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.

	• 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	• 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.
Unit 3* – Engineering** ***(18 hours)	**Responsibility / Autonomy** Figure out the technical and scientific approaches to site evaluation	
	Skills	**Knowledge**
Sub Surface Characterization Geotechnical site investigation Rock classification Stability in embankment dams Foundation Soil liquefaction Tunneling Stability analysis of tunnels Ground deformation	• Apply testing methods to analysis geothechnical proprieties • Apply fundamental geomechanics knowledge to solve stability problems • Apply simple method for foundation design	• 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

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.

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- Civil engineer
- Mining engineer
- Geological engineer