Funded doctoral thesis project starting in Fall 2023

Condensation of elements in the conditions of underground nuclear explosions: experiments and numerical simulations

Evaluating the environmental impacts of underground nuclear testing requires a thorough knowledge of the processes that took place following the explosion. Such explosions will have vaporized the surrounding rock basement and generated a cavity where vapor and melt (generally a silicate melt) coexist. The composition of both vapor and melt will rapidly evolve as the vapor condenses and the system cools off. The radionuclides produced by the explosion correspond to a large number of chemical elements that are part of radioactive decay chains. Depending on the elemental volatility and on the pressure-temperature path of the system, these large set of nuclides will partition between the magma, the country-rock surfaces and the vapor phases.

The objective of this PhD project is to construct a model for the condensation of elements in the conditions of underground nuclear explosions, based on thermodynamic and kinetic calculations that will be made possible with new experimental data acquired during this project. In detail, we will take advantage of computational thermodynamics combined with data obtained with a new generation Knudsen Effusion Mass Spectrometer recently installed at the ENS Lyon. High temperature experiments will be performed to determine the missing parameters necessary to characterize the volatility of the chemical elements of interest.

The first year of the PhD will be dedicated to obtaining experimental data. Synthetic rock samples will be prepared and doped with elements produced during fission. Most of these elements include some stable isotopes such that there will be no need to handle radioactivity. The case of actinides will only be dealt with using parameters from the literature. The synthetic samples will be introduced in the Knudsen Effusion Mass Spectrometer and this will enable to determine the relevant thermodynamic parameters during evaporation experiments. We will thus obtain the activity coefficients of these elements in silicate melts and their evaporation/condensation coefficients. During the second year of the PhD, we will calibrate a thermodynamic model describing the condensation of each element for a given rock composition at given temperature and pressure.

The condensation model and its kinetic parameters will be coupled with radioactive decay laws as well as a model for the cooling of underground nuclear cavities to predict quantitatively the condensation of radionuclides as a function of time. During the third year, this model will be used to better understand the distribution of radionuclides as a function of various parameters characterizing the nuclear cavity (types of magmas, connection to fracture network, depth, …) and their evolution with time. These results will then be compared with literature data related to various nuclear tests.

The ideal candidate should have an initial training in material sciences, chemistry or geochemistry with some knowledge in thermodynamics and physical chemistry and should have an interest in experimental methods (chemical separations, mass spectrometry and instrumentation) and be opened to environmental or geological questions. The PhD thesis is funded by the CEA and will be done in collaboration with ENS Lyon (Laboratoire de Géologie de Lyon) under the supervision of Bernard Bourdon (CNRS, ENS Lyon, bernard.bourdon@ens-lyon.fr) and Eric Pili (CEA, eric.pili@cea.fr). The PhD work will be located at ENS Lyon with a few visits to CEA, Bruyères-le-Châtel. Please contact the future supervisors for application and further information. Applications will be received until August 30th 2023 if position is not filled before.