What may be the consequences of a CO 2 leakage? Insights from soil gas measurements in an urban area – Clermont-Ferrand, French Massif Central

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Abstract

This project is aimed to better constrain the geographical distribution of CO_2 geological emanations in an urban context and to suggest recommendations for risk management. Natural emanations may have some similarities with emissions from an anthropogenic deep storage site that experiences unexpected gas releases. Such gas emanations may generate hazards to which local authorities have to face, especially those concerning human exposure. In 2015, the Regional Bureau of Environment, Physical Planning and Housing from the Auvergne District (DREAL) and the Clermont-Ferrand Urban Community (CLERMONT-CO) have co-financed site investigations to better characterize gas emanations over selected territories (7 cities) and to establish guidelines for the management of associated risks. Work has been done under the coordination of the Regional Prefecture.

Located in the Northern part of the French Massif Central, the Clermont-Ferrand city is a populated city (c.a. 140 000 inhabitants) that is located mostly over quaternary volcanic rocks belonging to a former maar structure. To the East, volcanic rocks are progressively replaced by continental formations belonging to the Tertiary graben of Limagne. The limit between sedimentary domain and basement/volcanic domain is underlined by deep-rooted normal faults along which several well-known mineral springs are emplaced.

Based on previous information – reports on accidents and fatalities – and on newly acquired data, this study has followed a ‘learning by doing’ approach. Data were collected for several gas species using different techniques: direct in the field monitoring using portable infrared gas analyzer (CO_2, CH_4, O_2), subsequent investigation techniques (^{222}Rn concentration measurements and CO_2 and CH_4 flux measurements), sampling and analyses delayed using gas chromatography (N_2, Ar, alkanes…) and gas spectrometry techniques (^4He). The results have been analysed each day in order to constantly refocus field acquisitions onto the most striking features. Such an approach highlights the huge complexity of gas emanations in urban areas, where buildings, surface reworking and other human impacts may lead to tortuous gas migration pathways. The migration along preferential pathways may drive to local accumulation and thus to dangerous situations for humans.

Some emblematic case studies are reported, with measurements in both soils and buildings. Local environmental background has been evaluated using continuous monitoring techniques at 0.40 to 0.60% for CO_2, (normal value is 0,04%) showing correlation with external forcing resulting from changes in atmospheric pressure or soil temperature. CO_2 concentrations, that may nearly represent 100% of the gas phase in the soil gas at some locations (max. 1 m depth), are reported together with strong depletion in O_2 (2.9% at minimum). The ingress of CO_2 linked to deep-seated processes (*e.g.* CO_2 of 'volcanic' origin) becomes the predominant factor when CO_2 concentrations are greater than 8% in volume. Strong enrichments in helium were found (up to 120 ppm) in gas efflux directly coming from building's basement but any measurement having a CO_2 concentration greater than 13% is highly enriched in helium. At the opposite, the study of helium has allowed the identification of locations with helium anomaly but without CO_2 abnormal concentration. This suggests that areas impacted by rising gas fluxes cannot be restricted to areas where CO_2 escapes. Extremely high CO_2 fluxes were monitored over manholes directly emplaced in the pavement of a street and ground level from adjacent house (from 0.9 to 5 litres of CO_2 per minute). Moreover, the CO_2 percentage in the gas flow is highly variable from one second to the other, exhibiting pulse-like emitting process. Such values, potentially leading to acute exposure, have to be considered with peculiar attention as they directly represent strong hazard to humans.

The results of the investigations were then interpreted in a risk management perspective based on the experience feedback from the Italian Civil Security. One reassuring point is that gas anomalies are very punctually localized and are thus easier to deal with when considering hazard management. A strong correlation with geological features (faults, maar structures) can be depicted, but the relation is not always clear, so the geology cannot directly be used to map the emission zones. Similarly, the correlation with radon is not significant enough to enable transposing the radon risk map for CO_2 risk characterisation. Besides, areas with high CO_2 concentrations may not correspond to areas with strong CO_2 flux (statement is the same with helium). This dissociation reveals the high complexity of gas migration. Regarding health hazards, CO_2 is a gas specie with threshold levels, from chronical exposure (relatively low concentration but exposure during hours) to acute exposure (high concentration during short time of exposure). Accumulation calculations with exposure model were performed. In some cases, the level of gas fluxes measured may lead to situations potentially dangerous for humans, depending on the factors that govern gas accumulation and thus exposure (i.e. confinement and low ventilation). To manage this risk, actions have been suggested, such as information of public, set up of preliminary actions on most sensitive points, analysis of experience feedback, especially on building protection against soil gas.

The management of leakage must encompass these aspects. From the CCS (Carbon Capture and Storage) management point of view, this study brings some interesting clues. The most complex issue concerns the influence of built structures, a point that remains not well understood even for locations where the gas risk is well defined. This points out the difficulty of building scenarios from the sole base of soil gas measurements as the migration of gas species from the ground to the building is a very complex phenomenon. Measurements also show that the gas signal can be highly variable in both space and time leading to even more complex management of gas emanations.