposited dose values obtained with the FASTRAD ray-tracing (filled squares) and reverse Monte Carlo (filled diamonds) methods for different package types. The calculation takes into account the electrons and the Bremsstrahlung photons. Results are compared to the NOVICE reverse Monte Carlo output (horizontal line). The FASTRAD reverse Monte Carlo output is coherent with the NOVICE one (less than 25% difference).

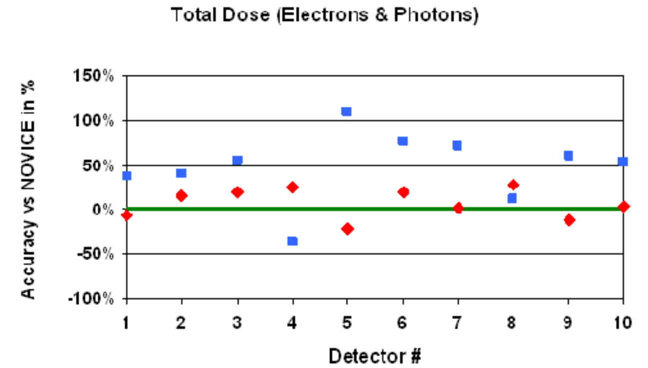

Fig. 6.a) Deposited dose comparison for various electronic components

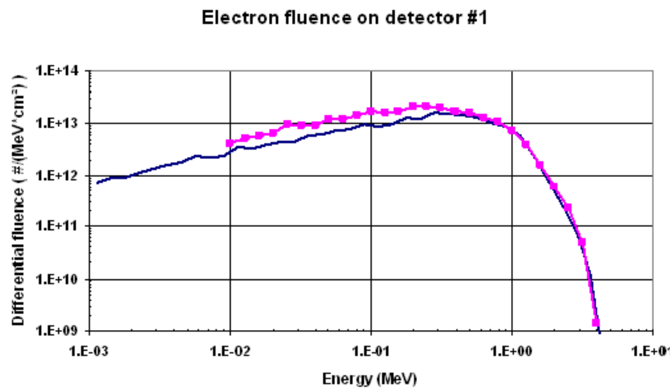

Fig. 6.b) Example of transmitted electron fluence.
The FASTRAD transmitted fluence (solid line) matches very well the NOVICE one.

2) Jovian environment

FASTRAD has been used for the radiation response study of a star tracker onboard the Jovian probe (JGO). Those calculations have been performed in partnership with EADS-SODERN during the ESA project : EVALUATION OF STR PERFORMANCE IN HIGH RADIATION ENVIRONMENTS (contract n°4000101530/10/NL/AF).

The Star Tracker, located outside the spacecraft, is exposed to a harsh environment during the mission (electrons with energies up to 1 GeV). The transmitted fluxes of electrons have been computed on different lenses along the optical path.

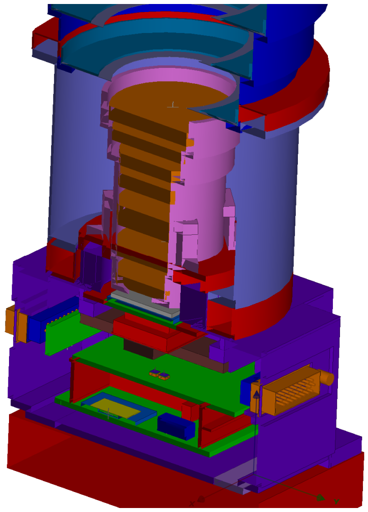

Fig. 7. Star Tracker cross section obtained using FASTRAD clipping tool.

Transmitted electron flux calculated with FASTRAD on the innermost lens is compared to the one obtained with NOVICE and to the incident electron flux (Fig. 8).

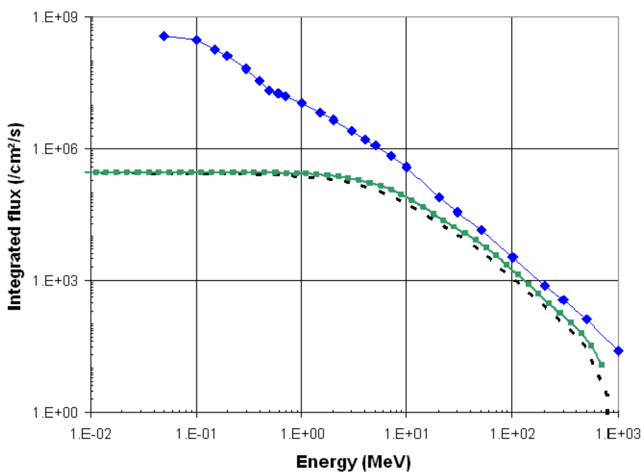

Fig. 8. Transmitted electron flux on the innermost lens of the Star Tracker in a Jovian environment computed by FASTRAD (solid line) and by NOVICE (dotted line). The incident flux (filled diamond) is given as an indication of the particle attenuation. All fluxes are integrated.

The FASTRAD transmitted flux matches very well the NOVICE one. This test case was really challenging due to the high energy electrons involved in the Jovian radiation belts and the high shielding mass around the calculated length (more than 5 g*cm $^{-2}$).

3) *Quasi-monoenergetic flux*

A CNES study (contract N°103953) is currently carried out to validate the reverse calculation results against actual test irradiation measurements. Within this validation we have to consider different kinds of dosimeters: TSD, Hexfet® Power MOSFETs and alanine pellets. HEXFET is a PMOS sensitive to deposited dose up to hundreds of krd.

They are irradiated under a 1 MeV electron beam. The incidence of the beam on the packages varies during the irradiation in order to obtain an isotropic irradiation. A dodecahedron was specially designed to allow an iso-angular distribution of the electron beams. Fig. 9 shows irradiation through one face of the simulated dodecahedron.

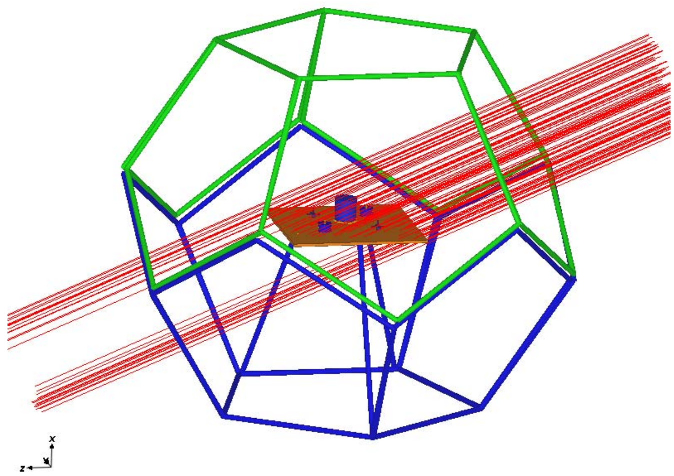

Fig. 9. Simulation display of one dosimeter irradiation.
Electron beam enters into the dodecahedron by one of its hollowed faces and hits the different dosimeters with the same incidence angle.

For the reverse calculations, the energy spectrum was described as a narrow peak around 1 MeV using a Gaussian law. Results from the two calculation tools match well.

TABLE I
FASTRAD AND NOVICE COMPARISON FOR A QUASI-MONOENERGETIC SPECTRUM

1 MeV electrons	TSD	HEXFET	Alanine Pellets
Fastrad (rd(Si))	6.33E-09	1.22E-08	1.20E-08
NOVICE (rd(Si))	6.76E-09	1.20E-08	1.13E-08
Difference (%)	-6.79	1.67	6.19

The dose calculation is performed using a normalized incident electron flux of 1 part*cm $^{-2}$*s $^{-1}$.

The comparison between values obtained through calculation and experimental measurement is on-going work.

V. Conclusion

FASTRAD is a radiation software used by engineers worldwide, including in its new release an efficient Monte Carlo algorithm. Both forward and reverse methods provide precise dose and flux calculation on complex geometry. FASTRAD MC results are coherent with those obtained by other Monte Carlo codes.

The new Monte Carlo modules have been used for on-demand developments dedicated to specific applications such as: X-ray inspection, Gamma bunker shielding,… The resulting tool combines the user-friendly interface of FASTRAD with the accuracy of the Monte Carlo tracking approach.

A visual post-processing module of the Monte Carlo calculation is being developed and will provide a new interactive way to analyze particle tracks.

VI. References

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