P2.3-203

SATEx (Subsurface-Atmosphere Tracer Experiment): Ground truth for the atmospheric detectability of xenon emitted from an underground cavity

Eric Pili[1], Charles Carrigan[2], Caroline Fitoussi[3], Yue Hao[4], Gabriel Couchaux[1]

[1]CEA, DAM, DIF, 91297 Arpajon, France.
[2]Stratify LLC, Livermore, CA, USA.
[3]LGLTPE, ENS Lyon, CNRS, Université Lyon 1, France.
[4]Lawrence Livermore National Laboratory, Livermore, CA, USA.

INTRODUCTION AND MAIN RESULTS

Following an underground nuclear explosion, gas seepage at the ground surface is limited to a very small fraction of the cavity source term. However, a model suggests that these diffuse emissions, integrated in space and time, could constitute an atmospheric source term that is detectable using current technology.

The ongoing SATEx project aims to verify this model by **injecting stable xenon along with SF_6 into an underground cavity and monitoring its seepage in the subsurface and in the atmosphere** at the Roselend Natural Laboratory (French Alps), a highly instrumented research facility dedicated to the study of underground nuclear test detection.

SnT 2025
8 SEPTEMBER ONLINE DAY
9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

SATEx (Subsurface-Atmosphere Tracer Experiment): Ground truth for the atmospheric detectability of xenon emitted from an underground cavity

Eric Pili, Charles Carrigan, Caroline Fitoussi, Yue Hao, Gabriel Couchaux

P2.3-203

The Roselend Natural Laboratory

The Roselend Natural Laboratory is a **unique facility dedicated to studying gas migration** through hard rock and soil under natural conditions at the field-scale.

This facility is composed of an **underground tunnel** terminated with a **cavity enclosed by an airtight bulkhead** and the land 55 meters above it. This facility is small enough to enable strong control of the conditions and relatively rapid tracer breakthrough; yet large enough to encompass the variability of all parameters.

The Roselend Natural Laboratory builds on **more than 30 years** of geophysical, geochemical and hydrological scientific research.

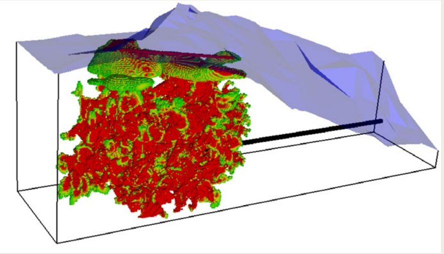
Past injections of SF_6 and other tracers into the cavity, along with breakthrough monitoring in the subsurface proved the concept. **The SATEx project is distinctive in its focus on the geosphere-atmosphere coupling**.

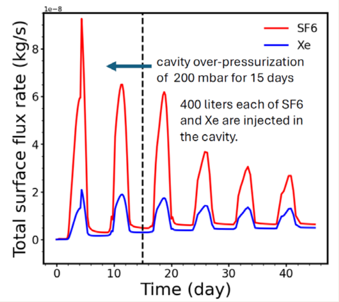
In the context of the SATEx project, **additional dedicated devices** were installed, including:

- a **rapid and large-volume atmospheric air sampling system** enables to fill scuba cylinders (15 liters, 300 bar),
- a **chromatographic device using Ag-zeolite columns to enrich Xe and SF_6, coupled with a magnetic-sector mass spectrometer**, enables highly sensitive detection of tracer breakthrough.

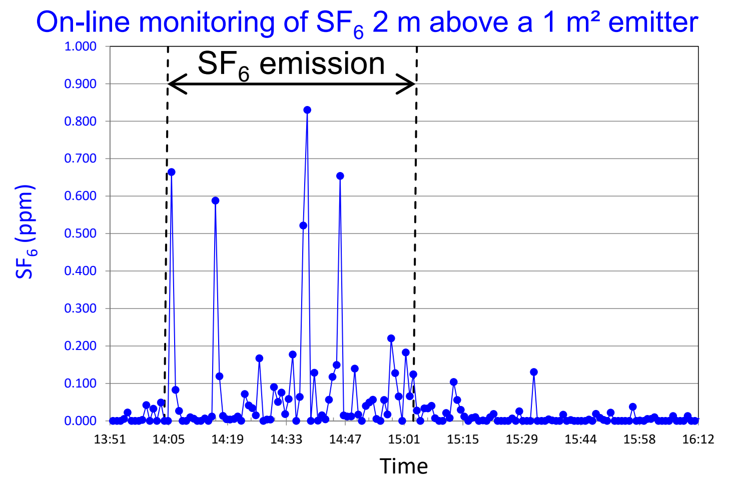
Preliminary results

A high-resolution dual-continuum fracture model, calibrated using prior tracer tests, was employed to simulate Xe and SF_6 transport and estimate the minimal quantity of tracer required for detection in the atmosphere above the seepage zone:

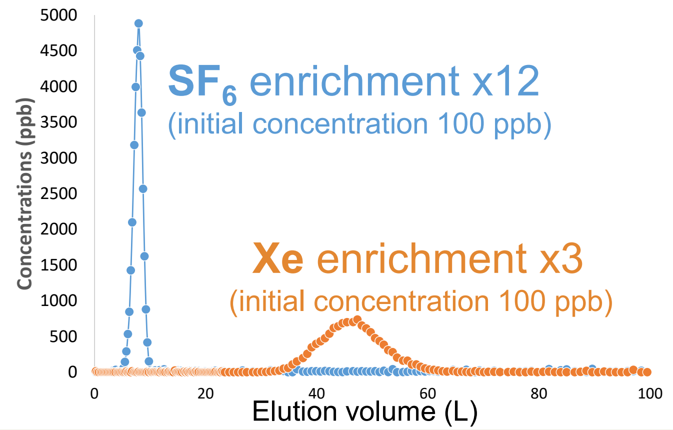




A **ground-to-atmosphere tracer test** was performed to quantify the atmospheric dilution (10 liters of pure SF_6 emitted during 1 hour over a 1 m² surface area with a variable wind, < 3 m/s):



Coupling of chromatographic Ag-zeolite columns with a magnetic-sector mass spectrometer:



What's next?

Summer 2026: **Injection of 450 liters of Xe and 900 liters of SF_6**, well-mixed, in the underground cavity, further pressurized to +200 mbar

Long-term and high-resolution monitoring of tracer breakthrough in the subsurface and in the atmosphere above the expected seepage area, at increasing distances from ground 0.

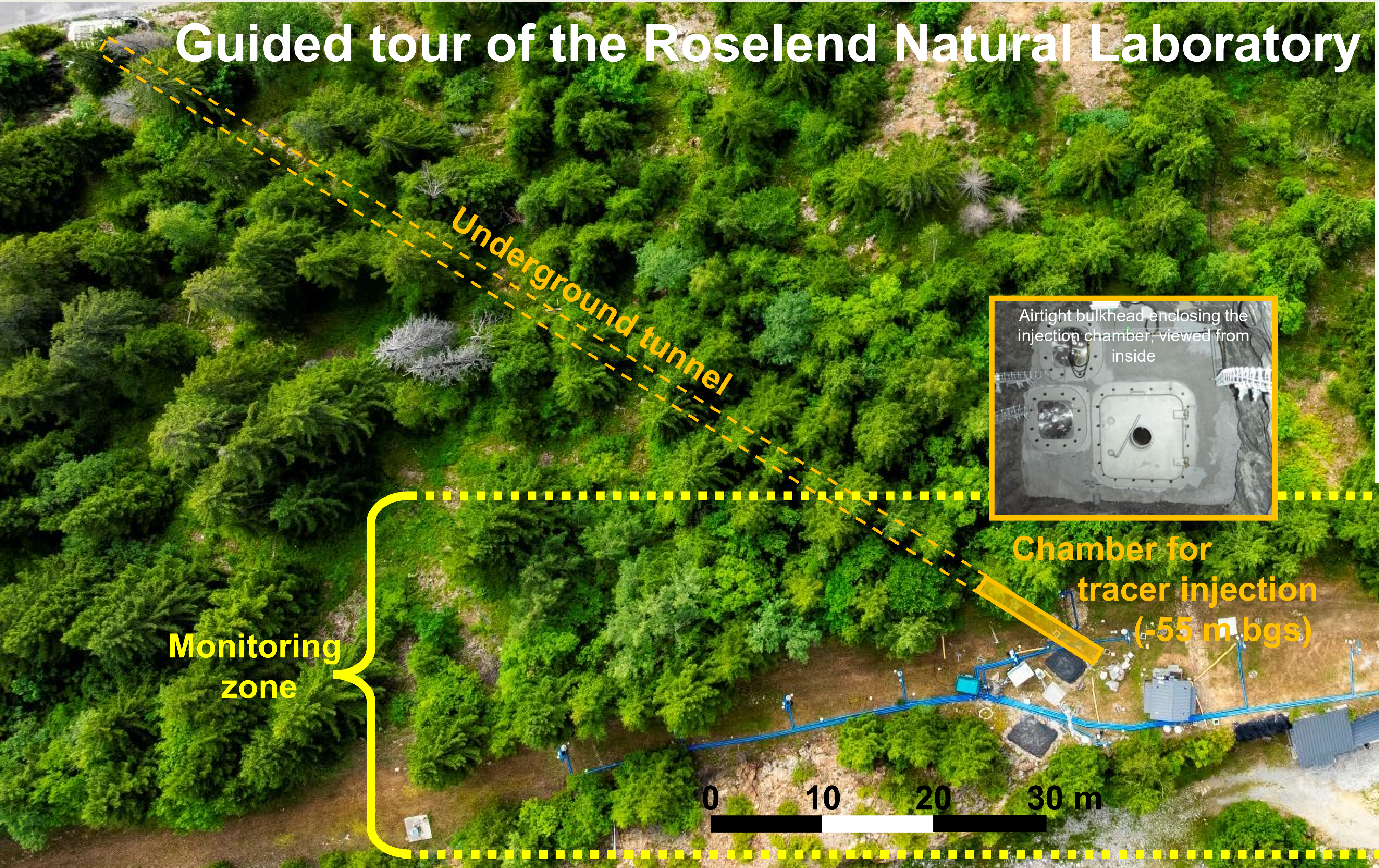
Particular attention given to the Xe/SF_6 ratios as well as the Xe and SF_6 concentrations vs. sampled volumes.

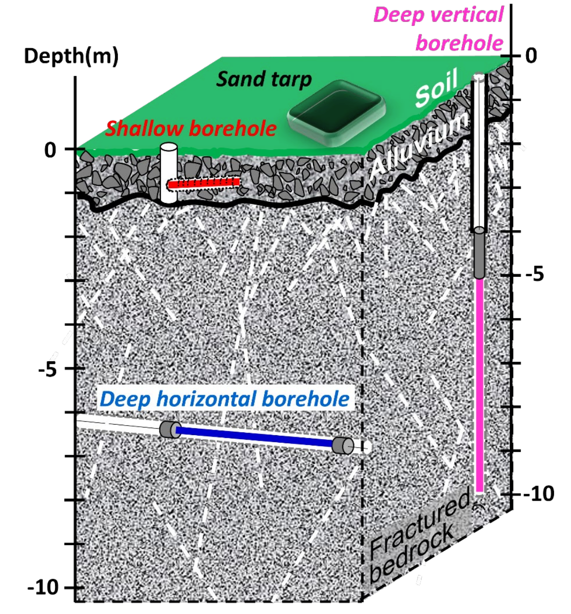
SnT 2025
8 SEPTEMBER
9 TO 12 SEPTEMBER
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

SATEx (Subsurface-Atmosphere Tracer Experiment): Ground truth for the atmospheric detectability of xenon emitted from an underground cavity

Eric Pili, Charles Carrigan, Caroline Fitoussi, Yue Hao, Gabriel Couchaux

P2.3-203



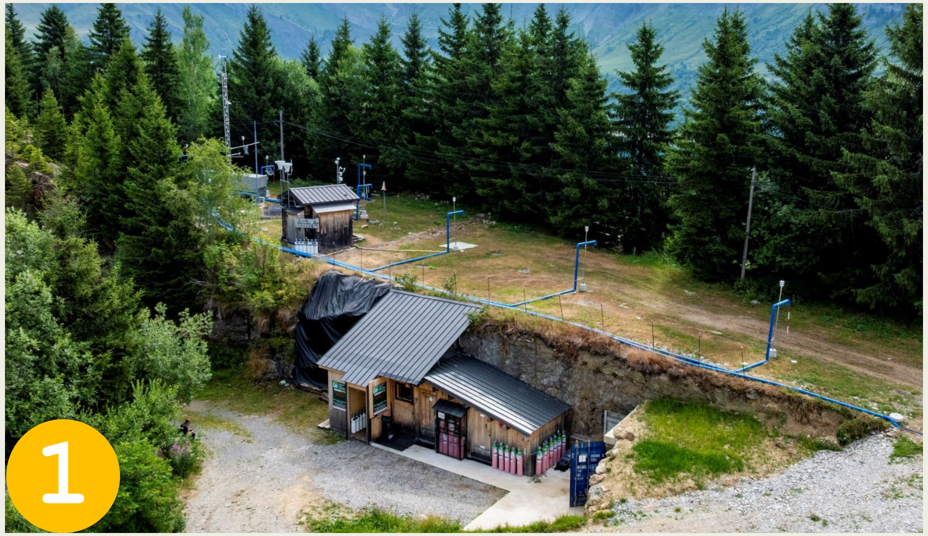


Variety of the devices used to monitor gas concentrations and fluxes in the subsurface.

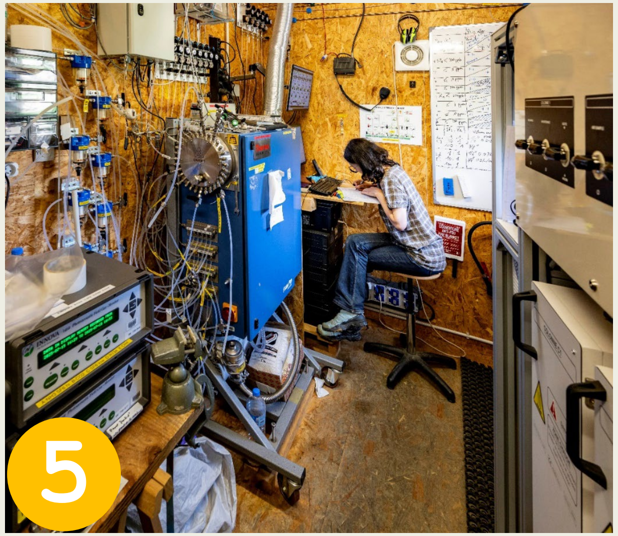
SATEx (Subsurface-Atmosphere Tracer Experiment): Ground truth for the atmospheric detectability of xenon emitted from an underground cavity

Eric Pili, Charles Carrigan, Caroline Fitoussi, Yue Hao, Gabriel Couchaux

P2.3-203



Guided tour of the Subsurface-Atmosphere Tracer Experiment



1. General view of the **monitoring zone above the injection chamber** that terminates the underground tunnel, with the atmospheric air sampling system network (Atmoduc), the meteorological stations and various shelters.
2. Close-up view of the **air sampling system network (Atmoduc).** The **meteorological conditions** are **monitored at each sampling point** for visualization of the transport of air masses.
3. Air masses transport is further visualized thanks to a **smoke generator** and a **bubble machine**.
4. Two compressors enable **scuba cylinders (15 liters, 300 bar)** to be filled rapidly with atmospheric air drawn through the Atmoduc at selected points according of the visualized transport of air masses.
5. The subsurface monitoring devices are plumbed directly to analytical devices (including a **mass spectrometer**) for analyses of tracer concentrations and naturally-occurring gas species. Air samples from scuba bottles are processed through a chromatographic device using **Ag-zeolite columns to enrich Xe and SF_6**, enabling highly sensitive detection of tracer breakthrough.
6. View of the **Xe and SF6 injection facility** near the airtight bulkhead of the underground cavity. A blower enables the cavity to be pressurized to +300 mbar.