Course offered for the PhD program
in Civil, Chemical and Environmental Engineering
Curriculum in Chemical, Materials and Process Engineering
Curriculum in Structural and Geotechnical Engineering, Mechanics and Materials
A.Y. 2022/2023 (XXXVIII cycle)

(The course is open for participation of students from other PhD cycles or programs)

1.Title

Nuclear Waste Management

2. Course Description

Deep geological disposal is one of the options for managing the spent nuclear fuel generated in nuclear power plants in many countries.

In Finland, the spent nuclear fuel is planned to be disposed in a geological repository based on the KBS-3 (kärnbränslesäkerhet in Swedish, nuclear fuel safety) method. As introduction, it will be presented the situation of the nuclear energy in different countries. The course will continue with the description of different disposal methods for the spent nuclear fuel, focussing on the KBS-3 and pointing out in the issues related with the behaviour of the clay barriers. The constitutive models needed to simulate the behaviour of the materials that make up the clay barriers will be described. These constitutive models must be implemented in computer codes for carrying out the simulations of parts of the disposal (only deposition holes, deposition holes and deposition tunnels) or even the entire disposal, for predicting its behaviour and perform the safety assessment. The constitutive models must be validated and parametrized, so it is necessary to perform laboratory tests in small scale, mock-up tests and "in situ" tests that will be described. Finally, it will be presented a short description about licensing process in Finland.

3. Course Organization

The course consists of lectures articulated in six modules. Here reported the main topic of each module:

I. Introduction: Nuclear Energy in Finland, Spain, Argentina and Italy. Nuclear waste issues. Fuel in the reactor. Fuel pellets, fuel rods and fuel assemblies. Cooling period. Nuclear waste storage: Interim storage in nuclear power plant (example in Ascó nuclear power plant). Central interim storage (examples in The Netherlands and Sweden). Deep geological disposal.

II. Multi-barrier system description: Metal canister. Canister parts. Cast iron insert and other components: steel tubes, screw and lid. Copper shell and weld. Encapsulation of the spent fuel and canister assembling in deposition holes. Clay barriers. Buffer. Compaction of blocks and pellets production. Assembling of blocks and pellets. Backfill with blocks and pellets and granular filling as alternative. Concrete plugs: Finnish and Swedish designs. The host rock. Planned tunnel network: deposition holes, deposition tunnels, central tunnels, shafts and access tunnel. Host rock alternatives: argillaceous claystone (Switzerland), saline rock (old option in Germany), tuff (old option in the United States) and crystalline rock (Finland and Sweden). Clay as host material: France. Host rock characterization. Laboratory and "in situ" tests. Surveys: Investigation trenches, boreholes, geophysical and groundwater flow investigations. Posiva Flow Log description for the identification and characterization of fractures. Rock thermal conductivity measurement. "In situ" stresses measurement.

III. Constitutive models and implementation: Unsaturated soils. Civil engineering and unsaturated soils. Embankments, reinforced soils and earth dams. Problems with unsaturated soils: Collapse, swelling and loss of shear strength. Growth of crystals in swelling phenomena. Balance equations of water, air and energy. Equilibrium restrictions: Psychrometric law and Henry's law. Constitutive models for the heat flow: Fourier's and Boltzmann's equations in conductive and

radiation heat flows. Water flow. Retention curve. Advective and non-advective flows. Water flow in unsaturated soils. Darcy's law and Fick's law. Molecular diffusion and mechanical dispersion. Second law of Newton for solving the mechanical coupling. Mechanical constitutive models. Linear elasticity, non-linear elasticity (state surfaces), Barcelona Basic Model (BBM) and Barcelona Expansive Model (BExM). Practical training with GiD. Preparation of geometries, assignment of initial and boundary conditions. Modelling with CODE_BRIGHT. Convergence criteria. Tolerances. Post-process with GiD. Practical cases: laboratory tests simulation and civil engineering case.

IV. Laboratory tests: Test for measuring parameters of the constitutive models. Thermal conductivity measurements. Tests for measuring the hydraulic conductivity. Tests with heat flow and vapour flow coupling. Infiltration tests. Oedometer tests. Uniaxial compression test, simple shear test, resonant column test and triaxial test for studying the shearing properties. Special tests set-ups. Hollow cylinder and suction controlled oedometer tests. Water retention curve measurement. Laboratory sensors. Load cells, pressure cells, LVDT, capacitive hygrometers, psychrometers and thermocouples. Concepts of full-scale (FS), hysteresis and linearity. Calibration of sensors. Measurement range and errors. Mock-up tests. FEBEX mock-up test and its simulation with CODE_BRIGHT. Tests in transparent and steel cells for erosion measurement. Big Bertha tests for the KBS-3H assessment. Special tests design: pinhole test and perforation hole test. Laboratory training: compaction of samples, oedometer tests and triaxial tests. Water retention curve measurements.

V. "In situ" tests: The "in situ" tests as demonstration tests for assembling the multi-barrier components and proofing the possible future retrieval. Underground laboratories: Mont Terri and Grimsel (Switzerland) and Äspö (Sweden). "In situ" tests in Onkalo® (Finland). Instrumentation and monitoring of "in situ" tests. Examples of "in situ" tests: "Canister Retrieval Test, CRT", "Full-scale Engineered Barriers EXperiment, FEBEX, "Alternative Buffer Materials, ABM", "Multi-purpose test, MPT", ventilation test (VE). "In situ" test simulation: MPT.

VI. Licensing process for the deep geological disposal in Finland: Management of the spent nuclear fuel generated in Loviisa and Olkiluoto nuclear power plants. Storage in Soviet Union. Looking for a site disposal in Finland and assessment of the different options. Finnish legislation. Public opinion management. Decision in Principle (DiP) and legal coverage for investigation in Olkiluoto. Construction license application. Operating license application.

4.Lecturer

Dr. Xavier Pintado

5. Duration and credits

20 hours (4 credits)

6. Activation mode and teaching period

The course will take place from the 22nd of May to the 2nd of June 2023. The minimum number of participants to activate the course is 3.

7. Registration

The deadline for registration is May 5th, 2023. Please send an e-mail simultaneously to: Xavier Pintado (xavier.pintado@mitta.fi), Domenico Gallipoli (domenico.gallipoli@unige.it) and Diana Bianchi (diana.bianchi@edu.unige.it).

8. Final exam

Only the active participation to the lessons is required.