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Condensation of the precursory elements of xenon isotopes produced by underground nuclear explosions

BERNARD BOURDON[1] AND ERIC PILI[2]

[1]LGLTPE, CNRS

[2]CEA, France

Presenting Author: bernard.bourdon@ens-lyon.fr

The measurement of four radioactive xenon isotopes potentially released to the atmosphere is a tool used to detect underground nuclear explosions [1]. In order to better understand the processes leading to this release and the relative proportion of the Xe isotopes following the explosion, it is important to take into account the effect of pressure and temperature evolutions on the condensation of the precursory elements of Xe in the fission decay chains. The high temperature leads to the melting of the surrounding rocks, thereby producing a magma where refractory fission products can get dissolved, while the more volatile ones can escape. As the magma cools down, these volatile species can get condensed in the magma or in more likely the cooler rubble pile that forms above the point of detonation. In this study, the vapor pressures and condensation temperatures of the elements that are precursors to radioactive xenon isotopes were determined using thermodynamic calculations corresponding to the bulk composition of the system.

Our results illustrate that there is a large difference between the condensation temperature of Sn, Sb, In, Te and I and their boiling temperatures that have been used as indicators of their volatility [1]. There is also a strong pressure dependence of these condensation temperatures, and a smaller dependence on the bulk composition of the system. Depending on the cooling and pressure decay timescale, this information can then be used to calculate the abundances of Xe isotope produced in the various decay chains. This study shows that it is important to describe properly the variation in condensation behavior for predicting precisely the total activity as well as the relative amounts of radioactive xenon gas produced after underground nuclear explosions.

[1] Carrigan, C.R. et al. (2020) Journal of Environmental Radioactivity 219, 106269.