High Performance Computing Simulations of Radiation Shielding with GEANT4: Simulating Space Radiation Environment. M. L. Lund,[1] C. Lambert[2], and T. Jevremovic[1], [1]University of Utah Nuclear Engineering Program matthewl.lund@utah.edu [2] Riverton High School

Introduction: The Apollo moon missions spacecraft radiation shielding consisted of the aluminum hull of the spacecraft protecting astronauts from galactic cosmic rays (GCRs), solar particle events (SPEs), and the Van Allen Radiation Belts. The prediction of dose rates for astronauts was difficult without the ability to make precise computationaly heavy simulations of the radiation environement. Currently several codes exist for modeling radiation transport such as HZETRN, HETC, FLUKA [1], CREME96 [2], and GEANT4 [3], which use different numerical methods or Monte Carlo methods analyzing just the shielding as a single sheet without the whole spacecraft. The European Space Agency (ESA) has developed several applications based on GEANT4: MULASSIS, GRAS, and SPENVIS for estimating dose rates; however, the DESIRE Project [4] is the only GEANT4 application to extensively model dosmetric data for astronauts using the complete geometry of a spacecraft for the effects of secondaries. The DESIRE Project was ran on a small cluster of 10 AMD Athlon 1667 MHz, single thread. This abstract presents the use of GEANT4.10 on a high performance computing cluster with new multithreading support and Open MPI to simulate dose rates for astronauts with new shielding materials and full size spacecraft geometry.

Methodology: We are currently studying three aspects of radiation shielding modeling: investigating possible new shielding materials using REMSIM [5], recreating the DESIRE study, and simulating the Apollo moon missions using GEANT4, all in a multithread and Open MPI multinode computer cluster. The Center for High Performance Computing at the Universitybuilt GEANT4 version 10.0, GDML support [6], Root [7], and MPI libraries on the Ember Cluster, which has 262 dual socket six core nodes with 2.8 GHz Intel Zeon Westmere X5660 processors using a Mellanoz QDR infinniband interconnect [8]. After initial testing, verification, and benchmarking, we built applications running on the Ember cluster for Open MPI and multithread.

New Shielding Material Simulations using REMSIM. REMSIM uses a particle source with a GCR or SPE spectrum passing through layers of shielding material into a water phantom (simulating a human body) for dose calculation. The existing REMSIM example in GEANT4.10 was converted to MPI and multithread. Using REMSIM twenty different shielding materials were simulated including several new materials not currently used in space missions: polyethylene, polyacrylate, borated polyethylene, crystalline boron nitride nanotubes, carbon fiber, and several different long polymer chains. Polyethylene and long polymer chain composites were choosen because of the high hydrogen content, which requires less collisions to slow down high energy particles. Boron-10 was selected for its high cross section for neutron absorption. Each material was tested with a thickness of 1 cm. The dose from each material was divided by the dose for no shielding to create a shielding effectiveness.

Recreating DESIRE Project. An application using GDML for geometry, QBBC physics list, and the sensitive detector class were created for multithread and MPI. Currently initial simulations are being created to benchmark against the DESIRE study to recreate the dosimetric data from the International Space Station. The same application will be used for Apollo studies. New simulations are currently using the DESIRE geometry in GDML (Geometry Descriptive Markup Language) format to validate the physics process of the new QBBC and QGSP_BIC_HP physics list along with testing the precission of multithread and multinode simulations.

Simulating the Apollo Mission. Geometry of the Apollo Command Module and Lunar Lander were created as GDML. The modeling of the Apollo mission is being broken down into separate stages for dose calculations: Low Earth Orbit (LEO), Van Allen Belt, lunar transit, and lunar surface. The individual dose rates for each segment are tallied and then summed across the segments to create a total dose for the astronauts that can be compared with literature available dosimetric data based on the TLDs' readings [9].

Results: Initial studies of shielding materials resulted in reduction of dose using nomex, Nextel, boron nitride, mylar, polyethylene, and borated polyethylene. Nextel and nomex are both used currently in Micometeroid and Orbital Debris shielding (MMOD) for the Interntaional Space Station. Boron nitride also performed well in reducing dose as shown in Figure 1. with negative signs representing a reduction in total dose. Boron nitride is the component of boron nanotubes, which could be used as a structural material.

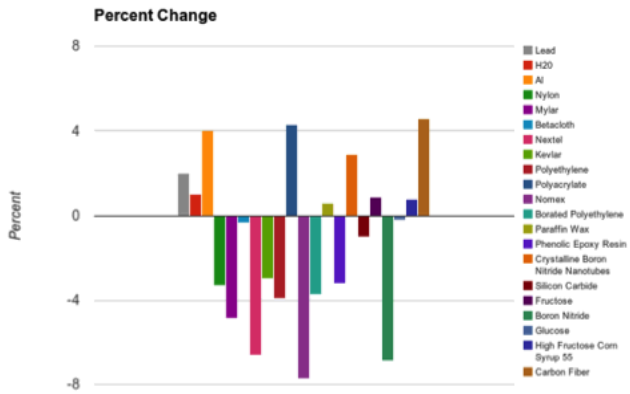

Figure 1: Shielding Effectiveness

The original GDML geometry files for the DESIRE project were benchmarked for performance on the Ember cluster using a GCR spectrum [10]. Ember ran the simulation of 1,000,000 particles multiple times using the QBBC physics list with eight threads in 62% of the time required to run on an Intel i7 2.0 GHz processor as shown in Table 1.

Table 1: Runtime Comparison

1,000,000 Particales	*Runtime (s)*	*Standard Deviation*
Ember 2.8 GHz	339.1	0.3
Intel i7 2.0 Ghz	546.6	25.7

The QGSP_BIC_HP physics list required more runtime with increasing number of threads due to the need to load cross section libraries in each thread. The materials referenced within the geometry required the physics list to find alternative cross sections requireing substantial more time. However, the QBBC physics list showed a decrease in computational runtime for 1,000,000 particles with the number of threads as can be seen from Figure 2.

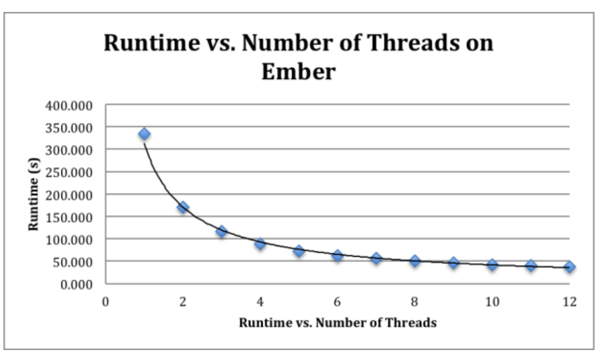

Figure 2: Runtime vs. Number of Threads on Ember

Discussion: Initial runs in GEANT4.10 with multi-threading and Open MPI on Ember have significntly increased the speed of simulation; however, currently dose rate is output by each individual node requiring summation. Further improvement in the application will allow for better analysis tools combining the data across nodes into a single output file allowing for faster data analysis.

Further study will include benchmarking and validatating the precission of the physics within the simulations. Comparison results with DESIRE project will validate the physics processes. Currently GEANT4 has no built-in error analysis similar to MCNP tally calculations of standard deviation, variance, relative error, and figure of merit, thus an error module for this application will be developed.

The next step in analyzing and optimizing new materials for radiation shielding will focus on varying thickness of materials, their combinations, and analysis of the effects of secondary particles generated due to primary interactions. Also the current model does not account for buildup effects. Ideal combinations of shielding material(s) will then be simulated on future spacecraft such as the Orion capsule to simulate astronaut dose rates during different radiation conditions for effectiveness and compared to Appolo missions.

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