240NU011 - Fundamentals of Nuclear Engineering and Radiological Protection

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 Compulsory)
MASTER'S DEGREE IN INDUSTRIAL ENGINEERING (Syllabus 2014). (Teaching unit Optional)
ECTS credits: 8
Teaching languages: English

Teaching staff

Coordinator: FRANCISCO CALVIÑO TAVARES
Others: First semester:
LLUIS BATET MIRACLE - 10
ALFREDO DE BLAS DEL HOYO - 10
FRANCISCO CALVIÑO TAVARES - 10
MARIA AMOR DUCH GUILLEN - 10
MERCE GINJAUME EGIDO - 10
JOSEP SEMPAU ROMA - 10

Degree competences to which the subject contributes

Specific:
1. Knowledge of the fundamentals needed to understand nuclear energy production by nuclear fission and fusion chain.
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
3. Ability to use ionizing radiation detectors, appropriate to the required application, together with the associated instrumentation.
4. Ability to apply radiation protection techniques to reduce the risks arising from the use of ionizing radiation.
5. 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.

Teaching methodology

MD.1. Learning contract. Agreement established between the professor and the student in order to achieve some learning results and some competences, by a sequence of actions to be carried out, both by the Professor and by the student, along the period of duration of the course. In a practical level is a review of this document.
MD.2. Lecture. Presentation by the Professor of synthesis information about a topic, process, method... The exposition is logically structured with the aim of providing some theory concepts, show the way to solve the different types of problems, point out the stages of the processes and standard procedures, indicate the correct way of using tools and calculation codes...
MD.3. Autonomous learning. Development of tasks (lectures, study and/or development of theory aspects, resolution of problems, report writing or memories...) according to the established instructions or guidelines, carried out by the student with the punctual supervision of the Professor.
MD.4. Cooperative learning. Development of the tasks by a small group of students (study or elaboration of theory aspects, resolution of problems, development of projects, experimental measures in the lab) which necessary require, for its correct fulfillment, of the work of each one of the members of the group.

1 / 10
Learning objectives of the subject

The student who has coursed the subject will have to be able to:
- Use the models of atomic and nuclear structure in order to explain the origin and nature of the atomic and nuclear radiation and justify the obtention of nuclear energy.
- Use the laws governing the temporary evolution of the radioactive substances for the calculation of its activity and the main radiations emitted.
- Describe the main interaction mechanisms of the nuclear and atomic radiations with the material and calculate the related magnitudes with these interactions.
- Analyse the kinematic of the nuclear reactions and derive the expressions allowing to calculate the energy of the products of the reaction.
- Easily manage the concept and the values gathered in the internationally recognised databases, of effective section, to carry out the calculation of the reaction tax, interaction of probability and other derived magnitudes, applying them to the interaction processes of the radiation with the material and nuclear reactions produced by neutrons
- Deduce and apply the equations governing the generation and temporary evolution of radionuclides in the bosom of a nuclear reactor
- Explain the basic physical processes of each type of detector of ionising radiation.
- Analyse how the interaction processes of the ionising particles influence in its detection.
- Carry out experimental measurements of the ionising radiations, analyse the results and determine the statistical and systematic associated errors.
- Assume a criteria which allows to determine with accuracy the characteristics of a radioactive source separating the contribution of the base associated to the measure.
- Select the most suitable detection system regarding on the type of ionising radiation, and the magnitudes which are expected to be taken.
- Identify the magnitudes used in the field of radiological protection and define them.
- Explain, in a basic level, the biological risks of the ionising radiations and the need of the limitation of the dose and the optimization techniques.
- Use the basic principles of justification, limitation and optimization, of the international system of radiological protection, to defend that the activities involving ionising radiations are compatible with the achieved global well-being, towards the individual and sustainability risks.
- Calculate the dose due to the most common ionising radiations due to the location of a nuclear power plant or a radioactive facility.
- Carry out correctly the radiation shielding, in simple situations, and contribute to the teamwork for the realization of complex shielding projects.
- Apply radiological protection techniques to reduce the risks derived from the use of ionising radiations.
- Justifiably select the suitable techniques for the realization of individual dosimetric surveillance of the professionals exposed.
- Identify the main codes available for the calculation of transport of ionising radiations, the type of particles which are able to manage, the valid range and the accuracy of the same. carry out easy calculations using these calculation codes

Study load

<table>
<thead>
<tr>
<th>Total learning time: 200h</th>
<th>Hours large group: 0h</th>
<th>0.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours medium group: 48h</td>
<td>24.00%</td>
<td></td>
</tr>
<tr>
<td>Hours small group: 24h</td>
<td>12.00%</td>
<td></td>
</tr>
<tr>
<td>Guided activities: 0h</td>
<td>0.00%</td>
<td></td>
</tr>
<tr>
<td>Self study: 128h</td>
<td>64.00%</td>
<td></td>
</tr>
</tbody>
</table>
### Content

#### 1. Basis of the atomic and nuclear physics. Radioactivity.

<table>
<thead>
<tr>
<th>Description:</th>
<th>Learning time: 20h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basis:</td>
<td>Theory classes: 6h</td>
</tr>
<tr>
<td></td>
<td>Practical classes: 2h</td>
</tr>
<tr>
<td></td>
<td>Self study: 12h</td>
</tr>
</tbody>
</table>

- **Basis:**
  1.1 Atomic models. Levels of energy
  1.2 Ionization and stimulation.
  1.3 Atomic radiations
  1.4 Fluorescence and phosphorescence
  1.5 X-rays
  1.6 Mass, radius, nuclear charge.
  1.7 Nuclear models. Levels of energy.
  1.8 Nuclear forces.
  1.9 Nuclear stability
  1.10 Nuclear bond energy

- **Radioactivity**
  1.11 Radioactive processes
  1.12 Laws of radioactive emissions
  1.13 Disintegration chain
  1.14 Artificial radioactivity. Activation
  1.15 Alpha radioactivity
  1.16 Beta radioactivity
  1.17 Emission of gamma rays
  1.18 Nuclear isomerism and intern conversion

Exposition and exercises which allow to get an idea of the atomic and nuclear structure. Emphasizing the concepts of the energetic levels and basic and stimulated states. Exposition and exercises about radioactivity, radioactivity processes, law of temporary evolution and emission of radionuclides.

#### Related activities:

- Expositive classes (6h)
- Resolution of the exercises in class (2h)
- Autonomous work. Theory and practical exercises (12h)

#### Specific objectives:

- Use the models of atomic and nuclear structure to explain the origin and nature of the atomic and nuclear radiations and justify the obtention of nuclear energy.
- Use the laws governing the temporary evolution of the radioactive substances for the calculation of its activity and the main radiations emitted.
2.1 EM interactions of charged particles and photons with the materia.

**Description:**
- 2.1.1 Mechanisms of loss of energy of the charged particles.
- 2.1.2 Ionization and stimulation. Braking radiation.
- 2.1.3 Braking power. Linear transfer of energy.
- 2.1.4 Scope
- 2.1.5 Interaction of the photons with the material
- 2.1.6 Interaction of the alpha particles
- 2.1.7 Interaction of the beta particles
- 2.1.8 Photoelectric effect
- 2.1.9 Compton effect
- 2.1.10 Production of torques
- 2.1.11 Attenuation and absorption of the gamma radiation

Exposition of the historical development of some basic concepts of this topic, description of the magnitudes which, in general terms, characterise the radiation fields and its effects on the material (flow, influx, effective section...) presentation of the main mechanisms of interaction between charged particles and the material, and between the photons and the material, emphasizing the available databases in the public domain, in its interpretation and in its practical use.

**Related activities:**
- Expositive classes (6h)
- Resolution of exercises in class (2h)
- Autonomous work. Theory and practical exercises (12h)

**Specific objectives:**
- Identify the basic concepts and the magnitudes of interest characterising the transport of the radiation and its effects on the material.
- Distinguish between direct or indirect ionising radiation and describe its properties. Identify and describe the main mechanisms of interaction between charged particles and the material.
- Identify and describe the main mechanisms of ionising interaction and describe its properties
- Expose the meaning of the braking power of the charged particles and its relation with the energy deposited in a natural environment.
- Identify and describe the main mechanisms of interaction between the photons and material.
2.2 Interaction of the neutrons with the material

Description:
Nuclear reactions
2.2.1. Description
2.2.2. Laws of conservation
2.2.3. Kinematics
2.2.4. Effective section
2.2.5. Resonance. The Breit-Wigner formula
2.2.6. Models for the study of nuclear reactions
2.2.7. Model of the compound core
2.2.8. Optical model
2.2.9. The Feshback model
2.2.10. Direct reactions
2.2.11. Neutron sources

Neutron interactions
2.2.12. Classification of the neutrons regarding to its energy.
2.2.13. Interactions of the neutrons with the material.
2.2.15. Radiant capture
2.2.16. Capture with the emission of charged particles

Introduction to the most relevant concepts for the study of the nuclear reactions induced by neutrons. Description of the basic models of the nuclear interactions allowing to understand qualitatively the performance of the effective section regarding to the energy of the incident neutron.

Related activities:
Expositive clases (6 h)
Resolution of the exercises in class (2 h)
Autonomous work. theory and practical exercises (12 h)

Specific objectives:
Analyse the kinematics of the nuclear reactions and derive the expressions which allow to calculate the energy of the products of the reaction
Easily manage the concept, and the gathered values in the internationally recognised databases, of effective sessions, to carry out the calculations of reaction taxes, the probability of interaction and other derived magnitudes, applying them to the interaction processes of the radiation with the material and the nuclear reactions produced by neutrons.
Deduce and apply the equations governing the formation and temporary evolution of the radionuclides in the bosom of a nuclear reactor.
### 3. Detection of the Ionising Radiation

**Learning time:** 35h

- **Theory classes:** 6h
- **Practical classes:** 8h
- **Laboratory classes:** 21h

<table>
<thead>
<tr>
<th>Description:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied statistics to the detection of radiation</td>
<td></td>
</tr>
<tr>
<td>3.1. Nature of ionising radiations</td>
<td></td>
</tr>
<tr>
<td>3.2. Characterization of the data</td>
<td></td>
</tr>
<tr>
<td>3.3. Statistical models applied to the detection of radiation</td>
<td></td>
</tr>
<tr>
<td>3.4. Statistical error in the experimental data</td>
<td></td>
</tr>
<tr>
<td>3.5. Statistical error in the measurement of the detection</td>
<td></td>
</tr>
<tr>
<td>3.6. Detection limits. The Currie criteria</td>
<td></td>
</tr>
<tr>
<td>3.7. Probability distribution of time interval.</td>
<td></td>
</tr>
</tbody>
</table>

General characteristics of the detectors of ionising radiation

3.8. Introduction.

3.9. Detector model of radiation. Detector as an electrical transducer

3.10. Operating regimes of the detectors

3.11. Efficiency

3.12. Downtime

3.13. Fundamentals of spectrometry

Detectors of ionising radiations


3.15. Detectors of gaseous ionising

3.16. Scintillation detectors

3.17. Semiconductors detectors

Description of the principles for the detection of radiation, types of measurement, state of art, stochastic nature of radiation and its influence in detection, uncertainty sources, basic scenario, sources of radiation background and its influence. Introduction to the basic instrumentation required to detect the ionising radiation and the different ways of operation. Measures of activities, attenuation and spectrometric characteristics of different sources using different types of detectors.

**Related activities:**

- Expositive classes (6 h)
- Resolution of exercises in class (2 h)
- Work in the lab (6 h)
- Autonomous work. Theory, practical exercises, reports (21 h)

**Specific objectives:**

- Explain the physical basic processes of each type of detector of ionising radiations
- Analyse the influence in the detection of the interaction processes of the ionising particles
- Carry out experimental measures of the ionising radiations, analyse the results and determine the associated statistical and systematical errors.
- Select the most appropriate detection system regarding to the type of ionising radiation, and the magnitudes which are expected to be measured.
## 4. Basis of the Radiological Protection

**Learning time:** 60h
- Theory classes: 14h
- Practical classes: 10h
- Self study: 36h

**Description:**
Magnitudes and radiological units
4.1. Introduction, classification of the magnitudes
4.2. Magnitudes defining the field of ionising radiation
4.3. Interaction coefficients (efficient section, interaction coefficients and energy transfer, linear transfer of energy)
4.4. Dosimetric magnitudes used in the radiological protection
4.5. Magnitudes used in the external and internal dosimetry

Biological effects of the ionising radiation
4.6. Interaction of the ionising radiations on the biological material
4.7. Effects of the ionising radiations on cells and tissues
4.8. Stochastic effects of the radiations: carcinogenesis and hereditary effects
4.9. Radiobiology and radioprotection

International system of radiological protection
4.10. Protection principles for workers
4.11. Radiological protection of the population
4.12. Radiological emergencies. Interventions
4.13. Dose limits

Determination of the dose of external irradiation
4.15. Dosimetry of photons
4.16. Dosimetry of neutrons
Calculation of shielding (analytical and semi-empirical models)
4.17. Shielding of charged particles
4.18. Shielding of electromagnetic radiation
4.19. Shielding of neutrons
4.20. Calculation codes

Protection against the external irradiation
4.21. Terms in the location
4.22. Basic protection techniques against the external irradiation

Protection against radioactive pollution
4.23. Concept of pollution. Ways of incorporation
4.24. Calculation of the dose due to radioactive pollution
4.25. Decontamination methods of people
4.26. Decontamination methods of materials or working surfaces

Individual surveillance
4.27. Systems for the surveillance of the external personal dosimetry
4.28. Systems for the surveillance of the internal personal dosimetry

Description of the theory concepts in which the radiological protection is based. Experimental determination of the magnitudes of radiological interest. Resolution of exercises and types of cases. Numerical calculation of shieldings.

Related activities:
Expositive classes (14 h)
Resolution of exercises and cases in class (4 h)
Work in the lab (6 h)
Autonomous work. Theory, practical and numerical exercises, reports (36 h)

**Specific objectives:**
Identify the magnitudes used in the area of radiological protection and define them.
Explain, in a basic level, the biological risks of the ionising radiations and the need to limitate the dosage and the optimization techniques.
Use the basic principles of justification, limitation and optimization, of the international system of radiological protection, to argue that the practice involving the ionising radiations are compatible with the achieved global welfare, against the individual risks and sustainability.
Calculate the most appropriate dosage due to the ionising radiations in the location of a nuclear plant or a radioactive facility.
Carry out correctly the calculation of the radiation shielding, in simple situations, and contribute to the teamwork for the realization of complex shielding projects.
Apply techniques for the radiological protection to deduct the risks resulting from the use of ionising radiations.
Justifiably select the appropriate techniques for the realization of the individual dosimetric surveillance of the professionally exposed personnel.
Identify the main available codes for the calculation of the transport of ionising radiations, the type of particles which are able to manage, the valid range and the accuracy. Carry out easy calculations using those calculation codes.

**Qualification system**

Tools:
IE.1. Written exams. Individual tests or in group in a class. Questions to be developed, questions of multiple answers (test), and resolution of problems will be used.
IE.3. Small reports. Carried out by the student out of the class, individually or in groups.
IE.4. Formal reports. Documents with a previously defined structure in which the experimental analysis results are dealt, of calculation codes, development of theory aspects, resolution of complex problems...
These will be carried out in groups
IE.7. The discretionary rating. The continuous monitoring of the student, carried out by the Professor, will allow to come to a judgement on their value about the globality of the learning process of the student.

Qualification sketch:
10% corresponds to the delivery (within the deadline), of at least 80% of the small-reports (10-15 small reports in total)
40% corresponds to the delivery (within the deadline) of 100% of the formal reports (5-7 reports in total)
30% corresponds to passing all the exams of minimum knowledge . These exams will value the basic concepts of the course and they must be passed with a qualification of 8 or more. There will be two opportunities to pass each exam.
20% corresponds to the individual written exams. One after each formal report.
10% corresponds to a discretionary rating. This part will be used to improve the qualification regarding to the involvement of the student in the subject.
Bibliography

Complementary:


