240NU215 - Monte Carlo Simulation of Radiation Transport

**Coordinating unit:** 240 - ETSEIB - Barcelona School of Industrial Engineering  
**Teaching unit:** 748 - FIS - Department of Physics  
**Academic year:** 2017  
**Degree:** MASTER'S DEGREE IN NUCLEAR ENGINEERING (Syllabus 2012). (Teaching unit Optional)  
**ECTS credits:** 4,5  
**Teaching languages:** English

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### 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

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### 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 which pretend to help students learn the concepts behind the Monte Carlo method, estimulating their ability to grasp the essential features and what is specific of each type of application. For the most part, exercises in this first group 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 the self learning and the cooperative learning methodologies will be applied, depending on the case.

### 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

<table>
<thead>
<tr>
<th>Total learning time: 112h 30m</th>
<th>Hours large group: 0h</th>
<th>0.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours medium group: 0h</td>
<td>0.00%</td>
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<tr>
<td>Hours small group: 40h 30m</td>
<td>36.00%</td>
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<tr>
<td>Guided activities: 0h</td>
<td>0.00%</td>
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<tr>
<td>Self study: 72h</td>
<td>64.00%</td>
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</tbody>
</table>
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<table>
<thead>
<tr>
<th>Content</th>
<th>Learning time:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Fundamentals of the Monte Carlo method</strong></td>
<td>10h</td>
</tr>
<tr>
<td>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.</td>
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<tr>
<td><strong>2. MC simulation of radiation transport</strong></td>
<td>5h</td>
</tr>
<tr>
<td>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.</td>
<td></td>
</tr>
<tr>
<td><strong>3. Photon and charged particle transport</strong></td>
<td>7h</td>
</tr>
<tr>
<td>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.</td>
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</tbody>
</table>
4. The MC code PENELOPE/ penEasy

<table>
<thead>
<tr>
<th>Learning time:</th>
<th>13h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory classes:</td>
<td>1h</td>
</tr>
<tr>
<td>Practical classes:</td>
<td>2h</td>
</tr>
<tr>
<td>Self study:</td>
<td>10h</td>
</tr>
</tbody>
</table>

**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.

5. Neutron transport

<table>
<thead>
<tr>
<th>Learning time:</th>
<th>5h</th>
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</thead>
<tbody>
<tr>
<td>Theory classes:</td>
<td>1h</td>
</tr>
<tr>
<td>Practical classes:</td>
<td>2h</td>
</tr>
<tr>
<td>Self study:</td>
<td>2h</td>
</tr>
</tbody>
</table>

**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.
## Planning of activities

<table>
<thead>
<tr>
<th>Topic</th>
<th>Hours: 18h</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. DOSE DISTRIBUTION IN A WATER SPECTRUM</strong></td>
<td>Laboratoy classes: 5h</td>
</tr>
<tr>
<td>Description:</td>
<td>Self study: 13h</td>
</tr>
<tr>
<td>- Calculate the dose distribution produced by a radiation beam in a semi-infinite water phantom.</td>
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<td>- See the effect of not transporting secondary particles.</td>
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<td>- Alter the transport physics to study the influence of particular interaction mechanisms on radiation transport.</td>
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</tr>
<tr>
<td><strong>2. GAMMA RAY SPECTROMETRY</strong></td>
<td>Laboratoy classes: 5h</td>
</tr>
<tr>
<td>Description:</td>
<td>Laboratoy classes: 13h</td>
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<tr>
<td>- Calculate the distribution of energy deposition events (that is, the spectrum) produced by a Co-60 source in a NaI detector.</td>
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<tr>
<td>- Analyse the different regions of the spectrum and identify the origin of the observed peaks.</td>
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<tr>
<td>- 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.</td>
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<tr>
<td><strong>3. ACCELERATOR HEAD</strong></td>
<td>Laboratoy classes: 5h</td>
</tr>
<tr>
<td>Description:</td>
<td>Laboratoy classes: 13h</td>
</tr>
<tr>
<td>- 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.</td>
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<tr>
<td>- Learn how to configure a source with Gaussian spectrum.</td>
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<tr>
<td>- Use a PSF to obtain a dose distribution.</td>
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<td>- Practice the use of variance reduction techniques: interaction forcing and particle splitting.</td>
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<tr>
<td><strong>4. VOXELISED GEOMETRIES</strong></td>
<td>Laboratoy classes: 5h</td>
</tr>
<tr>
<td>Description:</td>
<td>Self study: 13h</td>
</tr>
<tr>
<td>- Handle voxelized geometries.</td>
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<tr>
<td>- Combine quadric and voxelised geometries in a single simulation.</td>
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Qualification system

The evaluation is based on three elements:

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

Bibliography

Basic:


Complementary:


Others resources: