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IMPORTING CAD TO TRIPOLI®

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ABSTRACT

This paper presents the works presently conducted at CEA or in other research organization in the world to import CAD geometries to the TRIPOLI® Monte Carlo code. After having described the problem, we list the approach developed by CEA itself, as well as those developed outside CEA.

Key Words: TRIPOLI, Monte Carlo, CAD, geometry

1. The need of CAD import to Monte Carlo

The available computing power for industry is sharply rising, at always more affordable costs. This makes Monte Carlo simulations for new nuclear projects a more and more attractive tool, even from the design stage. It is generally admitted that up to 75% of the time needed to prepare a Monte Carlo input deck is devoted to actually building the geometrical part of it. Therefore many people from the engineering companies involved in the nuclear business are looking for a convenient way to use their already existing CAD models in their Monte Carlo calculations. This is thought to save time, add reliability, ease the model maintenance over the years, help maintain coherency between the various specialties involved in an engineering project.
CEA for its own needs is considering CAD import to TRIPOLI-4, its reference Monte Carlo tool, for many projects CEA is involved in : the LMJ project at CEA CESTA, the ITER project at CEA CADARACHE, and also generic radiation protection and shielding studies related to the French nuclear energy program.
TRIPOLI-4 [1,2] itself is the fourth generation of the TRIPOLI®[1][2] Monte Carlo codes family developed from the 60's by CEA. This 3D full pointwise code is dedicated to radiation protection and shielding, criticality and reactor physics projects. It is used as a reference tool by CEA, EDF and other industrial or institutional partners, and in the NURESIM [6] European project. It may be obtained from the NEA Databank [7] and RSICC [8].

2. Differences in geometry description for CAD and MC

Although very attractive, this idea is not straightforward to implement. Indeed, the usual process to describe a given scene with a CAD tool is very different from its equivalent in Monte Carlo codes, making difficult any translation from CAD to MC.
The CAD description is usually based on 2D sketchs on which the CAD designer applies 3D operations (extrusion, revolution, etc.) giving birth to *parts* (made of a unique material), then

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[1] TRIPOLI® is a registered trademark of CEA

[2] we gratefully acknowledge EDF support

assemblies made of different parts. Only the solid parts are described, the air volume filling the model is not useful for the generic needs of CAD (such as mechanical analysis). Although gaps and overlaps between parts and/or assemblies are not desirable, they may be accepted depending on the final applications and within reasonable limits. The level of details in the CAD models may be arbitrarily high (up to the bolts !).

The Monte Carlo codes are using either a surface based representation or a combinatorial one, or both. In a pure surface based description, one needs to describe individual cells (single material) by a set of surfaces and rules to define which half-space defined by every surface is used for the given cell. Only simple surfaces are allowed (quadric at most), and limitations are imposed on the description, such as that every points of the cell must be on the same side of each surface used in the cell description (this condition is generally called ‘convexity’). In a pure combinatorial description, the user will rely on a restricted list of predefined types of volumes (such as box, spheres, cones etc.) that are parameterized to the user needs and combined between them by Boolean operators to describe individual cells. Some codes are allowing surface based representation only, others permit the use of combinatorial objects that are *in fine* translated in surface based ones, some do allow a native use of truly combinatorial objects and surface based objects (case of TRIPOLI-4), some are purely relying on combinatorial geometry. In any case it is mandatory that no gaps or badly overlapping cells are present in the geometry, to prevent lost particles in the Monte Carlo calculation. And, an important difference with CAD, the air volume must be defined, to allow particle tracking in it. Finally, one must only represent the cells that are of interest with respect to the physics. A model filled with details of no importance for the particle tracking will be costly, and as run time is already a big drawback of Monte Carlo codes, this point is of huge importance.

A CAD software usually outputs Brep representation, which is representing the outside ‘skin’ of the model, the CAD viewers are especially efficient on these objects. The Monte Carlo tools generally have their own viewers, tailored to their own representation.

3. Example of routes from CAD to MC

A big part of efforts already reported in the world to import CAD to MC is coming from the fusion projects : either ITER, or NIF (DOE) or LMJ (CEA). Additionally, some radiation protection software projects in France and abroad are considering developing this feature in a near future.

In any case, it is necessary to begin from a CAD model that is adequate for Monte Carlo. This means that the model must not be overdetailed (no bolts !), and be corrected for gaps and overlaps. This is a strong assumption. Getting such a simplified and corrected CAD model from a generic one for a whole installation like NIF/LMJ or ITER may cost up to 6 man.month, which is the same order of magnitude as designing the same model from scratch directly in the MC representation (typically 2000 cells built from 5000 surfaces).

From such a model, the two main ideas already developed to import CAD to MC are :

- Development of an algorithm to import Brep to pure surface based representation, compliant with the ‘convexity’ requirement for the resulting cells, and able to ‘reasonably’ generate the air volume [3,4]. The brutal way to get the air volume is to use the complementation operator of the MC geometries, but this usually is highly inefficient with respect to particle tracking.

- exporting the CAD model to a polyhedron based geometry, verifying that the resulting model has all the good convexity, connexity and closeness properties. Then adding to the MC codes the capabilities to track particle directly in this polyhedron based geometry, rather than in its native geometry [5].

Recently CEA has proposed a third way for the LMJ project. Rather than beginning from the Brep, it is possible to extract the embedded building tree from CAD and to convert it to a combinatorial representation.

4. CAD import to TRIPOLI-4 : LMJ approach

CEA CESTA proposed to rely on a generic combinatorial model as an intermediate format between CAD and MC. The GDML standard, from CERN, has been chosen [10]. This format is understandable and editable by a human operator without any CAD software, it is coherent with the CAD building tree, and can handle the description of materials. It also makes possible the successive inclusion of models from CAD to build a more complex one. This generic intermediate format will allow coupling to various CAD softwares in the future, as well as various MC codes.

The import from CAD to MC is made in two steps :

- from the building tree information extracted from CAD : construction of the GDML representation
- from the GDML representation, construction of the MC geometry.

Pro|E, the reference CAD software for LMJ, is the first CAD to benefit from this approach. The building tree extraction and conversion to GDML is done through a dedicated application developed with the Protoolkit, an additional tool available from Pro|E.

Then the GDML model is imported to the Salomé Tripoli software. Salomé Tripoli was initially developed by CEA as a TRIPOLI-4 3D modeller. This tool offers the user a convenient way to describe a full TRIPOLI-4 input deck, not limited to the geometrical part. It is based upon the OpenCascade CAD library, from the Euriware Company [9]. Recently an import/export from and to GDML was added to Salome Tripoli for the CAD import purpose. From the GDML model, Salomé Tripoli is producing a combinatorial native TRIPOLI-4 model.

At present, a first version of the tool has been used on a LMJ CAD model. This model has been produced with MC in mind. Complex shapes such as nurbs are absent in the CAD files.

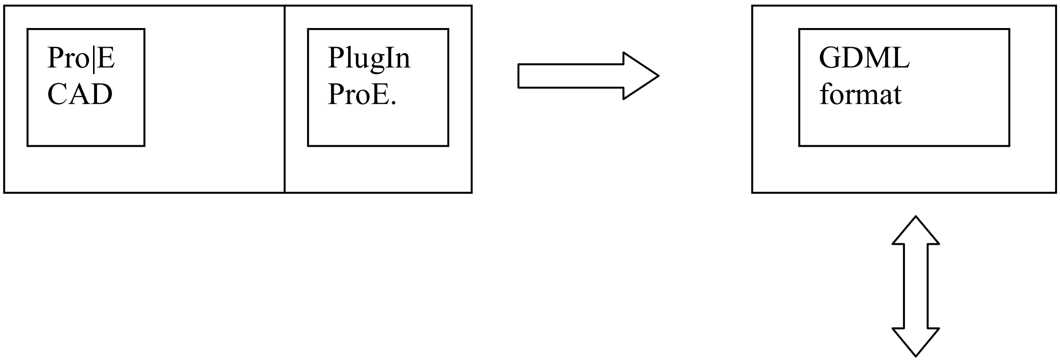
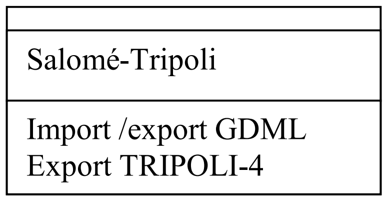
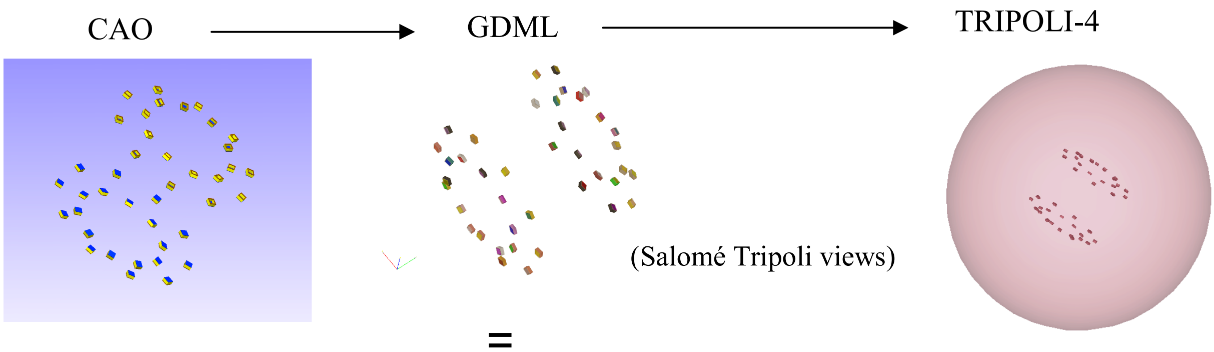


Figure 1 : Overall principle of CAD to TRIPOLI conversion, with GDML pivotal format with an example hereafter



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        <volumeref ref="200A0-1_MT6-ML-IMPAIR_5"/>
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(Part of GDML file)

The Salomé Tripoli tool allows successive imports of GDML files, to build complex scenes: it allows users to translate a single CAD file at a time or to work on multiple files constituting assemblies or even whole systems.

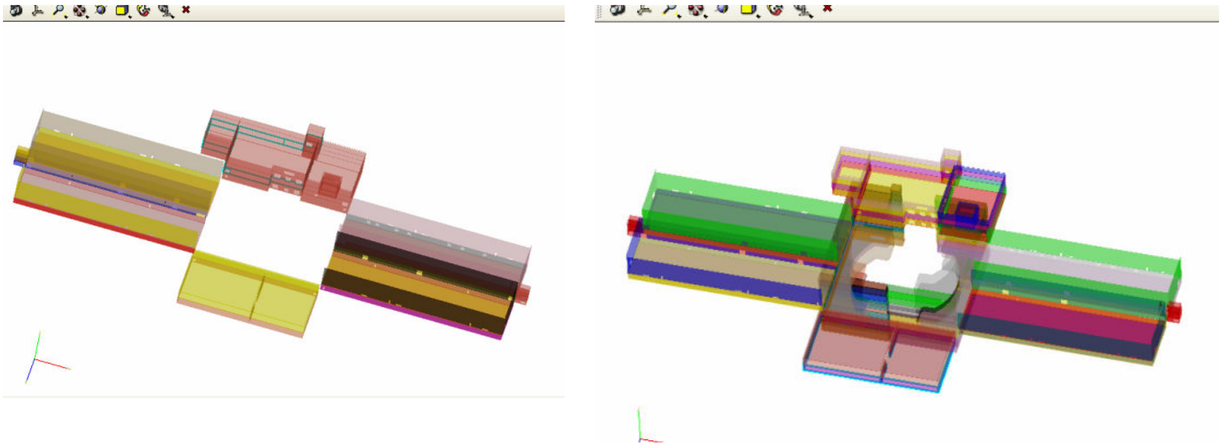

Figure 2 : LMJ halls, northern and southern buildings, GDML model viewed from Salomé Tripoli (left) ; previous buildings plus middle walls, same viewer (right) -courtesy of CEA CESTA-

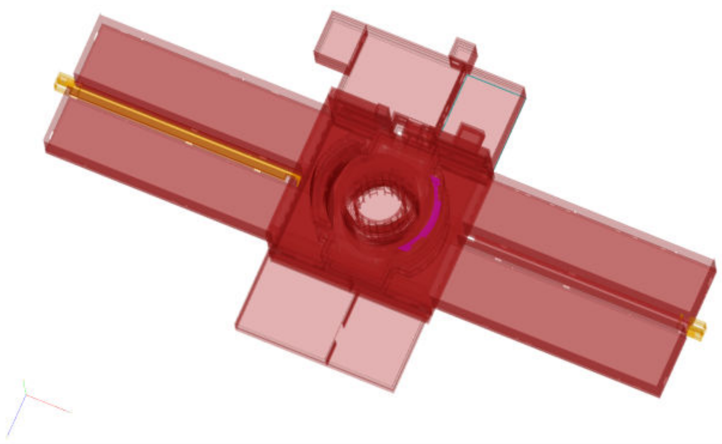

Figure 3 : LMJ building, GDML model viewed from Salomé Tripoli (courtesy of CEA CESTA)

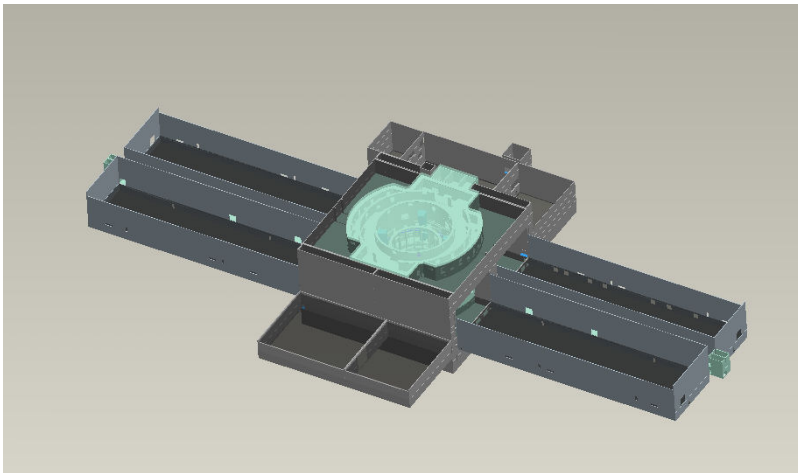

Figure 4 : Pro|E CAD model of LMJ (courtesy of CEA CESTA)

The translated files may be inspected graphically and modified if necessary (manually in the GDML file, or with Salomé Tripoli GUI).

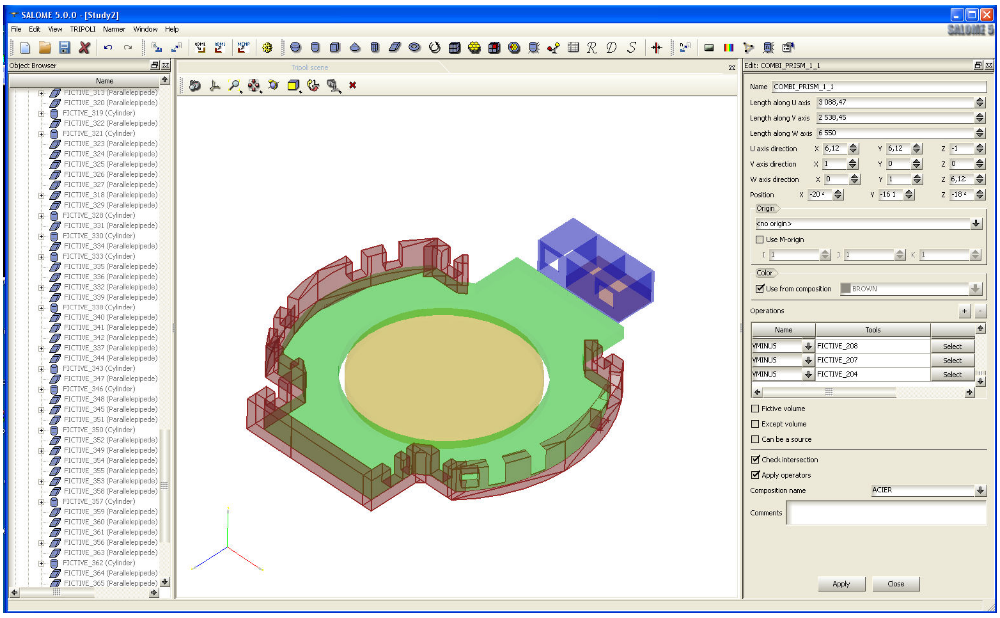

Figure 5 : Salomé Tripoli GUI (courtesy of CEA CESTA)

5. CAD import to TRIPOLI-4 : polyhedron based approach

In this approach a CAD file is exported into a polyhedron representation, and then this polyhedron representation is directly used in the tracking of the particles. To do that, it is necessary to couple TRIPOLI-4 and a polyhedron based geometry package. An important work has been done within TRIPOLI-4 to write a graphical API, enabling us to couple any third party library allowing the particle transport, which basically amounts to answering the three following questions : what volume is a particle in ?, what is the next volume the particle will be in ?, what distance is a particle from the next surface ?
In the second semester 2009 CEA and EDF will couple TRIPOLI-4 and an external polyhedron based geometry package (from EDF). The final application is a standalone radiation protection application that will be coupled to a data base of scenes available in a polyhedron representation.

6. CAD import developments outside CEA

6.1. The MCAM approach

MCAM [3] is a CAD/Monte Carlo interface developed by the FDS team of the Institute of Plasma Physics, Hefei, China. The three steps followed are decomposition, filling void spaces and then generating TRIPOLI-4 surface representation. The TRIPOLI-4 capability has been added in version 5 of MCAM, and actual TRIPOLI-4 runs have been successfully performed on a TRIPOLI-4 model of ITER, converted from a CATIA CAD file, as shown on figure 3

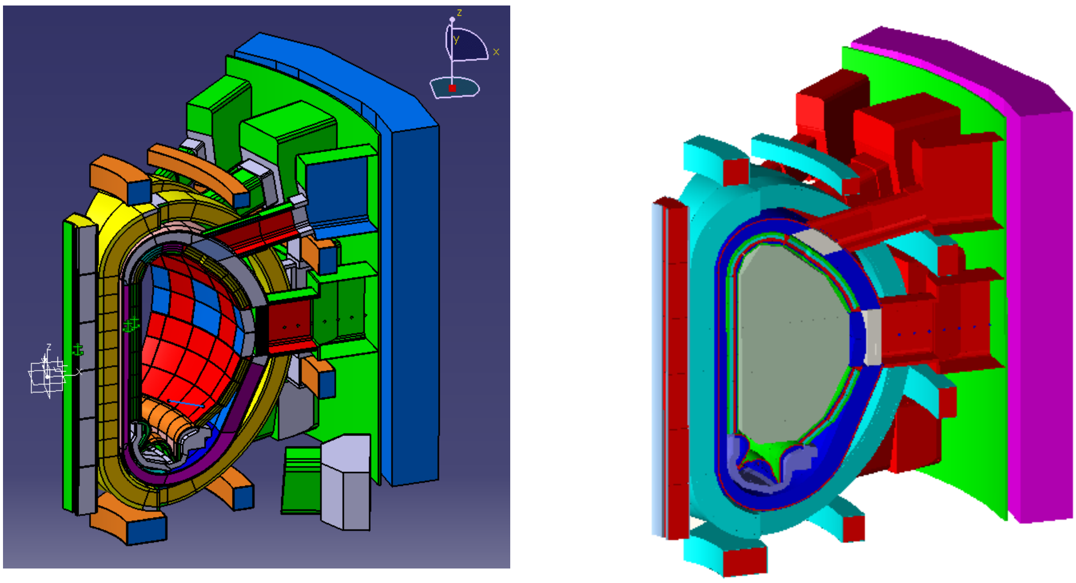

Figure 1 : ITER, 40° sector, left CATIA CAD model, right TRIPOLI model viewed in MCAM version 5, courtesy of ASIPP, FDS team

6.2. The McCad approach

This approach is developed by KIT. From a theoretical algorithm described in the reference [4], they propose the McCad software to import CAD data (BRep) to MCNP (surface based representation). This tool has been successfully used to import CAD CATIA model to MCNP5 [11]. Extension to TRIPOLI-4 surface representation is scheduled in the frame of the NURISP European project where both KIT and CEA will participate.

5. CONCLUSIONS

CAD to Monte Carlo is an important subject of both R&D and software development. Due to ever increasing computing power, MC is continuously gaining users in the nuclear industry. In return, the nuclear industry is willing to use its CAD models for MC calculations. This is not straightforward for many reasons:

- 2D sketchs and 3D operators for CAD, surface based or combinatorial representation for MC
- implicit air volume in CAD, explicit in MC, with ‘convexity’ rules
- level of pertinent details possibly very different
- CAD is more gap and overlap tolerant than MC
- CAD specialists and radiation protection specialists from 2 different worlds

A lot of efforts has already been devoted to this task, particularly in the fusion projects (ITER, NIF, LMJ). Generally two kinds of approaches are followed :

- traduction from Brep (CAD) to surface based representation
- direct MC tracking of particles in a polyhedron based geometry, exported from CAD.

These approaches have given good results on the reference ITER CAD model.
CEA is following a third way, based on the extraction of the CAD building tree and translation in a pivotal combinatorial format GDML, followed by an export to MC (eg combinatorial TRIPOLI-4). Some promising results are reported on a whole LMJ model (same complexity as ITER).
These results are very encouraging, but continuing efforts must be put on the subject to ensure that every kind of CAD model may ultimately benefit from this feature, and not models produced from the beginning with MC application in mind. Validation of computation efficiency on a real calculation case is presently studied.

REFERENCES

1. O Petit et al, “TRIPOLI-4 version 4 User Guide”, CEA-R-6169 (2008)..
2. JC Trama et al, “New features of TRIPOLI-4 version 5”, *International Conference on Radiation Shielding*, Pine Mountain, GA, USA, April 2008
3. L.Lu et al “Bidirectional Conversion between CAD Model and TRIPOLI Model : An Extending Function of MCAM”, *International Conference on the Physics of Reactors*, Interlaken, Switzerland, September 14-19, 2008.
4. H Tsige-Tamirat, U. Fischer, “CAD Interface for Monte Carlo Particle Transport Codes”, *The Monte Carlo Method: Versatility Unbounded in a Dynamic Computing World,* Chattanooga, TN, USA, April 17-21 2005

5. Timothy J. Tautges, "The Common Geometry Module (CGM): a Generic, Extensible Geometry Interface", *9th International Meshing Roundtable*, SAND2000-2207, Sandia National Laboratories, pp. 337-347, October 2000
6. www.nuresim.com
7. www.nea.fr/abs/html/nea-1716.html
8. www-rsicc.ornl.gov/
9. www.opencascade.org/
10. gdml.web.cern.ch/GDML/

11 http://mcnp-green.lanl.gov/index.html