Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Complete gas emission assessment of the Rittershoffen geothermal plant in the Upper Rhine Graben, France

Clio Bosia, Guillaume Ravier, Nicolas Cuenot, Eléonore Dalmais, Justine Mouchot

ES Géothermie, 5 rue de Lisbonne, 67300 Schilitgheim, France

clio.bosia@es.fr

Keywords: Upper Rhine Graben, Rittershoffen, Non Condensable Gas, Environmental monitoring, ZoDrEx

ABSTRACT

This study presents the ongoing methodology to assess gas emissions of the Rittershoffen geothermal plant in operation in terms of chemistry and amount of emitted volumes. Gas chemistry analyses are performed on samples taken at different venting valves in order to investigate gas chemistry at different pressure and temperature conditions. Quantity of gas released to the atmosphere is also evaluated thanks to gas flowmeters connected to venting valves. Chemistry and quantity investigation will be very important for gas emission assessment of the Rittershoffen geothermal plant.

Fractured crystalline basement at Rittershoffen is a Paleozoic granite. Thus the geothermal brine contains some radionuclide elements from ^{238}U decay chain. Even if the radionuclide content in scaling has been exhaustively characterized, presence of radon was never deeply investigated in geothermal plants in the Upper Rhine Graben. Radon can be a source of internal exposition for workers at geothermal plants. A first campaign to assess radon and dust emission in the geothermal plant facility and in the surrounding environment will be performed.

1. INTRODUCTION

1.1. Geothermal plant: the issue of gas emissions

Geothermal activities induce the emissions of several gases all along the lifecycle of the plant. The main gases produced by geothermal activities are Non Condensable Gases (NCGs), such as nitrogen (N_2), hydrogen (H_2), carbon dioxide (CO_2), carbon monoxide (CO) or hydrogen sulphide (H_2S) but also radiogenic gas issued from the U decay chain as radon (Rn).

NCGs generation and emissions may induce several consequences on the correct functioning of the geothermal plant, in particular inducing corrosion phenomena of the installation. Likewise, some gases and in particular Rn, may significantly affect the health and safety of the workers, the neighboring health and the natural environment close to the site. In order to prevent and minimize the technical, economical and societal risk of a geothermal exploitation, it is thus necessary to precisely assess the NCGs emissions of a plant through an exhaustive measurement program.

2.1. The ZoDrEx project

The GEOTERMICA project ZoDrEx aims at demonstrating drilling, completion and production technologies to increase the technical and economical chances of success in geothermal energy applications. The project groups 10 partners from Denmark, France, Germany, Spain and Switzerland including 5 industry leaders in drilling, completion equipment, project management and geothermal operations, 3 engineering organizations active in both the public and the private sectors and 2 prestigious academic research organizations (Meier, 2020).

The goal of ZoDrEx is to demonstrate that:

- Percussion drilling can be used and controlled in highly deviated trajectories to improve drilling efficiency in crystalline rocks thus leading to substantial cost reduction in geothermal well construction.
- Zonal isolation is the key to efficient Enhanced Geothermal System (EGS) stimulation and the selection of appropriate methods can be reliably performed. Additionally, ZoDrEx will have contributed to the development of more robust zonal isolation technologies.
- Operating EGS plants can be optimized through automation, protection against corrosion with more acceptable inhibitors, thoroughly monitored for ensuring the safety of the workers, the public and the environment.

In the frame work of the ZoDrEx project, ES-Géothermie extensively monitored and characterized all the potential emissions occurring at the EGS plant of Rittershoffen (France), including the gas emissions discussed in the present study. The results of this study will serve improve the safety of the Rittershoffen geothermal heat plant, elevating it to the highest standards in the world and become a reference for future monitoring best practices. The data obtained through ZoDrEx will also be used to perform a life cycle assessment and impact inventory of the Rittershoffen plant in the H2020 GEOENVI project.

2.2. The Rittershoffen geothermal plant

The heat plant of Rittershoffen has been developed in order to supply Roquette Frères Company, a bio-refinery, with geothermal heat for their industrial processes. This industrial user, located in Beinheim, France, totals 100 MWth of thermal needs. The geothermal heat plant, with an installed capacity of 27 MWth, is then providing the entire heat production to this company via an isolated heating transport loop of 15 km long (Ravier et al., 2017). The geothermal brine is produced at a temperature of 170°C from a production well, GRT-2 at a depth of 2700 m, penetrating into Triassic sedimentary layers and the top crystalline fractured basement interface (Baujard et al., 2015, Baujard et al., 2017, Figure 1).

The geothermal brine is pumped by a downhole line shaft pump and is flowing through a system of twelve consecutive tubular heat exchangers, (Ravier et al., 2016), and is fully reinjected without additional pump at an average temperature of 80°C into one injection well, GRT-1, having a depth of 2500 m (Figure 1). The geothermal plant has been successfully producing heat under commercial conditions since June 2016.

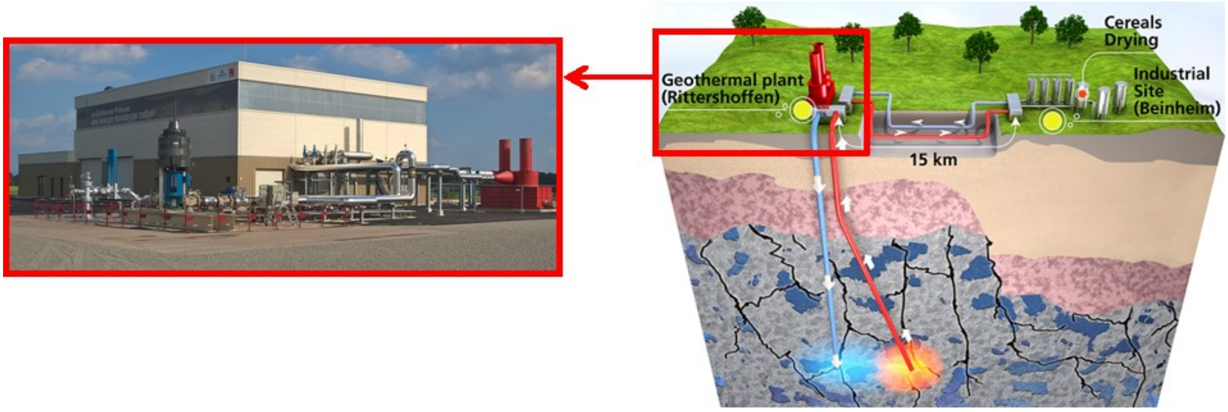

Figure 1: Sketch of the Rittershoffen geothermal project (source ES).

2. NON CONDENSABLE GAS EMISSION ASSESMENT

2.1. Origin of NCGs emission

The geothermal brine is a Na-Cl-Ca dominated brine (Mouchot et al., 2018), with a salinity of 100 g/L and a gas-liquid-ratio of 1:1. Main dissolved gas is CO_2 with a proportion of 89% in volume and the rest is mainly N_2 and CH_4, respectively 9% and 2% (Figure 2). He and Ar are present in minimal quantities, less than 0.3% each. The Gas Break Out (GBO) pressure was measured on site with a gas sample assembly designed by the downhole pump supplier (Figure 3). This device, installed on the production wellhead is used to measure the pressure at which NCGs come out of solution. Different measurements at production conditions gave a GBO pressure of about 20 bars.

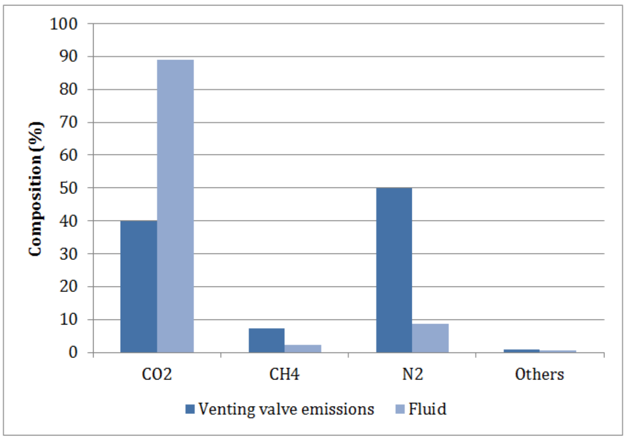

Figure 2: Chemical composition of the gas dissolved in the geothermal fluid and emitted at the degassing valve.

The geothermal heat plant was designed as a surface closed loop. Production wellhead pressure is controlled above the GBO pressure and dissolved gases in the brine are entirely reinjected. However, several small venting valves are installed in different parts of the geothermal loop in order to prevent accumulation of undissolved gas. Gases could come out of solution because of micro-degassing induced by turbulent flow in some part of the geothermal loop. As a consequence, a very small amount of gas is released time to time into the atmosphere.

In 2016, few weeks after the geothermal plant start-up, a gas sampling was performed on a venting valve on the production line at 164°C and 23 bars. Surprisingly, the results indicated that not CO_2 but nitrogen was the main emitted gas (50.0% of the total volume), then CO_2 and CH_4 with respectively 40.0% and 7.4% (Figure 2). Oxygen, hydrogen and Ar are also present in minimal quantities (less than 0.3 % each). This result pointed out that characterizing the gas fraction of the fluid is not sufficient to evaluate the NCGs emissions of a geothermal plant. Thus, a complete assessment of gases emission both in terms of chemistry and quantity is fundamental to understand and prevent degassing phenomena in the surface installation.

Figure 3: View of the gas sample assembly designed by the downhole pump supplier and of a venting valve on the piping installation (source ES).

2.2. Ongoing NCGs emission assessment

A methodology was developed to assess NCGs emission of the Rittershoffen geothermal plant in operational conditions. The aim of this approach is to characterize the chemical composition of gases as well as the total amount of the emissions. The analyses protocol was developed in 2019 and the ongoing measurements launched in second semester of 2019.

2.2.1. NCGs chemical composition

In order to assess the chemical composition of the NCGs emissions of the plant it was decided to perform gas analysis at all the emissions valve representative of different operational conditions of the plant. For this purpose, the 13 venting valves installed on the geothermal loop were mapped and their operation conditions (temperature and pressure) defined. This approach pointed out that the existing venting valves could be classified according to 6 different operation conditions, included between 5 to 25.4 bars and 85°C to 168 °C (Figure 4).

The methodology for gas analysis will thus include: i) sampling of the production and injection brine, ii) sampling at 6 venting valves, representative of the different operation conditions. In order to explore the impact of flow variations on the NCGs composition, wellhead pressure will be reduced during a short time to sample gas released by venting valves at the inlet and outlet of the heat exchangers at lower pressure than normal operating conditions.

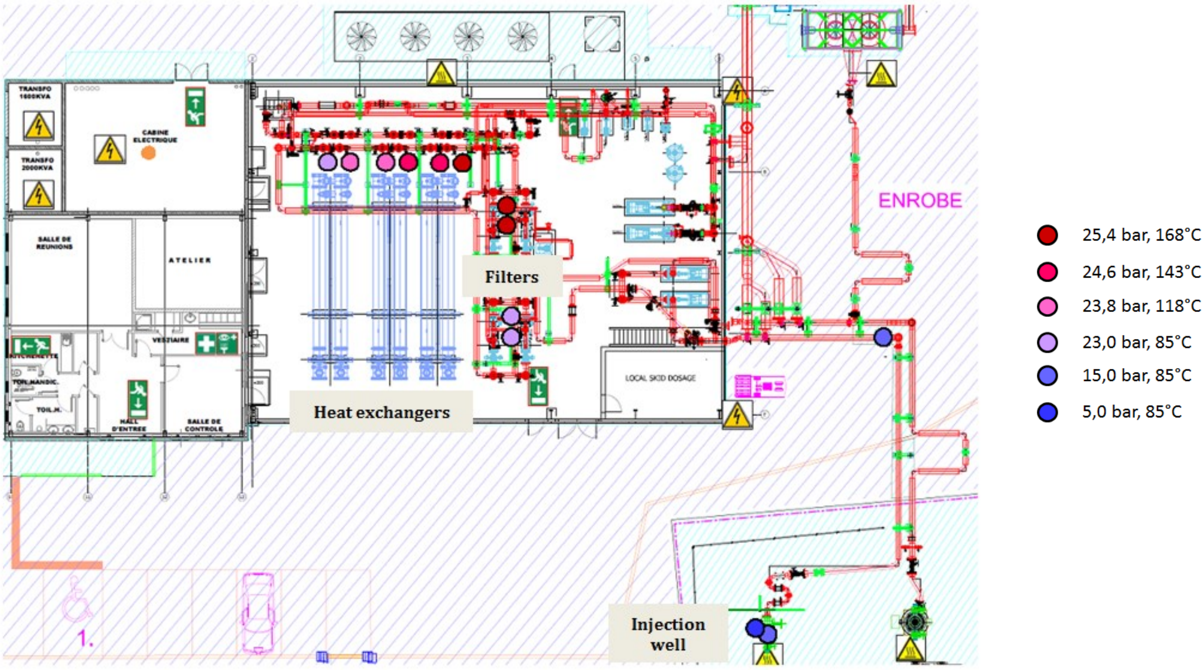

Figure 4: Mapping of the different venting valves on the geothermal loop in function of operation conditions.

A gas sample campaign based on the methodology developed in this study will be performed during the ZoDrEx project. This campaign will give a good overview of the gas chemistry released by venting valves in function of the operation condition and they will be compared to the one of the production and injection brine samples.

2.2.2. NCGs volume quantification

In parallel of the gas chemistry campaign, the quantity of gas released to the atmosphere by the venting valves is also evaluated through two gas flowmeters and a data logger purchased in 2019 (Figure 5). The gas flowmeter is installed at the outlet of venting valves, at ambient pressure condition (Figure 5). It was necessary to adapt exhaust pipe of the venting valves in order to connect the flowmeter, but also to insure with a siphon that no liquid water can be in contact with the sensor, which may very sensitive to the dropping water potentially released with the gas.

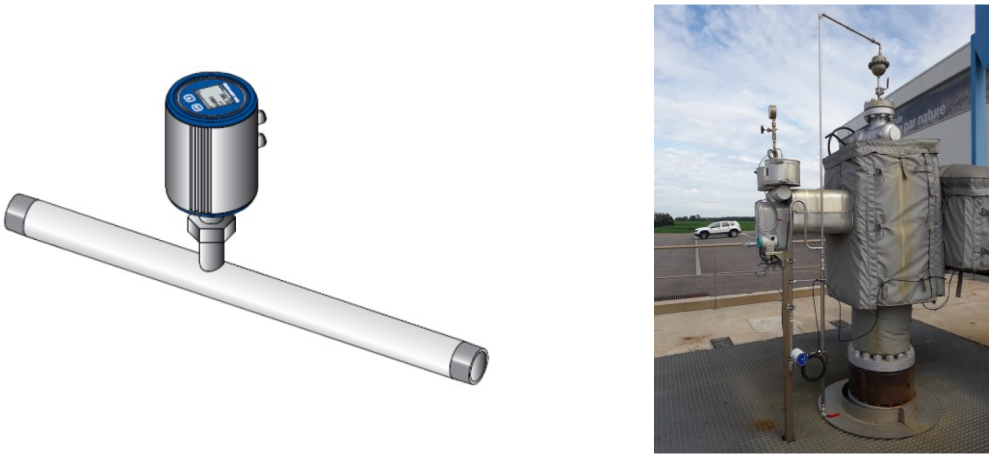

Figure 5: Draft of a gas flowmeter (BEKO) and view of an exhaust pipe at a venting valve of the injection well to connect it (source ES).

The measurement methodology consists to analyze all the venting valve emissions during one month, two at a time. NCGs volume quantification campaign started in July 2019 on two initial venting valves. After the first measurements campaign, that lasts at least 7 months, two to four venting valves will be monitored a second time in order to investigate the reproducibility of the measurements.

3. RADON AND RADIOACTIVE DUST ASSESMENT

Fractured crystalline basement at Rittershoffen is Paleozoic granite, presenting trace amount of U and Th. Consequently, the gas emissions of the plant, as well as the atmosphere around the exploitation site, might be enriched in radioactive atmospheric dust and/or radon-222, a gas produced by the disintegration of Ra-226. Concentrations in radioactive gas and particles might significantly vary depending on the geological context, the soil occupation, the season or even on additional contribution, such as the material used in the surface installation. The Rittershoffen brine presents enrichment in several radionuclides, including Ra 226, U and Th (Figure 6).

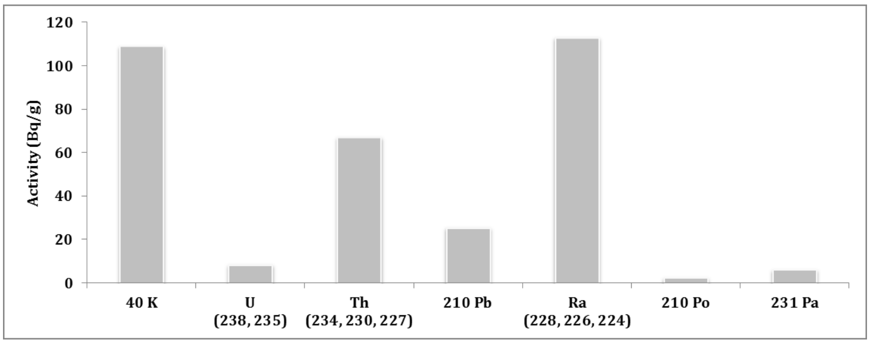

Figure 6: Radionuclides composition of the Rittershoffen geothermal water.

So far, no studies exist on radon and atmospheric dust presence for EGS geothermal plant in the Upper Rhine Graben, despite the well-known risk for the workers, the local population and the physical environment around the geothermal plants induced by their exposure and inhalation. In the scope of the ZoDrEx project, it has thus been decided to extensively evaluate the concentration and repartition of the radioactive atmospheric component at the Rittershoffen geothermal plant.

3.1. French legal context

The protection of workers, local inhabitants and natural environment with respect to the consequences of gas emissions from geothermal activities is afforded respectively through the Labor Law (*Code du Travail, articles R. 4451-136 à 139 et R. 4451-143*) and a Decree about Mining Activities and Underground Storage Activities *(Décret n°2006-649 du 2 juin 2006)*.
Those regulations constraints the owner and, when existing, the operator of the geothermal plant to the implementation of a monitoring plan including:

- Annual monitoring of the radionuclides concentrations in the atmospheric dust at the geothermal site and at the closest public or residential building located downwind of the plant ;
- Annual monitoring of the radon concentrations in the indoor and outdoor atmosphere of the geothermal site and in the air of the closest public or residential building located downwind of the plan ;
- Modalities of information of public and mining authorities about the results of the measurement campaign ;
- Ideally, the measurements of radon and radionuclides concentration before the construction of the plant, in order to characterize the "initial reference state".

As operator of the Rittershoffen plan, ES-Géothermie developed the monitoring strategy, which was conjunctly validated by ECOGI (the owner) and the local mining authority.

3.2. Radon assessment

The characterizations of radon concentration at the Rittershoffen plant is realized following the ISO standard 11665-4 by performing integrative measurements with solid state nuclear tracks detectors (Figure 7). It is a passive method, based on the exposition of a dosimetric film to radon gas and its daughter radionuclides, where Rn concentration is proportional to the fission track observed on the film.

Figure 7: Solid state nuclear tracks detector used for Rn measurements.

The monitoring protocol involves measurements on the geothermal site and on the surrounding environment.

<u>3.2.1. Indoor and outdoor air on the geothermal site</u>

Six points have been selected for indoor Rn analysis (Figure 8):

- The office space (1 point), a closed zone where employers spend a significant amount part of their working time ;
- The waste container zone (1 point), a closed zone where the exploitation industrial wastes, including radioactive material, are stored on site ;
- The equipment installation zone (4 points), a semi-open zone where are installed the heat-exchanger. In this zone, several points have been chosen, corresponding to the air extraction zone, the main circulation zone and the chemical products storage zone. The choice of the measurements points was performed in order to characterize the whole installation surface, but also to study the main critical zones in term of human safety and air circulation.

Five points have been selected for outdoor Rn analysis (Figure 8):

- The storage basin (1 point), where geothermal fluid and mud are stored on the site ;
- The external platform (1 point), on open zone crossed by the production and reinjection pipes ;
- The well caves (2 points), an open zone located below the ground level (- 3m), where preferential concentration of gases may occur ;
- The property limits (1 point). This point will be useful in order to compare Rn variation within the geothermal site and with the external environment.

<u>3.2.2. Outdoor air on the closed private homes downwind of the plant</u>

One point of measure will be realized on outdoor air of private homes (Figure 9). Following the regulation, the monitored houses should be the closest to the plant in downwind direction. For Rittershoffen geothermal plant, where the dominant wind direction is NE-SW (Figure 9), the selected homes are located at 600 m SW, in the village of Betschdorf. This measurement will allow evaluating the potential risk for local population induced by the geothermal activity.

<u>3.2.3. Outdoor air on the geothermal site before plant commissioning</u>

Ideally, one point of measure should be realized before starting all the activities of civil engineering, well drilling and plant construction. As the Rittershoffen plant is to date already in activity, another point was selected to represent an "initial reference state" for the plant. Due to the complex geological setting of the Upper Rhine Graben, presenting several major and minor faults with different permeability, the definition of the 'initial reference state'' appears to be a challenge. Michel-le pierres et al. (2010) showed important variations of Rn concentrations at Pechelbronn, an old oilfield close to Rittershoffen geothermal plant, related to major and minor regional faults, whose permeability enhanced natural radon convection. In addition to be localized in similar conditions with the exploited Rittershoffen's fault, the "initial reference state" site needs to be localized out of the local dominant winds in order to avoid disturbance from the plant. By consequent, it was decided to define the "initial reference state" site at 1 km North of the plant, following the direction of the main local fault (Figure 9).

3.2.4. Monitoring protocol

The monitoring protocol involve measurements performed by the end of 2019 during 1 month and repeated twice in order to take into account the variability induced by external factors. As no analyses were performed before, the initial campaign has been conceived to be totally exhaustive. In the future, the frequency, the duration and the number of analyses will be adjusted depending on the obtained results and on the evolution of the geothermal activity conditions.

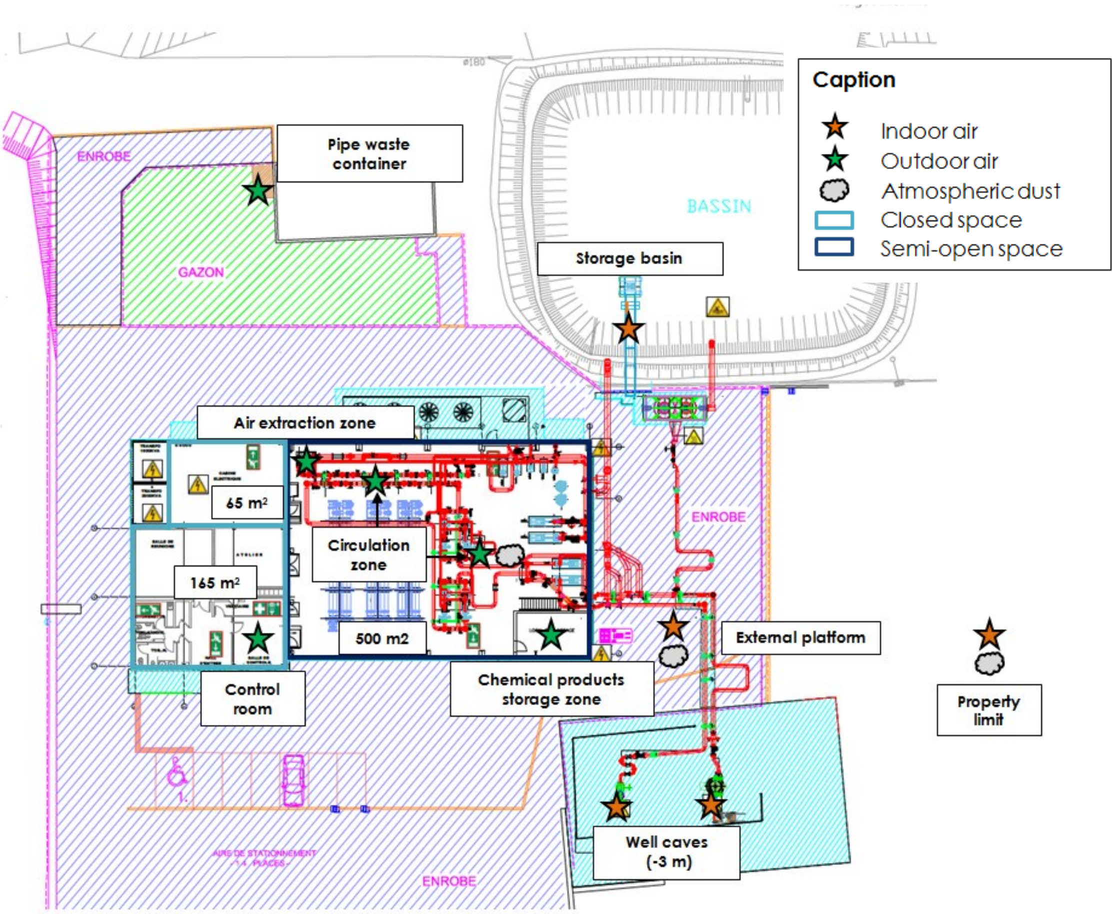

Figure 8: Location of Rn and radioactive atmospheric particles measurement points at the geothermal plant of Rittershoffen.

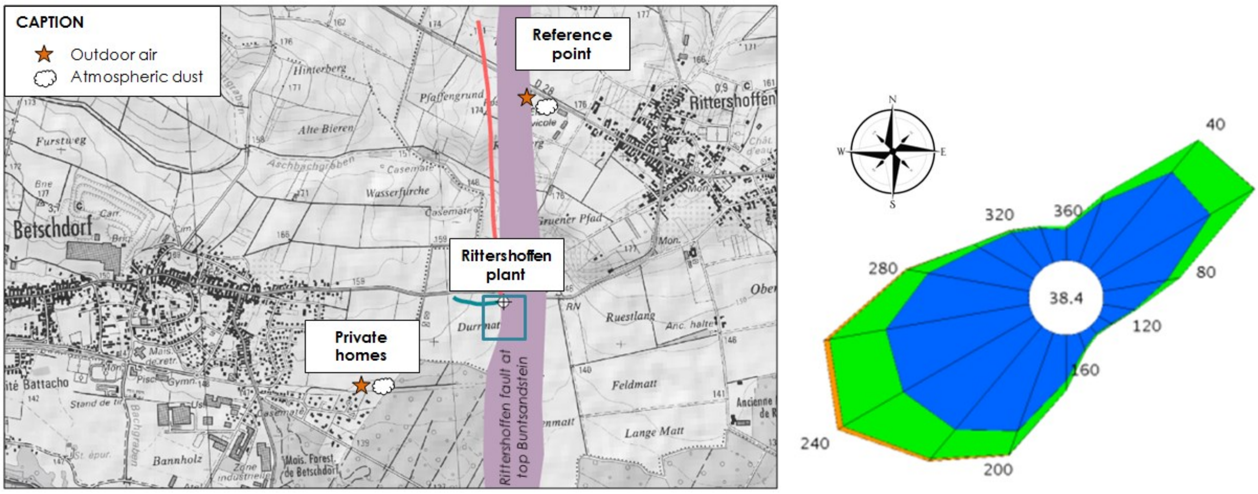

Figure 9: Location of Rn and radioactive atmospheric particles measurement points at the closest private home (Betschdorf) and as "initial reference state" and wind rose calculated for the geothermal plant of Rittershoffen.

3.3. Radioactive dust assessment

The characterizations of radioactive particles present in atmospheric dust at the Rittershoffen plant is realized following the ISO standard 11665-2 by performing integrative measurements with an *in situ* alpha dosimeter (Figure 10). Using a dosimeter allows measuring alpha emissions issued by Rn nuclides (Rn-222 and Rn-220) as well as by the alpha-emitting radionuclides of the U and Th chains, typically 238-U, 226-Ra, 210-Po, 234-U and 230-Th. At the same time, a filter collects the particles present in the air, whose radionuclides concentrations are analyzed by laboratory procedures. The goal of this analytical approach is to evaluate conjunctly the external and internal exposure of the population.

Figure 10: *In situ* alpha dosimeter for analysis of radioactive particles in the atmospheric dust.

3.3.1. Indoor and outdoor air on the geothermal site

One point has been selected for indoor atmospheric dust analysis and two for outdoor air. The points are located at the semi-open equipment installation zone, at the external platform and at the property limit of the plant (Figure 8).

3.3.2. Outdoor air on the closed private homes downwind of the plant

One point of measure will be realized on outdoor air of private homes. As for Rn, the monitored houses are located at 600 m SW, in the village of Betschdorf (Figure 9).

3.3.3. Outdoor air on the geothermal site before plant commissioning

Similarly to radon emission assessment, a point was selected to represent an "initial reference state" for the plant. This point is located 1 km north of the geothermal plant, up to the Rittershoffen fault and out of the dominant wind direction (Figure 9).

3.3.4. Monitoring protocol

Similarly to the Rn campaign, the monitoring protocol involves measurements on the geothermal site and on the surrounding environment. The analysis are performed during the autumn and winter season 2019/2020 and will last 1 month, duration at which the filter needs to be changed, and will be repeated twice. The frequency, the duration and the number of analysis will be adjusted in the future campaigns depending on the obtained results and on the evolution of the geothermal activity conditions.

4. PERSPECTIVES AND CONCLUSIONS

Analysis of NCGs chemical composition and volume quantification will provide a detailed overview of NCGs release by the venting valves in the atmosphere during operation. The results, and their correlations to operating condition (pressure, flowrate and temperature), will be very useful to perform a model of NCGs emission of the Rittershoffen geothermal plant during operation and evaluate the relative annual NCGs release. This approach will allow to update the Life Cycle Inventory (LCI) and Life Cycle Analyses (LCA) already performed on the Rittershoffen geothermal plant (Pratiwi et al., 2018) with the evaluation of the annual NCGs release.

Rittershoffen geothermal plant is also one of the case studies of the H2020 GEOENVI project, which goal is tackling the environmental concerns for deploying geothermal energy in Europe. Results of NCGs assessment, as well as radon and radioactive dust assessment will also be used in the framework of this H2020 project in the mapping of the environmental impacts and mitigation measures. In particular, results of the site LCI and LCA will be analyzed to generate a simplified model that can be used to evaluate the CO_2 content per thermal kW of the a geothermal heat plant in continental Europe.

The present study will also be useful to better characterize the gas break-out pressure of the geothermal brine, which constitutes to an important parameter for the design of the geothermal pipes and for the downhole pump setting depth. For this purpose, the performed NCGs assessment will be used to optimize the thermodynamic parameters of a numerical model for gas-liquid equilibrium of very salty brine.

Radon and radioactive dust assessment performed in the ZoDrEx project will be the first one on a geothermal plant in operation in France. Results of the campaign will be particularly useful for updating the risk evaluation in terms of exposure and inhalation of workers and local population around the geothermal plants. For this reason, the results will be presented and discussed with the local mining authority. In addition, this first campaign will allow defining the periodicity of the following measurements, which can be adapted in function of the results, especially if no impact is measured on the surrounding population.

Public acceptability of geothermal energy is an important topic for decision makers and natural radioactivity is one of the public concerns in the Upper Rhine Graben area (Chavot et al., 2018; Lagache et al., 2013). Results of the radon and radioactive dust assessment will provide factual data useful to reassure local population surrounding operating or on going geothermal project.

As far as initial assessment was not performed before the drilling and plant start-up in 2016, an "initial reference state" was located in the area of the geothermal plant. Rittershoffen's fault is known to be permeable and thus associated with potential, natural radon emissions, since the two wells of the geothermal plant are crossing it. Thus, results of the radon and radioactive dust assessment of the "initial reference state" will be very interesting to compare with the rest of the measurements and discriminate the impact of the plant operation from the geological context of permeable faults.

Acknowledgements

The authors acknowledge ECOGI for the Rittershoffen geothermal site access. This work was done in the framework of the GEOTHERMICA – ZoDrEx project supported by the European Union's Horizon 2020 research and innovation program under grant agreement N° 731 117. Particular thanks to the French Environment and Energy Management Agency (ADEME), contributing to the ZoDrEx project through the found "Investments for the Future". Financial support by the German Federal Ministry for Economic Affairs and Energy (BMWI) through the collaborative project SUBITO (0325790A) is also thanked.

REFERENCES

Baujard C., Genter A., Maurer V., Dalmais E., Graff J-J., 2015. ECOGI, a new deep EGS project in Alsace, Rhine Graben, France. In: World Geothermal Congress, Melbourne, Australia 19-25 April 2015.

Baujard C., Genter A.,Dalmais E., Maurer V., Hehn R., Rosillette R., Vidal J., Schmittbuhl J., 2017. Hydrothermal characterization of wells GRT-1 and GRT-2 in Rittershoffen, France: Implications on the understanding of natural flow systems in the Rhine Graben, Geothermics, 65, 255-268.

Mouchot J., Cuenot N., Bosia C., Genter A., Seibel O., Ravier G., Scheiber J.: First year of operation from EGS geothermal plants in Alsace, France: scaling issues, Stanford Geothermal Workshop 2018, Stanford, California, USA, 12-14 February 2018.

Chavot, P., Heimlich C., Masseran A., Serrano Y., Zoungrana J., Bodin C., 2018. Social shaping of deep geothermal projects in Alsace: publics, stakeholder attitudes and local democracy, Geothermal Energy, 21, 6-26.

Meier, P. 2020. ZoDrEx an European Endeavour for Optimising Zonal Isolation, Drilling and Exploitation of EGS Projects ; Proceedings World Geothermal Congress 2020 Reykjavik, Iceland, April 26 – May 2, 2020.

Michel-le pierres K., Gal F., Brach M., Guignat S., 2010. Radon, hlium and CO_2 measurements in soils overlying a former exploited oilfiel, Pechelbronn district, Bas-Rhin, France, Journal of Environmental Radioactivity, doi:10.1016/j.jenvrad.2010.05.006

Lagache, L., Genter, A., Baumgartner, J., Cuenot, N., Kolbel, Th., Texier, P., Villadangos, G., (2013). How is evaluated acceptability of an EGS project in Europe: the Soultz-Kutzenhausen geothermal project?. European Geothermal Congress 2013, Pisa, Italy, 3-7 June 2013.

Pratiwi, A., Ravier, G., Genter, A., 2018. Life-cycle climate-change impact assessment of enhanced geothermal system plants in the Upper Rhine Valley, Geothermics 75, 26-39.

Ravier G., Huttenloch P., Scheiber J., Perrot V., Sioly J-L., 2016. Design, manufacturing and commissioning of the ECOGI's heat exchangers at Ritterhsoffen (France): a case study. European Geothermal Conference 2016, Strasbourg, France, 19-24 Sept. 2016.

Ravier G., Harders V., El Aoud M., 2017. Rittershoffen geothermal heat plant. First geothermal heat plant for industrial uses worldwide, EuroHeat&Power, 3/2017 (9973).