White Paper
3D Geometry Visualization Capability for MCNP

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1 Introduction

The purpose of this white paper is to demonstrate the need for a 3D visualizer and graphical user interface for the Monte Carlo n-Particle (MCNP®) code. Advancing the state of the art in this area is expected to benefit analytic skill set development (improving human-technology interactions) improve coordination among researchers, reduce errors and biases in decision making and improve efficiency in the engineering/design workflow. For development efforts like this to succeed, close coordination between the software development team who maintain the capabilities of legacy codes such as MCNP and with specialists in software for human perception and cognition is necessary to maximize the usability of the aggregate suite of applications that are produced.

MCNP has been under active development at Los Alamos National Laboratory (LANL) since the mid 1940s and is now the gold standard among radiation transport codes. MCNP enjoys a user based of over 12,000 engineers and scientists around the world who have used it to analyze virtually every nuclear reactor and radiological facility in existence today. MCNP is routinely used for applications ranging from nuclear reactor design, radiation shielding, nuclear well logging, health physics, criticality safety to nuclear safeguards. Historically, the majority of development funding for MCNP has been focused on analytical methods and adding capabilities for representing nuclear physics phenomena, which has left minimal resources for modernization of the geometry and data visualization tools that engineers use while building 3D geometry models and interpreting the data produced during MCNP simulations.

The primary method of modeling geometry in MCNP is to combine analytical surfaces (planes, cylinders, spheres, toroids, cones, etc.) using Boolean logic to form 3D solid geometries in a process known as constructive solid geometry (CSG). MCNP uses the resulting 3D geometry model for three purposes: first to describe the position and shape of radiation sources that emit particles that are then tracked through 3D space, second to define the distribution of materials in that space which the radiation interacts with in its path, and finally to describe tally locations which are areas where engineers and scientists need to know how much and what type of radiation is present. The primary benefit of the CSG method is computational efficiency for tracking particles through modeled equipment. Also, for many geometry models exact representations can be constructed using the CSG technique rather than approximate geometry representations based on meshes. Finally, CSG models are built on relatively simple surface descriptions using human-readable text files. As such, the models can be easily updated and rerun for parameter/sensitivity studies which are particularly important in criticality safety analyses but also useful in iterative design processes where design parameters are regularly changing. The disadvantage of CSG is that MCNP currently only supports a 2D plotter to visualize these 3D models.

Los Alamos National Laboratory recently added the capability to describe geometry with unstructured mesh (UM) models in addition to the CSG method. The benefit of this new capability is that geometry can be built in modern computer aided design (CAD) tools like SpaceClaim, SolidWorks or AutoCAD all of which have 3D graphical interfaces that enhance the visualization of the geometry. Once the geometry models are completed they can be converted to a mesh format using commercial-off-the-shelf (COTS) meshing software like Attila4MC or ABAQUS and then used with MCNP. Unstructured mesh geometry is ideal for modeling complicated equipment that may not be well described by the supported surface types in MCNP (like swept compound curves) or where there are many fixed geometry features in the area of interest (like the facility in which a radiation source assembly is to be studied). The UM model can then be used by itself or in conjunction with CSG models to describe the location and shapes of sources, material, and tallies through which radiation can be tracked and analyzed. The visualization problem comes up again with this type of geometry as soon as the mesh model is read into MCNP where again there is only a 2D plotting capability. Therefore, verification of details like material assignments to space or the spatial relationship of meshed and CSG models has to be done by viewing multiple 2D slices through the aggregate 3D geometry model (a process that is tedious, time consuming, and error prone).

2 Current State-of-the-Art

To demonstrate the currently available geometry visualization capabilities of MCNP, a hybrid UM CSG model of the White Sands Fast Burst Reactor (WSFBR) facility in the White Sands Missile Range in southern New Mexico will be shown. To give understand the size and complexity of the facility being modeled, a Google Maps bird's-eye view of the facility is shown in Figure 1. The notable features evident in this picture include an earth mound, a few buildings, and a covered ramp structure.

Figure 1: Google Maps View Showing the White Sands Fast Burst Reactor Facility

Figure 2 shows a 3D CAD representation of a model that was built of the WSFBR facility and Figure warented3 provides a view of the corresponding UM model that was constructed from the CAD model. Together Figures 2 and 3 show the state-of-the-art design and engineering geometry visualization and analysis tools that are able to be run on standard desktop workstations. These models provide a great deal of visual information about the whole model in a single view. The CAD and UM geometry are also easily to visualize from multiple angles by panning, zooming, and rotating the model to gain even further insight. Figure 4 shows the 2D plotting capability of MCNP's current version, which is obviously far from the level of sophistication for state-of-the art engineering software. That being said, the MCNP plotter does do something that the more-advanced CAD-style visualization software packages cannot currently do: it can interpret and overlay MCNP CSG and UM geometry along with radiation transport results on the same plot. There are currently software packages, such as TecPlot and TranzViz, that have the ability to overlay the UM geometry and radiation transport results but currently the MCNP plotter is the only known utility that will accommodate all three (albeit only in 2D). The 2D MCNP plotter also does a good job of providing the engineer insight into the interior structure of the model, at least in the slice that is displayed. Note that this is a challenge for many mesh geometry viewers.

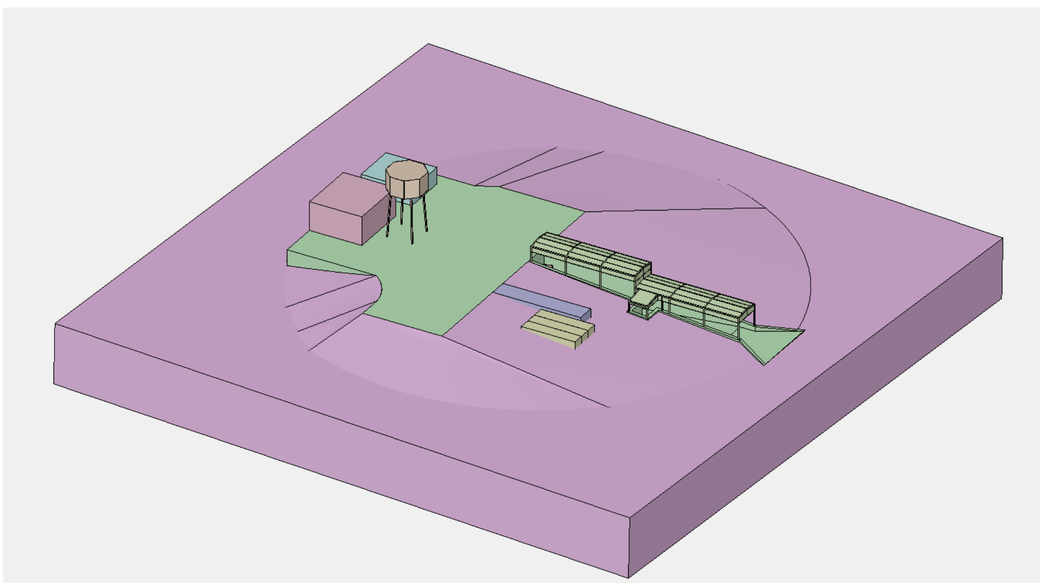

Figure 2: CAD Model of the White Sands Fast Burst Reactor Facility

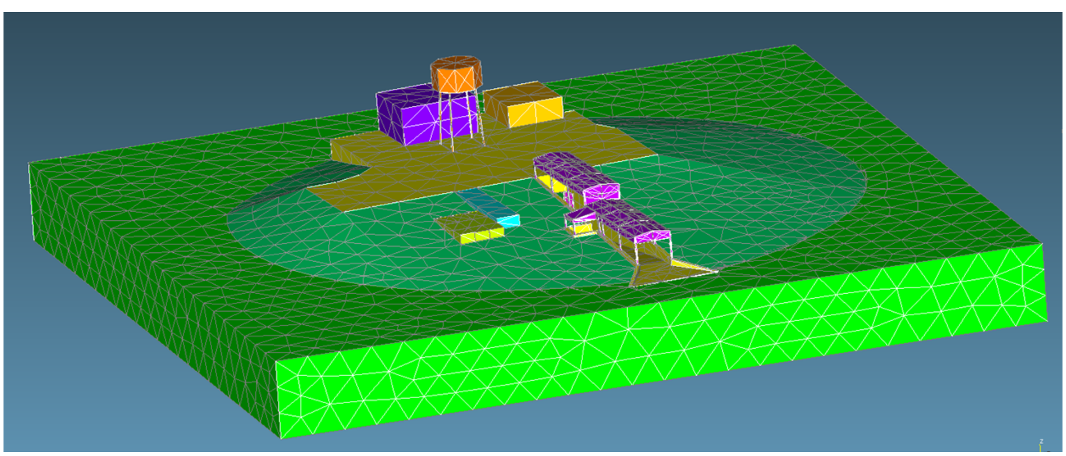

Figure 3: Visualization of Meshed Model of the WSBR in Attila4MC

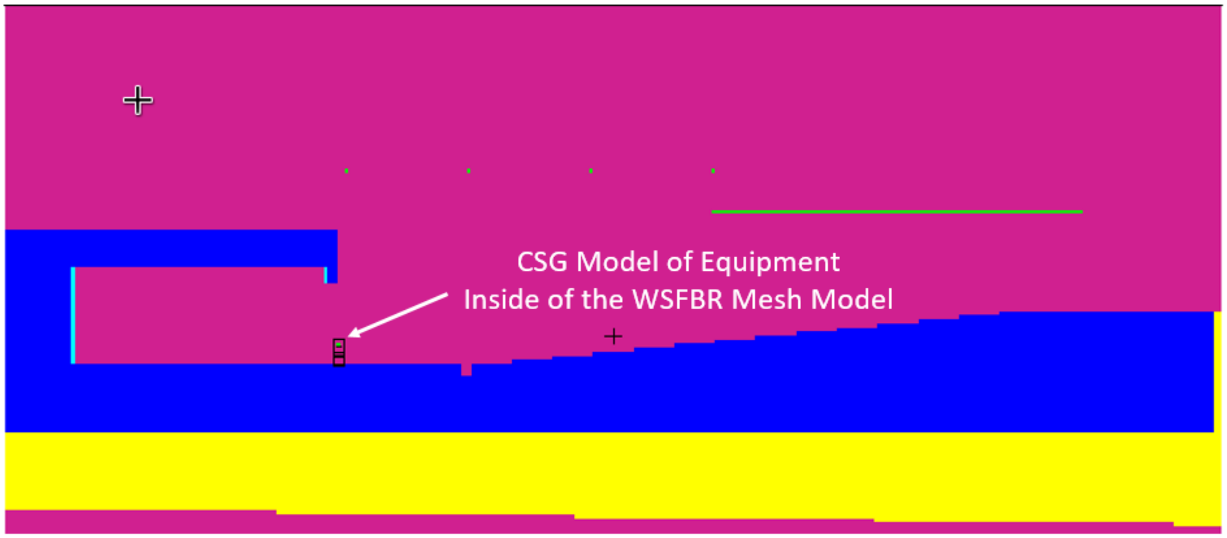

Figure 4: 2D Plot of the MCNP Model of the WSFBR Facility

3 Proposed Work

The work proposed here is to construct a single 3D geometry visualization tool with a well developed graphical user interface that has the ability to display CSG and UM geometry as well as source information and tally results. This could be done in many ways, but to reduce development time/cost and catch up to the state-of-the-art in the shortest possible time it is recommended that this tool leverage existing COTS CAD style geometry visualization technology to the greatest extent possible. The key features of this tool should include:

- 3D plotting of CSG, UM geometry, sources, and tallies and the ability to pan, zoom, and rotate the geometry model by the user in real time,
- The tool should be able to read MCNP tally output files so contour plots of radiation transport simulations can be overlaid on top of the geometry to maximize the contextual understanding of what is going on in the simulated radiation field,
- An ability to extract 2D slices at arbitrary planes in the 3D geometry that can be selected via the tool's graphical user interface (GUI) so the interior structure of the model can be quickly assessed,
- An ability to select and interrogate model parts and get information about materials properties as well as surface definitions that were used to define the part, and
- An ability to color the parts by material type as well as the ability to easily change the colors of a given material.

A stretch goal for this effort would be for the tool to incorporate a text editor so CSG could be developed and displayed in real time which would dramatically streamline the MCNP modeling workflow (which currently iterates between working in a text editor and the 2D MCNP plotter). Additional work may also be warranted to improve the human readability of the MCNP input file itself in conjunction with the visualization effort proposed here.

4 Conclusion

A software development effort relevant to the social and behavioral sciences is warranted to improve the usability of MCNP, which will enhance scientists, engineers, and health physics professional's ability to make good design and treatment decisions respectively. The primary benefits of such a tool would be a significant improvement in the human-MCNP-technology interactions by increasing the user's ability to extract information for the simulation data that is displayed in the context of the spaces they are modeling. This tool would also have the effect of reducing geometry definition errors and improving the engineering analysis workflow, which has the potential to dramatically reduce costs. Finally, this tool to would facilitate knowledge transfer from senior staff scientists in the greater nuclear engineering community who have constructed legacy MCNP models over the course of their careers to the next generation of engineers and scientists who will need to maintain them.