

Bridging Theory and Practice: A New Textbook, The Introduction to Nuclear Engineering Using OpenMC

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1. Introduction

Traditional nuclear engineering textbooks focus on analytical solutions rarely used in modern industry [1,2], which increasingly relies on Monte Carlo simulations. While standard Monte Carlo packages such as MCNP are heavily regulated and inaccessible to beginners, OpenMC offers a state-of-the-art, open-source alternative with a versatile Python API [3]. To bridge the gap between theory and practice, this forthcoming textbook integrates foundational nuclear concepts with hands-on OpenMC exercises. This paper briefly introduces the book's chapter contents and specific OpenMC examples, demonstrating how it equips students with both fundamental knowledge and practical skills for the nuclear industry.

2. The structure of the book

The textbook consists of nine chapters, structured to blend theoretical knowledge with computational practice. Chapters 1 and 2 guide readers through the essential computational setup, detailing the installation of a WSL2-based Linux environment, the OpenMC installation process, and basic OpenMC usage demonstrated through a Demon Core simulation. Chapters 3 through 8 cover the fundamental concepts of nuclear engineering. These core chapters delve into nuclear physics, nuclear reactions, nuclear power reactors, neutron diffusion and moderation, the diffusion equation, reactor theory, and time-dependent reactors. Finally, Chapter 9 focuses on practical applications, addressing real-world field problems by utilizing advanced examples provided by OpenMC.

3. OpenMC examples in the book

Each chapter features OpenMC exercises that correspond directly to the fundamental concepts discussed within it. Below is a selection of key OpenMC simulations presented in the book.

3.1. Cross section graphs (Chap.1)

After setting up Linux, Anaconda, Jupyter Notebook, and OpenMC with the ENDF/B-VIII.0 libraries, cross-section graphs of key nuclides were plotted to verify the installation. Using the `openmc.plot_xs()` command, users can visualize the cross-section of any nuclide for

any reaction type across any specified neutron energy range.

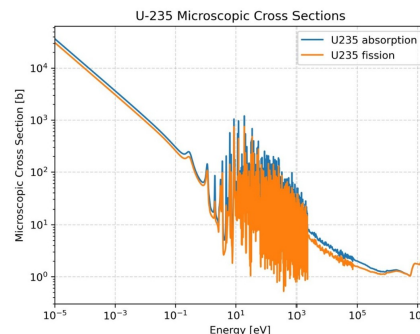


Figure 1. Fission and absorption cross-sections of ^{235}U plotted using `openmc.plot_xs()`.

3.2. Understanding OpenMC Inputs through the Demon Core Simulation (Chap.2)

During a 1946 criticality experiment, a slipped screwdriver caused a beryllium reflector to close over the 6.2 kg ^{239}Pu "Demon Core," triggering a supercritical excursion that claimed the life of physicist Louis Slotin. By modeling this historical event, the textbook provides step-by-step explanations of OpenMC input commands to calculate the effective multiplication factor (k_{eff}) as a function of the beryllium reflector's thickness. A major advantage of OpenMC is its programmatic flexibility; a single Python-based input script can evaluate k_{eff} across multiple reflector thicknesses and automatically plot the resulting graph.

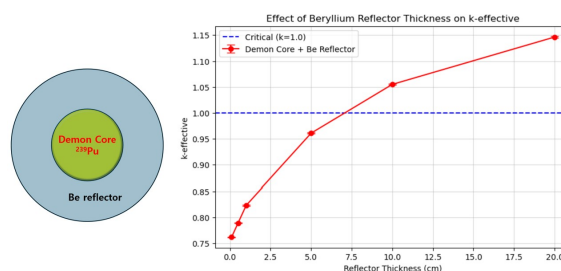


Figure 2. The Demon Core with a Be reflector and k_{eff} with respect to the Be reflector thickness.

3.3. Slowing down of neutrons (Chap.6)

Light water, heavy water, and graphite are excellent neutron moderators. OpenMC can accurately track the scattering of fast neutrons and determine the resulting energy spectrum after the slowing-down process. Figure 3 illustrates the neutron energy spectrum within a 1-

meter graphite sphere, generated by a 1 MeV fast neutron source located at its center.

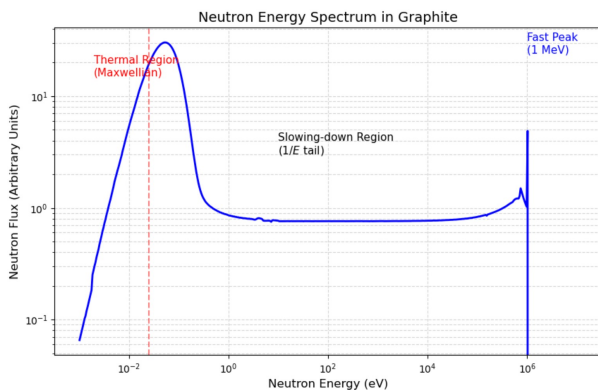


Figure 3. Neutron energy spectrum resulting from moderation by carbon atoms.

3.4. Reflector effects (Chap.7)

Analytically solving reflector effects on reactor criticality via the diffusion equation is often too complex, causing many students to lose interest. However, OpenMC's Monte Carlo approach visualizes these effects simply and clearly. Figure 4 shows a spherical homogeneous reactor with a fixed ^{235}U concentration (0.0145 g/cm^3 in water), demonstrating how different reflectors (light water, heavy water, beryllium, and carbon) alter its critical size, critical mass, and internal neutron flux.

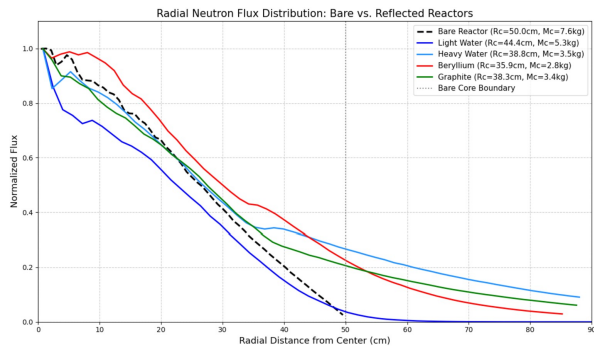


Figure 4. Reflector effects on the critical mass, size, and neutron flux of a homogeneous reactor.

3.5. Control rod worth (Chap.8)

Calculating control rod worth analytically in time-dependent reactor models is another notoriously complex problem. However, OpenMC significantly streamlines this process by simplifying the evaluation of control rod effects using the Monte Carlo method. Figure 5 shows the control rod worth with control rod insertion in a homogeneous reactor.

3.6. Advanced examples (Chap.9)

The OpenMC website provides valuable input examples for various nuclear fuels, reactors, and even tokamaks [4]. By utilizing these well-designed and validated inputs, users can confidently extend their research to more challenging analyses. Figure 6 illustrates the

modeling of TRISO fuel particles, demonstrating the depletion of ^{235}U and the generation of ^{239}Pu .

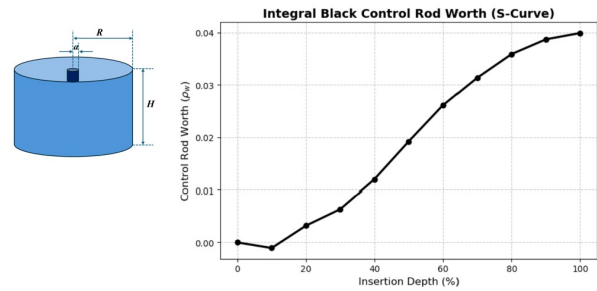


Figure 5. Control rod worth as a function of insertion depth.

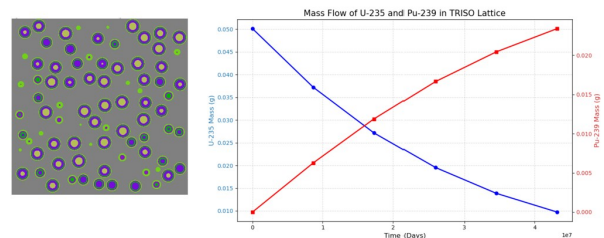


Figure 6. TRISO fuel model and the depletion of ^{235}U and generation of ^{239}Pu over operation time.

4. Conclusion

This forthcoming textbook represents a significant departure from traditional nuclear engineering literature, which has long been confined to purely analytical solutions. By integrating OpenMC into the core curriculum, the book provides readers with a unique opportunity to tackle practical, field-oriented problems. This approach not only deepens their theoretical understanding but also builds the essential hands-on experience required in the modern nuclear industry. The manuscript is currently under active development; the Korean edition is slated for completion by the end of 2026, with the English version scheduled for publication the following year.

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