Shielding benchmarks for Geant4 version 10

Tatsumi Koi on behalf of Geant4 collaboration
SLAC National Accelerator Laboratory, US

Abstract

Geant4 is a toolkit for the simulation of the passage of particles through matter. To show its capability in the shielding area, we have submitted Geant4 results for the "Inter-comparison Problems of Neutron Attenuation" to SATIF organisers since 2006. Version 10 is the latest and major update of Geant4 and has been publicly available since December 2013. We have validated the version against shielding benchmarks that were proposed in the past inter-comparison projects and obtained good agreement between measurements. A newly introduced INCL++ based physics list shows promising physics performance, however, it requires more CPU resources than others. The version supports multi-threaded application and multi-threading performance was tested with the SATIF-12 inter-comparison project. Computing time of same calculation is measured changing the number of threads used in calculation. The time decreased along with increase of number of thread. Power law index of -0.9 was obtained for the fitted curve. We also measured memory consumption and found that 80% of memory was shared among threads at initialisation time. Using multi-threaded application makes it easy to use full CPU resource of modern machines with less amount of memory.

Introduction

The Geant4 toolkit [1][2] provides a complete set of class libraries for Monte Carlo simulations of particle interactions in matter. It is used in many research fields and to demonstrate its capability in radiation protection and shielding calculations, we have participated in the "Inter-comparison" project since SATIF8 [3-5]. Utilising outputs from the project, we have developed a physics list of Geant4, dedicated to shielding application. The physics list is called as "Shielding" and it has been included in releases of Geant4 since version 9.4. Users can easily apply it in their shielding applications.

Geant4 version 10 is publicly available since December 2013 and it is the first major update of Geant4 in 7 years. Because it is a major update, there are many new features. Some of the new features relevant to shielding applications are described in the next section. Shielding benchmarks using Geant4 10.00 will be shown in the following section, as well as comparisons to thick target measurements. Supporting multi-threaded application is one of most important feature of this version. We will show the performance of multi-threaded application that we use for submitting the "inter-comparison" project of SATIF-12. Finally, we will give conclusions of shielding benchmarks for Geant4 version 10 from physics and computing performance views.

Geant4 version 10

Geant4 version 10 is the latest version of Geant4. Since this is a major update, many new features have been added to the release. However, there have been some discontinued features and also interface changes. As a result, user code may need to be modified. Some of the new features and updates of version 10 will be described.

Support for multi-threaded Geant4 applications is one of the key features of this version. Clock up of CPU becomes difficult for a decade and these days improvement in computing performance mainly comes from an increase in the number of CPU cores. Multi-threaded application enables the easy use of the entire CPU resource of the machine easily. Another advantage of multi-treaded applications is the possible usage of shared memory among threads. Using such shared memory for unchanged objects in simulations like geometry, physics table etc. reduces the total memory expenditure. Reducing memory consumption becomes important especially in many-core CPUs. We will show performance of an example of multi-threaded application in a later section.

Concerning physics developments, the Fritiof (FTF) model has been extended to handle nucleus-nucleus collisions from 3 GeV per nucleon and above. Geant4 now provides interaction models for almost all energy regions and species of Galactic Cosmic Ray. This will be beneficial to users of space applications. G4Nuclide Table has been introduced for collaboration work among models in the production of isomer and its decay. State data of the table are derived from ENSDF database. The Gheisha-like parameterised models LEP/HEP have been removed and more sophisticated models have been provided to replace them. New physics lists making use of the INCL++, a C++ version of the INCL cascade model, have been introduced. Choice of cross-section data set for various particles in reference physics lists has been improved in the two public releases immediately following the SATIF-11 meeting. Now most reference physics lists use a selection of data-sets similar to the shielding physics list.

Benchmarks for shielding applications

The first benchmark uses data from the BNL AGS shielding experiment [6]. In this experiment, 2.83 GeV and 24 GeV proton beam irradiate a mercury target. Secondary neutron fluences in the shielding material of concrete and iron were measured through activation of Bi samples embedded in the shielding. This measurement was employed in the inter-comparison projects at SATIF-9 and SATIF-10. The reaction rates of ^{209}Bi(n,4n)^{206}Bi and ^{209}Bi(n,6n)^{204}Bi were provided by the coordinator of the inter-comparison and the same reaction rates are used in our benchmark. Figure 1 shows the result of Geant4 version 10 with the shielding physics list. The agreement between simulation and measurement is very good especially in iron shielding. We performed the same benchmark with other reference physics lists in Geant4 version 10. The result with FTFP_INCLXX physics list, which uses INCL++ as cascade model, is shown in Figure 2. The agreement of FTFP_INCLXX in concrete shielding is even better than the shielding physics list that uses the Bertini-like cascade model. We also compare computing performances across the reference physics lists. Figure 3 shows the result. FTFP_INCLXX and QGSP_INCLXX, both of which use the INCL++ as cascade model, and require more CPU resource than other physics lists. The INCL physics lists expended most CPU time, followed by shielding. However, the shielding list is slow mainly because the high precision neutron model is used for low-energy neutron transport. The remaining reference physics lists tested were faster.

The second benchmark was a comparison against measurements of neutron production double differential cross-sections induced by protons bombarding a thick target. The configuration of this benchmark is similar to the problem of "Inter-comparison" project of SATIF-12. The benchmark result from FTFP_BERT, QGSP_BIC and FTFP_INCLXX physics lists are shown in Figure 4 with measurement of Ishibashi et al. [7]. The main difference among these physics lists is the cascade model used (Bertini-like, Binary cascade and INCL++). There are some differences in predicted cross-sections especially at high-energies, however; all three physics lists well reproduce the measurement in general. Because the target was a short disk perpendicular to the beam axis, strong attenuation at 90 degree was expected and observed in the simulation. However, this was not observed in the measurement.

All calculations in this section were performed with Geant4.10.00.p01.

Figure 1. Validation of result of shielding physics list to BLN AGS experiment

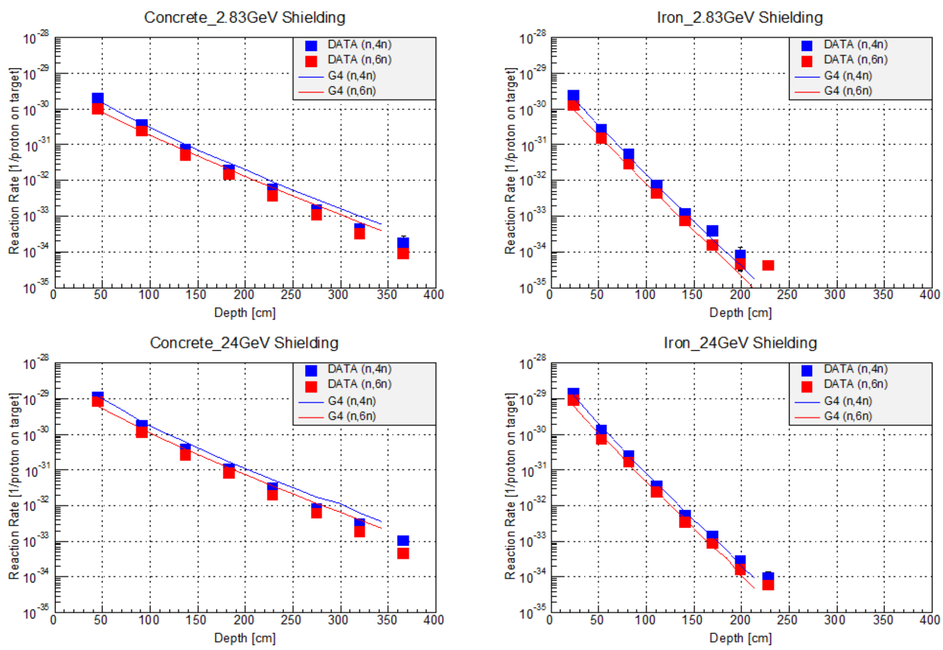
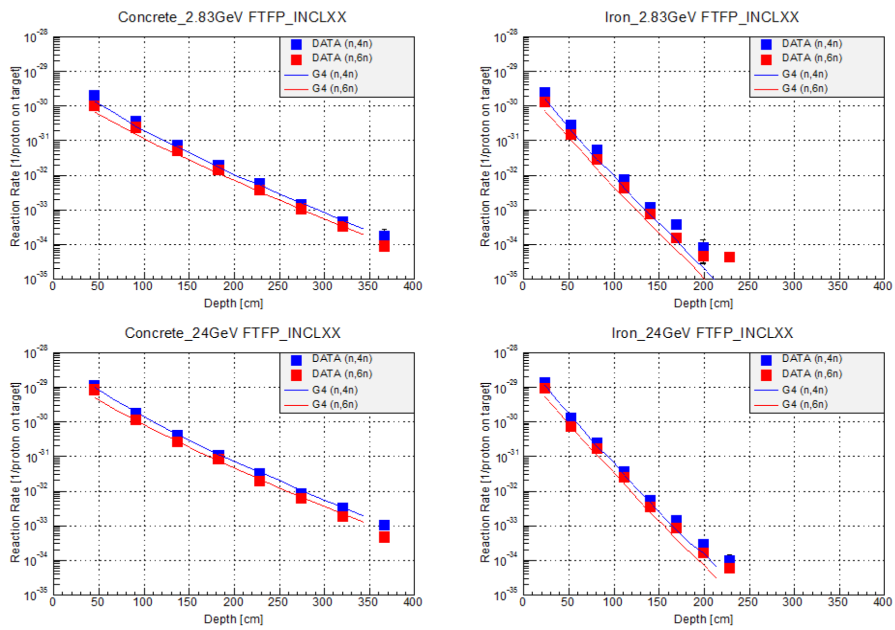


Figure 2. Validation of result of FTFP_INCLXX physics list to BLN AGS experiment



Testing performance of multi-threaded application

In this section, we demonstrate the performance of the multi-threaded application. Performance testing was performed with a multi-threaded application which we submitted to the "inter-comparison" project of SATIF-12. It calculates double differential neutron production cross-sections induced by protons on thick target. We used 100 GeV primary protons on thick gold target. The application was run on a machine consisting of two Intel Xenon E5620 CPU operating at 2.4 GHz. Each CPU has 4 cores; therefore a total of 8 physical cores were available. The machine has a 48GB memory and the OS is 64 bit version of Red Hat Enterprise Linux 6.3. The application was built using the Multi-threaded version of Geant4.10.00.p01 library and the GCC 4.4.7 compiler. We ran an application of 16k events changing the number of threads from 1 up to 8. We measured the total calculation time and memory consumption just after the initialisation phase of the calculation.

Figure 5 shows a decrease in calculation time vs the number of threads. A power law function was fitted to the result. The resulting power law index was -0.90. The index would be -1 in an ideal case. The calculation time included both initialisation and post-processing of calculation.that were basically running on single thread. The index was systematically risen by them, therefore we consider that the power law index of -0.90 in total is reasonably good. Memory consumption of the application was measured and single thread application uses 370 MB just after initialisation and 290 MB of them are shared in multi-threading calculation. Therefore, 80% of consumed memory was shared among threads. We also confirmed that the physical result of an eight-thread calculation is equivalent to the result for a single thread.

Figure 3. CPU performance among reference physics lists

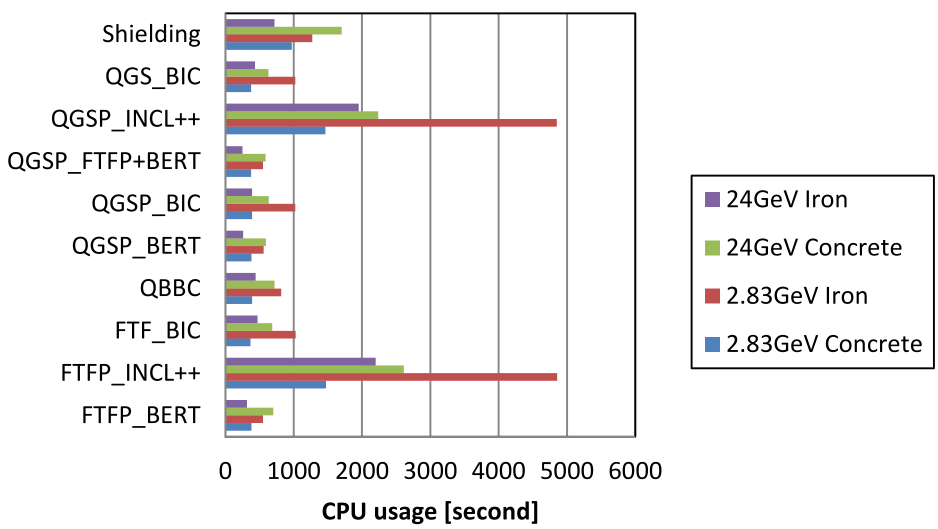


Figure 4. Validation among reference physics lists of (a) FTFP_BERT (b) QGSP_BIC and (c) FTFP_INCLXX to double differential neutron production cross-section

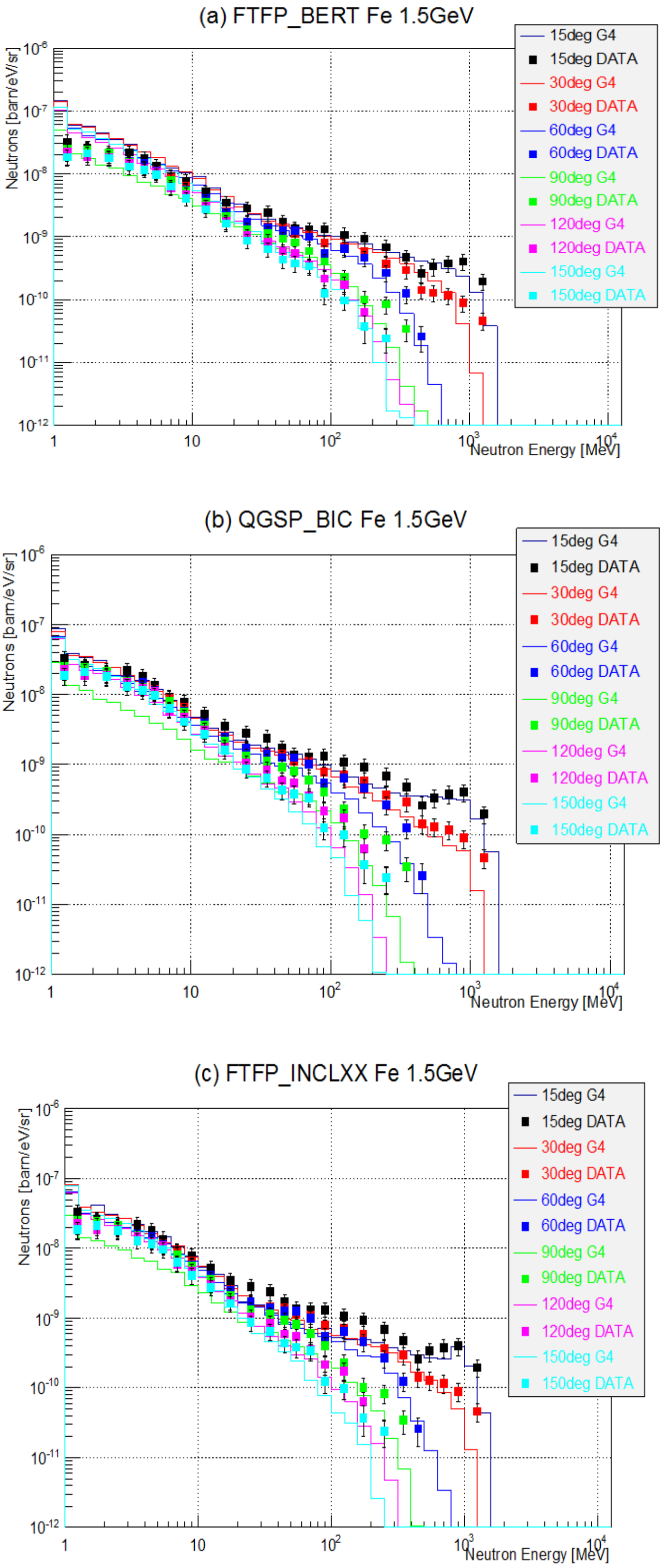
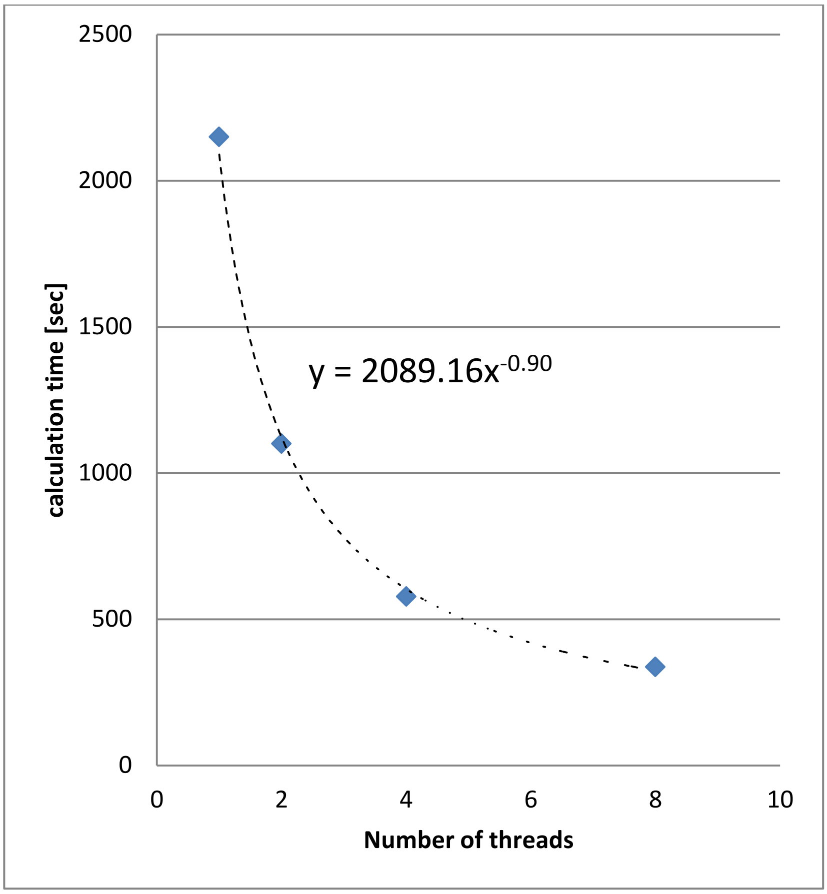


Figure 5. Multi-threading performance



Conclusions

We validated the performance of the Geant4 version 10 for shielding applications through the problems of SATIF "inter-comparison" projects. Neutron fluxes of BNL AGS experiment were well reproduced by calculation of Geant4 version 10 with the shielding physics list. A newly introduced FTFP_INCLXX physics list also gave good agreement and even better in the case of concrete absorbers. INCLXX physics lists show promising physics performance, however, they require more CPU resources than others. Double differential neutron production cross-sections are also compared across reference physics lists. All three cascade models (Bertini-like, Binary and INCL++) that are employed in reference physics lists show reasonable agreements to data. Multi-threaded applications are supported on the Geant4 version 10. Multi-threading performance and memory consumption were tested with application for SATIF-12 inter-comparison. Power law index of -0.90 is obtained for multi-threading performance and 80% of memory consumption was shared at initialisation time. Physically equivalent results were obtained from single and eight threads calculations. Multi-threaded application easily enables use of full CPU power of machine with smaller amounts of memory.

References

[1] S. Agostinelli, et al. (2003), "Geant4: a Simulation Toolkit", *Nucl. Instrum. Meth.* A 506 250.

[2] J. Allison et al. (2006), "Geant4 Developments and Applications", *IEEE Transactions on Nuclear Science* 53 No. 1, 270-278.

[3] H. Hirayama et al. (2006), "Inter-comparison of the Medium-Energy Neutron attenuation in Iron and Concrete (6)", *Proceedings of the Shielding Aspects of Accelerators, Targets and Irradiation Facilities – SATIF8*, Pohang Accelerator Laboratory, Republic of Korea, pp. 237-250.

[4] H. Hirayama et al. (2008), "Inter-comparison of the Medium-Energy Neutron attenuation in Iron and Concrete (7)", *Proceedings of the Shielding Aspects of Accelerators, Targets and Irradiation Facilities – SATIF9,* OECD/NEA, pp. 261-274, ORNL, US.

[5] H. Hirayama et al. (2010), "Inter-comparison of the Medium-Energy Neutron attenuation in Iron and Concrete (8)", *Proceedings of the Shielding Aspects of Accelerators, Targets and Irradiation Facilities – SATIF10*, OECD/NEA, pp. 217-233. CERN, Switzerland.

[6] N. Matsuda et al. (2008), "Analyses of Benchmark Problems for the Shielding Design of High Intensity Proton Accelerator Facilities", *JAEA-Technology* 2008-030.

[7] K. Ishibashi et al. (1997), "Measurement of Neutron- production Double-differential Cross Sections for Nuclear Spallation Reaction Induced by 0.8, 1.5 and 3.0 GeV Protons", *J. Nucl. Sci. Technol.*, 34, 529-537.