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The effect of condensation on radioxenon distribution between vapor and magma following underground nuclear explosions

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Underground nuclear explosions produce cavities that contain a magma and a vapor rapidly evolving due to cooling. During this early evolution, volatile fission products of U or Pu can be emitted to the atmosphere, thereby providing a means of detecting nuclear tests. In this framework, the radioactive Xe isotopes ^{131m}Xe, ^{133}Xe, ^{133m}Xe and ^{135}Xe (aka radioxenon) are of major interest. They are mostly produced by a decay chain of moderately volatile elements, respectively In, Sb, Sn, Te and I, that are likely to condense, potentially trapping the decay products in the magma.

Our goal is to understand the distribution of these radionuclides during the cooling of the cavity and to quantify the impact of condensation on the amount of radioxenon available for migration to the atmosphere. We have built a numerical model for predicting the distribution of radioxenon and its precursors between vapor and magma inside a cooling nuclear cavity, taking into account radioactive decay and condensation for each nuclide in a closed system. The net condensation flux for each radionuclide of interest (i.e. condensation flux - evaporation flux) was calculated with the Hertz-Knudsen law. The evaporation flux was determined for each species based on vapor pressures estimated from thermodynamic calculations of magma-vapor equilibrium. By summing the net condensation fluxes for all isotopologues, the net condensation flux of radioxenon precursors can be determined.

Volatile elements resulting from the decay of radioxenon precursors in the silicate melt phase are likely to be trapped in bubbles. The model results show that ^{131m}Xe and ^{133}Xe are 2 to 3 times less abundant in the vapor phase if trapping of I and Xe in bubbles is considered, provided that the condensation flux of less volatile precursors is large enough. Without trapping, the impact of condensation is minimal as volatile nuclides rapidly evaporate. In addition, a faster cooling rate maximizes the impact of condensation on the radioxenon budget.