Intermediary report on ENVRI+ - TransNational Access to Etna project "RAVE@Etna"
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This document is an intermediary report presenting the activities carried out in the field during campaigns C1 held in May 2018 (4 persons (Gauthier, Terray, Breton, Mallet) x 10 days), C1.5 (brief survey in July 2018 by 1 person (Terray) x 5 days) and C2 held in October 2018 (5 persons (Gauthier, Terray, Breton, Mallet and Billard) x 10 days).

Preliminary results arising from these field surveys are given in this intermediary report and a final report will be sent by the end of the project as soon as significant results will be gained from the analysis of samples gathered in October.

Introduction

Volcanoes are a major source of natural radioactivity injected into the atmosphere and dispersed into the local environment. The RAVE@Etna project uses an innovative, multi-disciplinary approach in order to study simultaneously for the first time ^{222}Rn and its decay products in volcanic gases and biological samples collected on and around Etna. Our team gathers Earth Scientists, Nuclear Physicists and Biologists in a collaborative effort which will a) allow better characterization of Etna as a source of natural radioactivity injected into the atmosphere; b) strengthen our knowledge on how the volcano works and impacts its local environment.

Main objectives of this project are thus threefold:

i) Benefit from innovative ^{222}Rn measurements in the diluted plume of Etna to implement existing degassing models (Terray et al., 2018) and derive sharper constraints on shallow magma dynamics and degassing processes. A long-term time-series of these parameters related to the style and intensity of degassing/eruptive activity will contribute to better volcanic hazard assessment.

ii) Use unprecedented ^{222}Rn measurements to quantify for the first time Etna's degassing budgets in terms of radionuclides injected into the atmosphere, and estimate radiation levels at the summit craters and at distances from the active vents, with implications for radiation safety and related health issues.

iii) Collect and analyze biological samples to study a) whether microbial (and other micro-organisms) life may exist under extreme conditions in a volcanic and radioactive environment and how it evolves to get adapted to it; b) how more evolved species (honeybees) react to this specific stress and may act as a dissemination factor of radioactivity through beehive products, with implications for life origin and evolution.

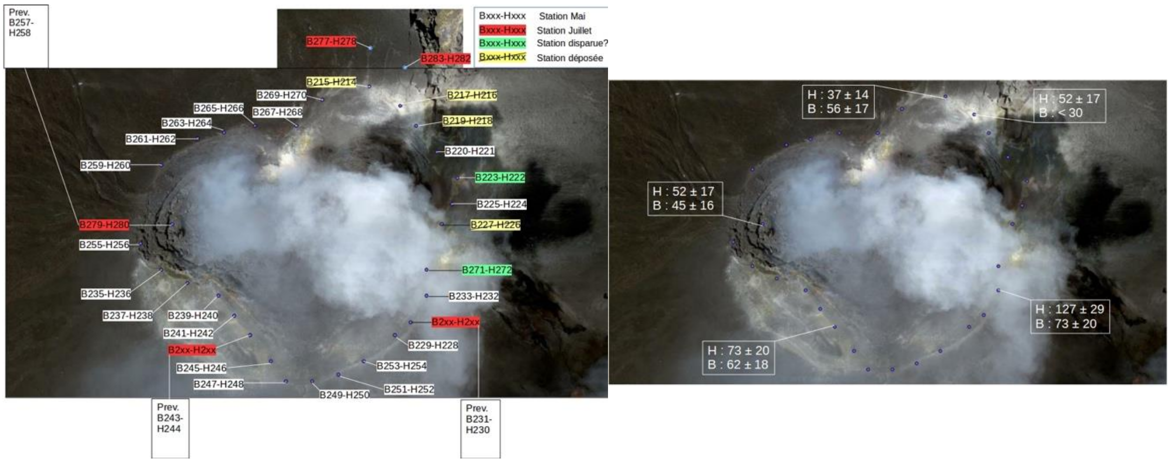
Estimation of ^{222}Rn concentration and associated radiation levels at Mt Etna summit

The first goal was to install passive radon detectors (like in-house radon-monitoring systems) around the central crater rim in order to estimate long-term radon activities in the plume.
Thirty wood sticks were carried to the central crater and installed at a 50-meter distance from each other around the rim. They were equipped with two radon dosimeters developed by the ALGADE Company (https://www.algade.com/), one at approximately 10 cm and the other at 100cm above the ground. In July 2018, Luca Terray was able to check that most of the wood sticks installed in

May were still in place, at the exception of a few that were exposed to very high temperatures - up to 350°c at 20 cm underground - along a fracture zone between the North-Est Crater and Voragine. He collected 10 dosimeters that were sent to ALGADE for immediate analysis. Image 4 provides the radon activity levels measured in Bq/m^3 by the dosimeters. These first results already show that radon levels are significant in the vicinity of the central craters, up to 130 Bq/m^3 on the eastern rim of Voragine. Average radon concentration based on the five collected stations is close to 70 Bq/m^3 one meter above the ground, a value slightly higher than that measured at ground level (50 Bq/m^3). The difference between radon concentrations in upwards position and at ground level is thought to reflect the influence of the diluted, yet radon-rich (~20 Bq/m^3), plume. Such concentrations in the diluted plume of Etna were also found using a different methodology, namely scintillation flasks with which we took plume samples during day time and had them counted overnight in Nicolosi.

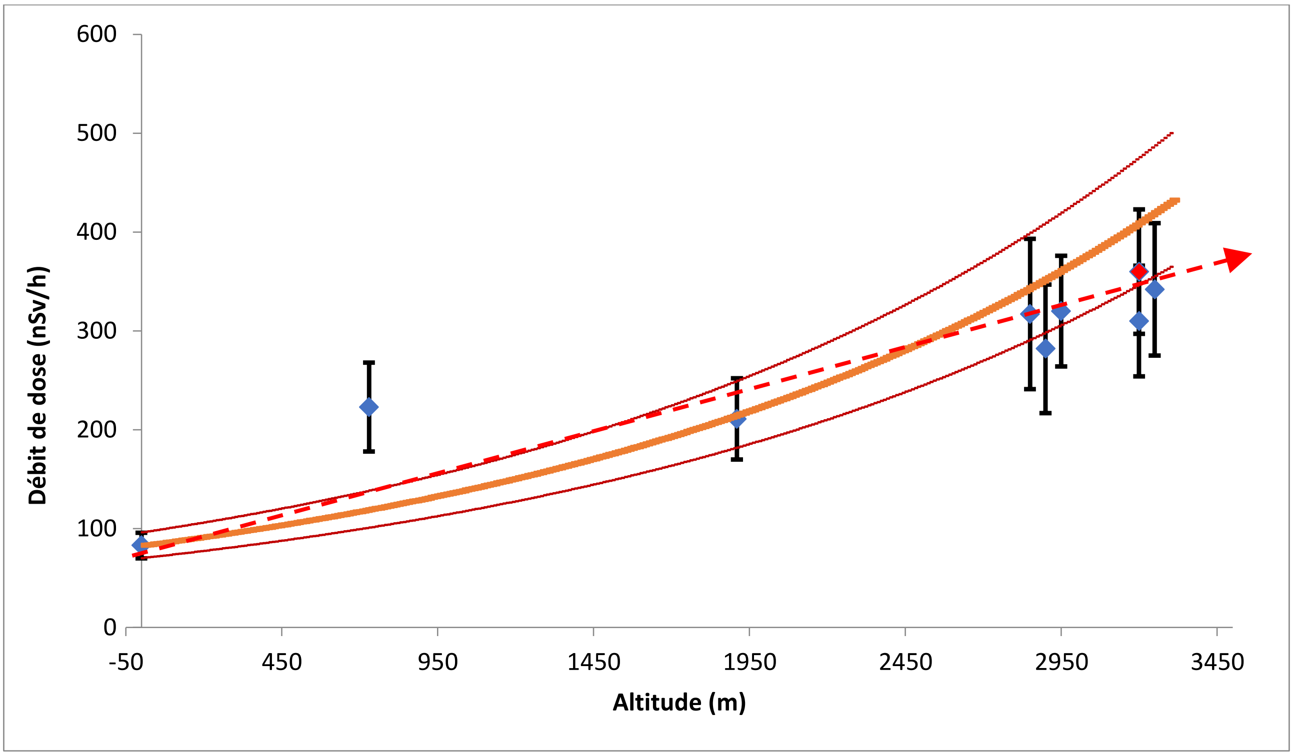
All other dosimeters (but 2 which got lost) installed in May and left in the field have been collected in October. Expected results will allow a much better characterization of long-term radon concentrations at summit craters, including reduced uncertainties on radon activities.

Legend: transport and installation of the radon dosimeters on wood sticks around Etna central crater.



Legend: location of the dosimeters installed in May (left) and first measurements from radon dosimeters collected in July 2018 by Luca Terray (right)

Complementary to passive radon measurements, background radioactivity levels were measured in different locations from sea level up to Etna's summit. We used a COLIBRI hand held radiation survey meter developed by Mirion Technologies. Although most recent measurements carried out in October will improve and validate the results shown below, this first survey shows that in spite of significant radon concentrations in the gas plume as well as all around the crater rim, natural radioactivity remains at low levels. Most of radiations indeed follow an increasing pattern from 0 to 3300 m asl, which is best explained by increased radioactivity at higher altitude due to cosmic rays, as exemplified in the figure below. It thus seems that as far as radioactivity is concerned, there is no major health issues working or visiting the summit area.

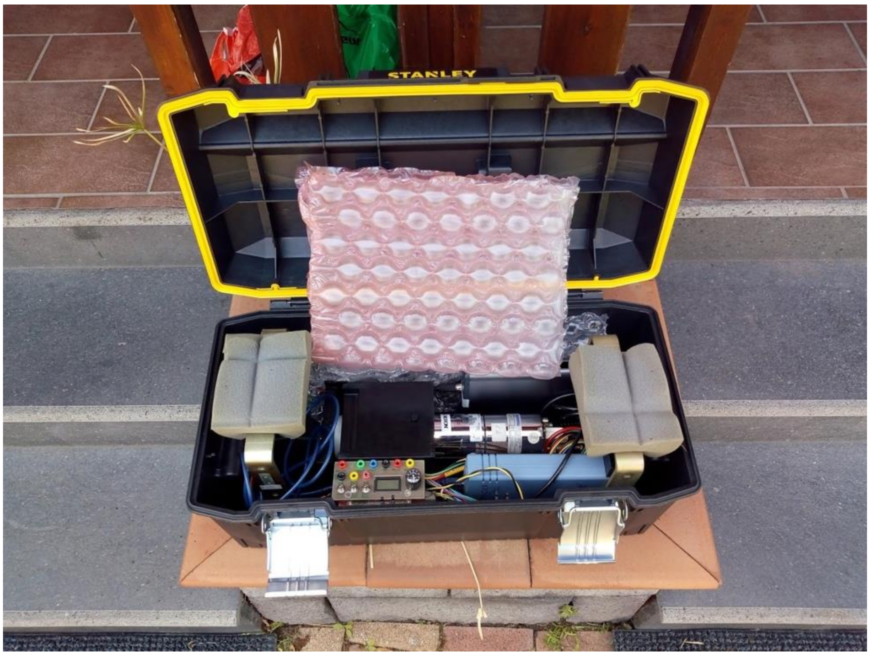


Legend: Radiation levels (in nSv/h) as a function of elevation above sea level. 0 m asl reference point was taken in Palermo; outlier corresponds to Nicolosi (700 m). Blue diamonds correspond to measurements made in a clear atmosphere with no obvious plume influence. Red diamond refers to a measurement made at the summit while a diluted plume was present at the sampling site. Although this latter value is the highest reported for Mount Etna, uncertainties are too large to allow us to relate increased radiations to the gas plume itself.

Radon analysis on volcanoes with in-situ observations of short-lived isotopes

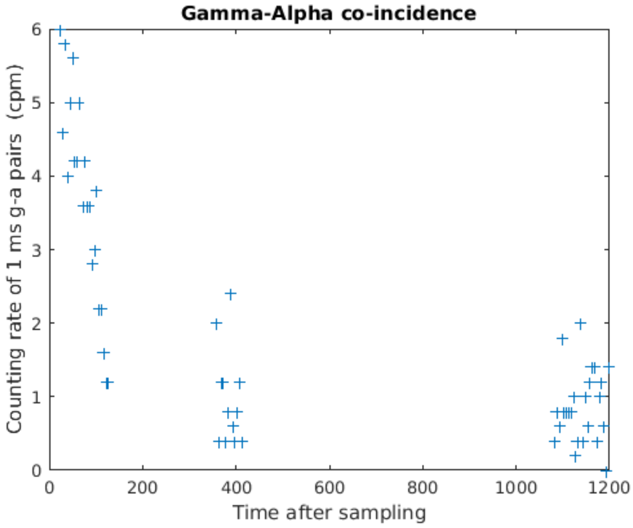
The field campaigns were also dedicated to the test of a new instrument currently under development at both LMV and LPC in Clermont-Ferrand, France. This device, named RAVIOLI (for Radon Analysis on Volcanoes with In-situ Observations of short-Lived Isotopes), is aimed at measuring very short-lived radioactivity of volcanic aerosols, mostly due to radon (and its immediate daughters: 218Po, 214Pb, 214Bi, 214Po) enrichments in volcanic plumes. Because the half-lives of these radionuclides do not exceed half-an-hour, the measurement has to be done right after aerosol collection on a filter. For this challenging reason, only one attempt of this measurement have been made so far (Lambert, 1979) by measuring gross alpha activity immediately after sampling, but unfortunately the employed method was not precise enough to yield a plume characterization compared to the atmosphere. Contrastingly, our prototype comprises two detectors which are able to detect not only alpha particles but also gamma rays and beta particles. This technological and methodological development will provide much more accurate measurements allowing us to monitor in real time the radioactive decay of the first radon daughters, and therefore, to provide robust quantification of radon concentration in the volcanic gas plume.

The RAVIOLI device was in a non-consolidated version last May (then slightly improved in October) and it had to be considered as a true prototype. Although only alpha and gamma detection systems were available on our instrument in May, we decided to carry several tests in the field in order to validate our approach. We deployed our instrument on several places of Mount Etna (see picture attached), mainly at Torre Del Filosofo and Punta Lucia for atmospheric background characterization, and also on Bocca Nuova crater rim for plume characterization.



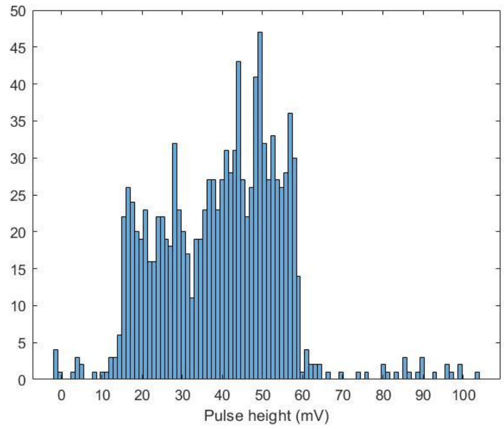
Legend: the device fitting in a single box includes one NaI scintillator with its photo-multiplier, a silicon semi-conductor detector, their alimentation, and the acquisition system.

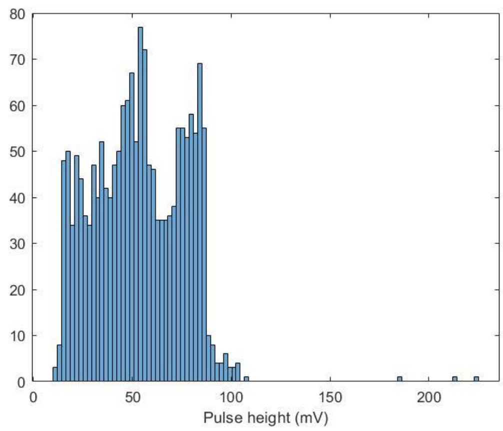
Our device proved efficient to detect the gamma-alpha coincidence due to the decay of the fast pair ^{214}Bi-^{214}Po (see figure below), which validates the concept of our instrument based on 2 detectors co-incidences.



Legend: The counting rate of gamma-alpha pairs as a function of time after sampling (in minutes). The counting rate during the first 2 hours is significantly higher than the background measured afterwards and decreases accordingly to the radioactive decay of 214Bi.

Alpha spectra of a sample have been also recorded (see figures). The two spectra acquired at two different periods (the first one during the 2 hours following filtration) and the second one day after, show different features. In the first one, an energy region after 60 mV appears, while it is not present in the second one. This could be well explained by the decay of ^{214}Po (E = 7.7 MeV) during the first two hours: after that, only ^{210}Po (5.3 MeV) remains in the filter.





<u>Legend:</u> histograms of alpha particle events recorded in our instrument during the first two hours after sampling (on the right) and 1 day after (on the left). In abscissa, pulse height is the analogic signal recorded by the instrument, it is equivalent to the energy deposited in the detector by the alpha particle.

The RAVIOLI device is now in a much more evolved and consolidated version, including efficient beta detection and low electronic noise on all channels (gamma using the NaI detector; alpha-beta using the PIPS detector) due to significant improvements on both power supply and real-time analysis. Moreover, we have made significant efforts to reduce both its weight and its size so that we should be able to easily deploy it in the summit area everywhere needed.

Influence of volcanic gas (including high radiation levels) for biological life under extreme conditions

Collection and analyses of beehive products:

Mount Etna summit area presents an astonishing concentration of flying insects, including many honeybees. In the framework of the RAVE@Etna project, we want to verify if honeybees exposed to volcanic gases i) may act as a carrier of natural radioactivity which could be spread out through beehive products; ii) have developed biological specifications allowing them to adapt to these extreme conditions. For this purpose, samples of honey, beeswax and pollens have been collected from beehives located in Palermo, Mascalucia, Giarre (outside of plume influence) and Monterosso Etneo (downwind the most frequent plume direction). Analyses are still in progress and cannot be conclusive at this point but the first results suggest that honey from Monterosso (chestnut honey) contains a small excess of ^{210}Pb, one of the most enriched radioisotopes in volcanic plumes. Further analyses, including polonium radiochemistry, will be conducted in order to support our hypothesis that bees living and gathering nectar and pollens in volcanic areas are able to give an enriched fingerprint to their products.

Collection and analysis of microorganisms growing in extreme conditions:

In order to study the diversity of bacteria and fungi communities submitted to extreme conditions related to volcanic gases and high levels of radioactivity, twenty one samples were taken for biological analyses from the summit and further downslope. These consist in rock and soil samples as well as gas, fumarole and snow samples.

Bacterial cells were detected in all the different samples (Figure 1.A). Higher abundances were found in ashes and soils, which have been all sampled on the central crater rim at Mont Etna's summit. The highest abundance of bacteria was obtained in the colored crust at Bocca Nova crater summit (Picture 1). A very interesting result is that some bacterial cells were detected in the gas plume, collected for only 2 hours (Figure 1.B) during the May campaign. Longer sampling times were used in October in order to collect much more cells and improve the counting, analyses being still under progress at that time. DNA extraction will be realized over some interesting samples, like plume gases, colored soil crusts, soils from vertical transept (20 cm) and ashes from other sites, under the direct influence of the gas plume or else at more remote locations where the plume is mostly virtually absent (e.g., Pizzi Deneri and Montagnola), in order to highlight the effects of volcanic gases and/or natural radioactivity on the bacterial and fungal communities biodiversity.

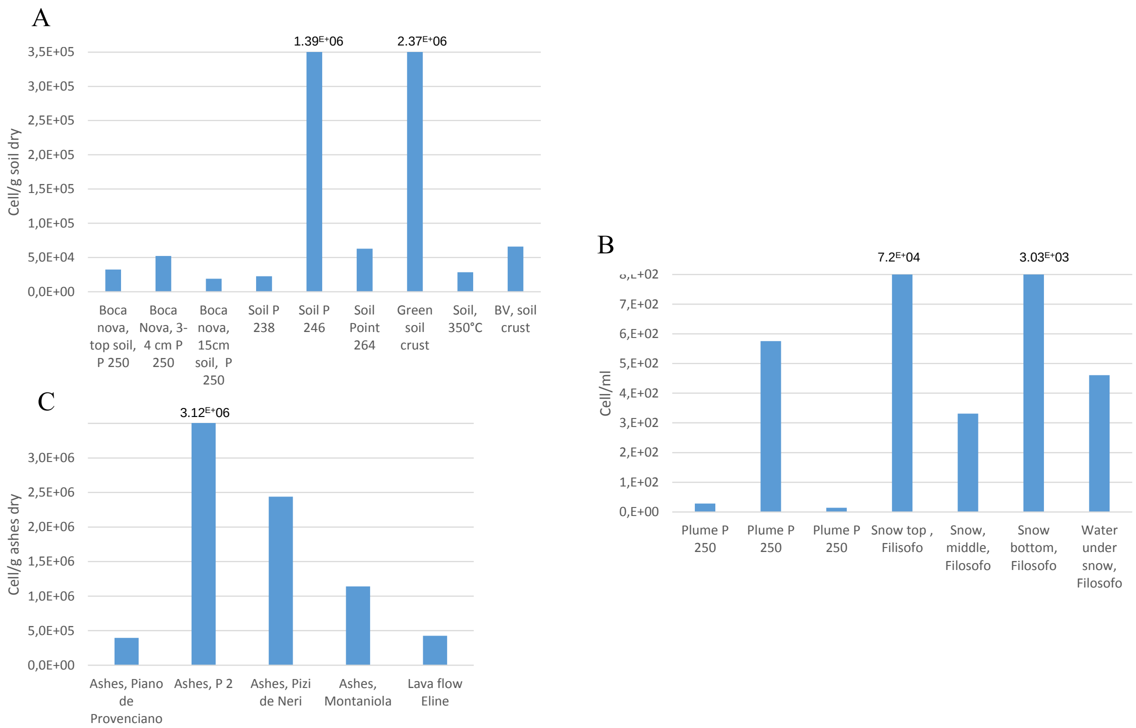


Figure 1 : Abundance (Cell/ml or cell/g soil dry) of bacteria in A) different type of soils collected on the central crater rim, B) gas plume and snow samples, C) ash spread around Mount Etna summit craters.

Picture 1: Colored crust soil at the Bocca Nova summit crater.