Course guide
240NU013 - 240NU013 - Reactor Physics and Thermal-Hydraulics

Last modified: 16/05/2023

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:** 7.5 **Languages:** English

LECTURER

Coordinating lecturer: Lluís Batet

Others: Jordi Freixa

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
1. Ability to use effectively, understand the operation and validity ranges, and interpret the results of thermal-hydraulic codes and fluid dynamic calculation.
2. 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.
3. Owning a theoretical and practical basis of reactor physics and thermal hydraulics that allow you to easily navigate issues related to plant operation and safety.

TEACHING METHODOLOGY

The course on reactor Physics and Thermal-Hydraulics is mainly based on theory sessions, with some practical sessions. Learning is completed by solving some specific problems out-of-the-classroom. Students will make autonomous use of a thermal-hydraulic system code to perform simulations and analyses.

As a result of the health crisis due to Covid19, the way in which sessions are delivered will be basically the same but with some nuances, depending on the existing conditions. In case of need, the sessions will be available in an online version.

The course combines asynchronous with synchronous activities, depending of the objective of each learning unit.

Note:

By synchronous we mean that interaction teacher-student takes place in the same timeframe. It is the case of contact (in the class-room) activities, and also the case of some online activities.

By asynchronous we mean that students perform the activity at their own pace (meeting the deadlines). It is the case, for instance, of many online activities, such as watching recorded videos or reading texts.

LEARNING OBJECTIVES OF THE SUBJECT

This course has the following objectives:

· Provide an overview of the phenomena involved in the thermal power generation in a fission nuclear reactor and of the conditions that make this generation feasible.
· Provide the analytical tools needed to compute the spatial distribution and the time evolution of the power production in a fission reactor
· Present, qualitatively and quantitatively, the dynamic phenomena affecting neutron multiplication within a reactor core, linking them with the contents of the Thermal-Hydraulics
· Provide the analytical tools needed to compute the energy balances, thermal fluxes and the coolant and fuel state in a fission reactor
· Provide the guidelines necessary to build a model of a nuclear reactor system, to simulate this system by means of a thermal-hydraulic system code, and to analyze the results obtained.

After following the course, students will be able to:

· Utilize nuclear data bases and describe the properties, in what concerns nuclear reactions with neutrons, of the most common nuclides in nuclear technology.
· Determine the reactivity of a multiplying medium knowing its composition and geometry.
· Understand, explain and apply the phenomena that may modify the reactivity of a power nuclear reactor and the several feedback effects that can take place in it.
· Determine the time evolution of the reactor's power level knowing the reactivity inserted and the magnitude of the feedback factors.
· Calculate the thermal power density distribution in the core of a critical reactor.
· Analyze the technical data book (an extract of the Nuclear Design Report) of a reactor and use it in a practical application.
· Utilize thermal-hydraulic calculation tools to determine the fuel's temperature and the state of the coolant in a given operational or accidental situation.
· Reason how thermal-hydraulic system codes model the complex thermal-hydraulic phenomena by means of scaling analysis and correlation of experimental data.

STUDY LOAD

Type	Hours	Percentage
Hours small group	7,5	4.00
Hours large group	60,0	32.00
Self study	120,0	64.00

Total learning time: 187.5 h

CONTENTS

1. Reactor Physics. Statics

Description:
This part of the course includes the neutron balance equations and the study of the diverse phenomena that may affect the neutron population in a nuclear reactor core. It ends with the formulation of the criticality condition; i.e. under what situation it is possible to maintain a steady fission chain-reaction.

Specific objectives:
At the end of this topic students should be able to:
· Explain the differences between neutron flux and neutron current
· Explain the different terms in the neutron balance equations (including transport equation)
· Explain the particular characteristics of the neutron diffusion theory
· Explain the process followed by a neutron from its birth from fission until it disappears of the system
· Describe the energy spectrum of neutrons in a nuclear reactor
· Explain the effect of temperature upon the resonance escape probability
· Calculate group parameters for thermal neutrons
· Explain the phenomena causing the thermal neutron spectrum to depart from the Maxwell-Boltzmann spectrum
· Solve the diffusion equation with two energy groups in practical cases
· Explain the four-factor formula
· Explain the physical meaning of the terms appearing in the criticality condition of both a bare reactor and a reflected reactor
· Explain what are the effects of heterogeneity (as compared to homogeneity) on the criticality of a nuclear reactor
· Analyze the effect of the composition on the multiplication factor
· Analyze how changes in the fuel, coolant and moderator of a commercial reactor affect the reactivity
· Solve the two-group reactor equation applied to bare and reflected reactors
· Explain the result of some basic operations on the reactor's reactivity

Related activities:
This part of the course includes some out-of-classroom activities that will consist in solving exercises using the knowledge acquired.

Full-or-part-time: 44h
Theory classes: 14h
Self study : 30h

2. Reactor Physics. Dynamics.

Description:
This part of the course includes the neutron kinetics and nuclear reactor dynamics; the first topic deals with the time variation of the neutron density after changes in the reactor conditions; the second one deals with the changes themselves.

Specific objectives:
At the end of this topic students should be able to:

· Explain the importance of delayed neutrons in a fission nuclear reactor
· Explain the terms that appear in the reactivity equation
· Describe the meaning of the solutions of the reactivity equation
· Describe and calculate the evolution of the neutron flux when reactivity is perturbed
· Explain the different phenomena that can modify the reactivity of a nuclear reactor core and the different feedback effects that can take place in it
· Analyze different cases of reactivity change with reactivity feedback
· Describe the effect that the evolution of the isotopic composition of the fuel has on the analysis
· Analyze the technical data book (nuclear design report) of a nuclear reactor and use it in a practical application

Related activities:
Besides typical expositive sessions, some exercises and practical sessions are programmed. Students will have to do, as well, some out-of-classroom activities, including solving some exercises using the acquired knowledge, and preparing the reports of the practical sessions.

Full-or-part-time: 37h
Theory classes: 12h
Self study : 25h

3. Thermal-Hydraulics. Introduction and phenomenology.

Description:
This part of the course will introduce the students to the extéense field of thermal hydraulics. Firstly, a complete view of the course topics will be provided. Thereafter the course will focus on the overall thermal balance of a light water reactor (LWR) in normal operation. In order to fully dive into the field of thermal hydraulics, the students will be introduced to an accidental situation in a pressurized water reactor and the related phenomenology. During this first part of the course, the basics of thermal hydraulics will be taught. This part includes as well a practical exercise of a first approach to the energy balance in a nuclear reactor, complemented with a practical session on steady-state calculations.

Specific objectives:
At the end of this topic students should be able to:

· Explain the thermal process that takes place in normal operation in a LWR.
· Explain the basic concepts of thermal hydraulics such as void fraction, subcooling, superheating, quality, hydraulic diameter, flow patterns and slip ratio.
· Detail the different flow patterns and heat transfer modes in two-phase flow.
· Explain how flow transitions may take place in the core of a nuclear reactor.
· Explain the different heat transfer processes that may take place in the core of a reactor.
· Explain the importance of thermal-hydraulics during a Large Break Loss-Of-Coolant-Accident.
· Explain some of the local phenomena that may occur in an accidental situation in a LWR.

Related activities:
Home-work for this part of the course includes a short exercise on overall plant balances and finishing the steady-state calculation started in the classroom.

Full-or-part-time: 26h
Theory classes: 16h
Self study : 10h

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4. Thermal-Hydraulics. Equation and codes.

Description:
In this part of the course, the formulation of the balance equations of mass, energy and momentum that govern two phase flow will be introduced. The different types of codes used in the field of thermal-hydraulics (system codes, sub-channel and computational fluid dynamics) will be described along with their related applications. This part includes as well a lecture on coupling between thermal-hydraulics and neutron-kinetics codes.

Specific objectives:
At the end of this topic students should be able to:

· Explain the representation of two-phase flows through the formulation of a set of balance equations.
· Explain the use of flow regime maps, correlations, hydraulic diameter and other concepts used in system codes and sub-channel codes.
· Explain the difference between the different types of codes and their applications.
· Perform simple caclulations with a system code.

Related activities:
Students will have a hands-on session with a system code so that they will be able to perform calculations using this code. One of the biggest activities of this course consists on performing a transient TH analysis using the code.

Full-or-part-time: 32h
Theory classes: 12h
Self study : 20h

5. Thermal hydraulics. Verification and validation .

Description:
In this part of the course, an overview of the verification and validation of thermal hydraulic codes will be provided. Examples of different experimental facilities of different sizes will be given and the related phenomena for which the rigs where designed will be described. The students will be introduced to the scaling principles that allow to experiment certain thermal hydraulic phenomena at reduced scale and allow to formulate correlations that are usable at different scales. In this part, the concept of "Validation test matrices" is introduced. There are specific sessions for separate and integral effect tests and one hands-on session on data bases of experimental facilities.

Specific objectives:
At the end of this topic students should be able to:

· Explain the process of verification and validation for computational tools.
· Explain the use of scaling techniques in the configuration of experimental facilities.
· Explain the different types and purposes of experimental facilities.
· Work with a particular experimental data base.
· Explain particular phenomena occurring during LWR accidental situations.

Related activities:
Students will have three activities related to this part:

· One activity related to the use of one experimental data base.
· One activity on experimentation of a particular phenomena at reduced scales.
· A follow up activity with the use of system codes.

Other activities related with system codes:

A journal article related to thermal hydraulics will be distributed to each student. Students will have to read and demonstrate they have understood it.

Full-or-part-time: 47h
Theory classes: 12h
Self study : 35h

GRADING SYSTEM

Final qualification will be calculated as 0.6 TH + 0.4 RP, being TH and RP the qualification obtained in the Thermal-hydraulic and Reactor Physics parts, respectively

TH = 0.5 THA + 0.5 THE
RP = 0.5 RPA + 0.5 RPE

Where THA and RPA are the qualifications of the corresponding assignments, whereas THE and RPE are the qualifications of the final exam.

The the relative weight of each of the assignments in the final mark will depend on their relative duration.

A minimum qualification of 5/10 is needed for each of the parts (TH and RP) separately.

As a result of the health crisis due to Covid19, the qualification method will be basically the same but with some nuances, depending on the existing conditions. Exams will be tailored to the students' situation, combining (if applicable) online questionnaires, long writing questions and oral questions.

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Basic:
- Duderstadt, James J; Hamilton, Louis J. Nuclear reactor analysis. New York: Wiley & Sons, cop. 1976. ISBN 0471223638.
- Lamarsh, John R; Baratta, Anthony J. Introduction to nuclear engineering. 3rd ed. Upper Saddle River: Prentice Hall, cop. 2001. ISBN 0201824981.
- Todreas, Neil E; Kazimi, Mujid S. Nuclear systems. New York: Hemisphere, 1990. ISBN 0891169369.
- Tong, L. S. Boiling crisis and critical heat flux. New York: University of Cornell, 1972.

Complementary:
- The RELAP5 Development Team. RELAP5/MOD3 code manual : volume I: Code structure, system models and solution methods [on line]. Washington, DC: U. S. Nuclear Regulatory Commission, 1995 [Consultation: 30/03/2023]. Available on: http://www.edasolutions.com/old/RELAP5/RELAP5M33/Manuals/volume1.pdf.
- Reventos, F.; Pretel, C.; Batet, L.; Izquierdo, J.; Arànega, M. "Teaching Basic Pressurized Water Reactor Core Thermal Hydraulics Following Worksheet Based Exercises". International Journal of Engineering Education [on line]. Gener 2009, vol. 25, núm. 6, p. 1183-1193 [Consultation: 06/10/2022]. Available on: https://www-ijee-ie.recursos.biblioteca.upc.edu/.- Reventós, F. ; Batet, L.; Llopis, C. ; Pretela, C. ; Salvat, M. ; Solc, I. "Advanced qualification process for ANAV NNP integral plant models for supporting plant operation and control". Nuclear engineering and design [on line]. Volume 237, Issue 1, January 2007, Pages 54-63 [Consultation: 20/04/2023]. Available on: https://www-sciencedirect-com.recursos.biblioteca.upc.edu/science/article/pii/S0029549306003694.