Course guide
240NU011 - 240NU011 - Fundamentals of Nuclear Engineering and Radiological Protection

Last modified: 15/06/2023

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

Degree: MASTER'S DEGREE IN NUCLEAR ENGINEERING (Syllabus 2012). (Compulsory subject).
MASTER'S DEGREE IN INDUSTRIAL ENGINEERING (Syllabus 2014). (Optional subject).

Academic year: 2023 **ECTS Credits:** 8.0 **Languages:** English

LECTURER

Coordinating lecturer: FRANCISCO CALVIÑO TAVARES

Others: Calviño Tavares, Francisco
Batet Miracle, Lluis
De Blas Del Hoyo, Alfredo
Casanovas Hoste, Adria
Duch Guillen, Maria Amor

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 agreement: An accord between teachers and students to achieve the learning outcomes and competencies through a sequence of actions to be carried out by both the teacher and the student throughout the subject. On a practical level, it will be a summary of this document.
MD.2. Lectures: Presentations by the teacher that provide a synthesis of a topic, process, method, etc. These presentations cover theoretical concepts, the solving of standard exercises, descriptions of standard processes or procedures, the use of instruments and computation codes, etc.
MD.3. Scheduled autonomous learning: Developments that the student carries out, following pre-established instructions or guidelines, with the supervision of the teacher.
MD.4. Cooperative learning: The development of tasks by a small group of students that necessarily requires the work of every member of the group.

LEARNING OBJECTIVES OF THE SUBJECT

The student will be able to:
-Use models of atomic and nuclear structure to explain the origin and nature of atomic and nuclear radiation, and justify the production of nuclear energy.
- Apply the laws of the time evolution of radioactive substances to calculate their activity and the main radiations emitted
- Describe the main mechanisms of interaction of atomic and nuclear radiation with matter, and calculate and use the magnitudes associated with these interactions.
- Analyze the kinematics of nuclear processes and derive the expressions that allow calculating the energies and linear momenta of the products of reactions and decays
- Handle with confidence the concept, and the values collected in internationally recognized databases, of cross-section, to perform calculations of reaction rate, probability of interaction, and other derived magnitudes, applying them to the processes of interaction of radiation with matter and nuclear reactions produced by neutrons.
- Deduce and apply the equations governing the formation and time evolution of radionuclides in a nuclear reactor
- Explain the basic physical processes of each type of ionizing radiation detector
- Analyze how the interaction processes of ionizing particles influence their detection
- Do experimental measurements of ionizing radiation, analyze the results, and determine the associated statistical and systematic errors
- Adopt criteria that allow determining precisely the characteristics of a radioactive source by correcting the contribution of the background associated with the measurement
- Select the most appropriate detection system depending on the type of ionizing radiation, and the magnitudes to be measured.
- Identify the quantities used in the area of radiation protection and define them.
- Explain, at a basic level, the biological risks of ionizing radiation and the need for dose limitation and optimization techniques
- Use the basic principles of justification, limitation, and optimization, of the international radiation protection system, to reason that practices involving ionizing radiation are compatible with the global well-being achieved, in the face of individual risks and sustainability.
- Calculate the dose due to the most common ionizing radiations at the site of a nuclear power plant or radioactive facility.
- Perform radiation simple shielding calculations, and contribute to working as a team on complex shielding projects.
- Apply radiation protection techniques to reduce the risks arising from the use of ionizing radiation.
- Select and justify the appropriate techniques for the measurement of individual dose surveillance of professionally exposed personnel.
- Identify the main codes available for the calculation of ionizing radiation transport, the type of particles they are capable of handling, the range of validity and their accuracy. Perform simple calculations using those calculation codes

STUDY LOAD

Type	Hours	Percentage
Self study	128,0	64.00
Hours large group	64,0	32.00
Hours small group	8,0	4.00

Total learning time: 200 h

CONTENTS

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

Description:
Fundamentals
1.1. Atomic models. Energy levels
1.2. Ionization and excitation
1.3. Atomic radiation
1.4. Fluorescence and phosphorescence
1.5. X-rays
1.6. Nuclear mass, radius and charge
1.7. Nuclear models. Energy levels
1.8. Nuclear forces
1.9. Nuclear stability
1.10. Nuclear binding energy

Radioactivity
1.11. Radioactive processes
1.12. Laws of radioactive emission
1.13. Decay chains
1.14. Artificial radioactivity. Activation
1.15. Alpha radioactivity
1.16. Beta radioactivity
1.17. Gamma-ray emission
1.18. Nuclear isomerism and internal conversion

Presentations and exercises on atomic and nuclear structure. Emphasizing the concepts of energy levels and fundamental and excited states.
Presentations and exercises on radioactivity, radioactive processes, the law of time evolution, and radionuclide emissions

Specific objectives:
Use models of atomic and nuclear structure to explain the origin and nature of atomic and nuclear radiation, and justify the production of nuclear energy.
Apply the laws of the time evolution of radioactive substances to calculate their activity and the main radiations emitted

Related activities:
Lectures
Resolution of exercises in class
Self-learning. Theoretical and practical exercises

Full-or-part-time: 20h
Theory classes: 6h
Practical classes: 2h
Self study : 12h

2.1 EM interactions of charged particles and photons with the materia.

Description:
2.1.1 Mechanisms of energy loss of charged particles
2.1.2 Ionization and excitation. Bremsstrahlung
2.1.3 Stopping power. Linear energy transfer
2.1.4 Range
2.1.5 Interaction of photons with matter
2.1.6 Interaction of alpha particles with matter
2.1.7 Interaction of beta particles with matter
2.1.8 Photoelectric effect
2.1.9 Compton effect
2.1.10 Pair production
2.1.11 Attenuation and absorption of gamma radiation

Description of the quantities that, in general terms, characterize radiation fields and their effects on matter (flux, fluence, cross-section, etc.).
Presentation of the main mechanisms of interaction between charged particles and matter, and between photons and matter, with emphasis on databases available in the public domain, their interpretation, and their practical use.
Exercise solving

Specific objectives:
Describe the main mechanisms of interaction of atomic and nuclear radiation with matter, and calculate and use the quantities related to these interactions.
Distinguish between directly and indirectly ionizing radiation, and describe their properties.
Identify and describe the main mechanisms of interaction between charged particles and matter.
Define the stopping power of charged particles and their relationship to the energy deposited in a matter.
Identify and describe the main mechanisms of interaction between photons and matter

Related activities:
Expositive classes
Resolution of exercises in class
Self-learning. Theory and practical exercises

Full-or-part-time: 20h
Theory classes: 6h
Practical classes: 2h
Self study : 12h

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.
2.2.14. Elastic and inelastic diffusion.
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 teh effective section regarding to the energy of the incident neutron.

Specific objectives:
- Describe the main mechanisms of interaction of atomic and nuclear radiation with matter, and calculate and use the magnitudes associated with these interactions.
- Analyze the kinematics of nuclear processes and derive the expressions that allow calculating the energies and linear momenta of the products of reactions and decays
- Handle with confidence the concept, and the values collected in internationally recognized databases, of cross-section, to perform calculations of reaction rate, probability of interaction, and other derived magnitudes, applying them to the processes of interaction of radiation with matter and nuclear reactions produced by neutrons.
- Deduce and apply the equations governing the formation and time evolution of radionuclides in a nuclear reactor

Related activities:
Lectures
Resolution of exercises in class
Self-learning. Theoretical and practical exercises
Long term assignment: Challenge

Full-or-part-time: 48h
Theory classes: 6h
Practical classes: 2h
Guided activities: 40h

3. Detection of the ionising radiation

Description:
Applied statistics to the detection of radiation
3.1. Nature of ionizing radiations
3.2. Characterization of the data
3.3. Statistical models applied to the detection of radiation
3.4. Statistical error in the experimental data
3.5. Statistical error in the measurement of the detection
3.6. Detection limits. The Currie criteria
3.7. Probability distribution of time interval.

General characteristics of the detectors of ionizing radiation
3.8. Introduction.
3.9. Detector model of radiation. A detector as an electrical transducer
3.10. Operating regimes of the detectors
3.11. Efficiency
3.12. Downtime
3.13. Fundaments of spectrometry

Detectors of ionizing radiations
3.14. Introduction. Structure of the topic
3.15. Detectors of gaseous ionizing
3.16. Scintillation detectors
3.17. Semiconductors detectors

Description of the principles of ionizing radiation detection, types of measurement, state of the art, stochastic nature of radiation and its influence on its detection, sources of uncertainty, sources of background radiation, and its influence. Introduction to the basic instrumentation required to detect ionizing radiation and the different modes of operation. Measurements of activities, attenuations, and spectrometric characteristics of several radioactive sources using different types of detectors.

Specific objectives:
- Explain the basic physical processes of each type of ionizing radiation detector
- Analyze how the interaction processes of ionizing particles influence their detection
- Do experimental measurements of ionizing radiation, analyze the results, and determine the associated statistical and systematic errors
- Adopt criteria that allow determining precisely the characteristics of a radioactive source by correcting the contribution of the background associated with the measurement
- Select the most appropriate detection system depending on the type of ionizing radiation, and the magnitudes to be measured.

Related activities:
Expositive classes
Resolution of exercises in class
Work in the lab
Autonomous work. Theory, practical exercises, reports
Long term assignment: Challenge

Full-or-part-time: 47h 20m
Theory classes: 6h
Practical classes: 8h
Laboratory classes: 33h 20m

4. Basis of the Radiological Protection

Description:
Quantities and radiological units
4.1. Introduction, classification of the quantities
4.2. Quantities defining the field of ionizing radiation
4.3. Interaction coefficients (efficient section, interaction coefficients, energy transfer, linear transfer of energy)

4.4. Dosimetric quantities used in the radiological protection
4.5. Quantities used in the external and internal dosimetry

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

The international system of radiological protection
4.10. Protection principles for workers
4.11. Radiological protection of the population
4.12. Types of exposure
4.13. Dose limits

Determination of the dose of external irradiation
4.14. Dosimetry of charged particles
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

Individual surveillance
4.23. Systems for the surveillance of the external personal dosimetry
4.24. Systems for the surveillance of the internal personal dosimetry

Description of the theoretical concepts on which radiological protection is based. Experimental determination of the magnitudes of radiological interest. Resolution of exercises and basic practical cases. Numerical calculation of shieldings.

Specific objectives:
- Identify the quantities used in the area of radiation protection and define them.
- Explain, at a basic level, the biological risks of ionizing radiation and the need for dose limitation and optimization techniques
- Use the basic principles of justification, limitation, and optimization, of the international radiation protection system, to reason that practices involving ionizing radiation are compatible with the global well-being achieved, in the face of individual risks and sustainability.
- Calculate the dose due to the most common ionizing radiations at the site of a nuclear power plant or radioactive facility.
- Perform radiation simple shielding calculations, and contribute to working as a team on complex shielding projects.
- Apply radiation protection techniques to reduce the risks arising from the use of ionizing radiation.
- Select and justify the appropriate techniques for the measurement of individual dose surveillance of professionally exposed personnel.
- Identify the main codes available for the calculation of ionizing radiation transport, the type of particles they are capable of handling, the range of validity and their accuracy. Perform simple calculations using those calculation codes.

Related activities:
Lectures
Resolution of exercises and practical cases in class
Self-learning. Theoretical, exercises, numerical computations, reports

Full-or-part-time: 64h
Theory classes: 14h
Practical classes: 10h
Self study : 40h

GRADING SYSTEM

Instruments:

IE. 1. Individual or group written exams. Development questions, Multiple choice questions (tquiz), Problem solving, etc.
IE. 3. Mini reports. Individual or group simple reports.
IE. 4. Formal reports. Documents with a predefined structure in which experimental result analysis, calculation codes, development of theoretical aspects, resolution of complex problems, etc. are addressed. They will be prepared in groups. Some will include presentations by students of the relevant contents of the report.
IE.7. Discretionary valuation. Value judgment of teachers on the globality of the student's learning process

Rating scheme:

20%: Short-term assignments. Mini reports (10-15 total)
30%: Long-term assignments. Formal reports (5-7 total) and presentations
10%: Long-term assignments. Individually written exams, after some of the formal reports.
40%: Threshold exams. On basic concepts of the subject. A score of 8 or higher must be obtained on each question. There will be two opportunities to pass each exam. Three Threshold exams
10%: Discretionary valuation. This section will be used to improve the grade depending on the student's involvement in the subject.

BIBLIOGRAPHY

Complementary:
- Knoll, Glenn F. Radiation detection and measurement. 4th ed. Hoboken, New Jersey: Wiley, cop. 2010. ISBN 9780894484568.
- Carron, N. J. An Introduction to the passage of energetic particles through matter [on line]. Boca Raton: Taylor & Francis, cop. 2007 [Consultation: 29/03/2023]. Available on: https://ebookcentral-proquest-com.recursos.biblioteca.upc.edu/lib/upcatalunya-ebooks/detail.action?pq-origsite=primo&docID=283193. ISBN 0429137397.
- International Commission on Radiation Units and Measurements. Fundamental quantities and units for ionizing radiation. Bethesda: ICRU, 1998. ISBN 0913394599.
- Stopping powers for electrons and positrons. Bethesda, Maryland: ICRU, 1984. ISBN 0913394475.
- Tsoulfanidis, Nicholas; Landsberger, Sheldon. Measurement and detection of radiation. 3rd ed. Boca Raton: CRC Press / Taylor & Francis Group, cop. 2011. ISBN 9780913392713.