2021 International Nuclear Atlantic Conference – INAC 2021 Virtual meeting, Brazil, November 29 – December 2, 2021

Agência Brasileira do ISBN
ISBN 978-85-99141-08-3
9 788599 141083

MONTE CARLO SIMULATION USING OPENMC CODE

Marco Antonio C. Lima[1], Daniel A P Palma[2] and Adino A. H. Almeida[2]

[1] Programa de Pós Graduação do Instituto de Engenharia Nuclear - PPGIEN
marcoantoniochaveslima@gmail.com

[2] Comissão Nacional de Energia Nuclear - CNEN
dapalma@cnen.gov.br / adino.almeida@cnen.gov.br

Abstract

The OpenMC is a Monte Carlo particle-photon transport simulation code developed and released in 2011 by the Massachusetts Institute of Technology. The main feature of this code is the Python API (Application Interface of Programming), considering Python a very popular programming tool. OpenMC is a recent open-source Monte Carlo Simulation code. Different from MCNP and SERPENT, both well established in the scientific community and benchmarked in several studies and publications, OpenMC has a long way to go and has been used extensively not only for its open-source code, but also because of its variety of simulations before restricted to MCNP and SERPENT. In this work, a light water SMR with a hexagonal-shaped fuel element was simulated using OpenMC code. The results of the simulation are compared to the benchmark BEAVRS also developed by MIT. The results shown that is possible, from neutron standpoint, to design a SMR based in the CAREM 25 reactor with materials available in the Brazilian industry.

1. Introduction

Nuclear energy is a great source of power without emitting greenhouse effect gases allied to higher power density 24/7 base in the electric system. However, after Fukushima accident, the costs of large-scale light water reactors have significantly increased. In part, due to safety concerns. On the opposite way, Small Modular Reactors (SMR), gained attention in the last 10 years. Smaller initial investment, passive safety systems, simplified licensing, small-sized reactors (can be produced in factories, hence the name modular), the possibility of installation in farthest regions, clusters of SMRs, installation in ships, submarines and ice-breakers among other uses that do not require a nuclear plant. Beyond the traditional light water SMR, other types are in state of development all over the world, like fast SMRs, gas cooled SMRS, just to name a few. Understanding the importance of the SMR recent developments, the parameters involved in the reactor control resulting from simulations using Monte Carlo method are an essential tool. This stochastic method are normally used in reactor physics analysis to estimate important values like flux, k effective, reactivity, fission rates and other reactions rates, power and the list continues. To have an estimative of these parameters in the development stage could be useful because all data available of simulations come from to large reactor simulations. Therefore, the size could be a factor that differ the neutronic and termohidraulic behavior associated to the SMRs. Their smaller active length will provide a smaller power, obviously, than the larger reactors, like PWRs. This fact relies the importance of simulations in order to predict how the SMR will operate.

2. The Simulation

2.1. CAREM 25 – SMR Model

The reactor CAREM 25 simulated in this work will be a hexagonal-shaped one. It contains 61 fuel elements, each with 108 fuel rods, 18 guide tubes and 1 tube for instrumentation, given 127 positions. Two enrichments will be used 1.8 and 3.4 % of U235. In specific positions, 18 of 108 rods contain burnable poison, mixed with the UO_2 with higher enrichment. The burnable poison is Gadolinium, Gd_2O_3. However, the rods are heterogenic in the axial direction, having no burnable poison in the upper and lower extremes. The moderator and refrigerator is light water and no pump is required. Natural circulation is responsible for refrigerating the core. The active length of the core is 140 cm. There is no boron in the moderator in this reactor. The absorber element will be in the form of control bars made by Ag-In-Cd entering in the core through the guide tubes. Below a section of the core, Figure 1, plotted by the OpenMC, where is possible to see the 61 fuel elements and highlighting the scheme of the central element, displaying the fuel rods (made of lower enrichment) in olive color, the control bars in pink and the instrumentation tube fulfill of light water in blue.

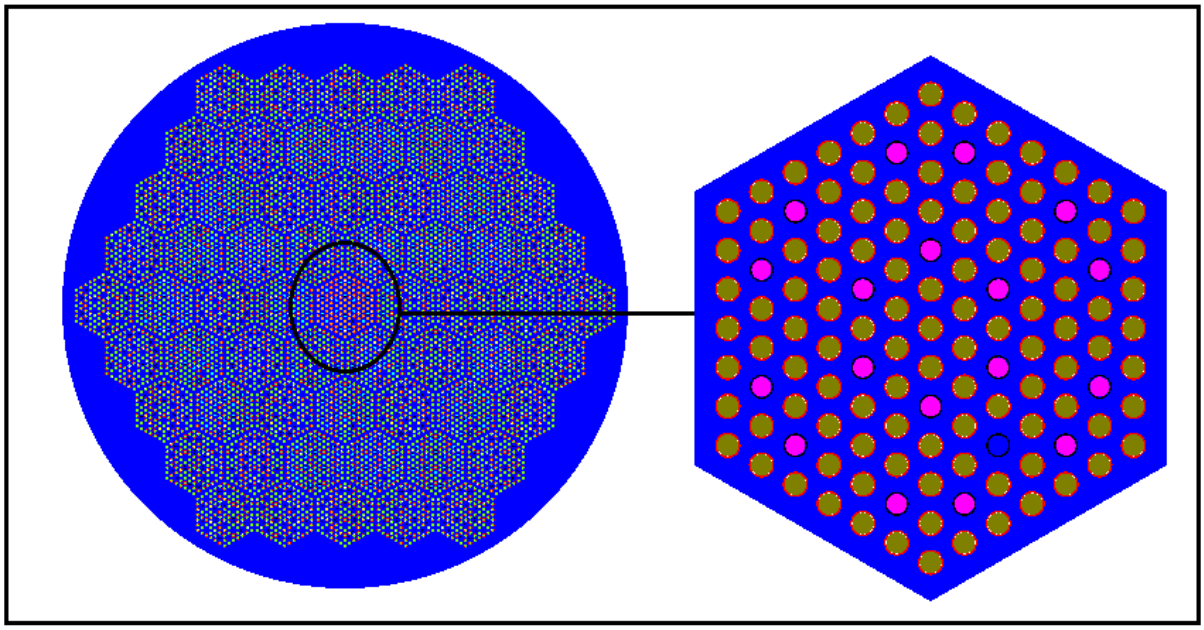

Figure 1: Core of the SMR and Central Element highlighted

2.1. Materials, Geometry and Settings Input Files

The OpenMC uses Python API to declare the materials, geometry and settings in files with the XML extension. The materials are the nuclides (or elements) that fill the regions defined in the geometry of the reactor. The cross section in this work is temperature compensated in ACE format and linear-interpolable. Python is an object-oriented programming language, which means that it is classes and subclasses structured. Each material, surface or settings parameters are objects that carry an identification number and attributes and methods specified by the class that defines them.

Like on others Monte Carlo simulators, OpenMC uses CSG (Constructive Solid Geometry) to build the system the user simulates and assign the materials to a specific region. Using CSG it is possible to build a 2D or 3D reactor e plot the model using the appropriate class.

2.3. Benchmark BEAVRS

The benchmark used to validate the simulation is BEAVRS (BENCHMARK FOR EVALUATION AND VALIDATION OF REACTORS SIMULATIONS), developed also by MIT Computation Reactor Physics Group. The model used for comparison is a 17x17-fuel element with soluble boron as absorbed element.

2.4. Structural Material

The structural material of the core will join the list of materials listed in the materials.xml file. The goal is considerate the core and its surroundings and evaluate how the rates of reaction occurring in the core are affected in the presence of absorbing materials. The baffle, grids and the two nozzles will join the materials as well as the regions they are assign.

3. Results

Simulations of the core of the SMR (Figure 1), output the values of the K-effective using three estimators: Collision, Track-length and Absorption. The combined estimator, named Combined K-effective, will be the comparative parameter against the one obtained with BEAVRS.). First simulation parameters: 'Eigenvalue-mode', 1000 particles, 100 batches, a starting source with dimensions of the core were the parameters in the simulation. Below, we can look the values of the K-effective with different estimators, the Combined K-effective and the leakage fraction:

	Mean	Standard Deviation (+/-)
K-effective (Collision)	1.05811	0.00415
K-effective (Track-length)	1.06088	0.00465
K-effective (Absorption)	1.05754	0.00354
Combined K-effective	1.05855	0.00321
Leakage Fraction	0.03619	0.00073

Number of particles increased to 10000:

	Mean	Standard Deviation (+/-)
K-effective (Collision)	1.05618	0.00137
K-effective (Track-length)	1.05667	0.00170
K-effective (Absorption)	1.05649	0.00130
Combined K-effective	1.05649	0.00115
Leakage Fraction	0.03335	0.00021

Number of particles increased to 100000:

	Mean	Standard Deviation (+/-)
K-effective (Collision)	1.05625	0.00073
K-effective (Track-length)	1.05619	0.00073
K-effective (Absorption)	1.05639	0.00067
Combined K-effective	1.05634	0.00065
Leakage Fraction	0.03317	0.00008

The value of Combined K-effective shows that this reactor is in the super critical range (above 1).

Multiplying for 10 three times the number of particles, the standard deviation of Combined K effective reduces from around 300pcm to 65pcm. The variance decrease as the number of statistics increases. Any other parameter of interest could have its precision refined by increasing the particles attribute in the input file.

4. Conclusion

The standard deviation could be lowered performing simulations with higher particles. Around 300pcm is rather high for standard deviation. The results are refined performing simulations with more than 1000 particles (2000, 5000, 10000 or 100000). However, will demand more computational work.

The CAREM 25 is a slightly reactive reactor as indicates K_{eff} in all simulations.

Acknowledgments

The following Brazilian institutions support this research project: Brazilian Council for Scientific and Technological Development (CNPq) and Brazilian Nuclear Energy Commission (CNEN).

References

1. Romano, Paul K., Horelik, Nicholas E., Herman, Bryan R., Nelson, Adam G, Folger, Benoit, Smith Kord, “OpenMC : A State-of-the-Art Monte Carlo Code for Research and Development”, Annals of Nuclear Energy, 82, 90-97 (2015) .
2. H.Boado,Magan, D.F. Delmastro, M. Markiewicz, E. Lopasso, F. Diez, M. Giménez, A. Rauscher t, S. Halpert, M. Chocrón, J.C. Dezzutti, H. Pirani, C. Balbi, A. Fittipaldi, M. Schlamp, G.M. Mur mis, H. Lis, “CAREM Project Status, Science and Technology of Nuclear Installations”, (2011), Article ID 140373
3. H. Boado,Magana, D.F. Delmastrob, M. Markiewiczb, E. Lopassob, F. Diez, M. Giménezb, A. Ra uschertb, S. Halperta, M. Chocrónc, J.C. Dezzuttic, H. Pirani, C. Balbi,”CAREM Prototype Construction and Licensing Status”, (2012), IAEA-CN-164–5S01
4. P. K. Romano, “The OpenMC Monte Carlo Code – OpenMC Documentation”, https:// mit-crpg.github.io/openmc. accessed August 15, 2021
5. IAEA, “Advances in SMR Design and Technology Developments”, IAEA Advanced Reactors Information System (ARIS),9-12 (2020)