EGS_Mesh: accurate radiation transport simulations in CAD meshes with EGSnrc

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Purpose: EGSnrc is a reference software for Monte Carlo simulation of radiation transport [1]. In the medical physics community, there is growing interest for tetrahedral mesh models as an alternative to conventional rectilinear voxel grids for modelling the human body with fewer, better conforming, and deformable geometrical elements. The general-purpose tetrahedral mesh library EGS_Mesh was implemented in EGSnrc to simulate radiation transport in such phantoms. This new library has immediate applications for simulating radiation transport in any mesh derived from industrial CAD models as well.

Methods: Results of EGSnrc calculations for absorbed dose in a tetrahedral mesh were compared against values obtained in an equivalent voxel representation. The new EGS_Mesh geometry was further validated using: 1) a strict Fano test to detect any deviation from theoretical transport equations; 2) a comparison of multiple-scattering and single-scattering transport to detect any issue with the boundary-crossing algorithm.

Results: Absorbed dose results for EGS_Mesh and the voxel geometry were found to agree within the statistical precision of the simulations. The EGS_Mesh simulation was 2–3 times slower compared to an equivalent voxel grid with a similar number of elements. A Fano test using a 2 MeV electron source was conducted on a tetrahedral mesh comprising roughly 1000 elements, which proved successful at the 0.1% uncertainty level. The multiple-scattering and single-scattering results were also found to agree within statistical precision.

Conclusions: EGS_Mesh has passed a number of stringent validation tests against established rectilinear voxel geometries and radiation transport theory. Being able to simulate tetrahedral phantoms heralds more complex scenarios using EGSnrc, such as dose calculations using the ICRP 145 reference human phantoms [2] (see Figure 1). EGS_Mesh also enables comparison with and validation of other major transport codes that handle tetrahedral meshes (Geant4, MCNP6, and PHITS). De facto, EGS_Mesh enables importing CAD models into EGSnrc for industrial applications.

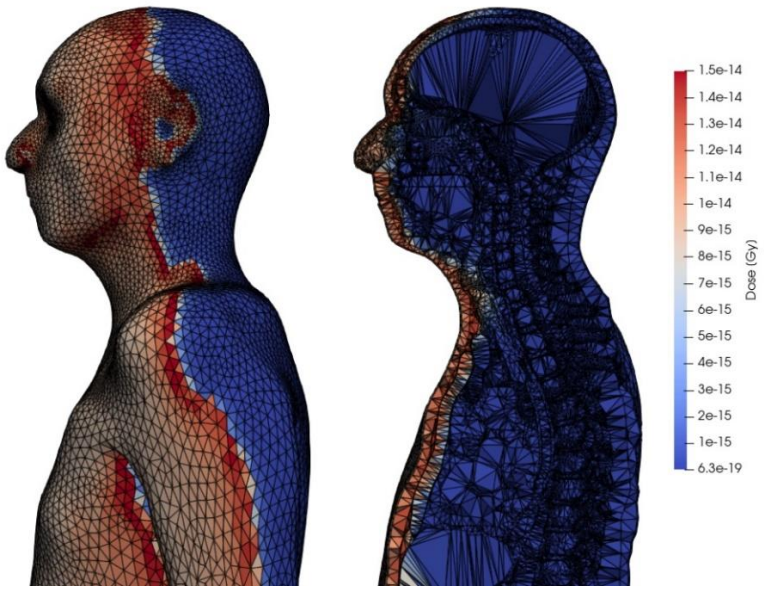

Figure 1. Preliminary EGS_Mesh results for the ICRP 145 adult male phantom (8.2 million tetrahedrons) exposed to a broad parallel 5MeV electron beam incident on the front of the phantom in vacuum.

Relevance to CIRMS: The new EGS_Mesh library allows both industrial and academic users to simulate CAD geometries in a tetrahedral mesh representation using EGSnrc. Modelling such geometries using constructive solid geometry techniques is error-prone and laborious, and EGS_Mesh offers an alternative method for simulating complex geometries without requiring simplification or loss of modelling fidelity. This work relates to the medical and industrial applications CIRMS focus areas by allowing researchers to simulate ever more complex computational phantoms. This work is part of the first author's master's thesis research, who aims to become a research scientist.

References:

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2. ICRP. "Adult mesh-type reference computational phantoms". ICRP Publication 145. *Ann. ICRP* 49(3) (2020).