Course guide
240NU215 - 240NU215 - Monte Carlo Simulation of Radiation Transport

Last modified: 13/03/2025

Unit in charge: Barcelona School of Industrial Engineering
Teaching unit: 748 - FIS - Department of Physics.

Degree: MASTER'S DEGREE IN NUCLEAR ENGINEERING (Syllabus 2012). (Optional subject).

Academic year: 2025 **ECTS Credits:** 4.5 **Languages:** English

LECTURER

Coordinating lecturer: JOSEP SEMPAU ROMA

Others:

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
1. Ability to use effectively, understand the operation and validity ranges, and interpret the results of transport calculation codes of electromagnetic radiation, charged particles and neutrons.
2. Knowledge of the mechanisms of interaction of ionizing radiation with matter and its relation to the different phenomena and applications of interest in nuclear technology

TEACHING METHODOLOGY

The course relies heavily on a methodology based on a combination of lectures and practical exercises. During the lecture sessions, the lecturer introduces fundamental concepts and the way in which these concepts are to be employed in order to solve practical problems, i.e., how to carry out computer simulations in practice.

The exercises are of two different kinds. The first kind involves exercises intended to help students learn the basic concepts underlying the Monte Carlo method, stimulating their ability to grasp the essential features and what is specific of each type of application. For the most part, exercises in this first cathegory do not require the execution of any simulation. The second part, more extensive, is made of a series of face-to-face sessions in which students will have to simulate several cases. During this part both self and cooperative learning methodologies will be applied, depending on the case.

Addendum:

As a result of the public health emergency declared for the COVID-19 epidemic of 2020, the methodology will be adapted to the new situation. This includes, but may not be limited to, teaching remotely using virtual meeting software platforms, increase in the number of asynchronous assignments to be submitted by students, etc.

These changes will be in place only during the spring semester of 2020.

LEARNING OBJECTIVES OF THE SUBJECT

At the end of this course, students should be able:

-To present the fundamental ideas behind the Monte Carlo (MC) method.
-To describe the methods and tools employed by codes based on the Monte Carlo method to perform their calculations.
-To describe the main features of the physics models in MC codes that are used for the simulation of radiation transport, with emphasis on the transport of photons, charged particles and neutrons.
-To operate efficiently the MC code PENELOPE/penEasy.
-To use MC codes to simulate some elemental problems related with industrial and medical applications.

STUDY LOAD

Type	Hours	Percentage
Hours small group	4,5	4.00
Self study	72,0	64.00
Hours large group	36,0	32.00

Total learning time: 112.5 h

CONTENTS

1. Fundamentals of the Monte Carlo method

Description:
After a short historical perspective, the following concepts are introduced: pseudo-random number generators; elements of probability theory; sampling of probability distributions; statistics and uncertainty.

Full-or-part-time: 10h
Theory classes: 2h
Practical classes: 4h
Self study : 4h

2. MC simulation of radiation transport

Description:
The peculiarities of MC simulation when applied to the problem of describing radiation transport are introduced: the physics of the transport are presented as an example of a Poisson process. The principles of variance reduction methods are discussed and the practical implementation of a limited number of these techniques is analysed in detail.

Full-or-part-time: 5h
Theory classes: 1h
Practical classes: 2h
Self study : 2h

3. Photon and charged particle transport

Description:
The basic physics properties of the transport of photons, electrons, positrons, protons and other heavy charged particles is described. The dominant interaction mechanisms and their associated differential cross sections (and the models employed to describe them) for some of these interactions are discussed in depth. Multiple scattering theories for charged particles are explained, as well as their application in condensed simulation methods. The trade-off between speed and accuracy is discussed and quantitative criteria is given as a tool to choose appropriate values of the transport parameters that are relevant for a given simulation problem.

Full-or-part-time: 7h
Theory classes: 3h
Practical classes: 2h
Self study : 2h

4. The MC code PENELOPE/penEasy

Description:
The MC code PENELOPE for the simulation of photon and electron transport is described. This includes: generation of material data files; definition of complex geometries; adaptation of input files to define radiation sources, quantities to be tallied and to steer the simulation; interpretation of output files and graphical representation of results; identification of potential problems, caveats and practical limitations of the simulation.

Full-or-part-time: 13h
Theory classes: 1h
Practical classes: 2h
Self study : 10h

5. Neutron transport

Description:
Neutron interactions are described and data bases for their determination introduced. A simulation code (MCNP or GEANT) will also be described at an introductory level.
Differences between charged particle and neutral particle transport are analysed.

Full-or-part-time: 5h
Theory classes: 1h
Practical classes: 2h
Self study : 2h

ACTIVITIES

1. DOSE DISTRIBUTION IN A WATER SPECTRUM

Description:
- Calculate the dose distribution produced by a radiation beam in a semi-infinite water phantom.
- See the effect of not transporting secondary particles.
- Alter the transport physics to study the influence of particular interaction mechanisms on radiation transport.

Full-or-part-time: 18h
Laboratory classes: 5h
Self study: 13h

2. GAMMA RAY SPECTROMETRY

Description:
- Calculate the distribution of energy deposition events (that is, the spectrum) produced by a Co-60 source in a NaI detector.
- Analyse the different regions of the spectrum and identify the origin of the observed peaks.
- Introduce an on-the-fly convolution of p(E) with a Gaussian to account for the widening of the peaks observed in a real detector.

Full-or-part-time: 18h
Laboratory classes: 5h
Laboratory classes: 13h

3. ACCELERATOR HEAD

Description:
- Generate a Phase Space File (PSF) for a simple linac model. The PSF contains the state of all particles coming out of the accelerator head.
- Learn how to configure a source with Gaussian spectrum.
- Use a PSF to obtain a dose distribution.
- Practice the use of variance reduction techniques: interaction forcing and particle splitting.

Full-or-part-time: 18h
Laboratory classes: 5h
Laboratory classes: 13h

4. VOXELISED GEOMETRIES

Description:
- Handle voxelized geometries.
- Combine quadric and voxelised geometries in a single simulation.

Full-or-part-time: 18h
Laboratory classes: 5h
Self study: 13h

GRADING SYSTEM

The evaluation is based on three elements:

Written reports of the exercise assigments (relative weight = 25%).
Oral presentations of the exercises (relative weight = 25%).
Final exam (relative weight = 50%).

Addendum:

As a result of the public health emergency declared for the COVID-19 epidemic of 2020, the assessment method will be adapted to the new situation. This implies that: (i) Oral presentations will be done remotely, using the technical resources provided by the UPC whenever necessary; (ii) exams will be held remotely using the technical resources provided by the UPC such as, e.g., the virtual campus. The weights of the different activities on the final mark are not altered by these changes.

These changes will be in place only during the spring semester of 2020.

BIBLIOGRAPHY

Basic:

- Kalos, Malvin H; Whitlock, Paula A. Monte Carlo methods [on line]. 2nd rev. ed. Weinheim: Wiley-Blackwell, cop. 2008 [Consultation: 27/05/2020]. Available on: https://onlinelibrary.wiley.com/doi/book/10.1002/9783527626212. ISBN 9783527407606.
- Francesc Salvat, Francesc ; Fernández-Varea, José María ; Sempau, Josep. PENELOPE-2008: A Code System for Monte Carlo Simulation of Electron and Photon Transport [on line]. Issy-les-Moulinaux, France: OECD Nuclear Energy Agency, 2009 [Consultation: 09/12/2013]. Available on: https://www.oecd-nea.org/science/pubs/2009/nea6416-penelope.pdf. ISBN 9789264990661.

Complementary:

- Jenkins, Theodore M; Nelson, Walter R; Rindi, Alessandro. Monte Carlo transport of electrons and photons. New York: Plenum Press, cop. 1988. ISBN 9780470177945.
- Bielajew, A.F. Fundamentals of the Monte Carlo method for neutral and charged particle transport [on line]. Ann Arbor, Michigan: University of Michigan, 2001 [Consultation: 29/10/2025]. Available on: http://www-personal.umich.edu/~bielajew/MCBook/book.pdf.
- Page, Clive G.. Professional Programmer's Guide to Fortran77 [on line]. Leicester: University of Leicester, 2005 [Consultation: 09/12/2013]. Available on: http://www.star.le.ac.uk/~cgp/prof77.html#tth_sEc1.