CIRTEN

Consorzio Interuniversitario per la Ricerca TEcnologica Nucleare

Preliminary list of learning outcomes of ANNETTE WP2 Courses for use in the interaction with stakeholders

Walter Ambrosini and Rosa Lo Frano

Pisa, May 18th, 2017

CIRTEN Report No. MR/ANH2020/012017 Version 1

SUMMARY

The present report summarises the information on WP2 courses in terms of learning outcomes (LOs) as collected up to the date of writing (mid-January 2017).

The Roadmap for WP2 issued early in summer 2016 envisaged a full collection of Learning Outcomes before the end of 2016. Actually, most of the material is now collected, though some incomplete submissions, needing further elaboration, still exist.

The received Learning Outcomes have been mostly collected in the form suggested by G-10 of JRC after an interaction that went on during summer 2016. In this interaction, the ANNETTE Consortium was informed that the previous rationale for collecting learning outcomes and published in EHRO-N reports was being changed, following slightly new paradigms.

However, some of the material is not yet available in the form proposed in the template set up by the Coordinator of WP2 in agreement with the received suggestions. In this respect, further work is needed to homogenise the format of presentation of course LOs.

TABLE OF CONTENTS

SUMMARY ii
TABLE OF CONTENTS iii
1. INTRODUCTION 4
2. PRELIMINARY LIST OF COURSES 7
3. PRELIMINARY LEARNING OUTCOMES OF COURSES 8
3.1 COURSES BY ESARDA 8
3.2 COURSES BY KIT (IFRT+INE+ANPS) 14
3.3 COURSES BY JRC-Directorate G-Nuclear Safety and Security 22
3.4 COURSES ON GEOLOGICAL WASTE DISPOSAL BY CVUT, UL, UPM 34
3.5 COURSES BY HORIA HULUBEI NATIONAL INSTITUTE 45
3.5 COURSES BY UPC 50
3.6 COURSE BY CVUT ON TRAINING REACTOR 53
3.7 COURSE BY UCL 56
3.8 COURSES BY UMAN 63
3.9 COURSES BY INSTN 67
3.10 COURSES BY UPM 76
3.11 COURSES BY CIRTEN 77
3.11 IN KIND FULL PROGRAMMES OFFERED FOR ANNETTE 92
3.12 IN KIND COURSES OFFERED BY STAKEHOLDERS 93
4. ANNETTE SUMMER SCHOOL 94
5. ROLE OF E-LEARNING AND MOOCs 95
6. ORGANISATION OF THE COURSES INTO TRACKS 97
6.1. Problems to be overcome 97
6.2. Full Master program attendance vs. selected course attendance 97
6.3. Worth of the released certifications 99
7. CONCLUDING REMARKS 101
REFERENCES 102

1. INTRODUCTION

The Courses proposed within the frame of ANNETTE were envisaged since the development of the proposal asking to invited participants about the possible offer on their side. The intention of this early action was to identify the potential of the consortium being set up, starting with a reasonable basis of courses to be coordinated in the "Master" and the "Summer Schools", being the main targets of the project.

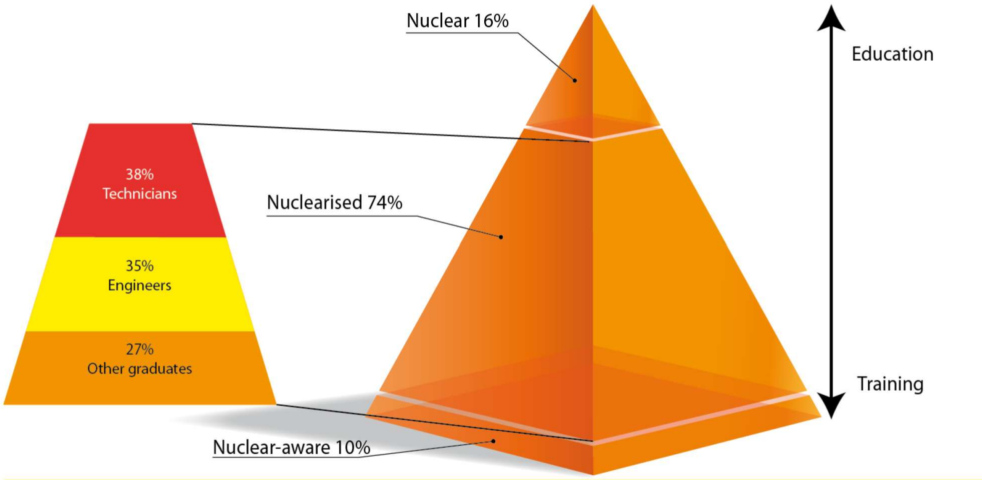
Since the very beginning, it was anyway considered the possibility that the Consortium Partners or even external organisations could contribute "in kind" existing or ready-to-go courses, in order to enrich the offer and to contribute to the coordination of the Education and Training in the different nuclear sectors on a wider basis. In fact, though the Consortium is relatively wide (25 Participants), in this first exercise it may be difficult that the identified course providers will cover all the interesting subjects in Nuclear Engineering / Safety, Radiation Protection, Waste Management and Geological Disposal and Fusion.

A major target of the project, therefore, in addition to set up a first "coordinated" E&T effort in the different mentioned nuclear sectors, to be qualified as a "Master of 60 ECTS", will be to set up the structure that will make sustainable this coordinated effort. This is why a first Work Package of the project was devoted to "coordination" and "advanced networking", as the acronym ANNETTE implies. So, coordinating efforts under the pan-European aegis of ANNETTE, as one of the actions of ENEN, even beyond the strict offer of the Consortium, is the longsighted aim that was prudently expressed as a long term strategy since the very beginning.

In the preliminary offer described below in terms of learning outcomes, the courses proposed by the Participants in adhering to the proposal are therefore mixed with "in-kind" offers, increasing the breadth of the covered matters and areas. The ongoing contacts with stakeholders is increasing this cooperation process, providing endorsement and catalysing new contributions.

However, even disregarding the full program offers by KIT (IFTR+INE+ANPS), by BNEN and by UCLAN, the present offer exceeds 120 ECTS (used as units in place of ECVETS, just for their correspondence with the teaching hours). This means that multiple paths can be designed for various learners wishing to complete the 60 ECTS master (including a project / thesis work), though the offer will be available also for those picking up just few matters out of the general offer for increasing their knowledge in limited areas.

Again and again, we need, in fact, to refer to the following Figure 1, depicting the breakdown of the nuclear workforce according to the analyses performed by EHRO-N.



Source: EHRO-N

Figure 1. Breakdown of nuclear workforce according to EHRO-N [1]

The interesting message coming from this and similar analyses taken into account in a previous CIRTEN Report [2] is that the offer to be coordinated within ANNETTE must serve different purposes and type of learners:

- nuclear specialists (in the share of 16%) wishing to deepen their knowledge by attending one or more courses provided in the offer; we must also consider "future" nuclear specialists who, having already a MSc in some discipline, wish to orient their education to become nuclear experts, to be included in the mentioned 16% or the workforce;
- specialists from other disciplines highly demanded in the nuclear workforce (e.g., electrical, chemical, mechanical, civil engineers or scientists) needing to be nuclearized at least in part by attending those which are often called "minor" courses in their global preparation;
- personnel that might need to receive a very basic information about the nuclear environment in which they have to work.

Which course will be useful for one or the other of the intended educational objectives is an issue that needs to be analysed on the basis of the full panorama of courses once completely collected. For the present time, the list of available courses under the umbrella of ANNETTE and of the related learning outcomes allows to be aware of the extent and suitability of the present effort.

We must anyway consider that more courses are being offered following the first interaction with some Stakeholders, who suggested that they can contribute. This contribution to the basic offer by the consortium is presently considered as one of the possible indicators of success of ANNETTE in its purpose to leave behind the project a sustainable structure of courses in a real pan-European effort. In this respect, the presently collected courses may constitute the center for coagulating a larger effort, making of ANNETTE much more than an additional European Fission Training Scheme. The final purpose, is in fact, to make of ANNETTE the tool by which ENEN, in its service to the European Union, can try to coordinate a substantial effort for maintaining and developing knowledge and skills in the nuclear sectors.

2. PRELIMINARY LIST OF COURSES

ESARDA Courses	"Nuclear Safeguards" Course in Advanced Master/VET
	Workshop on Safeguarding NFC
	Workshop on Proliferation Resistance
	Workshop on State-level Safeguards Concept
	Workshop on Safeguards-relevant Open Source Information
in kind	MOOC: Course "Introduction to Safeguards" (for students in Nuclear Engineering, Nuclear Energy etc.)
	ESARDA Course on Nuclear Safeguards
KIT (IFRT+INE+ANPS)	Fuel Cycles, Decommissioning, Waste Disposal and Safeguards
	Reactor Exercises
	Design Basis Accidents and its Simulation Tools
	Computational fluid dynamics with OpenFOAM
	Design of Pipelines against Earthquake Loads
KIT (IFRT+INE+ANPS)	1) Flow modelling in Fuel Assemblies
offered in-kind:	2) Monte Carlo criticality and shielding calculations (http://www.anps.kit.edu/307.php)
1/3 of the price	3) Reactor physics calculations with deterministic methods (http://www.anps.kit.edu/309.php)
for ANNETTE attendants	4) Beyond-design accidents, core-melt accidents (http://www.anps.kit.edu/311.php)
Information available on	5) Coupled Neutron Kinetics /Thermal Hydraulic Codes for Safety Assessment of Nuclear Power Plants (http://www.anps.kit.edu/313.php)
indicated website	6) Thermohydraulic Stability Analysis (http://www.anps.kit.edu/319.php)
	7) Technology and Management of the Decommissioning of Nuclear Facilities (http://www.anps.kit.edu/321.php)
	8) Containment thermohydraulics and hydrogen behavior
	9) Stress Analysis (http://www.anps.kit.edu/327.php)
	10) Light Water Reactor (LWR) core design and fuel management (http://www.anps.kit.edu/331.php)
	11) Light Water Reactor (LWR) core feedback and transient response (http://www.anps.kit.edu/333.php)
	12) Severe Accident Simulation in Liquid Metal Reactors (http://www.anps.kit.edu/293.php)
JRC-Directorate G-Nuclear Safety and Security	(1) Nuclear Fuels (including severe accident conditions); (as part of a master – contact person D. Manara)
	(2) Back end of the nuclear fuel cycle (as part of a master – contact person S. Van Winckel)
	(3) Hands-on training in the area of radiation protection (as part of a master – N. Rausch)
in kind	(4) International Summer School on Nuclear Decommissioning and Waste Management (K.Abbas) (5) Training Module on Planning RD&D towards Geological Disposal (including legal basis, ethical aspects, the role of storage, establishing national programs); (as contribution to a summer-school – contact persons G. Buckau and E.Kassim)
CVUT	Experimentation in Josef Underground Facility
UL	Site selection for radioactive waste disposal
UL+UPM	Radioactive waste disposal
IFIN-HH	Radon and its radiological impact
	Principles of Radiation Protection and International Framework. Regulatory Control
In kind	•Sealed and Unsealed Radioactive Sources. Classification. Characterization. Performance requirements. Associated risks.
	or
	•Particle accelerators and related radiation protection issues
UPC	Operation of Nuclear Power Plants. Practices with nuclear power plant conceptual simulator at UPC: 1 week (30 h - 6h/day) including 2 practical sessions each day. Power plant conceptual simulator : SIREP-1300
CVUT	Advanced training course at VR-1 reactor
UCL	Nuclear Thermal-hydraulics
	Single/two-phase choked flow applicable to the LOCA (for a Summer Course)
in-kind extension to BNEN Courses	
UMAN	NTEC N03 Radiation & Radiological Protection
	NTEC N06 Reactor Materials And Lifetime Behaviour
	NTEC N09 Policy, Regulation & Licensing
	NTEC N23 Radiological Environmental Impact Assessment
INSTN	Basic operation of nuclear reactors
	Neutronics for light water reactors
	Thermal Hydraulics of light water reactors
	Safety and operation of PWRs
UPM	1.Nuclear waste management course (6 ECTS)
	2.Radiological protection course (3 ECTS)
	3.Nuclear technology course (3 ECTS)
CIRTEN	Single and Two-Phase Thermal-hydraulics (for nuclear reactors)
(all in kind)	Structural design for Safety of Nuclear Reactors
	more to come
UCLAN	Nuclear Safety, Security and Safeguards (MSc)

3. PRELIMINARY LEARNING OUTCOMES OF COURSES

3.1 COURSES BY ESARDA

Course on "Nuclear Safeguards"		
Units and LO Statements		
Unit 1 – History of non-proliferation and safeguards (4 hours + case study assignment) ***UU***	**Responsibility / Autonomy** Autonomous capability to account for history of international safeguards	
	Skills	**Knowledge**
• Brief history of nuclear weapons • Historical evolution of non-proliferation and international nuclear safeguards • Different schools of thought with respect to International Relations • Nations staying outside or leaving international safeguards treaties • …	• Analyse the action of different states with respect to nuclear weaponisation, de-weaponisation or adherence to international treaties in the light of international relations and different schools of thought • …	• Be familiar with the historical use of nuclear weapons in military conflicts • Understand the historical development of non-proliferation and international safeguards • …
Assessment criteria: To demonstrate knowledge of the historical background of nuclear weapons and nuclear non-proliferation regimes. To demonstrate skills in the analysis of different state's action with respect to nuclear weapons and proliferation		
Assessment methods: Questions on historical background included in written examination. Additional assignment comprising theoretical case studies of states' historical actions.		
Unit 2 – Legal frameworks (3-4 hours) ***Jülich/SCK-CEN***	**Responsibility / Autonomy** Describe the basic principles of safeguards and its legal basis	
	Skills	**Knowledge**
• Basic principles of safeguards and non-proliferation • International non-proliferation treaties • Safeguards agreements • Safeguards approaches on the facility level and the State level	• Recognize the role of non-proliferation and safeguards • Design a generic safeguards approach for a nuclear facility • Outline a State-level safeguards approach	• Illustrate the basic concepts of nuclear safeguards (e.g. significant quantity, timeliness, ….) • Compare the international treaties on safeguards and arms control • Identify the steps for the development of a safeguards approach • …
Assessment criteria: To demonstrate understanding of the basic safeguards principles and of the main characteristics of the safeguards international treaties.		
Assessment methods: Short essay (1-2 pag. maximum) on State-level safeguards approach for a model country. Questions on the different learning units are included in the written examination.		
Unit 3 – Fuel cycle and non-proliferation (4 hours) ***UU***	**Responsibility / Autonomy** Mastering flows of sensitive nuclear materials in open and closed fuel cycles	
	Skills	**Knowledge**
• Open and closed fuel cycles • Facilities and technologies involved in each cycle step: ○ Mining	• Capability to account for material properties in each step of the nuclear fuel cycle(s) and to discuss the sensitivity to diversion of each step from a proliferation perspective	• Discriminate between fissile and fertile material • Distinguish the open fuel cycle from the closed fuel cycle • Recognise all steps of the nuclear fuel cycle(s)

<table>
<tr><td>

Milling
Refining & conversion
Fuel fabrication
Reactor operation
Spent fuel interim storage
Reprocessing / recycling
Encapsulation
Final reposition …

Sensitivity to diversion of fissile material in the steps of the fuel cycle
…

</td><td>
…
</td><td>

Understand the need and techniques for enrichment of natural uranium in U-235 for use in most commercial reactors
Understand the processes used for reprocessing or recycling of irradiated nuclear fuel
Identify possible proliferation issues related to each step in the fuel cycle(s)
…

</td></tr>
<tr><td colspan="3">Assessment criteria: To demonstrate knowledge of the open and closed fuel cycles and understanding of possible proliferation issues related to each cycle step.</td></tr>
<tr><td colspan="3">Assessment methods: Questions on diversion issues for the steps of the fuel cycles included in the written examination.</td></tr>
<tr><td rowspan="3">Unit 4 – Nuclear material accountancy
SCK-CEN
(1-2 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Understand the principles of nuclear material accountancy</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>

Nuclear material accountancy (NMA) in the context of nuclear safeguards
Structure of the nuclear material balance
Principles of statistics applied to NMA
Attribute/Variable sampling
…

</td><td>

Prepare a general sampling strategy to detect diversion scenarios
…

</td><td>

Explain the objectives of nuclear material accountancy
Explain the general structure of nuclear material balance in a facility
…

</td></tr>
<tr><td colspan="3">Assessment criteria: To demonstrate knowledge of nuclear material accountancy and basic principles of statistics needed for the NMA evaluation.</td></tr>
<tr><td colspan="3">Assessment methods: Questions on different learning units are included in the written examination.</td></tr>
<tr><td rowspan="3">Unit 5 – Probabilistic and statistical methods for nuclear safeguards
(4 lecture, 4 hours exercises) Jülich</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>

Basic probabilistic and statistical principles used in safeguards
Measurement errors and their propagation
Random inspection approaches
Inspection verification sampling plans

</td><td>

Can apply basic probability and statistical methods to simplified safeguards problems
Can thoroughly interpret confidence statements and results from statistical tests
Knows, how error variances are propagated
Can determine the achieved detection probability of random inspection approaches
Can calculate the required number of attribute samples to achieve a required non-detection probability

</td><td>

Use basic probability rules and explain the differences between discrete and continuous random variables
Describe the components of a statistical test and its use in safeguards
Describe error components and their importance in error propagation
Explain modelling assumptions of random inspection approaches
Explain assumptions for creating an attribute sampling plan

</td></tr>
<tr><td colspan="3">Assessment criteria: To demonstrate understanding of basic probabilistic and statistical principles applied in the field of nuclear material accountancy.</td></tr>
<tr><td colspan="3">Assessment methods: Questions on different learning units are included in the written examination and the exercises.</td></tr>
<tr><td rowspan="2">Unit 5 – Export control
(4 hours) JRC</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Understand Export control and how it contributes to nuclear safeguards and non-proliferation</td></tr>
</table>

<table>
<tr><td></td><td>Skills</td><td></td></tr>
<tr><td>• International Export Control Regimes
• Export control commitments required by the NPT, CSA and Additional Protocol
• Principles of the EU (Nuclear) Export Control Regime
• Nuclear dual-use items
• Illicit procurement and export control challenges</td><td>• Understand export control objectives
• Implement parts of the EU export control legal framework
• Assess whether items or technologies are subject to export control authorisations</td><td>• International Export Control Regimes
• Export control commitments required by the NPT, CSA and Additional Protocol
• Principles of the EU (Nuclear) Export Control Regime
• Nuclear dual-use items
• Illicit procurement and export control challenges</td></tr>
<tr><td colspan="3">Assessment criteria: To demonstrate knowledge of export control and of possible proliferation issues related to dual-use items</td></tr>
<tr><td colspan="3">Assessment methods: Questions on export control included in the written examination.</td></tr>
<tr><td rowspan="3">Unit 6 –Implementation of safeguards (4 hours) Jülich</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Understand how safeguards is implemented in a State</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Types of safeguards-relevant information
• Types of inspections activities and inspection techniques
• Design information verification / Basic technical characteristics
• Safeguards Regulatory Authorities
• State and Regional Systems of Accounting for and Control of nuclear material (SSACs/RSACs)
• Collaboration between regional and international inspectorates
• Typical issues during inspections
• …</td><td>• Distinguish between different types of safeguards-relevant information
• Discriminate between different types of inspections activities and inspection techniques
• Recognize the importance of collaboration between regional and international inspectorates
• Identify possible solutions for addressing typical issues during inspections
• …</td><td>• Understand the basic procedures and obligations of practical safeguards implementation on the operators’ and inspectorates’ side.
• Understand the process of design information verification / basic technical characteristics
• Understand the new partnership approach (NPA)
• …</td></tr>
<tr><td colspan="3">Assessment criteria: To demonstrate understanding of the practical implementation of safeguards on the States’ and inspectorates’ side.</td></tr>
<tr><td colspan="3">Assessment methods: Questions on implementation of safeguards included in written examination.</td></tr>
<tr><td rowspan="3">Unit 7 – Containment and Surveillance (C/S)
(4 hours lecture) JRC</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Be aware of the existing technological solution for C&S in nuclear safeguards</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• General presentation about C&S objectives, approaches and technologies
• Sealing technology
  ○ General presentation about seals (what is a seal, different types of seals)
  ○ Passive Seals, e.g. COBRA, metallic seals
  ○ Electronic seals (EOSS, AOLS, etc.)
  ○ Ultrasonic seals (US principles and US seal description)
• Surveillance technologies
  ○ Single- and multi-camera optical systems
  ○ Surveillance review software
  ○ 3D surveillance and change detection
• Smart sensors
• Containment Systems (cabinets, storage containers, conduits)</td><td>• Understand the most effective C&S technology to be adopted depending on the working scenario
• Design and set-up the solution based on the identified technology
• Analyse information generated by the solution and draw conclusions</td><td>• Be familiar with C&S technologies:
  ○ Different sealing technologies
  ○ Video surveillance
  ○ 3D technologies
  ○ Smart sensors
• Understand the objectives and requirements for C&S in nuclear safeguards, e.g. Continuity of Knowledge, Tamper Resistance, Vulnerability Assessment</td></tr>
</table>

• Remote Monitoring • Data encryption and authentication		
Assessment criteria: To demonstrate understanding of different C/S devices for Nuclear Safeguards		
Assessment methods: Questions about different equipments: why they are used and for which specific NS application		
Unit 8 – Non-Destructive Assay (NDA) (4 hours lectures + 4 hours hands-on exercises, if possible) UU	**Responsibility / Autonomy**	
	Autonomous capability to evaluate the use of NDA techniques in safeguards	
	Skills	**Knowledge**

• General principles of non-destructive measurements
• NDA techniques and instruments used in nuclear safeguards
  ○ Calorimetry
  ○ Gamma spectrometry
  ○ Neutron assay
  ○ Cherenkov light detection
• NDA techniques under development
  ○ Gamma tomography
  ○ …
• …
	• Draw conclusions on adequacy of measurement procedures in terms of accuracy and simplicity
	• Capability to select assessment technique depending on object
	• Apply counting statistics to determine precision in measured quantities
	• Hands-on experience of NDA techniques and procedures
	• …
		• Be familiar with NDA techniques and equipment used in nuclear safeguards
		• Connect properties of object under study with quantities available for NDA
		• Understand how equipment used must be adapted to properties of the object under study
		• Understand gamma spectroscopic methods and the influence on data quality from the selection of gamma-ray detection system
		• Have insight in NDA techniques under development
		• …

Assessment criteria: To demonstrate understanding of NDA of nuclear materials and capabilities to execute analysis of NDA data.		
Assessment methods: Questions on NDA techniques and equipment included in written examination. Hands-on exercise of a selected NDA technique, including written report of the exercise.		
Unit 9 – Destructive Analysis (DA) (4 hours + 2 hours desk top exercise) JRC	**Responsibility / Autonomy**	
	(…)	
	Skills	**Knowledge**

• General principles of DA analysis:
  ○ Dissolution techniques (metals, oxides, etc.)
  ○ Separation techniques (anion exchange, extraction chromatography, etc.)
  ○ Hydrolysis (UF_6)
• Nuclear material analysis
• Environmental analysis (bulk and particle swipes)
• DA techniques applied in safeguards (isotope ratios, content/concentration)
  ○ Mass spectrometry (TIMS, ICP-MS, LA-ICP-MS, SIMS, GSMS, FT-TIMS, etc.)
  ○ Alpha spectrometry
  ○ Controlled potential coulometry
  ○ Titrimetry
  ○ Hybrid K-edge
  ○ COMPUCEA
• Quality control tools:
  ○ Method validation
	• Selection of a proper DA approach depending on the type of a sample (environmental vs. nuclear sample)
	• Special sample analysis and isotopic fingerprinting for nuclear safety, security and safeguards
	• Instrument calibration (desk top exercise)
	• Uncertainty budget – top down and bottom up approach (desk top exercise)
	• …
		• Be familiar with DA techniques and instrumentation applied in nuclear safeguards
		• Be familiar with DA techniques applied in EURATOM/IAEA on-site laboratories
		• Be familiar with quality in analytical measurements
		• Acquire knowledge on the estimation of measurement uncertainty in DA
		• Be familiar with the quality system (international guidelines, ITVs and QC tools)
		• Be familiar with the significant quantities in safeguards
		• …

<table>
<tr><td colspan="2">

Document standards (ISO, ITVs, ASTM, etc.)
Reference materials (CRM, RM, etc.)
Inter-laboratory comparison (ILC)
Uncertainty estimation (GUM, etc.)

…
</td><td></td><td></td></tr>
<tr><td colspan="4">Assessment criteria: To demonstrate understanding of DA techniques for nuclear and environmental materials</td></tr>
<tr><td colspan="4">Assessment methods: Questions on DA techniques included in written examination.</td></tr>
<tr><td rowspan="3">Unit 10 – Novel technologies, approaches and methodologies (3-4 hours) Jülich</td><td colspan="3">Responsibility / Autonomy</td></tr>
<tr><td colspan="3">Scanning the horizon for potential technologies, approaches and methodologies</td></tr>
<tr><td colspan="2">Skills</td><td>Knowledge</td></tr>
<tr><td>

Technology foresight
Instrumentation toolkit for inspectors (“smart inspectors”)
Autonomous navigation and positioning for safeguards
Robots (including UAVs)
In-situ analysis
Artificial intelligence and machine learning
…

</td><td colspan="2">

Identify potential technologies, approaches and methodologies from non-traditional safeguards fields
Assess the impact of novel technologies, approaches and methodologies on the effectiveness and efficiency of safeguards
Consider the safety and security provisions as to the implementation of novel technologies, approaches and methodologies
…

</td><td>

Understand the need and basic process of technology foresight
Understand the basic principles and potentials of today’s novel technologies, approaches and methodologies
…

</td></tr>
<tr><td colspan="4">Assessment criteria: To demonstrate understanding of NDA of nuclear materials and capabilities to execute analysis of NDA data.</td></tr>
<tr><td colspan="4">Assessment methods: Questions on novel technologies, approaches and methodologies included in written examination.</td></tr>
<tr><td rowspan="3">Unit 11 – Physical protection (1-2 hours) SCK-CEN</td><td colspan="3">Responsibility / Autonomy</td></tr>
<tr><td colspan="3">Master the objectives and concepts of physical protection</td></tr>
<tr><td colspan="2">Skills</td><td>Knowledge</td></tr>
<tr><td>

Basic concepts of physical protection
Graded approach: nuclear and radioactive material categorization
Vital areas and access controlled areas
Overview of physical protection systems
…

</td><td colspan="2">

Design a general physical protection system for a nuclear facility
…

</td><td>

Explain the basic concepts of physical protection
Illustrate the graded approach and the differences between areas in a nuclear facility
…

</td></tr>
<tr><td colspan="4">Assessment criteria: To demonstrate knowledge and importance of physical protection systems.</td></tr>
<tr><td colspan="4">Assessment methods: Questions on the different learning units are included in the written examination</td></tr>
<tr><td rowspan="3">Unit 12 –Illicit trafficking (3-4 hours) SCK-CEN</td><td colspan="3">Responsibility / Autonomy</td></tr>
<tr><td colspan="3">Master the techniques to detect illicit trafficking of radioactive materials</td></tr>
<tr><td colspan="2">Skills</td><td>Knowledge</td></tr>
<tr><td>

Introduction and objectives
Legal basis
Detection equipment
Response to an alarm
Authorized uses of radioactive materials

</td><td colspan="2">

Recognize and compare detectors that can be used for the detection of illicit trafficking
Execute a general approach for the response to an alarm in case of illicit trafficking

</td><td>

Discuss the objectives and risks of illicit trafficking
Explain the legal basis for the detection of illicit trafficking
…

</td></tr>
</table>

<table>
<tr><td>• Cases of illicit trafficking
• …</td><td>• Differentiate between authorized uses of radioactive materials and cases of illicit trafficking
• …</td><td></td></tr>
<tr><td colspan="3">Assessment criteria: To demonstrate knowledge of illicit trafficking and available means to detect potential scenarios.</td></tr>
<tr><td colspan="3">Assessment methods: Questions on the illicit trafficking are included in the written examination.</td></tr>
<tr><td rowspan="3">Unit 14 – Upcoming challenges
(3-4 hours) Jülich</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Strengthening non-proliferation and safeguards</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Emerging technologies (incl. social media)
• Cyber-attacks
• Geopolitical developments
• Non-State actors, terrorism
• Future of legal frameworks
• …</td><td>• Identify and assess upcoming challenges for the safeguards system
• Apply risk analysis with regard to upcoming challenges
(…)</td><td>• Understand the potential influences on the safeguards system
• Understand the possible impact and consequences of future challenges for non-proliferation and safeguards
• (…)</td></tr>
<tr><td colspan="3">Assessment criteria: To demonstrate understanding of upcoming challenges and its implications to the safeguards system.</td></tr>
<tr><td colspan="3">Assessment methods: Questions on the upcoming challenges are included in the written examination.</td></tr>
</table>

Course applicable (in part or fully) for the following job profiles:

- Official in state authority for supervision of nuclear technology and materials
- Inspector working with in-field verification of nuclear materials and activities
- Employee in commercial enterprise with responsibility for nuclear materials accountancy

3.2 COURSES BY KIT (IFRT+INE+ANPS)

<table>
<tr><td colspan="3">Course on "Fuel Cycles, Decommissioning, Waste Disposal and Safeguards"
Aurelian F. Badea (IFRT), Xu Cheng (IFRT), Thorsten Schäfer (INE)</td></tr>
<tr><td>Units and LO Statements</td><td></td><td></td></tr>
<tr><td rowspan="3">Unit 1 – Fuel Cycles
(12 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomous background on the key concepts of the front end of the fuel cycle and transuranium elements in the nuclear fuel cycle</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Front end of the fuel cycle
  ○ Uranium exploration and mining
  ○ Uranium Enrichment
  ○ Fuel Fabrication
• Transuranium elements in the nuclear fuel cycle
  ○ Transuranium elements
  ○ Transuranium fuels
  ○ Reprocessing
  ○ TRU storage and waste disposal</td><td>• Characterise the industrial operations needed to produce a functional fuel element ready to be loaded in a nuclear reactor
• Comprehensive understanding of the technologically effective options for the treatment of TRU-elements</td><td>• Uranium resources, exploration, mining and milling, sites rehabilitation
• Enrichment technologies: gaseous diffusion, ultracentrifugation, other methods
• Elements of fuel design, fissile/fertile couple, fuel material, cladding materials, absorbers, LWR fuel, MOX fuel, other fuels
• Fundamental aspects of transuranium fuels, transuranium element fuel and target fabrication, irradiation behaviour of transuranium fuels
• Reprocessing, impact of transuranium elements on storage and waste disposal concepts</td></tr>
<tr><td rowspan="3">Unit 2 – Decommissioning of Nuclear Plants
(12 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Ability to recommend technological tools for decommissioning</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Decontamination Techniques
• Cutting and dismantling techniques
• Remote control techniques
• Spent-fuel and waste management</td><td>• Ability in choosing technological tools with respect to industrial safety, environmental impact minimization, waste disposal and spent fuel strategy. Ability on safety and structural analysis, short and long-term planning.</td><td>• Plant and site characterization, decontamination techniques
• Thermal cutting techniques, hydraulic cutting techniques, mechanical dismantling techniques
• Remote operation technologies, remote-system configurations
• Spent-fuel interim storage, waste management, the waste management facility (WMF)
• Safety, health and environmental protection</td></tr>
<tr><td rowspan="3">Unit 3 – Waste Disposal and Safeguards
(12 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Mastering scientific concepts and data underlying the management of the radioactive waste, basic knowledge on proliferation resistance and safeguards</td></tr>
<tr><td colspan="2"></td></tr>
</table>

<table>
<tr><th></th><th>Skills</th><th>Knowledge</th></tr>
<tr><td>Generalities on waste
Waste conditioning
Waste storage and disposal
Proliferation resistance
Safeguards</td><td>Use of scientific concepts and data underlying the management of the radioactive waste and basic knowledge on proliferation resistance and safeguards</td><td>Origin, nature, volume, and flux of waste
Management options
Conditioning of LL and IL waste in cement-based matrices
Conditioning of HL-LL waste in glass
Other conditionings for waste
Conditioning of spent fuel
Storage of long-lived waste and spent fuel
Geological disposal
Safety of waste disposal facilities
Material attractiveness
Non-proliferation impact assessments
Domestic safeguards: implementing a State System of Accounting and Control (SSAC)
IAEA inspection regime
Safeguards design, unattended monitoring, process monitoring, environmental sampling, statistics for accountancy</td></tr>
<tr><td>Assessment criteria
Demonstration of fundamental knowledge in fuel cycles, decommissioning, waste disposal and safeguards
Ability to understand technical aspects of this field</td><td></td><td></td></tr>
<tr><td>Recommended assessment methods:
Multiple choice examination [choosing among different options]
Written test
Face to face examination</td><td></td><td></td></tr>
</table>

Course applicable (in part) for the following job profiles:

- 1.0.01-02: Nuclear Safety Manager, Safety Assessment Specialist
- 1.0.10: Safety Design Engineer
- 3.7.01-05: Radioactive Waste Manager, Radioactive Waste Worker
- 3.9.01-06: Environmental Expert
- Researcher
- nuclearisation of "non-nuclear" engineers

Course on "Reactor Exercises"		
Units and LO Statements		
Unit 1 – Practical Course at SUR-100 (24 hours)	**Responsibility / Autonomy**	
	Ability in prediction of reactor behaviour and reactor operation	
	Skills	**Knowledge**
• Basic Concepts of Reactor Physics • Point Kinetics • Radiation Protection • Neutron Activation • Practical Reactor Operations	• Perform a simple process control function test for the reactor • Plan reactor operation accordingly with respect to reactor safety and requirements of experiments • Predict criticality based on subcritical experiments • Understand and comply with licensing requirements according to documentation, reactivity and other technical aspects during reactor operation • Awareness of radiation protection requirements during experiments with reactors and radioactive materials	• Calculation of binding Energy (Bethe-Weizsäcker-formula) • Mass defect and its link to binding energy • Nuclear fission, neutron production, delayed neutrons, fission spectrum, fission yield • Radioactivity, information available in nuclide charts • Basic knowledge of interaction cross sections • Nuclear reactions, activation • Point kinetics, factorisation of neutron flux in space and time, neutron diffusion, solutions for simple geometries • Subcritical neutron multiplication and geometric series • Concepts of reactivity, neutron multiplication factor, effect of delayed neutrons on neutron flux after reactivity change • Propagation of different radiation qualities • Basics of neutron activation analysis
Assessment criteria • Demonstration and application of fundamental knowledge in nuclear fission physics and reactor dynamics • Ability to understand technical and licensing aspects of reactor operation		
Recommended assessment methods: • Practical supervised reactor operation exercises • Written test • Face to face examination		

Course applicable (in part or fully) for the following job profiles:

- Nuclear engineers
- Safety engineers

Course on "Design Basis Accidents and Simulation Tools"		
Units and LO Statements		
Unit 1 – Lecture on Design Basis Accidents and its Simulation Tools (40 hours)	**Responsibility / Autonomy**	
	Autonomous use of numerical safety analysis tools to analyse design basis accidents	
	Skills	**Knowledge**

• Fundamental safety concepts of LWR
• Design basis accidents and role of safety demonstration
• Accident analysis methods
• Overview of safety analysis tools for DBA
• Physical models of numerical simulation tools for safety assessment
• Main modules and components of thermal hydraulic system codes e.g. TRACE and RELAP5
• Importance and methods for uncertainty quantification
• Approach for the development of plant models using system thermal hydraulic codes
• Hands on training to work with system thermal hydraulic codes
  ○ Simple models e.g. 1D core
  ○ Circuit models including primary/secondary components
  ○ Other component models e.g. Pressurizer, VALVES, PUMPS, etc.
  ○ Whole plant models with 1D and 3D thermal hydraulics
  ○ How to achieve stationary plant conditions
  ○ How to model controllers, trips and signals
• Use of the Pre- and Postprocessor SNAP for the development, running and animation of results
	• Describe the fundamentals of reactor safety and method for safety assessment
	• Describe the thermal-hydraulic and mathematical models built in in numerical tools for safety analysis
	• Describe important thermal hydraulic phenomena in LWR important for the model development to perform simulations
	• Describe methodological approach to simulate nuclear power plants using numerical tools
	• Describe the information needed to be collected in order to develop models for nuclear power plants simulations
	• Familiarity with numerical tools and the embedded code's uncertainties
		• Fundamentals of reactor safety and method for safety assessment
		• Thermal-hydraulic and mathematical models built in in numerical tools for safety analysis
		• Thermal hydraulic phenomena in LWR important for the model development to perform simulations
		• Methodological approach to simulate nuclear power plants using numerical tools
		• Which information is needed to be collected in order to develop models for nuclear power plants simulations
		• Numerical tools and the embedded code's uncertainties

Assessment criteria = • to demonstrate knowledge of fundamentals of nuclear power plants safety, operation and systems		

• To demonstrate understanding of main physical models implemented in the numerical safety analysis tools • To demonstrate the proper application of safety analysis tools regarding nodalisation, model selection, code numeric and , validation • Ability to understand main steps of safety demonstration • Ability to select accidental sequences for each reactor type • Ability to develop, run and evaluate with criticisms the results obtained by numerical codes applications		
Recommended assessment methods: • Written test , face to face examination • Multiple choice examination [choosing among different options] • Solution of computer exercises about simulations and the interpretation of results		

Course applicable (in part or fully) for the following job profiles:

- Safety engineer at nuclear power plants owners
- Safety engineer at TSO
- Safety engineer at regulatory bodies
- Engineers at manufacturers or other engineering companies dealing with assessment of safety aspects of nuclear power plants

<table>
<tr><th colspan="3">Course on “Computational fluid dynamics with OpenFOAM”</th></tr>
<tr><th>Units and LO Statements</th><th></th><th></th></tr>
<tr><td rowspan="3">Unit 1 – Lecture on Computational fluid dynamics with OpenFOAM (36 hours)</td><th colspan="2">Responsibility / Autonomy</th></tr>
<tr><td colspan="2">Autonomous use of thermal fluid-dynamics in a CFD-environment</td></tr>
<tr><th>Skills</th><th>Knowledge</th></tr>
<tr><td>• Overview of OpenFOAM
○ Documentation
○ code structure
○ directory organization of a case
• First OpenFOAM simulation
○ Lid-Driven Cavity
• Introduction to 3D flow in a circular pipe
• Information about probe & sample utilities to extract data
• m4-Scripting
○ mesh generation
• Kármán vortex street
• functionObjects
○ averaging
○ forces
• Programming
○ Temperature equation in a solver
○ new time-dependent boundary condition (BC)
• Working with new solver and BC
○ flows in heated cavity and pipe
• SnappyHexMesh
○ how to generate 3D complex meshes
• Summary & Best practice guidelines
○ tips for starting using efficiently OpenFoam</td><td>• Use some available solvers and utilities, modify existing solvers in order to adapt them to own needs
• Find help, documentation, answers to questions
• Use best practice guidelines to benchmark a solver</td><td>• Set up and handle a problem:
○ generate geometry and mesh; check the quality of the grid
○ apply initial and boundary conditions
○ define physical properties of materials, numerical schemes for discretizing terms in equations, algorithms to solve the equation system
○ monitor the run-time solution
○ improve convergence
○ post-processing the results (paraview, gnuplot, Matlab, OpenFoam utilities)</td></tr>
<tr><td>Assessment criteria
• Demonstration and application of fundamental knowledge of fluid dynamics.
• Ability to understand and use a complex software solution on a unix operation system</td><td></td><td></td></tr>
<tr><td>Recommended assessment methods:
• Written test,
• Face to face examination
• PC based exercises</td><td></td><td></td></tr>
</table>

Course applicable (in part or fully) for the following job profiles:

- Nuclear or safety engineers involved in fluid dynamics
- Engineers at manufacturing companies

Course on “Design of Pipelines against Earthquake Loads”		
Units and LO Statements		
Unit 1 – Lecture on Design of Pipelines against Earthquake Loads (40 hours)	**Responsibility / Autonomy** Autonomous use of pipe design rules against earthquake loads	
	Skills	**Knowledge**
• Basics of Seismology • Vibrations • Response Spectra • Resistance and Ductility • Reasonable Design of Buildings against Earthquakes • Calculation Methods DIN 4149 • Floor Response Spectra• Calculation Methods KTA 2201.4 • Countermeasures/Retrofitting • Exercises	• Interdisciplinary insight into earthquake engineering to civil and mechanical engineers and to alleviate the communication between both parties	• Basics of Seismology • Design of Buildings against Earthquakes • Calculation Methods DIN 4149 • Calculation Methods KTA 2201.4
Assessment criteria • Demonstration and application of fundamental knowledge in seismology and vibrations • Ability to apply earthquake countermeasure rules on pipe design		
Recommended assessment methods: • Written test • Face to face examination • Multiple choice examination [choosing among different options]		

Course applicable (in part or fully) for the following job profiles:

- Civil engineers
- Mechanical engineers
- Safety engineers

3.3 COURSES BY JRC-Directorate G-Nuclear Safety and Security

Course on "Nuclear Fuels"		
Units and LO Statements		
Unit 1 – Introduction to the fuel cycle and to different types of nuclear fuels. (3 hours)	**Responsibility / Autonomy**	
	Autonomous background on nuclear fuels and capability to identify different nuclear fuel cycles and scenarios	
	Skills	**Knowledge**
• Nuclear Fuel Scenario • Nuclear Fuel Cycle • Advanced Fuels	• Compare various aspects of different nuclear fuel cycles. • Manage complex work or study contexts involving nuclear materials and the nuclear fuel cycles. • Identify various stages of Nuclear Fuels Cycles.	• Have a solid background of the traditional and advanced Nuclear Fuels. • Distinguish between the different fuel properties in terms of performance, safeguard and safety. • Understand the different steps of Nuclear Fuel Cycles.
Unit 2 – Introduction to materials science of nuclear fuels. (3 hours)	**Responsibility / Autonomy**	
	Background on materials science applied to nuclear fuels and capability to identify different material characterisation methods.	
	Skills	**Knowledge**
• Relation between structure and properties of nuclear fuels. • Nuclear fuel chemistry. • Introduction to materials characterisation methods.	• Relate material properties to material structure. • Tailor some material properties based on material structure. • Foresee nuclear fuel behaviour in different chemical environments.	• Understand key links between material structure and properties. • Acquire key concepts about nuclear fuel chemistry. • Have a basic background in material structure characterisation methods, both experimental and computational.
Unit 3 – Thermodynamic properties of oxide fuel under normal and extreme conditions (4 hours)	**Responsibility / Autonomy**	
	Background on the main principles and parameters needed for a thorough thermodynamic description of the nuclear fuel behaviour under normal and off-normal conditions. Ability to identify off-normal fuel conditions and potential consequences.	
	Skills	**Knowledge**

<table>
<tr><td>Definition of thermodynamic parameters and relevant applications to nuclear fuels.
Introduction to experimental methods for the measurement of thermodynamic properties.
Phase diagrams and CALPHAD.
Equation of state of the nuclear fuel and thermodynamic description of extreme conditions.
Nuclear fuel behaviour during a core meltdown accident.
Uncertainty analysis.</td><td>Classify nuclear fuels based on their thermodynamic properties.
Identify phase stability conditions for nuclear fuel components.
Estimate the nuclear fuel behaviour in case of a loss-of-coolant event.</td><td>Understand the key principles and thermodynamic parameters for the nuclear fuel description.
Understand the CALPHAD approach.
Have a clear view of the nuclear fuel behaviour in a nuclear plant core meltdown accident.</td></tr>
<tr><td rowspan="3">Unit 4 – Nuclear fuel fabrication.
(3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomous background on the main techniques and aspects concerning the fabrication of nuclear fuels. Ability to identify risks related to the fabrication procedures.</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Synthesis of Nuclear Materials
Fuel Pin Preparation
Criticality aspects</td><td>Plan nuclear fuel preparation steps.
Estimate material preparation steps needed to optimise certain fuel properties.
Deal with risks connected with nuclear fuel preparation.</td><td>Understand the different procedures and steps of nuclear fuel fabrication.
Identify links between fuel fabrication and properties.
Be aware about potential risks related to fuel fabrication and processing.</td></tr>
<tr><td rowspan="3">Unit 5– Core layout, fuel burn-up and overview on Post Irradiation Examination (PIE).
(3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomous background on the nuclear fuel in-pile configuration and behaviour. Knowledge about methods for post-irradiation material handling and investigation.</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Description of the nuclear reactor core layout.
Description of the in-pile fuel behaviour.
Post-irradiation examination techniques.</td><td>Estimate the evolution of nuclear fuel properties depending on its irradiation history.
Deal with PIE techniques.
Conceive PIE activities.</td><td>Understand the basic concepts of a nuclear reactor core in LWRs.
Recognise the different aspects of in-pile fuel behaviour.
Acquire basic knowledge about post-irradiation examination techniques.</td></tr>
</table>

<table>
<tr><td rowspan="3">Unit 6– Fuel claddings for Light Water and Fast Reactors.
(3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomous background on the different types of nuclear fuel cladding and their main characteristics. Ability to estimate irradiation and corrosion effects on the cladding materials.</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Different types of fuel cladding.
Impact of irradiation and corrosion on cladding performance.</td><td>Select different cladding materials depending on the type of fuel and reactor.
Estimate the evolution of cladding properties depending on its thermal and irradiation history.
Estimate the cladding behaviour in the presence of a corrosive environment or in a plant accident.</td><td>Understand the fundamental properties needed in cladding materials for different types of nuclear reactors.
Build-up a background on in-pile cladding behaviour.
Understand the basic thermal, irradiation and corrosion effects on cladding materials. .</td></tr>
<tr><td rowspan="3">Unit 7– Radiation effects in oxide fuels. (3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomous background on radiation damage. Understanding of experimental and computational techniques for the study of radiation damage.</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Introduction to radiation damage and key parameters.
Microstructural evolution and fission gas behaviour.
Introduction to experimental techniques for the investigation of radiation damage in fuel materials.</td><td>Estimate the evolution of nuclear fuel properties due to irradiation effects, also based on simple atomistic models.
Predict the helium and fission gas behaviour in irradiated nuclear fuels depending on the irradiation and thermal history.
Select techniques for the analysis of radiation damage and gas behaviour in nuclear fuels.</td><td>Understand the basic concepts and parameters of radiation damage in nuclear materials.
Understand the helium and fission gas behaviour in irradiated nuclear fuels.
Acquire a background in the experimental techniques available to study radiation damage and gas behaviour in nuclear fuels.</td></tr>
<tr><td rowspan="3">Unit 8 – Thermo-mechanical properties of irradiated fuel and the experimental validation. (3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomous background on thermophysical properties of nuclear fuels. Ability to estimate irradiation effects on these properties and possible consequences on the fuel functioning.</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Experimental and computational tools for the determination of the fuel thermal</td><td>Foresee the effects of thermo-mechanical properties on the in-pile fuel behaviour during reactor functioning.</td><td>Learn the basic parameters defining thermo-mechanical properties of fresh and irradiated nuclear fuels.</td></tr>
</table>

conductivity, specific heat, dilatation coefficient, Young modulus, oxygen potential. • Irradiation effects on these properties.	• Estimate the possible evolution of thermos-mechanical properties depending on the fuel burn-up. • Select techniques for the determination of thermos-mechanical properties in fresh and irradiated nuclear fuels.	• Acquire a background in the experimental techniques available to analyse thermo-mechanical properties of nuclear fuels. • Understand the possible evolution of thermo-mechanical properties in irradiated nuclear fuels.
Unit 9 – Nuclear Fuel Modelling: An introduction to the TRANSURANUS code. (3 hours)	**Responsibility / Autonomy**	
	Autonomous background on viewpoint of nuclear fuel performance codes. Ability to understand the use and potential applications of a NFPC. Background in TRANSURANUS.	
	Skills	**Knowledge**
• Overview and main aspects of modelling the neutronic, thermal and mechanical behaviour of fuel rod and fission gas. • Short introduction to the TRANSURANUS code. • Case studies: fuel rod behaviour in normal conditions and under loss of coolant accident condition	• Accurately describe the behaviour of a LWR fuel element under various conditions. • Implement fuel performance analyses. • Use TRANSURANUS as a fuel performance code.	• Understand the essential parameters needed for an accurate description of the fuel rod's behaviour, both in normal operation and in a loss-of-coolant accident. • Understand the interrelations between chemical, physical, nuclear, thermal, metallurgical and mechanical properties of the fuel element. • Understand the conception and use of a fuel performance code. • Learn the basics of TRANSURANUS.

Unit 10 – Handling of Nuclear Materials: practical radioprotection and medical follow-up. (3 hours)	**Responsibility / Autonomy**	
	Autonomous background on the key concepts of radioactivity and radioprotection. Capability to identify risks and precautions required by handling nuclear fuels.	
	Skills	**Knowledge**
• Practical Radioprotection • Internal and External exposure to radiation sources • Medical Monitoring. • Practical Glove Box and Telemanipulator Exercise.	• Reasonably estimate the risks related to radioactivity and radioactive materials. • Know how to deal safely and practically with radioactive materials.	• Learn the basic concepts of radioactivity and its effects on the human body. • Understand the viewpoint and the fundamental parameters of radioprotection.

	• Understand and manage basic cases of irradiation and contamination. • Understand how to work with glove boxes and telemanipulators.	• Acquire a background on the basic techniques of radiation detection and protection, and on the medical follow-up. • Learn the basic principles and techniques to safely handle radioactive materials.
Assessment criteria = to demonstrate mastery and innovation, advanced skills, required to solve complex and unpredictable problems in a specialised field of "Nuclear Fuels"		
Recommended assessment methods: Practical and written test, face to face examination, grid test with multiple choices [choosing among different options].		

Course applicable (in part or fully) for the following job profiles:

- Undergraduate or graduate students in science or engineering willing to enrich their background on nuclear materials beyond academic knowledge.
- Professionals (scientists, engineers) working in non-nuclear fields needing a complete introduction to nuclear materials, fuels and radiation protection.
- Professionals (scientists, engineers, technicians) working in the nuclear field and needing a more advanced education on nuclear fuels and the nuclear fuel cycles.

<table>
<tr><th colspan="3">Course on “Back-end of the Nuclear Fuel Cycle”</th></tr>
<tr><th>Units and LO Statements</th><th colspan="2"></th></tr>
<tr><td rowspan="3">Unit 1 – Back-end of the nuclear fuel cycle: overview of all relevant options. (~3 hours)</td><th colspan="2">Responsibility / Autonomy</th></tr>
<tr><td colspan="2">Able to actively participate in discussions/explanations
on the back-end of the fuel cycle</td></tr>
<tr><th>Skills</th><th>Knowledge</th></tr>
<tr><td>Introduction to all possible nuclear fuel cycle options
spent fuel appearances
'open cycle' / 'closed cycle'
different type of high level nuclear waste
type of host rocks for geological disposal
the impact of oxidising/reducing environment
…
Introduction and explanation of technical terms related to geological disposal
near-field
far-field
retrievable
reversible
…</td><td>Compare the characteristics, risks and benefits of an 'open fuel cycle' versus a 'closed fuel cycle'
Explain the impact of redox conditions on spent fuel disposal
Discuss the different types of host rock for geological disposal
(…)</td><td>Characteristics of spent fuel and how these define the fuel cycle options
Understanding the different fuel cycle options
Distinction between 'open fuel cycle' and 'closed fuel cycle'
Definitions of different nuclear waste types
Characteristics of different host rocks for geological disposal
Definitions of technical terms related to geological disposal
(…)</td></tr>
<tr><td rowspan="3">Unit 2 – Extended spent fuel storage: challenges and scientific issues.
(~3 hours)</td><th colspan="2">Responsibility / Autonomy</th></tr>
<tr><td colspan="2">Autonomously judge impact of different spent fuel storage scenarios</td></tr>
<tr><th>Skills</th><th>Knowledge</th></tr>
<tr><td>Overview on spent fuel storage and research needed for extended storage strategies
at reactor pool
dry interim storage
wet interim storage
Main mechanisms potentially affecting the integrity of the spent fuel rods
Scientific and technological issues associated to extended interim storage (with focus on microstructural evolution of the spent fuel)
spent fuel alteration due to helium build-up
fuel rod properties evolution as function of time, temperature, environmental conditions
…
Consequences of extended storage on spent fuel retrieval (e.g. accident conditions during transportation)</td><td>Analyse different mechanisms affecting spent fuel rod's integrity
Judge the influence of different environmental conditions on spent fuel rod properties
Evaluate evolution of spent fuel rod properties as function of time and temperature
(…)</td><td>Outline different extended storage strategies
Describe spent fuel alteration during extended storage
State consequences of spent fuel extended storage on spent fuel handling (e.g. during transport, …)
(…)</td></tr>
</table>

<table>
<tr><td rowspan="3">Unit 3 – Legislation and ethics of radioactive waste management and disposal.
(~3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Responsibly discuss ethical considerations regarding nuclear waste disposal</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Overview of the problems related to nuclear waste disposal
• Ethical considerations regarding nuclear waste disposal
• General requirements of a geological repository
• The role of the EURATOM Waste Directive
• The link between the European directive and the JRC activities
• The Implementation status of the EURATOM Waste Directive (with examples, including single country vs. regional solutions)
• …</td><td>• Relate problems of nuclear waste disposal with requirements of a geological repository
• Combine ethical considerations regarding nuclear waste disposal with corresponding requirements of a geological repository
• Assess single country versus regional solutions for the implementation of the EURATOM Waste Directive
• (…)</td><td>• Identify requirements of a geological repository
• Outline the EURATOM Waste Directive
• Describe the implementation status of the EURATOM Waste Directive in EU-countries
• (…)</td></tr>
<tr><td rowspan="3">Unit 4 – Source term and radionuclide release in a geological repository.
(~3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomously analyse scientific literature regarding spent fuel corrosion</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Introduction of the 'source term' through the following topics:
○ non-disturbed and disturbed disposal scenario
○ chemical composition and evolution of spent fuel (UO_2, MOX) related to linear power and burn-up
○ chemical differences between fuel rim and fuel centre
○ scenarios with reducing and oxidising environments
○ near- and far field interphase
○ …
• The spent nuclear fuel corrosion processes (occurring when water comes in contact with fuel):
○ instant release fraction
○ long-term fuel corrosion processes (matrix dissolution)
○ modelling aspects
○ …
• …</td><td>• Compare fuel rim and fuel centre in terms of chemical composition and microstructure
• Compare scenarios in reducing environment with scenarios in oxidising environment
• Model spent nuclear fuel corrosion processes (short term and long term)
• (…)</td><td>• Relate chemical composition of spent fuel with burnup
• Describe near- and far-field interphases
• Define 'instant release fraction' and 'matrix dissolution'
• (…)</td></tr>
<tr><td rowspan="3">Unit 5 – Surface and electrochemical processes involved in the spent nuclear fuel corrosion.
(~3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Relate/combine spent fuel corrosion experimental results with the fundamental processes at the surface</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Surface chemistry and its role in studying corrosion processes:
○ what is an interface and how does it interact with the environment
○ what chemical processes are involved in the corrosion of a surface
○ the role of surface chemistry and structure
○ thin film studies
○ various surface spectroscopic techniques
○ …</td><td>• Relate thin film studies to spent fuel corrosion studies
• Assess various surface spectroscopic techniques for studying real processes in a repository
• Evaluate advantages and challenges of electrochemistry in spent fuel corrosion studies
• (…)</td><td>• Describe the role of a surface in its interaction with the environment
• Indicate what determines the stability of a surface
• Explain how electrochemistry can help in understanding spent fuel corrosion processes
• (…)</td></tr>
</table>

<table>
<tr><td>• Electrochemistry and its role in studying spent fuel corrosion processes
• …</td><td></td><td></td></tr>
<tr><td rowspan="3">Unit 6 – Reprocessing and Vitrification.
(~3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Able to actively participate in discussions/explanations on reprocessing nuclear fuel and vitrifying high level waste</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Introduction to the reprocessing of spent nuclear fuel as discharged from light water reactor
• Introduction to methods and technology for the vitrification of high level waste
• …</td><td>• Analyse pros and cons of closing the nuclear fuel cycle
• Evaluate glass as matrix for high level waste
• (…)</td><td>• Describe and illustrate the chemistry involved in the reprocessing of spent nuclear fuel
• Describe the practice of recycling Pu in MOX fuel
• Outline the vitrification process as applied for high level liquid waste
• (…)</td></tr>
<tr><td rowspan="3">Unit 7 – Partitioning of spent fuel: aqueous and pyro-chemical reprocessing.
(~3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Combine developments in partitioning technology with options in closing the fuel cycle</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Aqueous reprocessing:
○ principles for separation by solvent extraction
○ separation techniques and equipment
○ process development
○ highlights and examples from demonstration experiments (DIAMEX, SANEX, GANEX)
○ …
• Pyro-chemical reprocessing:
○ principles of pyro-chemical separation processes
○ advantages/disadvantages
○ types of treated fuels
○ instrumentation and principles of the different techniques
○ examples of particular processes worldwide including summary of studies within EC projects
○ …</td><td>• Calculate separation factors from experimental data
• Compare different reprocessing schemes: e.g. DIAMEX, SANEX, GANEX
• Summarise advantages/disadvantages of pyro-chemical reprocessing
• (…)</td><td>• Explain solvent extraction principles
• Describe industrial PUREX process
• Distinguish different pyro-chemical techniques and their instrumentation
• (…)</td></tr>
<tr><td rowspan="3">Unit 8 – Glass behaviour: the French case.
(~3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomously analyse scientific literature regarding glass as waste form for high level nuclear waste</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Case study: the French experience with developing nuclear glass matrices.
○ optimising the glass compositions
○ knowledge of the vitreous state
○ glass melt chemistry and properties
○ glass long term behaviour studies:</td><td>• Assess glass as matrix for high level waste
• Discuss the effects of radiation on the properties of glass
• Recommend how to validate long term behaviour models for glass as waste form
• (…)</td><td>• Describe characteristics of the vitreous state
• Identify the main points for optimising the glass composition
• Outline important criteria for a long term behaviour model
• (…)</td></tr>
</table>

▪ effects of radiation on the glass properties and structure ▪ leaching studies ▪ development / validation of long term behaviour models ○ …		
Unit 9 – The safety of a geological repository. (~3 hours)	**Responsibility / Autonomy** Able to actively participate in discussions/explanations on the safety of geological repositories	
	Skills	**Knowledge**
• The multi-barrier system of a geological repository for HLW forms • The (geo-)chemical barrier functions with respect to radionuclide retention • The behaviour of radionuclides in the near and far field ○ complexation with groundwater constituents ○ the solubility of secondary solid phases ○ co-precipitation with secondary phases ○ redox reactions ○ sorption to surfaces of solids of engineered barriers and the geo-matrix. • …	• Compare the challenges, risks and benefits of the different geological disposal methods ○ Near-field: waste packages + engineered zone and their evolution ○ Far-field: the rock options, their performance and interaction with the near-field • (...)	• Explain and justify the need for long-term disposal solutions • Explain the multi-barrier system of a geological repository for HLW • Describe the role of each barrier in terms of radionuclide retention • (…)
Assessment criteria = to demonstrate mastery innovation and advanced skills, required to solve complex and unpredictable problems in a specialised field of "Back-end of the fuel cycle"		
Recommended assessment methods: Practical and written test, face to face examination, grid test with multiple choices [choosing among different options].		

Course applicable (in part or fully) for the following job profiles:

- …
- …
- …

Course on “Radioprotection”		
Units and LO Statements		
Unit 1 – What is radioactivity? (~1:30 hours)	**Responsibility / Autonomy**	
	Basic understanding of the physical background of radioactivity	
	Skills	**Knowledge**

• History of radioactivity
• Atoms and nuclides
  ○ Neutrons
  ○ Protons
  ○ Electrons
• Radioactive decay: Alpha, beta, e-capture, gamma, IC, SF
• Types of radiation and features: Alpha, beta, neutron, gamma
• Activity:
  ○ decay law
  ○ decay chain
  ○ half-life
  ○ equilibrium
• Sources of radioactivity:
  ○ Primordial
  ○ Cosmogenic
  ○ anthropogenic
	• Compare the features of different types of radiation
	• Understand the different types of radioactive decay
	• Calculate radioactive decay using the decay law
	• Explain a simple decay chain and the impact of different half-lives on the equilibrium conditions
	• Follow a decay chain on the nuclide chart
		• Recall the atomic model and its constituents
		• Describe the different types of radiation
		• Define the decay law, decay constant, half-life, equilibrium, …
		• Describe different sources of radioactivity

Unit 2 – Interaction of radiation with matter (~1:30 hours)	**Responsibility / Autonomy**	
	Basic understanding on how radioactivity interacts with matter	
	Skills	**Knowledge**

• Classification of radioactivity according to its interaction with matter
  ○ Charged particles (alpha, beta,…)
  ○ Neutrons
  ○ Gamma-radiation
• Absorption of beta radiation
• Cerenkov radiation
• Interaction of Neutrons:
  ○ Elastic and inelastic collision of neutrons with nucleus
  ○ Absorption of neutrons
• Interaction of gamma radiation
  ○ Absorption of gamma rays
  ○ Half value layer (thickness) of absorbing materials
  ○ Energy-dependence: Photoelectric effect, Compton effect, pair production
  ○ Absorption coefficients
• Distance (inverse-square law)
• Biological effects:
  ○ Direct and indirect effects
	• Understand for which fields radioactivity is relevant
	• Compare different interaction with matter according to type of radiation
	• Calculate the intensity of radiation at different distances (using the inverse-square law)
	• Understand the difference between activity and dose
	• Assess different materials by their absorption coefficients for the absorption of gamma rays
		• Describe interactions of charged particles with the electron shell and with the nucleus
		• Define the half value layer thickness of absorbing materials and absorption coefficients
		• Explain the interaction of neutrons with matter
		• Describe some direct and indirect effects of radioactive radiation on biological matter

<table>
<tr>
<td>
◦ DNA damage
◦ Activity and dose
◦ Dosimetric values: equivalent dose, dose rate
◦ SI dose units
◦ Applications: Radiotherapy, alpha-immuno-therapy
</td>
<td></td>
<td></td>
</tr>
<tr>
<td rowspan="3">Unit 3 – Practical exercise.
(~3 hours)</td>
<td colspan="2">Responsibility / Autonomy</td>
</tr>
<tr>
<td colspan="2">Understanding the importance of choosing the right instruments and protection measures for a given goal</td>
</tr>
<tr>
<td>Skills</td>
<td>Knowledge</td>
</tr>
<tr>
<td>
• Practical measurement of radioactivity
• Demonstration of protection measures against radioactivity
</td>
<td>
• Apply procedures to make a measurement using different instruments
• Judge the results of the measurements
• Evaluate the results on a quantitative and qualitative basis
</td>
<td>
• Using the correct instrument for a given goal
• Describe the different protection measures for a given radiation type
</td>
</tr>
<tr>
<td rowspan="3">Unit 4 – Uses and risks (from dosimetric point of view).
(~3 hours)</td>
<td colspan="2">Responsibility / Autonomy</td>
</tr>
<tr>
<td colspan="2">Basic understanding of operational protection measures</td>
</tr>
<tr>
<td>Skills</td>
<td>Knowledge</td>
</tr>
<tr>
<td>
• Use and application of radioactive material
• External exposure:
◦ Physical and biological effects
◦ Sensitivity of cells, organs and body
◦ Dose dependence
• Internal exposure:
◦ Incorporation and re-distribution
• Need for protection:
◦ Biological effects
◦ dose vs. effect
◦ Principle of reducing radiation dose (ALARA)
◦ Dose from natural sources vs. anthropogenic sources
• Dosimetry: concept, quantities, and units:
◦ Common features of radiation: energy
◦ Physical quantities: absorbed dose, energy imparted
◦ Protection quantities: organ absorbed dose, effective dose, accumulated (committed) effective dose
◦ Operational quantities (monitoring measurements): ambient, directional, and personal dose equivalent
• Dose limits:
◦ International legislative framework
◦ International bodies
◦ Reference international documents (ICRP, EC Council Directive, ICRU)
• Operational radiation protection
◦ Fundamental principles and approach
◦ Measures to mitigate internal and external exposure (with practical examples)
</td>
<td>
• Analyse the approach to establish dose limits from available data
• Compare natural vs. anthropogenic radiation
• Understand how the radiation effect the human body, from molecular to whole body level
• Understand that different types of radiation transfer their energy in different manners
• Understand that the dose describes the energy transferred from radiation to any matter
• Distinguish between absorbed dose, the organ absorbed dose, and the organ equivalent dose
• Distinguish between effective dose and committed effective dose
• Relate annual occupational dose limits to the ALARA concept
• Describe general procedures in a nuclear facility for investigating dose levels
• Describe how to use a certain dosemeter to record the dose actually received
• Understand the different risks occuring in different workplaces
• Recognize the importance of knowledge to enable effective radiation protection
</td>
<td>
• Identify the different risks from different types of radiation
• Describe the difference between internal and external exposure
• List the different type of quantities, and their associated purposes
• identify the operational monitoring systems for internal exposure
• indicate the operational monitoring systems for external exposure
• list the international bodies setting radiation protection standards
• memorize the dose limits
• repeat which dosemeters exist, and when to use them
• List the chain of responsibilities for radiation protection in a nuclear workplace
</td>
</tr>
</table>

- Recording of dose from external exposure - Estimation of dose from incorporation - Practical measures for operational radiation protection, including laboratory visit - Public and environmental radiation protection - Pathways of exposure in the environment - Dose limits for public - Regulatory requirements to ensure compliance with dose limits for public - Responsible bodies		
Assessment criteria = to understand all aspects related to radiation and demonstrate mastery radiation protection required to address and solve several types of issues related to the field		
Recommended assessment methods: Practical test in representative environment, written test, face to face examination, grid test with multiple choices [choosing among different options].		

Course applicable (in part or fully) for the following job profiles:

- Technical staff without nuclear knowledge
- Administrative staff with technical knowledge
- Newcomers in the nuclear field
- PhD students and Postdocs

3.4 COURSES ON GEOLOGICAL WASTE DISPOSAL BY CVUT, UL, UPM

<table>
<tr><th colspan="3">Course “Experimentation in Josef Underground Facility”</th></tr>
<tr><th>Units and LO Statements</th><th></th><th></th></tr>
<tr><td rowspan="3">Unit 1 – Geotechnical testing of soils (24 hours)</td><th colspan="2">Responsibility / Autonomy</th></tr>
<tr><td colspan="2">Autonomous use of laboratory geotechnical testing methods to evaluate (some) properties of soils</td></tr>
<tr><th>Skills</th><th>Knowledge</th></tr>
<tr><td>• Geotechnical laboratory tests on soils
• Installation of bentonite seal by spraying
• Sampling and evaluation of bentonite seal</td><td>• Select proper test procedure (also with respect to specifics of bentonite behaviour)
• Performance of laboratory geotechnical tests
• Hands-on ability in the laboratory
• Collecting data
• Hands on experience with shotclay technology – clay spraying
• Sampling and quality evaluation of the compacted material (layer)
• Results interpretation</td><td>• Basics of soil mechanics
• Soil composition (main minerals), clay mineralogy
• Definitions of principal geotechnical parameters and reminder of typical range of values
    o Density, specific density
    o Water content
    o Degree of saturation
    o Atterberg limits
    o Grain size curve
    o Thermal conductivity
    o Hydraulic conductivity
• Reminder of water flow in soils (Darcy-s law)
• Compaction of soils (Proctor test, Fuller-s curve)
• Sampling of soils
• Principle of shotcrete technology</td></tr>
<tr><td rowspan="3">Unit 2 – In-situ testing of the rock mass (16 hours)</td><th colspan="2">Responsibility / Autonomy</th></tr>
<tr><td colspan="2">Autonomous use of in-situ geotechnical testing methods to evaluate (some) properties of rock mass</td></tr>
<tr><th>Skills</th><th>Knowledge</th></tr>
<tr><td>• In-situ tests on gas and water permeability of the rock mass
• Thermometer assembly and installation
• Data transfer and processing</td><td>• Select proper test procedure of gas (or water) permeability test in a single borehole, incl. selection of proper equipment (esp. packers)
• Performance of gas or water permeability tests
• Data collecting and analyses, evaluation
• Manufacturing (assembling, cabling) of thermometers and their installation into the boreholes
• Data processing</td><td>• Basics of rock mechanics
• Creation and properties of excavated damaged zone (EDZ)
• Rock mass index classification systems (RQD, Q)
• Gas and water flow in rock mass
• (Principal) theory of sensing of physical parameters</td></tr>
</table>

Assessment criteria = to demonstrate skills to perform tests and evaluate results in the field of "geotechnical laboratory and in-situ testing"		
Recommended assessment methods: Practical demonstration of performance of laboratory and in-situ tests, presentation (discussion) of results and their interpretation.		

Note: as this course is planned for one week it covers only narrow selection of large number of laboratory and in-situ methods. Emphasis is put on hands-on experience during the week. Therefore, also the skills and autonomy may be related only to the selected methods…

EQF 4 or5?

Course applicable for the following job profiles:

1.1.01.Site Characterization Manager
1.1.05-06 Geological and environmental specialist

As the job profiles do not cover geological disposal the main area of the course LO is out of the list.

Course on "Site selection for radioactive waste disposal" (4 ECTS)		
Units and LO Statements		
Unit 1 – Introduction ***(2 hours)***	**Responsibility / Autonomy**	
	Figure out the general scope of site selection	
	Skills	**Knowledge**
Scoping Screening Evaluation	• Differentiate the three steps of site selection. • Determine adequate framework for each step.	• Identify site selection criteria
Units and LO Statements		
Unit 2– Host formation geological conditions ***(15 hours)***	**Responsibility / Autonomy**	
	Understand the basic elements necessary for an adequate site	
	Skills	**Knowledge**
Geological structure Geophysics Geochemical properties Mechanical and thermal properties Hydrogeological conditions	• Interpret sub-surface geology • determine the sense of fault movement. • Classify faults and fractures, identify the rock-types associated with them. • Apply suitable analysis techniques and geophysical models in the interpretation of the results. • Solve rotational problems • Analyze complex structural data. • Synthesize information from geologic samples, maps and other sources • Assess plausible schemes for deducing geoscientific information by data synthesis. • Explain the uncertainty and possible sources of error in data	• Read geologic maps • Identify folds and fold systems strata, unconformities, faults and folds. • Formulate the concepts of stress and force • Explain the concepts of normal and shear stresses • Explain the concepts of hydrostatic and deviatoric stresses. • Formulate the concept of strain, stain types and their measurement • Explain elastic and viscous strain in rock behavior • Describ the effects of temperature and temperature gradient on rock strength, and the mechanisms of rock deformation. • Explain relation between pore fluid pressure and strain rate. • Explain physical properties of waters and their role in groundwater movement.

	• Distinguish between confined and unconfined aquifers • Describe how groundwater flows through acquifers. • Assess the occurrence and availability of subsurface water • Explain link between shear stress, faulting and earthquakes.	• Understand the origin of groundwater and how contaminants move in groundwater. • Discuss Chemical controls on soil formation and radioactive isotope geochemistry • Identify the physical processes governing the behavior of common geophysical systems. • Explain the principles of applying geophysical methods
Unit 2* – Environment stability** ***(9 hours)	**Responsibility / Autonomy**	
	Understand the impact of adverse events on disposal site	
	Skills	**Knowledge**
Climate change External hazards Tectonic development **Slope Instability** Volcanism Floods hazard **Radioactivity sources, impacts and mitigation**	• Evaluate the various factors that shape climate. • Assess the risk of climate change to disposal sites and processes • Ability to integrate the various scientific factors contributing to hazard assessment • Analyse relationship between neo-tectonics and the earthquakes • Analyze data to identify trends occurring in volcanic eruptions and global climate change and weather impacts. • Use rainfall runoff model • Process flood analysis data and generate a flood hazard map • Apply methods for flood risk estimation in basic cases. • Use Control Factors of Earthquake Ground Motion in prediction models	• Demonstrate a solid understanding of the climate system • Describe how past climates contribute to current understanding of climate change. • Explain the consequences, risks, and uncertainties of climate change. • Explain ecosystems and climate interactions problems related to the underground waste disposal. • Explain typology of hazards including their spatial and temporal distribution • Identify and understand the causes and impacts of various hazards • Explain concepts and principles of risk • Explain concepts and principles of vulnerability • Apply statistical approaches to risk estimation and modelling.

<table>
<tr><td></td><td>Use numerical models in flood modelling and forecasting.
Characterize of the pore water pressures in slopes in drained and undrained conditions
Use methods for slope stability assessment, modelling of slope movement and back-analysis of failed slopes</td><td>demonstrate knowledge and understanding on basic geodynamics
Demonstrate knowledge and understanding on the three main types of plate boundary (and how they interact at triple junctions
Describe the different types of volcanoes.
Explain Propagation of Seismic Waves, Source Factor, Path Factor, Site Factor
Discus Seismic Intensity Scales, Ground Motion Severity Measures
Explain deterministic and probabilistic Seismic Hazard Assessment
Relate effects and impacts of radioactive source emissions to the vulnerability / sensitivity of the surrounding environment.
Describe chemical and transport processes relevant to the fate of discharges / emissions.</td></tr>
<tr><td rowspan="3">Unit 3 – Engineering
(18 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Figure out the technical and scientific approaches to site evaluation</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Sub Surface Characterization
Geotechnical site investigation
Rock classification
Stability in embankment dams
Foundation
Soil liquefaction
Tunneling
Stability analysis of tunnels
Ground deformation</td><td>Apply testing methods to analysis geothechnical proprieties
Apply fundamental geomechanics knowledge to solve stability problems
Apply simple method for foundation design</td><td>Specify the site investigation requirements and their strengths and limitations for tunnel design and construction in soils and rock
Classify subsurface materials with relation to their excavation and support performance</td></tr>
</table>

Ground improvement Risk mitigation and management techniques Costs analysis	• Use modelling techniques for the prediction of the performance of geotechnical structures. • Use the Finite Element method • Carry out a basic design of tunnels and rock support • Evaluate tunnel excavation method from technical and construction aspects • Analyse cost and time for underground construction • Apply risk management principles of tunnel	• Select the appropriate tunneling method • Select the appropriate lining system • Explain links between rock type, groundwater, tunnel diameter and depths • Comprehend the theoritical principles of soil and rock mechanics • Explain liquefaction phenomena • Explain stress-strain relationships • Explain the development of lateral stresses
Unit 4 –* Socio-economic issues *(4 hours)	**Responsibility / Autonomy**	
	Understand the importance of social and economic issues on decision making	
	Skills	**Knowledge**
Environmental Regulations National and international guidelines Public acceptance Economics of safety	• Apply systems of control and regulation • Apply economics of safety • Demonstrate ability to manage risk quantification and social equity	• Be aware of international history of waste disposal regulation • Demonstrate knowledge and understanding of Environmental Management Systems and ISO14001 • Have a broad understanding of economic, environmental, and political issues that influence the choice of waste disposal site. • Express sensitivity towards social and corporate responsibilities. • Explain economics of safety regarding individual and society
Assessment criteria • Demonstration and application of fundamental knowledge in geoscience		

Ability to understand technical and engineering aspects of site selection		
Recommended assessment methods: written exam		

Course in French language (can be partly offered in English) for second year of Master degree in Civil and Mining engineering.

Course applicable (in part or fully) for the following job profiles:

- Civil engineer
- Mining engineer
- Geological engineer

Course on "Radioactive waste disposal" (4 ECTS)		
Units and LO Statements		
Unit 1* – Overview of nuclear fuel cycle and radioactive waste generation *(9 hours)	**Responsibility / Autonomy** Figure out the general scope of fuel cycle	
	Skills	**Knowledge**
Basic principles Mining and milling Fuel fabrication Power reactors Irradiated fuel, reprocessing, recycling Front-end and back-end waste treatment Management of safety	• Apply theoretical basis for nuclear fission and fusion • Apply the basic physics and engineering principles in which the production of nuclear energy is based • Estimate waste produced during the different stages of the fuel cycle • Debate waste types and phase separation processes • Demonstrate how to manage front-end and back-end wastes in nuclear fuel cycle • Demonstrate a detailed understanding of the mining and processing of uranium ore • Demonstrate a detailed understanding of fuel	• Explain why some atoms are radioactive while others are not • Discuss the forces operating inside the nucleus • Describe the fundamentals of Uranium mining, milling and conversions • Describe Uranium enrichment methods • Detail fuel reprocessing techniques • Describe the chemical and physical changes that the fuel undergoes during reactor operation • Discuss open fuel cycle versus closed fuel cycle

	enrichment and production of the fuel assemblies	• Classify nuclear waste and understand the process for treating nuclear waste • Appreciate the safety and environmental considerations involved in the fuel cycle • Explain disposal management options for low, intermediate and high level radioactive waste
Units and LO Statements		
Unit 2*– Overview of nuclear waste disposal *(9 hours)	**Responsibility / Autonomy**	
	Understand the basic concept of radioactive waste disposal	
	Skills	**Knowledge**
Disposal options for radioactive waste Guiding principles and regulatory process Treatment of radioactive waste Disposal of Low Level Waste Spent nuclear fuel interim storage Main components of a geologic repository program, Principle of multibarriers Engineered Barrier Systems for geologic repository Post-Closure Safety Analysis of a repository and total system performance assessment Survey of international repository programs	• provide a quantitative estimate of the performance indicator in the form a probability distribution. • Estimate the isolation capability of a geological disposal • estimates the post-closure radiologic risk • Construct bentonite swilling pressure vs dry density graph • Discuss the principle of total system performance	• Explain the characteristics of radioactive wastes and disposal methods • Describe how radioactive wastes are classified • Identify three types of packaging for radioactive materials • Describe package testing procedures for radioactive materials • Identify six types of radioactive waste • Explain French geological disposal programs and the role of the regulator. • Explain other international geological disposal programs. • Describe the fabrication methods of vitrified glass and their properties

		• Describe the corrosion process of waste package • Explain properties, design, and behaviour of bentonite buffer materials • Explain the migration behaviour of water and radionuclides in the bentonite buffer materials • Explain the overall performance of the disposal • estimates the post-closure radiologic risk and the uncertainty associated
Unit 3* – Use of THM coupled process** ***(15 hours)		
	Responsibility / Autonomy	
	Understand the thermos-hydro-mechanical behaviour of multi-barrier disposal	
	Skills	**Knowledge**
How to build a THM coupled model Diffusive coupled model for heat transfer Diffusive coupled model for fluids transport Coupled model for mechanical behaviour Model for soil suction Modelling uncertainties Example of THM coupling in bentonite behaviour analysis and assessment	• Recognize when coupled approach is appropriate to solve a behavior assessment problem • Recognize fundamental parameters in coupled process models • Be able to apply the principles of thermodynamics equilibrium for the establishment of simplified behaviour models • Establish simplified suction diagram • Select appropriate analytical technique for THM modeling • Apply numerical programming techniques to solve THM coupled problems • Analyse the simulation results	• Formulate continuity equation • Formulate mass conservation equation • Formulate energy conservation equation • Formulate momentum conservation equation • Explain transport equations, convection–diffusion equation, Boltzmann transport equation and Navier–Stokes equations. • Explain Eulerian and Lagrangian approaches • Explain Darcy law • Explain Kozeny-Carman law • Explain Fick law • Discuss stress-strain relationship • Explain effective stress

		• Characterize the behavior of a system in terms of the nature of its variables, interactions and state changes. .

Unit 4* – Natural analogues** ***(12 hours)	**Responsibility / Autonomy**	
	Understand the role of natural analogues in processes relevant to geological disposal	
	Skills	**Knowledge**
Natural geological and geochemical systems Uranium ore Hydrothermal systems Natural occurrences of repository materials Archaeological analogues **Analogues of repository materials** Natural analogues in the support of performance assessment.	• Illustrate the influence of thermal cracking of vitrified waste by examining the effects of surface area on long-term alteration • Demonstrate the ability to analyze data from natural and archaeological sites • Use scientific methods to explore natural phenomena, including observation, hypothesis development, measurement and data collection, experimentation, evaluation of evidence, and employment of mathematical analysis	• Discussion of the quantitative and qualitative roles of natural analogues study in radioactive waste disposal • Explain the extent of the primary uranium ore body as an analogue • Explain the extent of hydrothermal system which induced some secondary uranium mobilization • Discuss Uranium isotope studies combined with groundwater dating and groundwater flow pathwaysas a natural analogue • Explain how natural volcanic glasses can inform about

	• Compare corrosion data from laboratory experiments and several natural analogue sources • Illustrate alkaline groundwater reaction with the natural bentonite over time period	borosilicate glass of vitrified high-level waste • Identify natural analogue for long-term behaviour of copper waste canister • Identify natural analogue for long-term behaviour of steel waste canister • Identify natural analogue for long-term behaviour of bentonite buffer • Explain thermal metamorphism of limestone as an analogue of to cementitious materials • Give examples of analogues to different host rocks • Discuss Cigar Lake case • Discuss Oklo case • Explain potential roles of analogues in performance assessments • Give examples of field measurement in archaeological sites as prediction tool for long term corrosion studies.
Assessment criteria • Demonstration and application of fundamental knowledge in geoscience • Ability to understand technical and engineering aspects of waste disposal		
Recommended assessment methods: written exam and case study report		

Course in French language (can be partly offered in English) for second year of Master degree.

Course applicable (in part or fully) for the following job profiles:

- Civil engineer
- Mining engineer
- Geological engineer

3.5 COURSES BY HORIA HULUBEI NATIONAL INSTITUTE

<table>
<tr><th colspan="3">Course on “Radon and its radiological impact”</th></tr>
<tr><td>Units and LO Statements</td><td></td><td></td></tr>
<tr><td rowspan="3">Unit 1 –Radiological characterisation of radon (1 ECTS)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomously apply radon measurements and characterisation from radiological protection point of view</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Analyzes radon origin and its spread in environment, according to UNSCEAR reports in terms of their radiological impact

Evaluates radon influence over the precise measurement of low activity samples in order to assure the survey of the environment

Applies the specific methods for the measurement of radon activity in order to verify the compliance with established reference levels</td><td>• Select and use of the appropriate equipment in the measurement of radon in various media
• Use special physical quantities specific to radon measurement
• Apply methods and use appropriate equipment for the measurement of radon and progeny concentrations in different places – quality assurance
• Apply the correct methods/procedures for measurement of radon activity in various media: in air, in water, in soil, at home and working places
• Apply radon background corrections when measuring various low activity samples in different phases of NPP operation</td><td>• Describe the uranium-radium-radon and daughters decay chain characteristics
• Knowledge and interpretation of UNSCEAR data bases
• Describe the specific quantities in radon measurement: activity (SI and non SI units) and energy (Potential Alpha Energy Concentration, Equilibrium factor)
• Understand of the methods for subtraction of background influence in low activity samples, applying the principles of the ISO11929/2010 standard</td></tr>
<tr><td rowspan="3">Unit 2 – Regulatory control on exposure to indoor radon in dwellings and workplaces (1 ECTS)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomously apply radiation protection against radon in workplaces and at home</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Analyzes the European and international documents in terms of radon exposure requirements

Applies the national regulatory requirements regarding radon exposure in order to implement of</td><td>• Accomplishment of the international legislation (EC Directive 59/2013) regarding radon, in the light of the ICRP PUBLICATION 115 /2010
• Apply the relevant regulations and guidance for the existing exposure situations involving exposure to radon</td><td>• Specify the relevant international Documents: EC59/2013, ICRP115/2010, etc.
• Describe the regulatory requirements regarding radon exposure in workplaces and at home
• Describe the calculation of dose to activity conversion factors to be applied in evaluation of doses due to radon exposure</td></tr>
</table>

the optimisation process for exposures in existing exposure situations Applies radon specific dosimetric assessments in order to ensure the adequate level of radiation protection in workplaces and at home	• Calculation of the doses for personnel being irradiated from distance or incorporating radon and daughters, at home and at work places • Calculation of the effective doses due to radon (internal and external) exposure	
Assessment criteria = to demonstrate mastery and innovation, advanced skills, required to solve complex and unpredictable problems in a specialised field of "Radon measurement and dose evaluation"		
Recommended assessment methods: Practical and written test, face to face examination, grid test with multiple choices [choosing among different options].		

Course applicable (in part or fully) for the following job profiles:

- Radiation Protection Officer (in uranium mining, uranium processing, fuel fabrication)
- Radiation Protection Officer (in NPP operation and radioactive waste management)
- Professionals of Public Health Service (Physicists, Chemists)
- Professionals of Environment Monitoring

<table>
<tr><th colspan="3">Course on “Principles of Radiation Protection and International Framework. Regulatory Control”</th></tr>
<tr><th>Units and LO Statements</th><th></th><th></th></tr>
<tr><td rowspan="3">Unit 1 – Principles of radiation protection (1 ECTS)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomously apply radiation protection principles in practices with radiation sources</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Applies the fundamental principle of justification to planned, emergency and existing exposure situations in terms of decision whether the exposure would do more good than harm.

Evaluates the level of protection of the exposure situations in order to find the optimised radiological protection solution.

Applies the dose limits principle for occupational and public exposure in planned exposure situations in order to comply with the regulatory requirements.</td><td>• Use the operational quantities that can be measured and from which the equivalent dose and the effective dose can be assessed
• Estimate the doses from radiation exposures in order to relate the radiation dose to radiation risk (detriment) taking into account variations in the biological effectiveness of radiations of different quality as well as the varying sensitivity of organs and tissues to ionising radiation
• Analyse stochastic effects and tissue reactions within Linear-non-threshold (LNT) model and, respectively, threshold doses for deterministic effects
• Use the dose quantities for prospective dose assessment in planned exposure situations for optimisation
• Use and implement the concepts of dose constraint and reference level in conjunction with the optimisation of protection in order to restrict individual doses
• Use the dose quantities for retrospective dose assessments for proving the compliance with dose limits
• Design a planned situation having regard of potential exposures that may result from deviations from normal operating conditions and from the related issues of the safety and security of radiation sources
• Perform the justification process, taking into account the risks and benefits
• Develop an organisational policy to keep doses to the personnel ALARA
• Apply measures to limit staff and public exposure</td><td>• Reminder of dose quantities and their units
- absorbed dose - fundamental physical quantity
- the radiological protection quantities used to specify exposure limits
- operational quantities for area and individual monitoring of external exposures
• Describe the biological effects of radiation and the differences between deterministic and stochastic effects
• Definitions and characterisation of the different exposure situations (planned, emergency and existing exposure situations)
• Distinction between the categories of exposures: occupational exposures, public exposures and medical exposures
• Describe the basic principles of radiation protection, as outlined by the ICRP
• Understand the need for justification for all exposure situations
• Explain the ALARA concept as a source-related principle
• Describe practical dose reduction strategies for workers and the public, including the use of shielding and dose monitoring
• Understand the principle of application of dose limits in planned exposure situations as individual-related principle</td></tr>
</table>

<table>
<tr><td></td><td>

- Put into practice the basic measures of preventing unnecessary exposure (time, distance, shielding)
- List relevant dose limits for workers (including organ doses), for pregnant workers and general public
- Identify possible deviations from planned operating procedures and accidents, as well as assess the resulting dose and evaluate the detriment associated with that dose
- Develop the protection strategies for application in emergency exposure situations, using the reference levels in the process of optimisation
- Implement optimised protection strategies, which are established by the authorities, for reducing the individual doses to below the adopted reference levels

</td><td></td></tr>
<tr><td rowspan="3">Unit 2 – International Framework. Regulatory Control (1 ECTS)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomously apply European and national legislation and regulations in radiation protection</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>

Analyzes the European and international radiation protection framework in terms of its impact on the national regulatory process.

Applies the regulatory control concepts and tools in order to achieve an appropriate standard of radiological protection.

Applies the requirements of European directives and national regulations in order to ensuring the adequate level of radiological safety of the radiation sources.

</td><td>

- Find and apply the relevant regulations and guidance for the planned exposure situation within its responsibility
- For each exposure situation, apply European and national laws, regulations, recommendations and standards related to radiation safety
- Understand the relationship between legislation, regulatory authority and primary responsibility for radiation safety
- Apply of the concepts of exclusion, exemption and clearance with respect to own practice
- Identify the legal radiation protection obligations in daily practice
- Understand the requirements of the legislation regarding the notification, authorisation, registration, licensing within own activity
- Apply the legal requirements and practical solutions which can be used to enhance safe storage, handling and disposal of radioactive materials

</td><td>

- List international and European bodies involved in radiation protection regulatory processes
- Specify the relevant regulatory framework (Recommendations, Standards, Directives, Regulations, etc.) governing the use of ionising radiation in own country and the EU
- Understand the main concepts associated with the scope of radiological protection regulations (exclusion and exemption)
- Describe the main elements of the infrastructure required for regulatory control (legal framework, regulatory authority, additional organisations, etc.)
- Tools used for regulatory control of practices: notification and authorisation (registration and licensing)
- Describe the requirements for regulatory compliance with respect to the management and use of radiation sources, including requirements for storage, shielding, record-keeping and audit, as well as the disposal of radioactive waste and the transportation of radioactive substances

</td></tr>
<tr><td>Assessment criteria = to demonstrate mastery and innovation, advanced skills, required to solve complex</td><td></td><td></td></tr>
</table>

and unpredictable problems in applying of radiation protection principles		
Recommended assessment methods: Practical and written test, face to face examination, grid test with multiple choices [choosing among different options].		

Course applicable (in part or fully) for the following job profiles:

- Radiation Protection Officer (in various types of practices)
- Radiation Protection Expert
- Medical Physics Expert
- Nuclear specialists
- Specialists from other disciplines demanded in the nuclear workforce

3.5 COURSES BY UPC

<table>
<tr><td colspan="3">Course on “Operation of Nuclear Power Plants”
A. de Blas (UPC)</td></tr>
<tr><td>Units and LO Statements</td><td></td><td></td></tr>
<tr><td rowspan="3">Unit 1 –Presentation of the Nuclear Power Plant Conceptual Simulator SIREP-1300 (3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Make use of the SIREP-1300 conceptual simulator</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Understand the SIREP-1300 simulator, the equations, the models and the interface to operate it.</td><td>• Use of the conceptual simulator SIREP-1300
• Apply methodology to control the simulator</td><td>• Organization of the simulator: simulation modules
• Limitations of the simulator
• Simulation speed and partial boosting
• File management
• Synoptic representations of the simulator behaviour
• General description of the REP-1300 series simulators</td></tr>
<tr><td rowspan="3">Unit 2 –Practice 1: Reactor kinetics parameters (3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Test the behaviour of main kinetic parameters and equations</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Study the basic principles of reactor kinetics, the influence of parameters and the response of state variations on subcriticity and supercriticity.</td><td>• Knowledge of reactor parameters
• Understanding of concepts as reactor period, bending time, prompt jump among others</td><td>• Reactor kinetic parameters
• Instantaneous and delayed neutrons
• Kinetic equations
• Reactor’s period and bending time
• Estimation of the proportion of delayed neutrons</td></tr>
<tr><td rowspan="3">Unit 2 – Practice 2: Subcritical approach (3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Study of the start and shutdown of nuclear reactor</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Practice the methodology to start a nuclear power plant and control of parameters previous the starting</td><td>• Understand the methodology to start the nuclear reactor
• Study the parameters involved on the start and main problems
• Characterisation of the initial state of a reactor</td><td>• Reactor shutdown states
• Hot and cold shutdown
• Calculation of multiplication subcritical factor
• Boron dilution
• Starting neutron sources
• Reactivity after refuelling</td></tr>
</table>

<table>
<tr><td rowspan="3">Unit 3 – Practice 3: Reactivity temperature effects (3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Analyse the effects of temperature on the reactivity and power</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Study transient phenomena due a change on the temperature in fuel and moderator during normal operation of the nuclear reactor, and the effects on the reactivity</td><td>• Knowledge of theoretical concepts of temperature effects in nuclear reactors
• Understand the reactivity calculations and reactivity feedback</td><td>• Study of the behaviour of fuel temperature coefficient
• Study of the behaviour of moderator temperature coefficient
• Temperature effects
• Effects of reactivity feedback at nominal power</td></tr>
<tr><td rowspan="3">Unit 4 – Practice 4: Isothermal coefficient and moderator coefficient (3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Characterisation of the nuclear reactor by means of isothermal coefficient</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Estimative calculation of the isothermal coefficient studying different situations of the power plant, from the cold shutdown states to hot shutdown states</td><td>• Knowledge of the meaning of isothermal coefficient
• Understand the influence of isothermal coefficient on the reactor behaviour and stability</td><td>• Moderation relation
• Doppler effect and moderator effect
• Calculation of feedback coefficients
• Influence on the reactor stability</td></tr>
<tr><td rowspan="3">Unit 5 – Practice 5: Reactor start and reactor load variations (3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Study the effects of poisons on the reactor start after a shutdown</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Study the start of a nuclear reactor after and automatic shutdown, describe 3 cases to start I again and test the behaviour of the reactor in these 3 cases.</td><td>• Understand the poisoning effects and origin of poisoning
• Knowledge of Xe-135 and Sm-149 origin and equations
• Knowledge of nuclear reactor control parameters</td><td>• Reactivity balances
• Poisoning effects
• Xe-135 and Sm-14449 in the fuel production
• Antireactivity
• The poisoning effect control</td></tr>
<tr><td rowspan="3">Unit 6 – Practice 6: Reactor standard states-I (3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Transition from operation at nominal power to hot zero power</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Study the main operation restrictions, taking care of vessel protections, primary pumps, presurizer and steam generators.</td><td>• Knowledge of primary cooling system
• Understanding of volumetric and chemical control system
• Knowledge of residual heat extraction system</td><td>• Calculation of reactivity effects on the core during boration of primary
• Calculation of boron concentration
• Study the boration process</td></tr>
</table>

Unit 7 – Practice 7: Reactor standard states-II (3 hours)	**Responsibility / Autonomy**	
	Transition from hot zero power to cold zero power	
	Skills	**Knowledge**
Study and understand the process of cold shutdown on a nuclear reactor	• Knowledge of cold shutdown concept • Understanding of the systems involved on a cold shutdown • Mechanisms of heat extraction in a cold and hot shutdown	• Study of feedback effects (Doppler and moderator) and neutronic poisons • Plot the Xenon profile concentration and justify the axial asymmetry • Processes to achieve the cold shutdown • Define the generic states of cold shutdown and hot shutdown
Unit 8 – Practice 8: Control rod calibration (3 hours)	**Responsibility / Autonomy**	
	Study the effectiveness of control rods and measure the reactivity of them	
	Skills	**Knowledge**
Understand the methodology of control rod calibration and main procedures	• Knowledge of control rod properties • Understand the need of control rod calibration • Knowledge control rods composition and differentiation between grey and black control rods	• Calibration of control rods by interchange • Calibration by dilution • Study of boron effectiveness related to boron concentration in the moderator
Unit 9 – Practice 9: Reactor auto-stabilization (3 hours)	**Responsibility / Autonomy**	
	Study the procedures to stabilize the reactor	
	Skills	**Knowledge**
Analyse some techniques to stabilize the reactor during operation at nominal power	• Knowledge of reactor perturbations theory • Understand the Doppler effect in reactor core • Knowledge of auto-stabilization process	• Study the primary perturbation at the beginning of reactor life • Study the primary perturbation at the reactor mid-life • Study the secondary perturbation at the beginning of life • Study the importance of Doppler effect
Recommended assessment methods: Individual face to face examination. The student must be able to operate the simulator solving a situation during the operation of the power plant		

Course applicable (in part or fully) for the following job profiles:

- Operation of a nuclear power plant
- Radiation Protection Officer (in NPP operation)

3.6 COURSE BY CVUT ON TRAINING REACTOR

<table>
<tr><th colspan="3">Training course on VR-1 Training Reactor</th></tr>
<tr><th>Units and LO Statements</th><th colspan="2"></th></tr>
<tr><td rowspan="3">Unit 1 – Neutron Detection and Neutron Flux Distribution Measurement (3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Independent measurement, typically 2 students in a group</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Basic Principles of Neutron Detection
Classification of Gas-filled Neutron Detectors
Detectors Used in Measurement at VR-1 Reactor
Characteristics of Gas Neutron Detectors
Measurement of Characteristics of Gas Neutron Detectors
Determination of Relative Thermal Neutron Distribution
Dead Time of Detection System</td><td>the unit is targeted to neutron detection and neutron flux distribution measurement
information about different detectors of neutrons
practical measurement of neutron flux and neutron distribution is carried out</td><td>neutron detectors, their characteristics and properties
Gas-filled Neutron Detector
10B(n,α) reaction
6Li(n,t) reaction
3He(n,p) reaction
neutron induced fission reaction
157Gd(n,γ) reaction
dead time of detectors</td></tr>
<tr><td rowspan="3">Unit 2 – Delayed Neutron Detection (3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Independent measurement, typically 2 students in a group</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Prompt and Delayed Neutrons Generation
Delayed Neutron Groups and Their Properties
Influence of Delayed Neutrons on the Reactor Dynamics
Determination of Delayed Neutrons Properties
Determination of Uranium Content Using Delayed Neutron Counting</td><td>measurement of delayed neutrons
measurement of uranium content using delayed neutron measurement</td><td>basic information about delayed neutrons
groups of delayed neutrons
influence of delayed neutrons to reactor dynamics</td></tr>
<tr><td rowspan="3">Unit 3 – Reactor Kinetics Study (3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Independent measurement, typically 2 students in a group</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Zero Power Reactor without Delayed Neutrons
Point Kinetics Theory with Delayed Neutrons
Pulse Response</td><td>finding the critical state of the reactor
observation of subcritical and supercritical reactor</td><td>behaviour of reactor without and with delayed neutrons
point kinetics of the reactor
pulse, transient and frequency response of the reactor</td></tr>
</table>

<table>
<tr><td>Transient Response
Frequency Response
Study of Reactor Kinetics at the VR-1 Reactor</td><td></td><td>critical, subcritical and supercritical reactor</td></tr>
<tr><td rowspan="3">Unit 4 – Reactor Dynamics Study
(3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Independent measurement, typically 2 students in a group</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Reactivity Feedback and Reactor Dynamics
Study of Reactor Dynamics at the VR-1 Reactor
Void Coefficient Measurement
Temperature Reactivity Effect Measurement</td><td>experiments with air bubbles in undermoderated and overmoderated part of the reactor, influence of the reactivity
influence of temperature to reactivity</td><td>reactivity feedback and its influence to reactor dynamics
undermoderated and overmoderated parts of reactors and influence of void coefficients
temperature feedback in reactor and importance to nuclear safety</td></tr>
<tr><td rowspan="3">Unit 5 – Reactivity Measurement
(3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Independent measurement, typically 2 students in a group</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Reactivity Definition
Rod Drop and Source Jerk Methods
Positive Period Method
Reactimeter</td><td>measurement of reactivity using rod, drop, source jerk and positive periods methods
reaktimeter measurement</td><td>definition of reactivity
theory of rod drop, source jerk and positive periods methods for reactivity measurement
reaktimeter theory</td></tr>
<tr><td rowspan="3">Unit 6 – Control Rod Calibration
(3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Independent measurement, typically 2 students in a group</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Types of Control Rods
Integral and Differential Control Rod Worth
Control Rod Calibration by Inverse Rate Method
Dynamic Determination of Control Rod Worth
Mutual Control Rod Calibration</td><td>measurement of the control rod calibration using inverse rate, dynamic and mutual control methods</td><td>types of control rods
control rod worth
inverse rate, dynamic and mutual control methods for rod calibrations</td></tr>
<tr><td rowspan="3">Unit 7 – Critical Experiment
(3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Independent measurement, typically 2 students in a group</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>Theory
Approaching the Critical State at the VR-1 Reactor
Safety Notes</td><td>finding of exact critical state of the reactor
practical use of methods for approaching the critical state</td><td>methods for achievement of critical state of reactor
methods for approaching critical state of reactor</td></tr>
<tr><td></td><td colspan="2">Responsibility / Autonomy</td></tr>
</table>

<table>
<tr><td rowspan="2">Unit 8 – Digital Safety and Control System of the VR-1 Reactor
(3 hours)</td><td colspan="2">Mainly common training of all participants</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Reactor I&C Basics
• VR-1 Reactor I&C Structure
• Safety Features of I&C
• I&C Safety Classification
• Reactor I&C Components</td><td>• detailed information about reactor I&C requirements, properties and functionality
• demonstration of reactor I&C features</td><td>• requirement on I&C
• standards for reactor I&C
• categorization of I&C with respect to nuclear safety
• VR-1 reactor I&C, its structure, components and their functions
• computer based I&C</td></tr>
<tr><td rowspan="3">Unit 9 – Start-up and Operation of the VR-1 Reactor
(3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Individual operation of the reactor under supervision of qualified person</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Reactor Regimes and Modes
• Safety and Warning Signals
• Use of HMI for Reactor Control
• Start-up of the Reactor
• Demonstration of Reactor Utilization</td><td>• start-up and control or the reactor under supervision of qualified personel
• automatic and manual operation, influence of delayed neutrons to reactor control
• safety features of the reactor I&C, demonstration of shut down because of power an power rate exceeding</td><td>• methodology of the reactor start- up and operation
• warning and safety signals of the reactor
• methods of reactor operation</td></tr>
<tr><td>Assessment criteria evaluation of tests regarding the theory educated before practical training (for each theory lecture in the reactor hall classroom before practical training), evaluation of protocols from individual units, discussion with participants.</td><td></td><td></td></tr>
<tr><td>Recommended assessment methods: evaluation of written tests regarding the theory, protocols evaluation.</td><td></td><td></td></tr>
</table>

3.7 COURSE BY UCL

Course on "Nuclear thermal-hydraulics" (BNEN model, 2 week course including lectures/practice- 1 day project)		
Units and LO Statements		
Unit 1 – Thermal design principles (2h)	**Responsibility / Autonomy**	
	Figure out the basics parameter involved in thermal design/characterisation of a nuclear reactor	
	Skills	**Knowledge**
At the end of the unit students should be able to: • Know, define and write the important parameters characterizing from the thermal-hydraulic point of view a fission nuclear reactor • Figure out the main limitations of reactor performances in terms critical heat flux phenomena	• Define/write the plant thermal efficiency from a thermodynamic point • Figure out the main limitation (thermodynamics, materials) according the technology: PWR/BWR • Write and figure out the thermal design limitations in terms of DNBR and CPR and figure out the difference • Write/figure out the 2 main figures of merit of reactor performance: specific power and power density	• First principle of thermodynamic • Carnot efficiency • Basic pool/flow boiling process (Nukiyama curve) • Definition of DNBR/CPR • Definition of power rates
Unit 2 – Reactor heat generation (2h)	**Responsibility / Autonomy**	
	Understand and figure out the source of thermal power generation and its relation with basic reactor physics	
	Skills	**Knowledge**
At the end of the unit students should be able to: • To write the power rates profiles in a single fuel pin or homogeneous reactor un the frame of a single group approximation • To calculate an average neutron flux for achieving an average power • To calculate the residual power decrease according time after a reactor shutdown	• explain the process of energy deposition in a nuclear fission reactor • make the link between the volumetric heat release, neutron flux, enrichment, fission cross sections, and energy per fission in the case of a single group assumption • write a heat balance at the fuel pin and reactor scale using power rates • Calculate the shutdown heat/power generation rate	• Concept of radioactive decay • Concept of prompt and delay neutrons • Concept of fission cross-sections and neutron flux • Volume/surface/length averaging of power rates and their relation • Integration of power rates in space and in time
Unit 3 – Transport equations single-phase – Reminders (2h)	**Responsibility / Autonomy**	
	Use and apply to a specific case the different forms of conservation equations to solve a problem or formulate a computer model	
	Skills	**Knowledge**

<table>
<tr><td>At the end of the unit students should be able to:
• Derive the different forms (either local for a computer model or algebraic for an engineering model) of transport equations to a specific problem</td><td>• From an integral global balance equation derive the local conservation equation
• Integrate a local conservation equation over a control volume (arbitrary) to derive the engineer balance form (in +out equals source, algebraic form)
• Know and use the mechanical energy equations (2 forms) also known as shaft work equations
• Derive/write and figure out the entropy source term
• Figure out the complete set of Navier-Stokes equations +energy/entropy and the need for closure relations
• Know the general approach for turbulent flows</td><td>• General integral form of conservation equation (application to mass, momentum, total internal energy)
• Definition of a total/lagrangian derivative
• Definition/physical meaning of a gradient
• Definition/physical meaning of a divergent
• Divergence theorem
• Leibnitz rule
• Reynolds transport theorem
• Ensemble averaging for turbulent flows</td></tr>
<tr><td rowspan="3">Unit 4 – Transport equations two-phase (4h)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Figure out and use the different two-phase flow models and derive appropriate (problem specific) a 1D two-phase flow model</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>At the end of the unit students should be able to:
• Know the main parameters characterizing a two-phase flow
• Set up the correct model according the assumption relevant to a two-phase flow pattern or according the required information
• Elaborate a 1D model relevant to a given configuration including the necessary assumptions to set up a well posed set of equations
• Understand the model formulation according the case in a system code such as CATHARE or RELAP</td><td>• Know the different flow pattern and existence of flow regime maps
• Know how and when to use the different averaged void fractions
• Know how and when to use the different averages qualities
• Figure out the mechanic and thermodynamic equilibrium
• Establish the relation between void fraction and quality under different mechanic and thermodynamic equilibrium assumptions
• Know to establish the phasic local transport equations (generic form) and jump conditions at the interface
• Know to derive the 1D set of transport equation by integrating the local phasic equation over a cross-section
• Know to derive the mixture equations</td><td>• Definition of phase density function
• Definition of void fraction
• Definition of space phase averaging (volume/surface)
• Definition of time averaging
• Relations between averages
• Definition of static and flow quality
• Definition of thermodynamic equilibrium quality
• Definition of mass flux densities
• Concept of superficial velocity
• Limit form of Leibnitz and divergence theorems in 1D</td></tr>
<tr><td rowspan="3">Unit 5 – Thermodynamic of conversion systems (non-flow case) (3h)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Calculate and evaluate the performance of an energy conversion system based on a Rankine-Hirn cycle</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
</table>

<table>
<tr><td>At the end of the unit students should be able to:
To establish a full energy analysis of a steam cycle
To establish a full exergy analysis of a steam cycle
including the usual features such as bleeding-off (steam extraction) and reheating.</td><td>Define and calculate the efficiency of a driving machine (turbine) or of an operating machine (pump)
Write and calculate an energy balance for a heat exchanger
Write and calculate an energy balance for a whole cycle
Define/write and calculate the overall energy efficiency of a steam cycle
Understand and figure out the main operating parameter on the overall efficiency
Understand and figure out the concept of exergy and apply it to the different component
Write/derive the exergy losses as driving/operating machines, valves, and heat exchangers, derive the associated efficiencies
Write and analyse the overall exergy analysis of the steam cycle
Figure out and calculate a steam extraction
Figure out and calculate a steam reheat</td><td>First principle of thermodynamics
Second principle of thermodynamics including the concept of entropy generation
Isentropic efficiency
Polytropic efficiency
Carnot efficiency
Exergy concept and definition
Exergy analysis of a working machines
Exergy analysis of a heat transfer
Concept of exergy efficiencies</td></tr>
<tr><td rowspan="3">Unit 6 – Thermodynamic of containment and pressurizer (steady flow case) (2h)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Calculate or design the features of a containment and a pressurizer to prescribed conditions</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>At the end of the unit students should be able to:
Apply the first principle of thermodynamics in transient situation and for closed/open system to calculate the final state (pressure/volume) equilibrium of a reactor containment/pressurizzer knowing the initial state and prescribed conditions.</td><td>Figure out the main parameters/systems responsible of the final pressure within the containment after a LOCA or MSLB
Calculate the necessary volume of the containment to reach a maximum pressure after a LOCA or MSLB
Calculate the final pressure of an existing containment after a LOCA or MSLB
Calculate the response of a pressurizer under prescribed conditions of insurge and outsurge.</td><td>Transient first principle of thermodynamics for closed and open systems
Humid air theory
Saturation conditions</td></tr>
<tr><td></td><td colspan="2">Responsibility / Autonomy</td></tr>
</table>

Unit 7 – Thermal analysis of fuel elements (2h)	Evaluate the heat transfer between the fuel pellet and the coolant along the burnup in a nuclear reactor	
	Skills	**Knowledge**
At the end of the unit students should be able to: • Calculate the temperature profiles through the different layers between the fuel pellet and the coolant and according the burnup of the fuel • To know the consequence of this in terms of reactor operation taking into account the design limit of the reactor according the technology (PWR/BWR, LMFBR)	• Figure out the main parameters involved in the heat transfer between the fuel pellet and the coolant • Calculate the temperature profile in a cylindrical fuel pellet under known boundary conditions • Calculate the temperature profile in a restructured (hollow) fuel pellet under known boundary condition • Evaluate the gap conductance • Write/figure out the complete thermal resistance between the fuel pellet and the coolant and the full temperature profile • Figure out implication for the operation margin along the fuel burnup for a PWR/BWR and a LMFBR	• Heat conduction equation and assumptions • Fourier Law's • Linearization of the heat equation • Thermal resistance/conductance • Integrating heat equation in Cartesian and polar coordinates
Unit 8 – Single phase fluid mechanics/heat transfer (2h)	**Responsibility / Autonomy**	
	Characterize pressure drop and heat transfer in a complex pipe system including rod bundles	
	Skills	**Knowledge**
At the end of the unit students should be able to: • Calculate/evaluate a pressure drop through a pipe system including regular and form pressure drop • Calculate/evaluate a heat transfer coefficient • Knowing how to take into account the entrance region effect (developing) • Apply these concept to a subchannel and a bare/full rod bundle (correlations)	• Know the generalized Bernoulli equation and figure out the different terms • Figure out the link between dissipative losses in the mechanical energy conservation equation and pressure drop • How to calculate regular pressure drop in all possible regime (laminar, smooth turbulent, rough turbulent) • Figure out the available pressure drop correlations for subchannels, bare and full rod bundle and transverse pressure drop • Know to use the Fourier and Newton laws in heat transfer • Figure out the different heat transfers modes and associated assumptions in the transport equations • Know how to put equations into non-dimensional form and derive the	• Definition of viscosity and shear stresses • Definition of vorticity/irrotationnal flows • Integrating kinetic energy equation along a streamline • Integrating momentum equation in 1D through a pipe • Integrating energy equation in 1D through a pipe • Definition of friction coefficient • Definition of Reynolds number • Definition of Brinkman number • Definition of Nusselt • Definition of Prandtl • Definition of Grashoff • Colebrook Formula • Moody Diagram • Dependence of friction coefficient and Reynolds for different regime • Dittus Boelter correlation • Reynolds analogy

<table>
<tr><td></td><td>associated non-dimensional numbers including their physical meaning
Evaluating a heat transfer coefficient according the flow regime
Evaluate the entrance regions effects (for the momentum and thermal point of view) according the flow regime and fluid properties</td><td></td></tr>
<tr><td rowspan="3">Unit 9 – Two-phase fluid mechanics (4h)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Characterizing a pressure drop in a two phase flow</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>At the end of the unit students should be able to:
Know the procces of obtaining two-phase flow maps including the associated parameters (theorical/empirical)
Understand the assumption related to a flow model and the consequence in the equation, e.g. the void/quality relations
To evaluate a pressure drop in a two-phase flow and calculate the terms in a simple frame (HEM)</td><td>Know the main flow regime maps and the associated parameter
Figure out the flooding and flow reversal process including CCFL
Know the void-quality relations according the two-phase model including the drift flux model
Know the concepts to calculate two-phase pressure drops: Lockhart Martinelli and Nelson-Martinelli
Know how to compute two-phase pressure drop in a HEM frame</td><td>Relation of film equilibrium
Balance equation for a bubble equilibrium and droplet equilibrium
Weber number
Drift flux model
Integration of momentum equation
Void fraction/quality relations according the different assumptions
Two-phase multipliers definition/calculation according the assumptions</td></tr>
<tr><td rowspan="3">Unit 10 – Two-phase heat transfer (4h)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Characterize/evaluate flow boiling regimes</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>At the end of the unit students should be able to:
Figure out to different boiling regimes and phases
Evaluate the critical heat fluxes in pool boiling
Properly use the available correlations to evaluate the boiling regime</td><td>Figure out the pool boiling and flow boiling and their differences
Understand the basic principle of homogeneous and heterogeneous nucleation and the governing parameters driving each process
Understand the theoretical roots of pool boiling correlations
Characterize maximum and minimum critical heat fluxes
Describe and characterize (evaluate/calculate) subcooled boiling and saturated boiling</td><td>Critical heat flux
Laplace equation
Contact angle
Wettability
Linear hydrodynamic stability analysis
Bergles Rohsenow model (onset NB)
Saha Zuber model (departure)
Chen correlation (saturated)
Empirical correlation for critical heat flux in flow boiling (from vendors)</td></tr>
<tr><td rowspan="2">Unit 11 – Single heated channel (4h)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Evaluate the flow and heat transfer in a boiling channel</td></tr>
</table>

	Skills	Knowledge
At the end of the unit students should be able to: • Evaluate the pressure drop characteristic of a boiling channel including a single phase-subcooled boiling-saturated boing-superheated parts (channel characteristic) • Evaluate the stability of the operating point of this channel under a fixed external characteristic (pump) • Determine the bulk temperature profile, the wall temperature profile and the associated fuel centreline temperature profile under the same conditions	• Formulate the 1D set of equations (mass, momentum, energy) of a two-phase mixture in a straight channel • Do the necessary assumption to tackle single phase flows, two-phase flows according several models (mechanics, thermodynamics non-equilibrium) • Integrate the 1D equation over a single phase heated channel • Integrate the 1D equations over a two-phase flow channel under equilibrium (mechanic+thermodynamic) • Integrate the 1D equations to take into account thermodynamic non equilibrium, e.g assuming a nucleate boiling and a saturated boiling region • Obtain from these integrations the pressure drop profiles and temperature profile (flow temperature, wall temperature) along the channel • Figure out the possible shape of a two-phase flow pressure drop characteristics (S shape) • Evaluating if a two-phase flow channel is stable or not when fed by an external characteristics (pump)	• 1D mixture equations • assumptions: incompressibility, delineation behaviour • Integrating the energy /momentum equations taking into account a cosine profile for the flux over the different part of the channel • Levy's correlation • Characteristic curves and operating point • Stability of an operating point
Assessment criteria TBD		
Recommended assessment methods: 1. Written test including - theoretical part: concept, understanding, derivation of equations/models - practical part: solve a problem by engineering tools/method/approach 2. 1 day project + report about implementation of a 1D boiling channel: pressure drop plus temperature profiles under different conditions and different approach (full equilibrium and non-equilibrium)		

Course applicable (in part or fully) for the following job profiles:

- 1.0.10. Safety Design Engineer
- 1.2.09. System Design Engineer
- 1.2.12. HVAC Design Engineer
- 2.2.02. Senior Reactor Operator/CRO
- 2.2.01. Shift Engineer
- 2.2.05. Turbine Operator
- 2.8.01. Mechanical Design Engineer
- 2.9.02. System Responsible Engineer

3.8 COURSES BY UMAN

<table>
<tr><th colspan="3">NTEC N03 Radiation & Radiological Protection</th></tr>
<tr><th>Units and LO Statements</th><th colspan="2"></th></tr>
<tr><th rowspan="3">(35 hours direct contact, 150 total study)
or (150 hours of eLearning)</th><th colspan="2">Responsibility / Autonomy</th></tr>
<tr><td colspan="2">EQF Level 7</td></tr>
<tr><th>Skills</th><th>Knowledge</th></tr>
<tr><td>Summary
Explains the properties of different types of radiation occurring as a result of nuclear processes and identifies means whereby levels of radiation and dosages can be detected and measured. The principles of radiation protection and shielding are outlined and demonstrated through practical experience with radioactive sources and detection equipment. The module concludes with an overview of ionising radiation regulations and legislation governing the impact of radiation on people and the environment. The safe handling of accidents is illustrated through case studies of real incidents.
Syllabus
• The nucleus and nuclear processes
• Radiation and radiation detection
• Biological effects of radiation
• Assessment of radiation exposure
• Dosimetry
• Ionising radiations regulations
• Evaluating the effects of exposure to radiation
• Practical laboratory: introduction to radiation detectors and monitors
• Practical laboratory: demonstration of properties of nuclear radiation
• Case studies – safe handling of accidents</td><td>• Appreciation of the principles governing the design of radiological protection equipment
• Understanding of Ionising Radiation Regulations
• Practical experience of radiation detection equipment</td><td>• A full understanding of the sources, types of radiation and hazards associated with nuclear processes
• Knowledge of radiation detection and monitoring equipment</td></tr>
</table>

<table>
<tr><th colspan="3">NTEC N06 Reactor Materials And Lifetime Behaviour</th></tr>
<tr><th>Units and LO Statements</th><th colspan="2"></th></tr>
<tr><th rowspan="3">(35 hours direct contact, 150 total study)</th><th colspan="2">Responsibility / Autonomy</th></tr>
<tr><td colspan="2">EQF Level 7</td></tr>
<tr><th>Skills</th><th>Knowledge</th></tr>
<tr><td>Summary
This module describes the science and engineering of reactor materials, and the factors that influence the lifetime of these materials, including corrosion, environmentally-assisted fracture, and irradiation embrittlement. Other topics covered in this module include fracture mechanics and structural integrity, non-destructive evaluation techniques, as well as plant monitoring and lifetime issues. Also considered are materials specifications and fabrication processes for materials used in nuclear power systems.
Syllabus
• Materials Science and Engineering
• Structure and Properties of Metals and Alloys used in Reactor Systems
• Corrosion
• Graphite - Mechanics and Lifetime
• Fracture Mechanics
• Non-Destructive Testing and Plant Monitoring
• Lifetime Issues including Radiation Damage
• Materials Specification and Fabrication for high reliability in nuclear power systems</td><td>• The ability to perform basic structural integrity assessment using the R6 code.
• An appreciation of the methods of non-destructive testing and plant monitoring.
• An appreciation of the factors which limit the lifetime of reactor components, such as radiation damage.
• An appreciation of the specifications and methods of material fabrication for reliable performance in nuclear power system environments.</td><td>• An understanding of the materials science structure/property relationships of key reactor materials, and how these are affected by corrosion and the environment (Light Water Reactors, AGRs).
• An understanding of the methods of structural integrity assessment of reactor pressure vessels.</td></tr>
</table>

NTEC N09 Policy, Regulation & Licensing		
Units and LO Statements		
(35 hours direct contact, 150 total study)	**Responsibility / Autonomy**	
	EQF Level 7	
	Skills	**Knowledge**
Summary Regulatory issues necessarily impact upon the development of national policy in environmental and energy areas. This module covers the international and national legal frameworks for nuclear power and radioactive waste management. The roles of the various regulatory bodies and other players are discussed. The module also addresses the role of the decommissioning of nuclear facilities and UK radioactive waste management policies and national strategies. Students are introduced to basic legal principles as applied in the nuclear sector and are shown how to read case law and apply their knowledge to legal problems. **Syllabus** • Introduction to legal systems Working with statutes and case law Nuclear law • The regulatory framework and institutional arrangements including public bodies involved in determining nuclear policy and regulating the industry at international, European and national levels and the context in which they work. • Nuclear Industry Policy and Regulation. Energy Act 2008 and new build. • Nuclear licensing and delicensing under the Nuclear Installations Act. • Safety assessment, plant justification, engineering substantiation, competency standards. • Environmental Permitting Regulations 2010 and the National Strategy for Radioactive • Discharges 2001 – 2020. Nuclear liabilities under international and national law. • Radioactive waste management – legacy waste and new build waste • UK Radioactive Waste Policy – the MRWS process.	• Explain the policy context in which the nuclear industry operates. • Explain the principles guiding regulation in the nuclear industry and comment on the way that they are used. • Describe clearly the governing bodies, nationally and internationally, responsible for formulating policy, promulgating laws and regulations and enforcing them. • Explain clearly the responsibility of the employer and the individual in respect of ensuring nuclear safety.	• List key legal instruments and explain why they have been made. • Identify the legislation applicable to the student's organisation, and how this is applied.

NTEC N23 Radiological Environmental Impact Assessment		
Units and LO Statements		
(35 hours direct contact, 150 total study)	**Responsibility / Autonomy**	
	EQF Level 7	
	Skills	**Knowledge**
Syllabus • Overview of REIA Requirements, Basic Concepts • Atmospheric Dispersion Modelling • Deposition Processes • Exposure Pathways I Airborne and Deposited Activity • Exposure Pathways II Foodstuffs • Team-Based Assignment using PC-CREAM 08 • Marine Dispersion Modelling • Exposure Pathways III Marine Pathways • Environmental Radiation Monitoring • Laboratory-based Exercise Environmental Assay • Radioactive Discharges in the UK – a Perspective • Regulatory Issues and International Perspectives	• Explain the purpose of radiological environmental impact assessment (REIA) and identify the circumstances in which theoretical (predictive) and measurement- based assessments are required. • Use 'state-of-the-art' models effectively and intelligently to analyse the dispersion of radionuclides through the atmospheric, terrestrial and marine environments. • Develop and apply dosimetric models to analyse the radiological impact of discharges on critical groups and the population as a whole by estimating individual and collective doses. • Explain the special circumstances pertaining to C-14 and tritium (H-3) discharges and develop and apply specialist models to estimate the radiological impact of such emissions. • Explain the methods used to measure environmental radiation and devise appropriate monitoring strategies for different types of discharge. • Undertake a critical appraisal of actual radioactive discharges and associated impact assessments and undertake cost-benefit analyses for various discharge abatement proposals.	• Understand the physical and chemical behaviour of radionuclides released into atmospheric and marine environments. • Describe the UK regulatory framework pertaining to radioactive discharges and explain how international treaty obligations will impact on future regulatory requirements.

3.9 COURSES BY INSTN

Course on "Basic operation of nuclear reactors" P. Anzieu, B. Lescop, C. Renault, M. Moiron (CEA)		
Units and LO Statements		
Unit 1 –Principles of a nuclear reactor (9 hours)	**Responsibility / Autonomy** Understanding the principles on which nuclear reactors are based	
	Skills	**Knowledge**
- **Reactor principle and systems** • Neutron interaction, Cross section, Fission • Reactor principle, Reactor systems • Examples of Research and Industrial reactors **The neutron kinetics** • Equations of kinetics • Study of the critical state • Sub- and Super-critical states **Thermal hydraulics**. • Water as a coolant: fluid properties • Energy balance and fuel temperature • Heat transfer in (research) reactors • Pressure drops and coolant flow rate • Thermal and hydraulic design **Basic safety** • General principles • Safety Analysis Methods • Performance of Safety Analysis • Case study	• Integrate and apply theory and kinetics of nuclear reactors. • Apply reactor thermal hydraulics. • Approach and manage the reactor operation. • Explain physics underlying the reactor operation. • Assess safety principles and background	• Basic nuclear interaction in a reactor core • Main core elements • Reason for moderating neutrons • Reason for core stability • Reactivity variation and management • Core thermal hydraulics and heat transfer main characteristics • Safety principles • Safety analysis
Unit 2 – Basic operation of a nuclear reactor (18 hours)	**Responsibility / Autonomy** Identifying the issues in basic operation of nuclear reactors	
	Skills	**Knowledge**
Reactor operation • Operational aspects – limitation of the reactivity • Reactor start up and operation • Temperature effect • Core poisoning (Xenon, Samarium) **Practical course on the ISIS training reactor** • Fuel loading • Approach to criticality • Reactor start up and stabilization	• Approach and manage the reactor operation. • Explain physics underlying the reactor operation. • Operate an experimental reactor	• Reactivity variation and management • Use of control rods • Control rod efficiency measurement • Main effects during core operation • Complexity of a reactor system • Links among the main reactor equipment • Operational safety

• Manual and Automatic control • Measurement of a control rod worth • Effect of the core loading modification • Study of fast reactivity transient • Temperature effect **Practical course on a software application** • PWR normal and accidental conditions • Study of the Core poisoning by Samarium and Xenon		

Course applicable for the following job profiles:

- 1.0.01: Nuclear Safety Manager
- 1.0.02: Safety Assessment Specialist
- 1.0.10: Safety Design Engineer
- 1.2.01: Design Manager
- 1.2.09. System Design Engineer
- 2.0.01. Plant Manager
- 2.1.03. Production Manager
- 2.1.06. Engineering Manager
- 2.1.07. Operation Manager
- 2.1.04. Training Officer
- 2.2.01. Shift Engineer
- 2.2.02. Senior Reactor Operator/CRO
- 2.6.01. Safety and Security Manager
- 2.8.07. Reactor Physicist

Course on "Operation and safety of PWRs" C. Renault, P. Dumaz, L. Gicquel (CEA) + Specialists (AREVA) + Specialists (EDF)		
Units and LO Statements		
Unit 1 – Operation under normal conditions (29 hours)	**Responsibility / Autonomy** Understanding the architecture and related operation of a PWR	
	Skills	**Knowledge**

• Architecture and functional analysis of PWRs (primary and secondary components, containment building, auxiliary systems)
• PWR normal operation
  ○ base load operation
  ○ start-up procedures
  ○ shutdown procedures
• PWR control aspects
  ○ load-follow operation
  ○ performance of control modes
• Safety in operation
  ○ regulation
  ○ protection systems and procedures
  ○ typical operational transients
• PWR core and fuel management
	• Understand basic principles of PWRs operation
	• Be able to connect safety equipment with their function
	• Understand the needs of safety regulation
	• Link the safety needs to their related equipment
		• Basic principle or PWRs
		  ○ Core physics
		  ○ Thermal-hydraulics
		• 1300 MWe PWR architecture
		  ○ Function and design of safety equipment
		• Comparison to other designs
		• Normal operation.
		  ○ base load operation
		  ○ start-up
		  ○ shutdown
		• Safety in operation.

Unit 2 – Safety in accidental conditions (27 hours)	**Responsibility / Autonomy** Mastering the safety approach in the management of transient and accident operation	
	Skills	**Knowledge**

• PWR safety approach
  ○ Deterministic approach
  ○ Probabilistic approach
  ○ Calculation tools
• Practicals on PWR simulator and training reactor.
• PWR safety systems
• Accidental scenarios
  ○ Loss Of Coolant Accidents (LOCA)
  ○ Steam Generator Tube Ruptures (SGTR)
  ○ Steam Line Secondary Break
  ○ Reactivity Initiated Accidents (RIA).
• Post-accident management (state-oriented approach)
• Innovative tracks of LWRs
  ○ burn-up, conversion ratio, materials and fuels
	• Make safety study while referring to safety regulation
	• Use the most appropriate safety approach
	• Get familiar with realistic PWR complex operation
	• Understand the main accident sequences and the role of operators
		• Safety study rules.
		• Safety methodologies.
		• In situ analysis of reactor control.
		• Realistic operational transients.
		• Main accident sequences of a PWR.
		  ○ Loss Of Coolant Accidents (LOCA).
		  ○ Steam Generator Tube Ruptures (SGTR).
		  ○ Steam Line Secondary Break.
		  ○ Reactivity Initiated Accidents (RIA).
		• The TMI-2 accident.
		  ○ Initiators.
		  ○ Development.
		  ○ Consequences.
		• Innovative designs.

Course applicable (in part) for the following job profiles:

- 1.0.01: Nuclear Safety Manager
- 1.0.02: Safety Assessment Specialist
- 1.0.10: Safety Design Engineer
- 1.2.01: Design Manager
- 1.2.09. System Design Engineer
- 1.4.07. Licensing Manager
- 2.1.06. Engineering Manager
- 2.1.07. Operation Manager
- 2.2.01. Shift Engineer
- 2.2.02. Senior Reactor Operator/CRO
- 2.6.01. Safety and Security Manager

<table>
<tr><td colspan="3">Course on “Neutronics for light water reactors”
M. Moiron, Ch. Diop, (CEA)</td></tr>
<tr><td>Units and LO Statements</td><td></td><td></td></tr>
<tr><td rowspan="3">Unit 1 – Phenomenology
(30 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Understanding the phenomena resulting from neutron-nucleus interactions inside a reactor core</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Introductory nuclear physics: nucleus properties, radioactivity, nuclear reactions, cross-sections.
• Introduction to neutronics: energy domains, neutron current, flux and spectrum, reaction rates, neutron balance.
• Diffusion equation: Fick's law, one group diffusion theory, critical conditions, “geometrical buckling”.
• Neutron slowing down and thermalisation: elastic and inelastic scattering, lethargy, resonance absorption.
• Reactor kinetics: reactivity, prompt and delayed neutrons precursors, Nordheim's equation.
• Temperature and poisoning effects, fuel evolution, Pu recycling.</td><td>• Design, at a preliminary level, Light Water Reactors from a neutron physics point of view
• Connect reactor physics to the operation of a Light Water Reactor
• Analyse, at a preliminary level, the reactivity control safety function of a Light Water Reactor</td><td>• Nucleus characteristics and nuclear models
• Stable and natural radioactive nuclei
• Radioactivity
• Disintegration law, activity.
• Conservation laws, cross-sections.
• Fission and fusion reaction, energy release.
• Elastic scattering - energy loss and lethargy
• Radioactive decay and modeling, microscopic and macroscopic cross-sections, mean free path
• Fission energy balance, prompt and delayed neutron emission, fission products.
• Neutron energy domains and associated characteristics. The four factors formula, neutron leakage.
• Diffusion approximation. Fick’s law.
• One group diffusion theory, the homogeneous bare reactor.
• Resonance neutron absorption, probability to escape, self-shielding and effective cross section.
• Thermalisation equation, behaviour of the real spectrum.
• Multiplication factor, reactivity, prompt and delay neutrons, kinetics, Nordheim’s equation.
• Temperature and poisoning effects, Xenon and Samarium effect, spatial instability.
• Fuel evolution, fluency, burn-up.
• Fissile and fertile nuclei, conversion factor.
• Core management with partial reloading. Plutonium recycling.
• Multigroup theory.</td></tr>
<tr><td rowspan="3">Unit 2 – Advanced models and application to reactors
(28 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Evaluating phenomena under normal or accidental operation by their modelling</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
</table>

• Neutron transport equation, multigroup theory.
• Monte Carlo methods.
• Calculation scheme with deterministic codes.
• Reactor control and power distribution control.
• Reactivity accident.
• Comparisons of PWR, VVER, BWR and research reactors.
• Hands-on sessions:
  ○ On the ISIS training reactor
  ○ On a PWR simulator
• Laboratory sessions:
  ○ Calculation with a deterministic code
  ○ Calculation with a Monte-Carlo code
	• Take into account the main characteristics of a given water reactor technology
	• Design, in a detailed way, Light Water Reactors from a neutron physics point of view
	• Connect reactor physics to the operation of a Light Water Reactor
	• Analyse in detailed the reactivity control safety function of a Light Water Reactor
	• Calculate reactor core characteristics
		• Approach to criticality, reactor start-up, divergence, doubling time, delayed neutron influence, reactivity control, load follow.
		• Neutron transport equation
		• Integral and integral-differential forms– principles of the deterministic and probabilistic methods.
		• Multigroup theory
		• Notions on the treatment of nuclear data – solving in two steps, assembly and core calculations – principle of the multi cell assembly calculation.
		• Cell calculation using the deterministic code APOLLO
		• Criticality calculation using the Monte Carlo code TRIPOLI
		• Functional description of VVERs, PWRs and BWRs
		• Safety constraints, the three barriers, operation at constant nominal power, load follow.
		• Temperature and power effects, Xe and Sm concentration, soluble boron, rod cluster control assemblies (RCCA).
		• Power distribution control.

Course applicable (in part) for the following job profiles:

- 1.0.01: Nuclear Safety Manager
- 1.0.02: Safety Assessment Specialist
- 1.0.10: Safety Design Engineer
- 1.2.01: Design Manager
- 1.2.09. System Design Engineer
- 2.1.06. Engineering Manager
- 2.1.07. Operation Manager
- 2.1.04. Training Officer
- 2.2.01. Shift Engineer
- 2.2.02. Senior Reactor Operator/CRO
- 2.6.01. Safety and Security Manager
- 2.8.07. Reactor Physicist

<table>
<tr><td colspan="3">Course on “Thermal-hydraulics of light water reactors”
D. Bestion, J. Garnier, P. Dumaz, O. Grégoire, and others (CEA)</td></tr>
<tr><td>Units and LO Statements</td><td></td><td></td></tr>
<tr><td rowspan="3">Unit 1 – Basic thermal-hydraulics module (24 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Understanding the general aspects of Thermal-Hydraulics</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• General background
o General background on fluids.
o Equation of State and fluid properties.
o Viscosity and stress tensor.
o Particular case of water as a coolant and a working fluid. Comparison with other fluids.
• Thermodynamics
o Background on first and second principle of thermodynamics.
o Energy conversion in Light Water Reactors.
o Principle of the Rankine cycle.
o Rankine cycle efficiency and improvements.
• Fuel thermal analysis
o Physical properties of fuel material.
o Heat conduction equations.
o Steady-state solution in rod and plate geometry.
o Gap conductance under operating conditions.
o Design of fuel.
• Single-phase flow
o Principle of transport equation using Gauss and Leibniz theorems.
o Derivation and integral of mass, momentum and energy transport equations.
o Laminar and turbulent flow regimes.
o Time average equations for turbulent flows and specific closure.
o Classical solutions for laminar flow.
o One-dimensional flow modelling. Heat transfer and wall friction.
• Two-phase flow
o Introduction to two-phase flow.
o Definition of two-phase parameters.
o Review of two-phase models.
o Derivation of transport equations.
o Relationships between velocities, void fraction and qualities.</td><td>• Ask equation for single-phase flows
• Simplifiy hydraulic model to solve it
• Solve analytical simplified equations
• Ask heat transfer equation for fuel rod
• Solve it
• Understand main parameters of the water coolant
• Design the preliminary thermal-hydraulic behaviour of a component
• Have in mind the two-phase flow general characteristics for reactor design</td><td>• Equation of State.
• Fluid properties (Compressibility, surface tension).
• Viscosity and stress tensor.
• Water properties.
• Thermodynamics of the power conversion system.
• Efficiency of a NPP.
• Oxide Fuel material thermal properties and conductivity integral.
• Equations for the conduction of heat.
• Analytical solutions of the heat equation.
• Fluid transport equation.
• Flow regimes.
• Time average simplified equations for turbulent and laminar single-phase flows.
• Existing two-phase flow models.
• Critical heat flux.</td></tr>
</table>

○ Boiling heat transfer: from nucleate boiling to Critical Heat Flux. ○ Two-phase pressure drops.		
Unit 2 – Advanced Thermal-hydraulics module (29 hours)	**Responsibility / Autonomy**	
	Mastering specific models and issues for Light Water Reactors	
	Skills	**Knowledge**
• Introduction to LWR design ○ General principles on reactor safety and performances. ○ Overview of PWR, BWR and VVER. ○ Specific issues for thermal hydraulic design under operating conditions. ○ Examples of modeling issues in Design Basis Accidents. • Main limiting phenomena ○ Flow instabilities in reactors. ○ Static instabilities. ○ Analysis of dynamic instabilities. ○ Boiling crisis in fuel assemblies. ○ Critical Heat Flux prediction. • Multi-scale modeling ○ Introduction to multi-scale modeling. ○ Multi-scale analysis of boiling flow: different existing numerical methods. ○ Specific models for system. ○ Advanced models for system codes. Limit and improvements of the two-fluid model. ○ CMFD models and closure laws for boiling flow. ○ DNB and dryout investigation using CMFD. • Numerical methods and physical validation ○ Numerical analysis of Navier-Stokes two-fluid equations. ○ Required properties of numerical schemes. ○ Numerical methods for DNS. ○ Numerical models for averaged models. ○ Instrumentation and experimental analysis. ○ Examples of validation programs.	• Ask equation for two-phase flows • Simplify thermal hydraulic model to solve it • Understand main parameters of the boiling water coolant • Design the preliminary thermal-hydraulic behaviour of a component • Take into account two-phase flow general characteristics for reactor design • Propose the best numerical solving method. • Define a validation program for two-phase flow problems.	• Static and dynamic flow instabilities. • Ledinegg criterion. • Critical heat flux modelling. • Classical correlations and corrections for reactor conditions. • Different scales in two-phase flow. • Main existing numerical methods to solve a boiling flow: ○ Numerical Simulation and pseudo-DNS. ○ Large Eddy Simulation. ○ Interface Tracking Method. ○ Reynolds-Averaged Navier Stokes simulations • Range of validity of the methods • Governing equations of a two-fluid model. • Specific models for a system code. ○ Break flow and choked flow, ○ Stratification and Kelvin-Helmoltz instability, ○ Counter-Current Flow Limitation, ○ Condensation, ○ Pumps… • Limit of the two-fluid model. Possible improvements: two-phase turbulence, interfacial area, multi-field. • Closure laws for boiling flow: wall transfer, interfacial transfer, polydispersity effect in bubbly flow. • General knowledge on numerical methods. ○ Pressure-based versus Riemann solvers. • Existing instrumentation for two-phase flow.

Course applicable (in part) for the following job profiles:

- 1.0.01: Nuclear Safety Manager
- 1.0.02: Safety Assessment Specialist
- 1.0.10: Safety Design Engineer

- 1.2.01: Design Manager
- 1.2.05. Mechanical Design Engineer
- 1.2.09. System Design Engineer
- 2.1.06. Engineering Manager
- 2.1.07. Operation Manager
- 2.1.04. Training Officer
- 2.2.01. Shift Engineer
- 2.2.02. Senior Reactor Operator/CRO
- 2.6.01. Safety and Security Manager
- 2.8.01. Mechanical Design Engineer

3.10 COURSES BY UPM

(…)

3.11 COURSES BY CIRTEN

Content and Minimum Learning Outcomes for the Course of Single- and Two Phase Thermal-hydraulics

W. Ambrosini

Course on “Single and Two-Phase Thermal-hydraulics”		
Units and LO Statements		
Unit 1 – Fluids and Balance Equations (5 hours)	**Responsibility / Autonomy**	
	Autonomous use of thermal fluid-dynamics principles and balance equations (EQF=7)	
	Skills	**Knowledge**

• Basic Concepts about Fluids
• Fluid Models and Flow Regimes (single-phase)
• Balance Equations for Single-Phase Fluids
    ○ General Concepts
    ○ Useful Mathematical Relationships
    ○ Level of Detail in Balance Equations
    ○ Integral Lumped Parameter Equations
    ○ Partial Differential Balance Equations
    ○ Need for Closure Laws
	• Being able to characterise the state of a fluid on the basis of commonly used thermodynamic diagrams
	• Critical capability to select an appropriate flow model considering the intended application
	• Ability to apply the Gibbs rule for determining the number of independent variables for a fluid in conditions of interest for nuclear reactors
	• Ability to relate the basic laws of physics to the balance equations adopted in thermal fluid-dynamics
	• Ability to convert surface integrals of advection and diffusion terms in balance equations to volume integrals
	• Ability to write balance equations in Eulerian and Lagrangian form
	• Capability to clearly explain the origin of the enthalpy function
	• Ability to write and apply lumped parameter balance equations to simple systems (filling a volume of water, heat exchanger, forces on a pipe bend)
	• Ability to retrieve the mass, momentum and energy equations from the general formulation of partial differential balance equations
		• Definitions and practical characterisation of fluids
		• Distinction among the ranges of existence of vapour and gases, liquids and solids
		• Reminder of p-T and p-v diagrams for a single component substance
		• Distinction between the different fluid models adopted in thermal-hydraulics
		• Understanding the characteristics and limitations of different fluid models (e.g., compressible vs., incompressible flows; viscous vs. inviscid fluids, etc.)
		• Understanding the usefulness of the Boussinesq fluids approximation
		• Extensive and intensive properties
		• Concept of equilibrium
		• Gibbs rule for variance determination
		• General concept of balance and its applications in fluid-dynamics
		• Eulerian and Lagrangian points of view for writing integral and differential equations
		• Divergence theorem and of the Leibniz rule in deriving balance equations
		• Understanding the relation between Eulerian and Lagrangian forms of balance equations

	• Ability to deal easily with differential operators (divergence and gradients of constant, vectors and tensors) • Ability to retrieve from the general forms of balance equations the cases applicable to particular conditions; e.g.: continuity for an incompressible fluid; momentum for a fluid static condition; etc. • Capability to derive the mechanical energy balance equation from momentum equation • Capability to apply the Bernoulli equation for inviscid and incompressible fluids to typical practical situations: variable area ducts, Venturi nozzle, Pitot tube, Torricelli theorem case • Capability to show the relation of the thermal energy equation in Lagrangian form to the 1st Principle of Thermo-dynamics • General skills in applying balance equations in their different forms: no “fear” of mathematics • Mastering the mathematical tools for balance equations and being able to apply them in particular cases of practical interest • Capability to identify independent variables in balance equations, variables defined by the use of state relationships, variables needed constitutive laws	• Integral and differential balance equations: control volumes, control masses, points and particles • Knowledge of lumped parameter equations for mass, energy and momentum in Eulerian and Lagrangian form and of their differences • Understanding the role of enthalpy in the advection terms in energy equation • Understanding the derivation and the general form of partial differential balance equations for a generic extensive property • Bernoulli equation for inviscid fluid • Understanding the role of Bernoulli in generating lift over an airfoil and in spinning bodies • Knowing the difference between the Bernoulli equation and the generalised Bernoulli equation, also for compressible fluids • Knowing and understanding the energy equation terms and its forms: total energy and thermal energy • Understanding the need for state relationships and closure laws in balance equations for single phase fluids
Unit 2 – Laminar Flow, Navier-Stokes Equations and Boundary Layer Phenomena ***(5 hours)***	**Responsibility / Autonomy**	
	Autonomous use of thermal fluid-dynamics models for laminar flow conditions(EQF=7)	
	Skills	**Knowledge**
• Basic Concepts about Laminar Flow • Newtonian and Non-Newtonian Fluids • Short Overview on Non-Newtonian Fluids • Laminar Flow of Newtonian Fluids	• Ability to use the convention for the definition of the shear stress on a surface orthogonal to an axis directed in the direction of another axis • Ability to calculate a shear stress at the wall for different fluids given the velocity distribution	• Understanding at a basic level the difference between turbulent and laminar flow, Newtonian and non-Newtonian fluids • Understanding the role of viscosity in the Newton’s law for shear stress and the role of shear stress components as a the negative of momentum fluxes

• Navier-Stokes Equations • Dimensional Analysis of Navier-Stokes Equations • Typical Applications of Navier-Stokes Equations • Few Concepts about Rotational and Irrotational Flows • Boundary Layer Phenomena and Equations	• Remembering the order of magnitude of viscosity for most important fluids (water, gases, etc.) • Capability to write the components of the tensors of rotation and deformation rates • Being able to write the constitutive law for shear stress for Newtonian fluids in laminar flow • Ability to write the Navier-Stokes equations and to explain the meaning of each term appearing in them • Ability to discuss the appropriate boundary conditions to be applied to the Navier-Stokes equations and to the Euler equations • Practical ability in making dimensionless the momentum balance equations to obtain dimensionless parameters • Ability to solve classical problems related to laminar flow: smooth falling film and Poiseuille flow in a circular duct • Ability to relate the Darcy-Weisbach and the Fanning friction factors on the basis of a force balance on the fluid in a circular pipe • Ability to make use of the practical relationships for evaluating from drag and lift on typical bodies exposed to a free stream • Ability to write the momentum equations for the 2D "boundary layer" approximation, explaining the approximations made to reach the related form	• Analogy between the kinematic viscosity and the thermal diffusivity • Understanding the trends of viscosity with temperature for liquid and gases • Knowing the behaviour of the main non-Newtonian fluid models • Understanding the mathematical expressions for expansion and shrinking, rotation and deformation rates of a fluid element • General constitutive law for the deviatoric stressing a fluid (general Newton's law of viscosity) • Knowledge and understanding of the development leading from momentum equation to the Navier-Stokes equations for laminar flow of a Newtonian fluid at constant density and viscosity • Knowledge and understanding of the Euler equations • Knowledge and understanding of the dimensionless parameters appearing in the dimensionless form of the Navier-Stokes equations and of the limit cases for large Re, Fr, etc.. • Clear understanding of the d'Alembert paradox • Knowledge of the definition of "boundary layer" • Clear understanding of the proposal of Prandtl about the partitioning of the flow into the two regions of boundary layer and the free stream • Knowledge of the consequences of the Poiseuille-Hagen law • Knowledge and understanding of the practical usefulness of the Darcy-Weisbach relationship and of the related friction factor • Understanding the role of the reciprocal of the Re appearing in the Poiseuille law for laminar flow, in view of the Darcy-Weisbach relationship

		• Understanding and remembering the difference between Darcy-Weisbach and the Fanning friction factors • Knowledge of the definition of the “hydraulic diameter” and understanding of its practical usefulness • Knowledge of basic concepts about rotational and irrotational flows: vorticity, circulation, rigid body rotation, potential vortex, vorticity in the Couette flow, Kelvin theorem; understanding of their general meaning • Knowledge of the structure of a fluid-dynamic boundary layer in laminar and turbulent conditions • Understanding of the “favourable” and “adverse” pressure gradient conditions • Knowledge and understanding (K&U) of wake phenomena with and without separation • K&U of the pressure distribution over a bluff body assuming boundary layer separation: reminder of the d’Alembert paradox • K&U of boundary layer transition phenomena at the entrance of a pipe in laminar and turbulent flows • K&U of the approximations leading from the Navier-Stokes equations to their “boundary layer” approximation • General understanding of the methodology adopted by Blasius for reaching the solution of the boundary layer equations in the case of zero pressure gradient, with main reference to: a) self-similarity of the solution; b) definition of the stream function; c) generality of the reached solution for a laminar boundary layer on a flat plate; d) consequences of the characteristics of the numerically determined profile on the evaluation of the shear stress at the wall

<table>
<tr><td rowspan="3">Unit 3 – Heat Transfer in Laminar Flow (4 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomous use of thermal fluid-dynamics models for laminar flow conditions(EQF=7)</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Few Basic Remarks on Heat Transfer Mechanisms
• Thermal Energy Balance in Terms of Temperature
• Heat Transfer Problems in Laminar Flow
  ○ Thermal Boundary Layer over a Flat Plate
  ○ Heat transfer in a circular pipe with laminar flow</td><td>• Remembering the order of magnitude of thermal conductivity for several materials adopted in technical applications
• Remembering the order of magnitude of convective heat transfer coefficients in typical conditions
• Ability to make use of current textbooks and manuals on heat transfer to select the appropriate correlation for forced or free convection, external or internal flow
• Ability to write the different forms of the energy balance equations in terms of temperature
• Ability to relate the Blasius solution for the velocity distribution in a boundary layer to the corresponding solution for the thermal boundary layer in the case of Pr=1 and in the case of Pr ≠ 1
• Remembering the order of magnitude of the heat transfer coefficient in a laminar flow in a circular pipe, also considering the different boundary conditions
• Ability to select from heat transfer textbooks the appropriate thermal entry length correlations</td><td>• Knowledge of the basic laws of heat conduction
• Understanding the problem of the transient behaviour of a flat plate with convective boundary conditions on the two surfaces
• Dimensional analysis of the above problem
• Knowledge and understanding of the main dimensionless parameters appearing in the dimensionless form of the above problem
• Knowledge of the basic laws of heat convection
• Meanings of the Nusselt number
• Knowledge and understanding of the meaning of the main dimensionless parameters appearing in correlations for heat transfer in forced and free convection: Re, Gr, Pr, Gr/Re^2
• General K&U of the main phenomena and relationship to be considered in heat radiation problems: coefficients of emissivity, absorption and transmission; Boltzmann’s constant and the basic law of radiation; grey bodies; view factors; radiosity
• Understanding the root of the different forms of thermal energy balance equation written in terms of temperature
• Understanding the role of viscous dissipation of heat (e.g., in the warming up of a reactor plant by pumps)
• K&U of the dimensionless numbers appearing in the dimensionless form of the energy balance equation (Pe, Br)
• K&U of the limit forms of the energy balance equation for a still fluid or a solid (the “heat equation”)</td></tr>
</table>

<table>
<tr><td></td><td></td><td><u>Clear understanding</u> of the basis of the analogy between heat and momentum transfer considering the related energy and momentum equations in boundary layer form
Understanding the role of the Stanton number
Understanding the developments leading to the evaluation of the convective heat transfer coefficient in laminar flow in a circular pipe
K&U of the effects of flow and thermal development at the entrance of a pipe on heat transfer: Graetz number and thermal and combined entry length problems</td></tr>
<tr><td rowspan="3">Unit 4 – Momentum and Heat Transfer in Turbulent Flow (5 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomous use of thermal fluid-dynamics models for turbulent flow conditions (EQF=7)</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>General Remarks on Turbulent Flow
Statistical Treatment of Turbulent Flow
Momentum Transfer in Turbulent Flow
Eddy Viscosity
Velocity distribution in turbulent flow
Distributed Pressure Drops and Friction Factors in Turbulent Flow
Singular Pressure Drops
Few remarks on Pump Characteristics
Heat Transfer in Turbulent Flow
Eddy Diffusivity
Reynolds Analogy for Flow on a Flat Plate
Heat Transfer in Ducts with Forced Convection</td><td>With the aid of the Van Dyke photographic textbook, clarify your understanding of the transition to turbulence in different conditions
Capability to distinguish between turbulence intensity and turbulence kinetic energy and to write the related definitions
Capability to write the general balance equation for a given extensive property in time-averaged form, clearly identifying the meaning of each term
Capability to explain the classical trends of turbulence intensity and turbulent and viscous shear stresses with the distance from a wall
Remembering the classical definitions of w+ and y+ quite often adopted in turbulence
Capability to draw a qualitative sketch of the radial distribution of velocity in a pipe in laminar and turbulent conditions
Capability to draw the Moody diagram explaining all its relevant features
Remembering the order of magnitude of friction factor in typical turbulent flow conditions ($2\text{-}3\times10^{-2}$)</td><td>Understanding the origin of instabilities leading to turbulence in different fluid systems (flat plate, pipes, jets, wakes from bluff bodies)
Clear understanding of the basics and the purposes of the statistical treatment of turbulence flow by Reynolds
K&U of the classical process of writing balance equations in terms of time averaged variables and of the change of perspective in considering <u>the residual terms coming from advection as diffusion due to turbulence</u>
K&U of the concepts of eddy viscosity and eddy diffusivity as used in the Boussinesq assumption and in the treatment of turbulent heat flux
Knowledge of classical algebraic models for taking into account eddy viscosity
K&U of the arguments at the basis of the derivation of the classical universal profile of velocity in a turbulent boundary layer
Clear K&U of the following aspects:
trend of frictional pressure drop as a function of velocity in a smooth pipe for turbulent and laminar flow</td></tr>
</table>

○ Remarks on Heat Transfer in Free Convection	• Remembering the order of magnitude of pipe roughness [m] for different pipe materials • Capability to identify the most important singular pressure drops occurring in a series of pipes on the basis of the gallery presented in the lecture notes and available in the suggested textbooks • Capability to select the appropriate singular pressure drop coefficients for the different irregularities present in a pipe on the basis of suggested textbooks • Ability to discriminate among the different types of valves in terms of their pressure drops • Ability to calculate the hydraulic diameter for different pipe cross sections and to make use of it in correlations • Ability to evaluate the required pump power on the basis of the delivered head and of flow rate; ability to determine the required motor power • Remembering the classical heat transfer correlations for forced flow in single-phase conditions • Ability to recognise and adopt the classical corrections for heat transfer accounting for entrance effects • Ability to clearly explain the use of the "Boussinesq fluid" assumption in free convection problems (why constant density almost everywhere, except for the evaluation of buoyancy effects?) • Being able to select the most appropriate free convection heat transfer correlation for a given situation using handbooks.	○ detailed features of the Moody diagram for friction factor ○ approximate laws for friction factors in turbulent flow in smooth pipes (Blasius and McAdams) • Knowledge of the existence of several numerical approximation of the Moody diagram (Colebrook, Swamee & Jain, Churchill) • K&U of the reasons leading to singular pressure drops on the basis of the phenomena leading to kinetic energy dissipation (separation of boundary layer, vena contracta, recirculations in bends, etc.) • K&U of the main working characteristics of a pump: determination of the working point, meaning of NPSH (requested and available, control of flow by "downstream" valve throttling) • K&U of the relationship leading to evaluate turbulent heat flux on the basis of thermal eddy diffusivity • K&U of the Reynolds and Colburn analogies for heat and momentum transfer and of its consequences in deriving forced flow heat transfer correlations • K&U of the entrance effects in turbulent flow and of the different approaches • K&U of the general principles at the basis of the treatment of free convection flows
Unit 5a – Natural Circulation in Single-Phase Flow (2 hours)	**Responsibility / Autonomy**	
	Autonomous use of thermal fluid-dynamics models for predicting natural circulation (EQF=7)	
	Skills	**Knowledge**
• Balance Equations for One-Dimensional Single-Phase Flow • Single-Phase Natural Circulation • Application	• Ability to apply momentum and energy balance equations for a simple natural circulation loop to calculate the steady state flow rate	• Knowledge of the importance of natural circulation in industry, with reference to nuclear reactor applications • Understanding the process of obtaining balance equation for natural circulation of a Boussinesq fluid

<table>
<tr><td>• Single-Phase instabilities: strange but true!</td><td>• Ability to calculate the steady state natural circulation flow rate in a simple loop given the heating power, the characteristics of the fluid and the geometry of the loop</td><td>• Understanding the role of buoyancy and friction in determining the steady state flow rate in a natural circulation loop
• General knowledge of the problems involved in the occurrence of unstable behaviour in single phase natural circulation loop</td></tr>
<tr><td rowspan="3">Unit 5b – Notes on Compressible Single-Phase Flow
(3 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomous use of models for compressible flows (EQF=7)</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• General Considerations
• Sound Speed
• The Hugoniot relationship
• Critical Flow in a convergent duct
• The de Laval nozzle</td><td>• Ability to calculate the sound speed for an ideal gas
• Ability to apply the relationship for calculating the critical flow of an ideal gas given its upstream conditions
• Capability to explain the main features of the pressure and velocity distributions in a de Laval nozzle.</td><td>• Definition of compressibility and its relation to the sound speed
• Definition of sound speed and understanding of its derivation
• Understanding the effect that a finite sound speed introduce in the propagation of information in a flowing fluid: 1D and multi-d cases
• Knowledge of the Hugoniot relationship and understanding of its consequence for converging-diverging ducts with compressible flows
• Understanding the reasons for the establishment of critical flow in a converging pipe</td></tr>
<tr><td rowspan="3">Unit 5c – More on Turbulence (
(4 hours)</td><td colspan="2">Responsibility / Autonomy</td></tr>
<tr><td colspan="2">Autonomous use of turbulence models (EQF=7)</td></tr>
<tr><td>Skills</td><td>Knowledge</td></tr>
<tr><td>• Length Scales in Turbulence
• Direct Numerical Simulation
• Large Eddy Simulation
• Reynolds Averaged Navier-Stokes Equations
• Algebraic Models
• One-Equation Models
• Two-Equation Models</td><td>• Ability to schematically draw the spectrum of turbulent energy distribution, explaining its relevant features
• Ability to clearly explain the differences between the DNS, LES and RANS techniques making reference to the energy cascade and to the spectrum of turbulent kinetic energy
• Ability to recognise in the equations for the turbulence stresses and turbulence kinetic energy the transient, advective, diffusive and source-sink terms</td><td>• Understanding the concept of energy cascade and the role of dissipation of turbulent kinetic energy
• Understanding the meaning of the Kolmogorov scales of turbulence
• Understanding the reasons why the turbulence phenomenon can be studied in the assumption of the fluid as a continuum
• Understanding of the main features of DNS techniques in relation to the energy cascade</td></tr>
</table>

• Considerations on meshing at the wall: wall functions and low y+ refinement	• Ability to write in a basic form the transport equation for turbulence kinetic energy • Capability to write and describe the main features of the transport equations of two-equation turbulence models • Discriminating the need for using wall function or low-Reynolds approaches at the walls	• Understanding the main features of LES techniques and their differences with respect to DNS, on one side, and RANS, on the other • Understanding the role of spatial "filtering" in LES and of the need for subgrid scale models • Understanding the role of time averaging in RANS models and the different levels of closure (zero, one and two equations) • K&U of the mixing length model as a representative of the class of algebraic models • Understanding the need for transport equations to track the effects of turbulence in space and time • Understanding the process necessary to derive transport equations for the components of the specific Reynolds stress tensor and for turbulence kinetic energy • Understanding the need for closures in one-equation models and the issue of their incompleteness • Understanding the link between the calculation of k, ε and turbulent viscosity • Understanding the need for two equation models for achieving some degree of completeness in turbulence modelling • K&U of the form of k-ε and k-ω transport equations • Understanding the difference between the use of "wall functions" and the adoption of low-Reynolds number models
Unit 6 – Two-Phase Flow: General Definitions, Flow Regime Maps and Balance Equations (9 hours)	**Responsibility / Autonomy**	
	Autonomous use of two-phase flow balance equations (EQF=7)	
	Skills	**Knowledge**
• General Definitions • Flow Regimes ○ Main Observed Phenomena ○ Flow Regime Maps	• Ability to relate basic characteristic two-phase variables with each other in combinations useful for writing correlations	• Knowledge of the main variable useful for characterising two phase flow • Knowledge of the relation between void fraction, dynamic quality and slip ratio

○ Flow Regime Transition Criteria • Balance Equations for Two-Phase Flow ○ General Remarks ○ One-Dimensional Homogeneous Equilibrium Model ○ One-Dimensional Two-Fluid Model ○ Remarks on Balance Equations for Two-Phase Flow ○ Semi-empirical Approaches for Mixture Models ○ Mathematical Character of Balance Equations for Two-Phase Flow	• Capability to use flow regime maps and phase transition criteria to approximately establish the existence of a flow regime • Capability to write and explain the main differential ans source terms in two-phase flow balance equations with different levels of approximation • Capability to apply void-quality relationship to evaluate void fraction by the drift-flux model	• Flow regimes in vertical adiabatic and heated ducts • Heat transfer and flow regimes in a vertical boiling pipe • Flow regimes in horizontal flow • Flow regime maps and their use: flow regime transition criteria • Flow regime maps as implemented in system codes • Form of the one-dimensional Homogeneous Equilibrium two-phase balance equations and their derivation • One dimensional two-fluid model equations and their derivation form first conservation principles • Usual form of the balance equations for two-phase flow with thermal and mechanical non-equilibrium: main assumptions underlying their derivation • Drift flux model in the Zuber-Findlay and Wallis forms • Mathematical character of two-phase flow equations and ill-posedness of some two-fluid models
Unit 7 – Pressure Drops and Heat Transfer in Two-Phase Flow (10 hours)	**Responsibility / Autonomy**	
	Autonomous use of models for pressure drop and heat transfer in two-phase flow (EQF=7)	
	Skills	**Knowledge**
• Pressure Drops in Two-Phase Flow ○ General Definitions ○ The Homogeneous Equilibrium model ○ The Lockhart and Martinelli Model ○ The Martinelli-Nelson Model ○ Other Models ○ Codes and Two-Phase Pressure Drops • Boiling Heat Transfer ○ Conditions for the Occurrence of Boiling	• Capability to apply the two-phase flow multipliers to evaluate pressure drops: use of classical diagrams for relevant parameters • Capability to identify in the relevant literature and apply the appropriate heat transfer correlations according to an identified boiling heat transfer regime • Mastery of concepts and definitions of relevant parameters entering correlations for heat transfer in boiling conditions • Explaining the mechanisms of decrease of condensation heat transfer efficiency in the presence of noncondensable gases	• Two-phase flow multipliers for two-phase pressure drops in the different existing forms • Understanding how the two-phase flow multiplier approach (mixture model) may be applied in two-fluids models (separated flow models) • Mechanical equilibrium between pressure and surface tension in a bubble and its consequence for liquid superheating at boiling inception • Phenomena in pool boiling and the Nukiyama curve • Correlation for pool boiling and its incipience in the various regions of the Nukiyama curve • Phenomenological description of the boiling crisis (CHF, DNB, dry-out) in pool and flow boiling • Definitions of DNBR, MCHFR and MCPR

<table>
<tr>
<td>

<li style="list-style-type:circle">Phenomenological Description of Pool Boiling
<li style="list-style-type:circle">Quantitative Evaluation of Pool Boiling Phenomena
<li style="list-style-type:circle">Phenomenological Description of Flow Boiling
<li style="list-style-type:circle">Quantitative Evaluation of Flow Boiling Phenomena

Condensation

General Remarks
Filmwise Condensation
Effect of Noncondensable Gases
The analogy between Heat and Mass Transfer
Superposition of latent and convective heat transfer during condensation
Two-Phase Heat Transfer in Codes

</td>
<td>

Explaining the applicability of the analogy between heat and mass transfer in condensation (and evaporation) conditions

</td>
<td>

Classical graphical representation of CHF and heat transfer phenomena in the plots of the collier “Boling and Condensation” textbook
Correlations for heat transfer in flow boiling
Approaches and correlations for DNB and dry-out in flow boiling: Tong F-factor critical quality-critical boiling length approaches
Filmwise condensation phenomena in the case of pure vapours: Nusselt theory
Effect of noncondensable gases on condensation, analogy between heat and mass transfer, Colburn-Hougen approach for superposing latent and sensible heat transfer during condensation
General knowledge of the treatment of heat transfer in system codes for thermal-hydraulic safety analyses

</td>
</tr>
<tr>
<td rowspan="3">Unit 8 – Some Specific Phenomena in Two-Phase Flow: Critical Flow, Flooding and Boiling Channel Instabilities
(5 hours)</td>
<td colspan="2">Responsibility / Autonomy</td>
</tr>
<tr>
<td colspan="2">Autonomous use of models for critical flow, flooding and boiling channel instabilities (EQF=7)</td>
</tr>
<tr>
<td>Skills</td>
<td>Knowledge</td>
</tr>
<tr>
<td>

Critical Flow

General Description of the Phenomenon
Importance of the Phenomenon for Nuclear Technology
Mathematical Explanation of the Phenomenon

</td>
<td>

Use of the characteristic lines to explain the existence of chocked flow
Describing the use of the “characteristic equation” to determine chocked flow conditions for a give two-phase flow model
Capability to discriminate between different chocked flow models for a given nuclear reactor application
Capability to explain the reasons for the occurrence of flooding and CCFL

</td>
<td>

Phenomenological and mathematical understanding of chocked flow
Two-phase, thermal equilibrium critical flow models: HEM, Fauske and Moody models
Non-equilibrium modelling of critical flow in two-phase conditions
Phenomenological description of flooding and CCFL phenomena in bare pipes and in nuclear fuel bundles
Wallis type interpretation of flooding and CCFL

</td>
</tr>
</table>

○ Reminder of Critical Flow for a Perfect Gas ○ Two-Phase Critical Flow Models • Flooding ○ Phenomenological Description ○ Quantitative Prediction • Boiling Channel Instabilities ○ Classification of Instabilities ○ Static Instabilities ○ Dynamic Instabilities ○ Tools for Predicting Boiling Instabilities	• Application of existing correlations for predicting flooding • Capability to explain the effect of different parameters in static and dynamic two-phase flow instabilities • Capability to show on a NPCH-NSUB plane the regions for different kinds of instabilities	• Wallis and Kutateladze dimensionless parameters for correlating flooding phenomena • Classification of two-phase flow instabilities into static and dynamic: different types of instabilities • Ledinegg instability and approximate justification of its occurrence • Density wave oscillation instabilities and their physical roots • Dimensionless parameters for the characterisation of two-phase flow instabilities • Parametric effects on the occurrence of density wave instabilities • Time-domain and frequency domain approaches for predicting instabilities • Instabilities in BWRs and "exclusion region" in the power-flow map of a boiling water reactor
Unit E1 – Basic Exercises on Heat Conduction (3 hours)	**Responsibility / Autonomy**	
	Autonomous use of quantitative evaluation techniques for predicting heat conduction (EQF=7)	
	Skills	**Knowledge**
• Transient heat conduction in a flat plate by numerical models • Steady-state heat conduction in a 2D domain by numerical models • Steady-state and transient temperature distribution in a nuclear fuel rod by manual calculations and numerical models	• Use of the MATLAB routine for transient heat conduction in a flat plate and critical discussion of the obtained results • Use of the MATLAB routine for steady state heat conduction in a 2D domain and critical discussion of the obtained results • Manual calculations of the steady state temperature distribution in a nuclear fuel rod of given geometry and properties and use of the MATLAB routine in transient conditions with critical analysis of the results; simulation and explanation of the effects of temperature redistribution in the presence of SCRAM and critical heat flux conditions	• Understanding a MATLAB routine for numerically calculating the transient temperature distribution in a flat plate with Dirichlet (1st kind) boundary conditions • Understanding a MATLAB routine for numerically calculating the steady state distribution of temperature in a rectangular 2D domain with assigned volumetric power, geometry and thermal properties • Understanding a MATLAB routine for numerically calculating the transient behaviour of a nuclear fuel rod and comparing the numerical equations with the classical manual solution for temperature drops in a nuclear fuel rod

Unit E2 – Examples of Application of Lumped Parameter Balance Equations (4 hours)	**Responsibility / Autonomy**	
	Autonomous use of quantitative evaluation techniques for predicting two-phase flow in large capacitances (EQF=7)	
	Skills	**Knowledge**
• Lumped parameter two-phase flow models	• Capability to apply the equations to pressurization and depressurization of the capacity because of inflow and outflow: critical discussion of the results: manual calculations and use of the FORTRAN program • Compare the capabilities of the equilibrium and non-equilibrium models in the application to nuclear reactor components (e.g., the pressurizer) • Describe the limitations of each model to treat non-equilibrium phenomena between the phases and in each phase • Ability to critically discuss simulated thermal hydraulic phenomena for the non-equilibrium two-phase flow capacity knowing the model and its limitations • Ability to calculate an approximation of the first pressure peak in a dry containment given the initial conditions and the mass and energy release	• Lumped parameter balance equations for a two-phase capacitance with thermal equilibrium between liquid and vapour • Understanding a FORTRAN program implementing the above balance equations • Lumped parameter balance equations for a two-phase capacitance with thermal non-equilibrium between liquid and vapour • Understand the plotted results of obtained by a non-equilibrium code model for different inflow and outflow cases • Approximations to perform hand calculations of the first pressure peak after a LOCA in a dry containment, knowing the initial mass and energy content in the primary system and other relevant information
Unit E3 – Basic Balances for LWRs (2 hours)	**Responsibility / Autonomy**	
	Autonomous use of simple quantitative evaluation techniques for LWR analysis (EQF=7)	
	Skills	**Knowledge**
• Basic mass and energy balances in PWRs • Basic mass and energy balances in BWRs and Steam Generators	• Capability to perform simple single-phase fluid hand calculations along a the subchannel of a PWR core with usual simplifying assumptions. Calculation of core flow rate given the thermal power and the typical temperature difference across the reactor core • Capability to apply the simple mass and energy balances in a BWR vessel to calculate the main parameters	• Basic equations to evaluate the coolant temperature distribution along a PWR subchannel estimating the temperatures in the fuel centreline and at the clad surface • Basic energy balances in a BWR core (or in a Steam Generator) for analysing core, recirculation and steam line flows
Unit E4 – Basic Applications of CFD Codes (4 hours)	**Responsibility / Autonomy**	
	Critical interpretation of the results of a CFD code (EQF=7)	
	Skills	**Knowledge**

• Flow in circular pipes • Flow in a reactor vessel • Condensation in the presence of noncondensable gases • Heat transfer to water at supercritical pressure	• Application of a CFD code to laminar and turbulent Poiseuillle incompressible flow in a circular pipe (model already available) • Application of a CFD code in evaluating the flow patterns in a downcomer + lower plenum system (model already available) • Application of a CFD code to condensation in the presence of noncondensable gases in a square channel cooled on one side (model already available) • Application of a CFD code to heat transfer to supercritical pressure water (model already available)	• Radial velocity profiles of a fluid within a circular pipe in laminar and turbulent incompressible flow • Flow patterns in a simplified downcomer+lower plenum model • Modelling condensation rates over a flat plate (CONAN Facility installed at UniPi) • Heat transfer to supercritical pressure water in a circular pipe in mixed convection: deteriorated heat transfer phenomena and effect of gravity
Unit E5 – Basic Applications of the RELAP5 Code ***(3 hours)***	**Responsibility / Autonomy** Critical interpretation of the results of a system code (EQF=7)	
	Skills	**Knowledge**
• Essential summary on balance equation discretisation by the RELAP5 code • Boiling channel stability • Natural and gas-injection enhanced circulation in a loop	• Application of the RELAP5 code to predict unstable behaviour in a 1D heated, two-phase flow duct • Application of the RELAP5 code to predict natural and gas-injection enhanced natural circulation in a loop	• Basics about numerical discretisation by a staggered mesh method: nodes and junctions • Instability phenomena in a BWR single-boiling channel with imposed pressure drop • Natural and gas-injection enhanced circulation phenomena in an experimental loop (ANGIE Facility at UniPi)
Assessment criteria = to demonstrate mastery of basic thermal-hydraulic phenomena and simulation techniques for nuclear reactor applications		
Recommended assessment methods: Written test and oral face to face interview		

Course applicable (in part or fully) for the following job profiles:

Nuclear Experts (16% in EHRO-N analysis) and "Nuclearised" Experts:

1.0.02 Safety Assessment Specialist

1.0.10. Safety Design Engineer

1.2.01. Design Manager

1.2.12. HVAC Design Engineer

2.0.01. Plant Manager

2.1.06. Engineering Manager

2.1.07. Operation Manager

2.1.02. Licensing Officer

2.1.04. Training Officer

2.5.01. Chemistry Manager

2.6.01. Safety and Security Manager

The course is also applicable to the basic education of **future researchers, University teachers and Industry trainers** in nuclear reactor thermal-hydraulics

3.11 IN KIND FULL PROGRAMMES OFFERED FOR ANNETTE

As already mentioned, the availability for ANNETTE of basic course programmes with a renowned tradition of teaching within ENEN is functional to allow some learner pick a number of the available courses to establish his/her educational path starting from different levels. In addition to the ANNETTE Courses specifically set up for Continuous Professional Development (CPD), these courses, that have partly a CPD nature, will in fact allow to complete specific educational paths.

The following programs by the **AREVA NUCLEAR PROFESSIONAL SCHOOL** are offered at 1/3 of the prize for ANNETTE attendees:

1) Flow modelling in Fuel Assemblies
2) Monte Carlo criticality and shielding calculations (http://www.anps.kit.edu/307.php)
3) Reactor physics calculations with deterministic methods (http://www.anps.kit.edu/309.php)
4) Beyond-design accidents, core-melt accidents (http://www.anps.kit.edu/311.php)
5) Coupled Neutron Kinetics /Thermal Hydraulic Codes for Safety Assessment of Nuclear Power Plants (http://www.anps.kit.edu/313.php)
6) Thermohydraulic Stability Analysis (http://www.anps.kit.edu/319.php)
7) Technology and Management of the Decommissioning of Nuclear Facilities (http://www.anps.kit.edu/321.php)
8) Containment thermohydraulics and hydrogen behavior
9) Stress Analysis (http://www.anps.kit.edu/327.php)
10) Light Water Reactor (LWR) core design and fuel management (http://www.anps.kit.edu/331.php)
11) Light Water Reactor (LWR) core feedback and transient response (http://www.anps.kit.edu/333.php)
12) Severe Accident Simulation in Liquid Metal Reactors (http://www.anps.kit.edu/293.php)

In addition, the **University of Central Lancashire** proposes under the umbrella of ANNETTE the courses of the Nuclear Safety, Security and Safeguards Master of Science (http://www.uclan.ac.uk/courses/msc_nuclear_safety_security_safeguards.php)

The **Belgian Nuclear Education Network (BNEN)** offers its courses, being part of a "Master after Master"(http://bnen.sckcen.be/en/Programme/Programme_overview) that was one of the programmes which inspired the paradigm of the European Master of Science in Nuclear Engineering award, released by ENEN.

ESARDA will also offer an existing course on safeguards, whose 2016 edition was organised as in Figure 2.

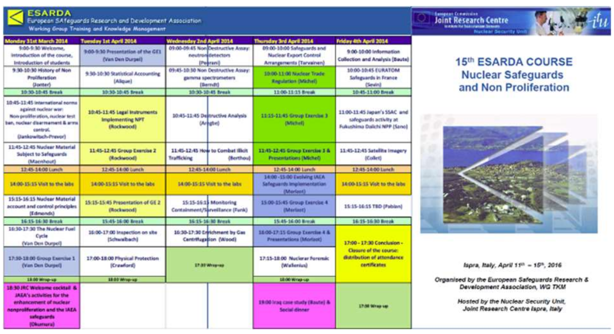


Figure 2. Leaflet of the ESARDA Course on Nuclear Safeguards for year 2016

The **Joint Research Centre** proposes to put into the ANNETTE loop its Summer School on Nuclear Decommissioning and Waste Management, whose leaflet from last year is reported the following Figure 3.

Figure 3. Leaflet of the JRC Course on Decommissioning from year 2016

3.12 IN KIND COURSES OFFERED BY STAKEHOLDERS

After the first interaction with Stakeholders, further proposals are being evaluated from:

- MELODI: radiation protection courses in the frame of the CONCERT project;
- EdF: possible offer of courses on nuclear materials;
- Fortum: courses on some areas like SMR licensing, nuclear licensing;
- Ansaldo Nucleare: suggested that industry may provide seminars on specific subjects: to be further explored;
- IAEA: suggesting the introduction of courses on Nuclear Energy Management, Nuclear Knowledge Management and more in general a Nuclear Management Academy;
- GENTLE: possibly making available some of its intersemester courses.

These contributions, which have in part to be confirmed, are being considered with the greatest interest for the following reasons:

- they may make real a network of connections that the win-win proposal of coordinating the ongoing nuclear E&T activities in Europe may trigger;
- they enlarge the capabilities of the first core of courses, to be delivered in 2018, waiting to establish at the end of the project a sustainable “advanced networking” (i.e., ANNETTE under ENEN);
- they provide longer term sustainability to European Fission Training Schemes (EFTS) produced in previous projects.

4. ANNETTE SUMMER SCHOOL

Aalto University will contribute the organisation of a Summer School on "Current and Future Challenges of Nuclear Power Production", to be held in its first edition in 2018. The Summer School will be organised by inviting renowned experts in the various nuclear fields.

At the Kick-off Meeting of ANNETTE (February 2016) the following possible characteristics of the summer school were proposed for discussion:

- possibility to put the course lectures (video?) online;
- three parallel tracks, 3 ECTS each;
- post-school web-based work (incl. online lectures): additional 2x3 ECTS also for school participants.

These details will need to be finalised in due time.

Other Participants already offered contributions for the Summer School during the Kick-off Meeting of ANNETTE, among which:

- **JRC-ITU:** Spent fuel and radioactive waste management (including legal basis, ethical aspects, the role of storage, establishing national programs);
- **UL**: two of the lectures proposed for the Master can be adapted to the summer school format; lectures for a larger audience can also be proposed, for instance about the treatment of uncertainty;
- **UCL**: SBL/LBL e.g. two phase choked flows with hands-on/case studies over an in-house software);
- **UMAN:** promised help with arranging or running the Summer School (TBD);
- **UPM:** they can adapt one or two of the lectures proposed for the master to the summer school format; lectures for a larger audience can also be proposed, for instance about nuclear safety culture.

Whatever the availabilities proposed at the Kick-off Meeting of ANNETTE, the lectures to be included in the Summer Course, in similarity with those of the Master Programme, will be specifically designed in order to propose an attractive and successful event, that may become also a teaser for the ANNETTE Master courses. An online delivery of the courses is planned.

At the time of writing this version of the report, a Committee has been already formed under Aalto University coordination, in order to set up the programme of the Summer School.

5. ROLE OF E-LEARNING AND MOOCs

The delivery of lectures in the form of e-learning, in its variety of forms (synchronous, asynchronous, blended e-learning, MOOCs, etc.) has been one of the means discussed with EC at the time of project approval in order to enhance its impact. Leaving after the end of the project a wake of e-learning courses (and MOOCs) under the aegis of ANNETTE is one of the objectives considered to have a high level priority within the project.

On one hand, it is clear that courses for Continuous Professional Development (CPD) have some parts of hands-on practices that are difficult to be performed in the distance. On the other hand, broadcasting or making available on the web at least the most pretty theoretical parts of the courses may function as an effective tool to attract students to the fascinating nuclear matters, stimulating a full enrolment also to the practical sessions.

During the Kick-off Meeting of ANNETTE, some of the participants already proposed their availability to cast their products in terms of e-learning. In particular:

- **ESARDA** proposed to prepare e-learning modules in the long term; a MOOC: Course “Introduction to Safeguards” (for students in Nuclear Engineering, Nuclear Energy, etc.) could be also prepared;
- **KIT (IFRT+INE+ANPS)** declared the possibility to deliver all the proposed courses in terms of e-learning, with the exception of the one on Computational fluid dynamics with OpenFOAM, for which it is impossible to deliver the learning outcomes in the distance;
- as said, the summer course of **AALTO** will be probably entirely broadcasted or made available on the web;
- **JRC-ITU** proposed the two courses (1) Nuclear fuel behaviour and characterisation (including severe accident conditions) (2) Back end of the nuclear fuel cycle in e-learning or MOOC format;
- **CVUT FNSPE** does not provide e-learning now, but could prepare online experiments at the VR-1 nuclear training reactor;
- **UL** suggested that both synchronous and asynchronous e-learning methods will be proposed for its courses;
- **HH-IFIN** stated that new e-learning ideas/tools could be developed for supporting understanding of Radiation Protection principles: examples of applications already in place were presented;
- **UCL** suggested the possibility to organise/implement the hands-on part related to the course “Leaks calculation during a LOCA” on the web via an interactive applet;
- **UMAN** communicated that the course N03 Radiation and Radiological Protection is available in eLearning format;
- **CIRTEN** proposed its courses in e-learning format (MOOC to be evaluated)**.**

Moreover, e-learning and MOOCs features were convincingly presented during the Kick-off Meeting in Pisa (February 2016) and at the special event organised on the subject before the General Assembly in Geel (March 2016). UNED and other specialists in the field presented the use that was being made at their institutions of IT for didactic purposes. These events and the support proposed by UNED to participants needing to get familiar with these techniques will certainly stimulate interest for the enhanced use of e-learning and MOOCs that was one of the promises of the Consortium at the time of accepting the financing by the European Commission.

At the time of writing, an initiative has been taken by UNED to hold a Teleconference and make available to the ANNETTE Beneficiaries a tutorial for making an effective use of e-learning tools in the preparation of their courses.

6. ORGANISATION OF THE COURSES INTO TRACKS

6.1. Problems to be overcome

As already mentioned in this report and elsewhere, the collection of courses from different nuclear fields (nuclear engineering / safety, radiation protection and waste management and geological disposal), together with basic courses for general education in nuclear energy, will make possible to organise the 60 ECTS Master into different tracks, devoted to specific areas. These tracks will be available to those who would like to enrol into the full Master Course, as opposed to those picking up few courses of their specific interest.

At the time of writing, a Working Group has been set up to cope with this challenge; however in order to provide full indications :

- it will be necessary to wait for the parallel work being performed in WP5 and WP6 for nuclear safety culture and the nuclearisation of fusion, respectively, in order to get a complete picture of the courses available for identifying culturally coherent tracks;
- it will be also necessary to obtain final confirmation of the modality of delivery of different courses (face-to-face or online); in fact, whenever group of courses will not be available online, they should be mostly considered as a single package, to be offered to learners particularly interested in the combination offered “on site” by an Institution; the freedom in the choice among courses delivered online is a further motivation to favour the different forms of e-learning.

Furthermore, the structuring of courses in coherent tracks of 60 ECTS (including a project and/or thesis work) poses the problem of final accreditation. Two possibilities in this regard are envisaged:

- the release of a final certification by ENEN, collecting the single certifications released by the Institutions which delivered the courses (Universities or Research and Training Centres);
- the establishment of a joint “second level” master for CPD among Universities of different Countries where second level masters are available; this will provide an official and legally recognised title jointly released by Higher Education Institutions with the active cooperation between Universities and Research Centres.

Nevertheless, it seems appropriate to consider since now possible schemes for learners being involved in the studies.

6.2. Full Master program attendance vs. selected course attendance

In view of Continuous Professional Development (CPD), it is not straightforward to envisage that a professional will stop his/her activity for a full year to attend a 60 ECTS Master Course in Nuclear Matters. This kind of experience was quite common before the Fukushima Accident, in the period of the renaissance, when non-nuclear engineers were prepared for being hired by companies operating since decades in the nuclear business or suddenly jumping into it in a period of market expansion. “Nuclearisation” was at the time a magic word, worth of spending a full year to cope with fascinating matters in order to gain profitable competences.

In the present situation, we are instead facing a phase of lower job market attractiveness in which the flexibility of the offer and the effectiveness of the transfer of Knowledge and Skills at the appropriate level of Responsibility / Autonomy represent important aspects. In this regard, asynchronous e-learning can facilitate the attendance of courses to those who, engaged in a (nuclear or non-nuclear) profession, wish to know more about new matters and achieve a further qualification in a life-long-learning perspective.

These matters may belong to a set of "basic" nuclear courses or to "advanced" topical lectures and seminars, thus adapting the offer to the different starting conditions of the learners and to their objectives for competence improvement.

We have therefore to consider different possible learning schemes. These schemes are assumed to be agreed and approved by a specific Board within ANNETTE before implementation and will constitute the approved study plan of the learner. Criteria for approving study plans must be developed and/or specific pre-accepted study plans can be proposed by the Board.

- Full program attendance with no possibility of e-learning
  In this case, the learner will choose among the different offered modules, mostly basing on groups of courses (e.g., for about 15-20 ECTS) offered by a few institutions, in order to avoid too frequent displacements. In fact, this will require spending relatively long periods in different places throughout Europe to attend lectures and pass the final examinations. An internship for project or thesis work can be included in the study plan, thus completing the attended courses with a personal elaboration.
  This scheme will lead to the release of certifications of the single modules plus the release of a final title, issued by ENEN and/or by a cluster of Universities having established a joint second level master.
- Full program attendance with possibility of e-learning
  This case is similar to the above one, with the advantage that the choice of e-learning will introduce a better freedom for attending courses that, in the limit of what considered reasonable by the above mentioned Board set up within ANNETTE, may be attended and passed in more many different places. Displacements can be limited to the phases of final examinations, unless suitable and reliable techniques for examination in the distance will be adopted. The final internship / thesis work may be selected to be performed in a specific place, especially considering the wide offer of internships that research centres within ANNETTE are proposing. *Also, this scheme will lead to the release of certifications of the single modules plus the release of a final title, issued by ENEN and/or by a cluster of Universities having established a joint second level master.*

- Partial or “incremental” program attendance (with or without e-learning)

  It is likely that professionals interested in CPD will have a short time for further education or training in a specific field, willing to be better qualified in their profession. The companies for which they work, for instance, may be interested to promote this improved qualification and will allow from time to time for limited periods to be invested in education and training. Obviously enough, the availability of e-learning modules, whenever applicable to the specific matter, may facilitate the choice of the course provider. After attending the course(s) and passing the related examination(s), the learner will receive a certification from the course provider; this certification can be a specific item in a “learning” or “skill” passport, which can stay alone in this collection or can be piled up with previous or future items. In the case in which the amount of collected items in the passport will reach an established range of ECTS (or ECVETs), the learner can propose to the specific Board set up in ANNETTE to complete his/her studies with a final internship, in order to be granted a final certification, in similarity with the case of the two previous schemes. Of course, this last step is not mandatory.

As it can be noted, the variety of ways in which the education and training opportunities can be taken profit of by learners in the proposed schemes is particularly rich, as it should be to allow the learner customise his/her path in knowledge and skill acquisition. The presence of e-learning (whenever possible) is definitely an important ingredient to spread the E&T opportunities all around Europe, overcoming problems of cross border mobility.

6.3. Worth of the released certifications

The issues discussed above were mainly relating to the availability of E&T opportunities and to the capability of learners to access them. A specific discussion deserves the subsequent use that learners may do of the received certifications.

Obviously enough, the prestige of the received certifications is linked to the prestige of the institutions releasing them. So, a certification released by a University or a Training/Research Centre having a high international reputation will be generally very well valued by End-Users. However, the purpose of ENEN through ANNETTE goes well beyond these specific aspects.

The European Nuclear Education Network Association, being a supranational entity, can release certifications having no specific legal value in any of the Member States of Europe, which anyway may constitute supranational reference titles whose value depends mainly on:

- the composition of the Boards releasing them, e.g. including representatives of Academia, Research, Regulatory and Industrial Bodies from different states;
- the quality evaluation of the processes leading to the release of a certification.

Informal discussions had with members of the nuclear research and industrial world confirmed that there is a great interest in establishing such cross-border certifications, thus saving money and effort in the qualification of personnel and making finally true the dream of cross border mobility of workers and specialists throughout Europe.

7. CONCLUDING REMARKS

The effort spent in setting up a preliminary offer of courses since the preparation of the ANNETTE proposal is being rewarded by the collection of learning outcomes for courses already proposed at that time and for additional ones, proposed later on as in-kind contributions.

Though the collection of learning outcomes is only preliminary and will be revised after receiving suggestions from the Advisory Board and the End-User Group, a picture having adequate variety in the different matters clearly appears. In this regard, though it will be impossible to cover all the gaps and eliminate any useless superposition, the target pursued in this effort is to set up a structure with a reasonable content of courses in the nuclear fields (Nuclear Engineering / Safety, Radiation Protection, Waste Management and Geological Disposal) that may be sustainable in the wake of the ANNETTE project when it will find its end in 2019.

The courses on nuclear safety culture (WP5) and for the nuclearisation of fusion (WP6) will complete the panorama, adding additional richness to the present offer.

REFERENCES

[1] Veronika Simonovska, Ulrik von Estorff, 2012, Putting into Perspective the Supply of and Demand for Nuclear Experts by 2020 Within the EU-27 Nuclear Energy Sector, JRC Scientific and Policy Reports, Report EUR 25291 EN

http://ehron.jrc.ec.europa.eu/sites/ehron/files/documents/public/ldna26443enn.pdf

[2] Walter Ambrosini and Rosa Lo Frano, First approach summary on needs in nuclear E&T and proposal for a Template of Learning Outcomes, Pisa, August 4th, 2016, CIRTEN Report No. MR/ANH2020/012016