Course on "Radioactive waste disposal" (3 ECTS)		
Units and LO Statements		
Introduction and Overview of nuclear fuel cycle and radioactive waste generation ***(12 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 Disposal options for radioactive waste Guiding principles and regulatory process 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 enrichment and production of the fuel assemblies • Discuss the principle of disposal system performance	• 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 • 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 • Explain the characteristics of radioactive wastes and disposal methods • Describe how radioactive wastes are classified • Identify three types of packaging for radioactive materials
Modelling and THM coupled process ***(12 hours)***		
	Responsibility / Autonomy	
	Understand the thermos-hydro-mechanical behaviour of multi-barrier disposal	
	Skills	**Knowledge**
How to build a THM coupled model Groundwater modelling Diffusive coupled model for fluids transport Model for soil suction Geo-statistics	• Recognize when coupled approach is appropriate to solve a behavior assessment problem • Recognize fundamental parameters in transport process models	• Formulate continuity equation • Formulate mass conservation equation • Formulate energy conservation equation • Formulate momentum conservation equation

Example of THM coupling in bentonite behaviour analysis and assessment	• Be able to apply the principles of thermodynamics equilibrium for the establishment of simplified behaviour models • Select appropriate analytical technique for THM modeling • Apply numerical programming techniques • Analyse the simulation results	• 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.
Natural analogues ***(6 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 • Compare corrosion data from laboratory experiments and several natural analogue sources • Illustrate alkaline groundwater reaction with the natural bentonite over time period	• 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 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		
Recommended assessment methods: written exam and case study report		