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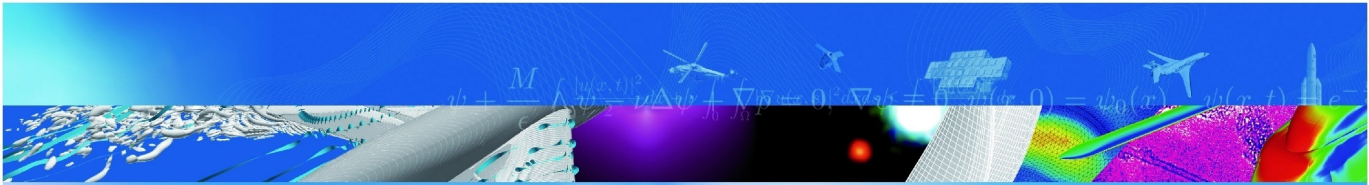
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## ADVANCED CAD TOOL AND EXPERIMENTAL INTEGRATION OF GRAS/GEANT-4 FOR INTERNAL CHARGING ANALYSIS IN SPIS

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### ABSTRACT

Future space missions present an increasing need for an accurate modelling of internal charging effects. New internal charging modules of SPIS-IC require a prior computation of the deposited dose, charge and energy by an external Monte-Carlo based tool, like ESA/GRAS. In such multi-physics modelling, the modelling process must be considered as a whole and through an Integrated Modelling Environment (IME). A first experimental integration of GRAS into SPIS and a new CAD editor for GDML files, EDGE, are presented.

### 1. INTRODUCTION: MULTI-PHYSICS MODELLING IN SPACE ENVIRONMENT

Future scientific missions and commercial platforms present new needs and challenges in terms of modelling space environment effects. ESA's Juice Jovian mission is expected to cross intense and highly various radiating and plasma environments, potentially leading to severe radiation and internal charging effects. In parallel, the new generation of commercial missions, like massive constellations, is marked by a massive use of non-hardened components or ions thrusters and are expected to fly in MEO. Cumulated doses and charges may lead to strong internal electric fields and risks of discharges, potentially dangerous for embedded equipment and payload. Design and shielding must be carefully computed and more accurate numerical models needed.

To cover self-consistently all involving physics, it is generally needed to chain different numerical models and consider the global modelling process as a whole. Various stability and boundary conditions must be respected; geometrical descriptions compliant with the different simulation kernels; material properties and environment applied. Last, data must be passed between each model with a minimum of alterations.

Such operations are hard to perform manually. Moreover, the requested expertise covering a large range of physics, it makes the simulations difficult to drive by non-experts. A unified user interface, helping the user to properly follow the whole modelling process in a coherent way, is needed. This is the purpose of Integrated Modelling Environments or IMEs. IMEs aim to integrate the various numerical kernels as well as

pre/post-processing tools, like Computer-Aided Design (CAD) editors, in a common frame, to perform needed data exchanges/conversions and to make the global modelling process easier and safer.

### 2. COUPLED RADIATIONS/INTERNAL CHARGING ANALYSIS

A coupled radiations/internal charging analysis is a typical example of such complex multi-physics modelling, considering three main steps:

- 1- Construction of geometrical model(s);
- 2- Computation of the deposited energy, charge and dose, using a Monte-Carlo model;
- 3- Computation of the evolutions of the inner charges and electric fields with a 3D charging code.

This global process may be completed by extra treatments, like the adaptation of geometries or the meshing of the computational domain, performed by the IME. *Figure 1* summarizes this approach and the data exchange performed by the IME.

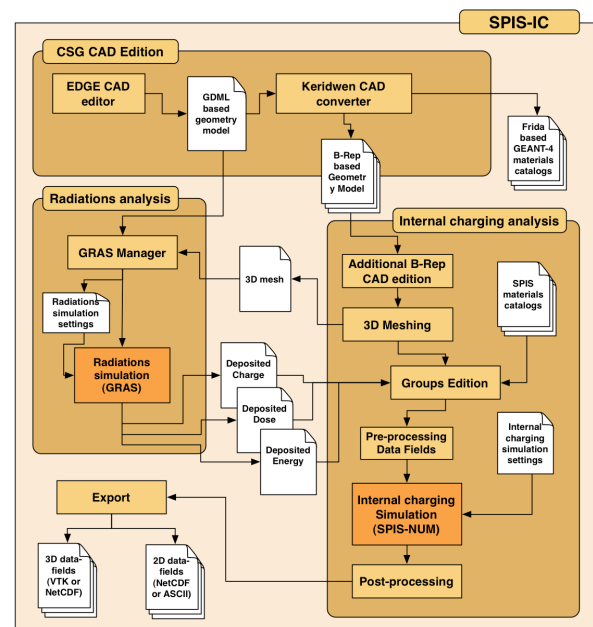


Figure 1 - Global modelling process

Using direct 3D Monte-Carlo models, the GEANT-4 library became with years one of the reference tool for detailed and accurate radiations analysis in the scientific community [1]. Based on GEANT-4, the ESA/GRAS application [2] is a standalone application especially designed for the modelling of the radiations effects of the space environment.

Since 2001, SPIS is widely used for surface charging analysis [4][5]. Open-source and available through the SPINE community [6], SPIS is based on an electrostatic 3D PIC model, SPIS-NUM and an unstructured mesh. In the frame of the several projects, ESA has encouraged the development of new numerical models to compute internal charging effects as well. These efforts, added to ONERA's internal R&D activities, have recently led to a dedicated branch of the software, called SPIS-IC, for Internal Charging simulations. Detailed models are presented in [7].

If previous ESA initiatives, like the Elshield, CIRSOS and 3DMICS projects, have explored the possibilities to interface both simulation kernels, initiate conversion bridges for exchanged data and identify the collaboration scenarios, the global simulation remained still complex and difficult to follow in an industrial context.

In parallel, SPIS already includes its own IME, called SPIS-UI, gathering rich pre and post-processing capabilities, like B-Rep CAD tools, mesher, properties and groups editors. A central data model performs the data exchanges and conversions. A configurable state-machine drives the user step-by-step along the modelling chain.

SPIS-UI is itself based on the multi-purpose and open-source Keridwen solution, developed by Artenum [8]. As a modular toolbox dedicated to scientific computing, Keridwen gathers all needed components to develop tailored IMEs. Designed around a modular architecture, where each functional block is embedded into normalised OSGi bundles, it can easily be extended and adapted to new application fields. Thanks to this technological basis, SPIS-UI/Keridwen was the logical choice as common IME and the present work has focused on the development and the integration of a new GDML CAD editor, EDGE, and a new radiation analysis module based on GRAS into SPIS-IC.

### 3. GEOMETRICAL MODELLING: THE EDGE SOLUTION

The construction of an accurate geometrical description is the first imperative step for a proper simulation of a 3D system. One of the practical limitations regarding the use of GEANT-4 in an engineering context was the lack of reliable WYSIWYG CAD modeller. Indeed,

GEANT-4's geometrical description – and thus ESA/GRAS's one – is based on the specific Constructive Solid Geometry approach (CSG), generally using the GDML format [3]. At the opposite, SPIS, as most of CAD tools, requires a Boundary Representation (B-Rep) CAD model.

To address this issue, a new WYSIWYG GDML editor, called EDGE for Extended Gdml Editor, has been fully developed at Artenum on internal R&D fundings. Based on the CAD module of the Keridwen IME, EDGE can be used as standalone application as well as OSGi bundle in SPIS-UI. EDGE allows loading/saving GDML files but also creating ex-nihilo and editing geometries by simple composition of fundamental shapes defined in the GDML format. The characteristics of each shape (e.g. dimensions, position, orientation...) can be simply set through a dedicated GUI. Geometrical operations (i.e. duplication, translation, rotation) are supported but Boolean one not yet. A Cassandra based rendered [9] allows visualising the result in 3D. EDGE supports hierarchized structures in the composition of geometrical concepts. *Fig. 2* presents a view of EDGE's GUI.

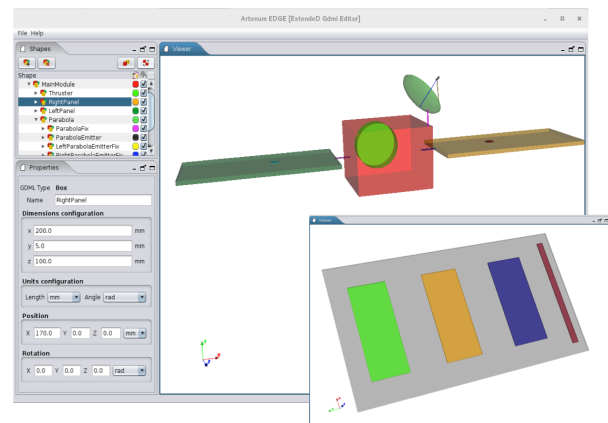


Figure 2 - View EDGE GUI

The generated GDML file is directly compliant with ESA/GRAS but to be loaded into SPIS a conversion into a B-Rep equivalent model is firstly needed. This is performed using the CSG-to-B-Rep decomposition function of Keridwen CAD. In this approach, for each CSG concept an equivalent B-Rep based geometry is associated using pre-defined templates. The CSG-to-B-Rep conversion is then geometrically and topologically exact. Reciprocally, it is also possible to import B-Rep based models, in the Gmsh mesh format, and convert it into GDML. However, in this case, the conversion is done by tessellation of surfaces and then exported into a GDML tessellated solid. This feature also allows to model more complexes geometries not directly supported through the CSG atomic shapes available in GDML format.

#### 4. NEW GEANT-4/GRAS BASED RADIATION ANALYSIS MODULE

To allow a complete radiations/internal charging analysis in a simple and integrated manner, a new and experimental *Gras Manager* bundle has been developed and integrated into SPIS-IC. This one integrates the ESA GRAS tools in a non-intrusive way (i.e. no alteration/modification of GRAS), through a simple system call. The *Gras Manager* includes a dedicated GUI allowing the user to define in an easy way the script file (i.e. mac file) setting the complete GRAS simulation. Several pre-set mac file templates are proposed to help non-expert users. The GDML file initially built using EDGE can also directly be passed and transferred to GRAS. Currently, material properties should still be applied manually by editing the input GDML file, but an improvement of the properties and groups editor of SPIS is planned in a near future. The progression of the simulation is returned to the GUI of the *Gras Manager* for real time control. **Figure 3** shows a view of *Gras Manager* GUI.

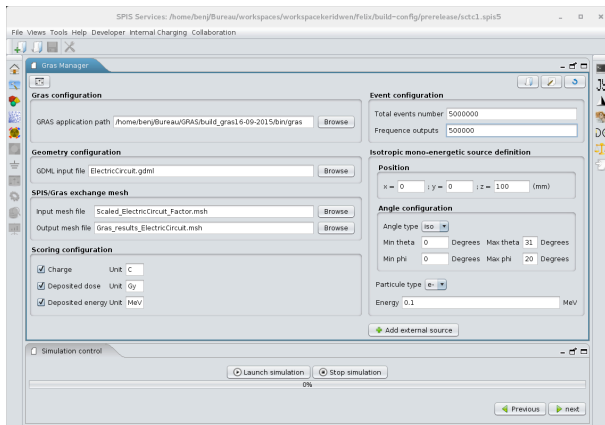


Figure 3 - View of the *Gras Manager* in SPIS-IC

At the issue of the GRAS simulation, deposited dose, energy and charges are converted into fields deployed on the mesh (i.e. data fields). These ones are automatically pre-loaded in the *Groups and Properties Editor* of SPIS, letting the possibility for the user to use them as inputs for the charging analysis with SPIS, as illustrated in **Figure 4**.

The internal charging analysis can then be performed with SPIS-NUM in a similar way than for classic surface plasma interactions, considering that in the present case the computational domain corresponds here to the spacecraft materials themselves and not the surrounding plasma. In order to help the simulation settings, pre-set templates of global parameters are proposed to the user. Last, key outputs, like the electrical field in the dielectric volumes, can be visualised in the post-processing module of SPIS.

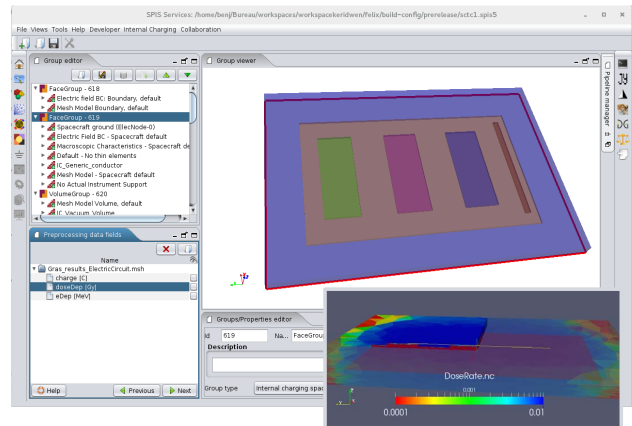


Figure 4 - View of the SPIS Properties and Groups Editor with the previously computed fields as initial conditions for the charging simulation.

#### 5. APPLICATION CASE

Advanced applications cases and models are presented in [7]. But as simple illustration of the internal charging capabilities of SPIS-IC, the radiations induced internal charging of a multilayer printed circuit board (PCB) has been performed. This system is constituted of a classic FR4 epoxy board and a set of metallic patches. The objective of this test is to study the effect of grounded and floating surface patches on flat dielectric samples, simulating at first level the configuration of circuit board configuration. The presence of a grounded patch would strongly affect the lateral and longitudinal electric field configuration in the dielectric material. This configuration should further charge transfer to and on the surfaces. The epoxy sample is 1.5 mm thick and is metallised on its back-face and separated from the sample holder by few millimeters distance.

The GDML is composed of 5 boxes representing the different elements of the motherboard. We have chosen to not represent the sample holder as the tests we planned to do are with electron energy not sufficient to traverse the dielectrics. The charging geometry is the same as in GDML but with a surrounding box which is created to simulate the vacuum outside the motherboard. Two patches are grounded and the two other are left electrically floating (respectively in green/blue and pink/brown in the view of *Groups Manager* in **Figure 4**). The sample has been considered as exposed to sources of electrons with two different levels of energy, 400 keV and 100 keV respectively for the implantation into the material bulk and overall bulk dose injection. In GRAS, the source has been chosen as isotropic mono-energetic at 400 keV and 100 keV respectively. The source is at 100 mm in the +z direction from the sample surface. In order to optimize the calculation, an irradiation maximum angle of +31° has been chosen. In this file, the patches and the wire are in aluminium. The dielectric volume is done in FR4 with a Geant4 material

called “Mat\_FR4”. **Figure 5** shows the deposited dose rate resulting from the simulation with GRAS and considered as input for the charging analysis with SPIS.

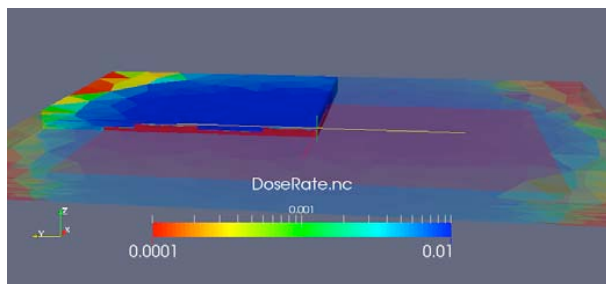


Figure 5 - Deposited dose rate computed with GRAS.

Regarding the charging simulation, six volume materials have been defined: the metal patches and the wire (generic conductor in SPIS); the vacuum (with a zero conductivity); the FR 4 Epoxy. **Fig. 6** presents the evolution of the potential (Volt) versus time (second). Potential sensors IC24 and IC27 correspond to the floating conductors. Charges being evacuated through the dielectric of the epoxy board only and the conductivity of this last one remaining weak, the final potential of the floating patches can reach several thousands volts negative. If the level of deposited energy is high enough and the distance between floating elements and grounded conductors, arcings may potentially occur if elements are not properly grounded. This simplistic example shows that radiations effects may induce significant internal charging whatever the simplicity and apparent rusticity of the simulated devices. This also confirms the relevance of the multi-model approach and a realistic 3D description for such simulations. **Fig. 7** corresponds to the final potential.

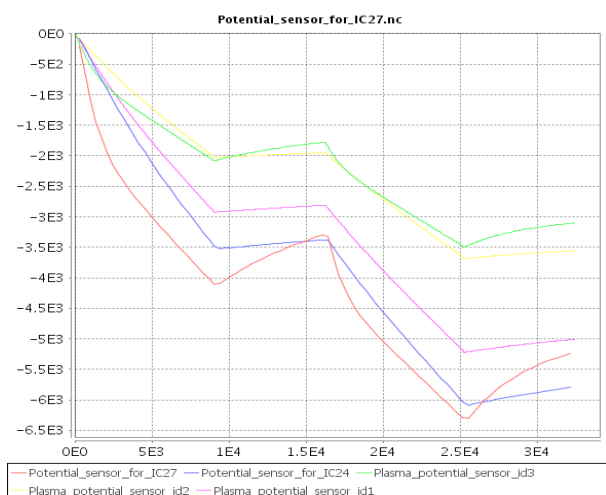


Figure 6 – Electrical potential (Volt) evolution versus time (second)

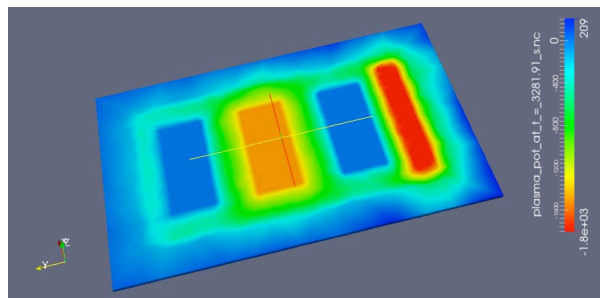


Figure 7 - Final electric potential (Volt).

## 6. CONCLUSION AND PERSPECTIVES

A first experimental integration of radiation analysis tools, ESA/GRAS, and the internal charging simulation core of SPIS-IC into a unified IME has been presented. This work has confirmed the relevance of an integrated approach for a multi-physics modelling, especially in radiations / internal charging analysis. The newly developed GDML CAD editor EDGE contributes to the simplification of the geometrical description for GEANT-4 based simulations and the generation of an equivalent geometry compliant with SPIS-IC for internal charging analysis. Most of these new tools are expected to be available as advanced functionalities in the frame of the ONERA/Artemum SPIS-Services offer ([www.spis-services.eu](http://www.spis-services.eu)).

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