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PREPARATORY COMMISSION

COMPREHENSIVE
NUCLEAR-TEST-BAN
TREATY ORGANIZATION

A Software Tool for Exploring Scientific Methods to Estimate the Radioxenon Background with more Confidence

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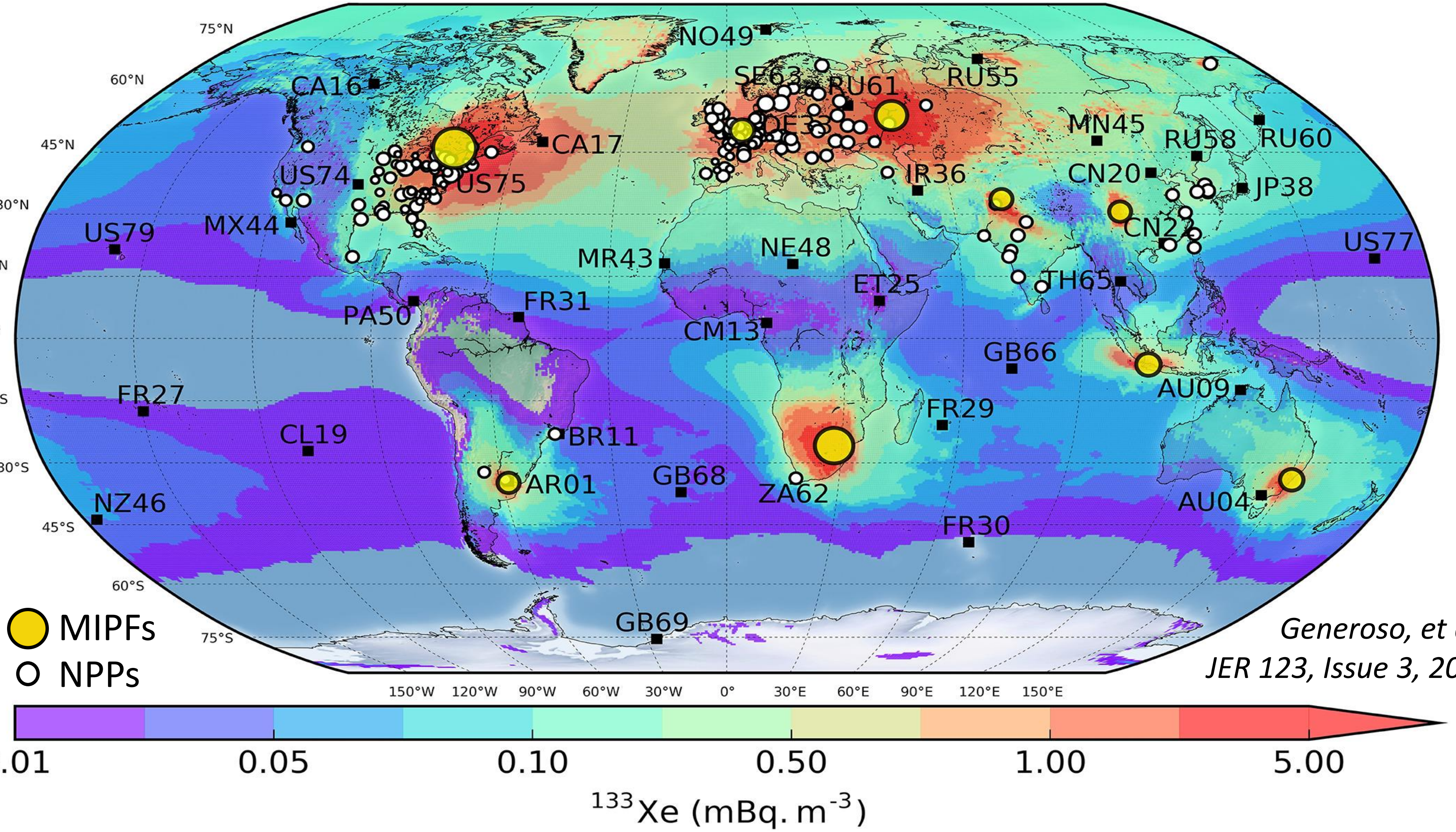
Jolanta Kuśmierczyk-Michulec, Martin Kalinowski, Mark Prior

The persistent presence of up to four non-naturally occurring CTBT-relevant radioxenons in a highly dynamic atmosphere makes a positive association of an IMS detection with a nuclear test challenging.



Generoso, et al., JER 123, Issue 3, 2018

^{131m}Xe	(11.96 days)
^{133m}Xe	(5.244 days)
^{133}Xe	(2.198 days)
^{135}Xe	(9.143 hours)

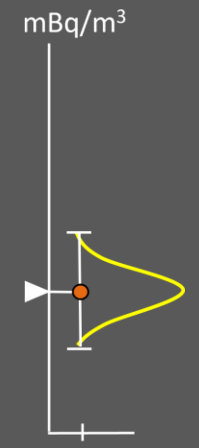
*Compute the **influence** of specific **xenon sources** on IMS observations by associating the stations' sample data (**receptor**) with data from emissions (**source**) through source-receptor sensitivity ATM data (**transport**).*

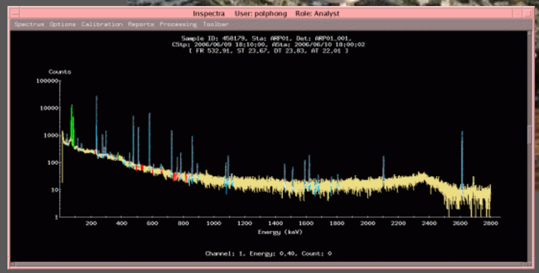
With more confidence

Data (products) from the CTBTO

IMS RN **stations**: noble gas (NG) sample data for detection

- Globally collected high-quality samples.
- Data with statistics inside (Gaussian)
  - Quantity: **Activity concentration (mBq m^{-3})**
  - Space: Point source, locations fixed
  - Time: Every 6, 12, or 24 hours (depending on sample system version)





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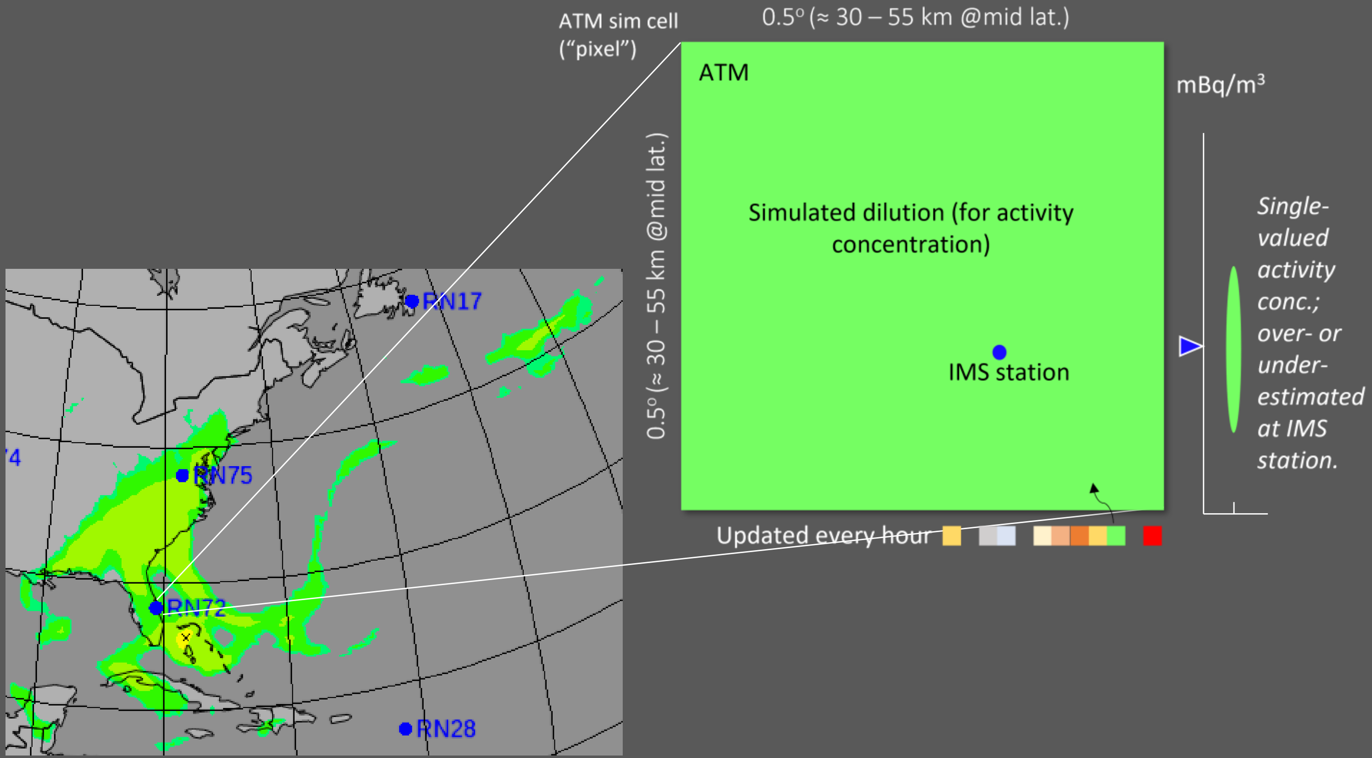
With more confidence

Data (products) from the CTBTO

ATM pipeline: atmospheric **transport** modelling data

- Using high-quality global weather data to link radioisotope detections at IMS stations with nuclear explosions (and v.v.).
- Data with no statistics inside:
    - Quantity: Dispersion of tracers given as a **dilution (m^{-3})** or **activity concentration ($mBq\ m^{-3}$)**
    - Space: 0.5° x 0.5°
    - Time: 1 hour



*Compute the **influence** of specific **xenon sources** on IMS observations by associating the stations' sample data (**receptor**) with data from emissions (**source**) through source-receptor sensitivity ATM data (**transport**).*

With more confidence

Non-CTBTO data

Established noble gas sources (emissions from MIPFs, NPPs, and NRRs)

- Quantity: **Activity (Bq)**
- Space: Point source, locations fixed
- Time: ***Fragmented*** timeframes and averages; low and high granularity
  - mean day course;
  - weekly source variation (difference between days of the week);
  - monthly / seasonal source variation (difference between weeks/months of the year);
  - an annual average?;
  - downtimes of the facility (times with zero emissions).

"*Integrate a flag in the operational environment; update Reviewed Radionuclide Report according to its outcome.*"

Current *background estimation* efforts at the IDC

- Background estimation
- Source term estimation – *background as input*
- Data fusion – *implicitly (future)*

Optimization and probabilistic approaches/methods:

- Inverse modelling; linear regression
- Bayesian inference
- Monte Carlo

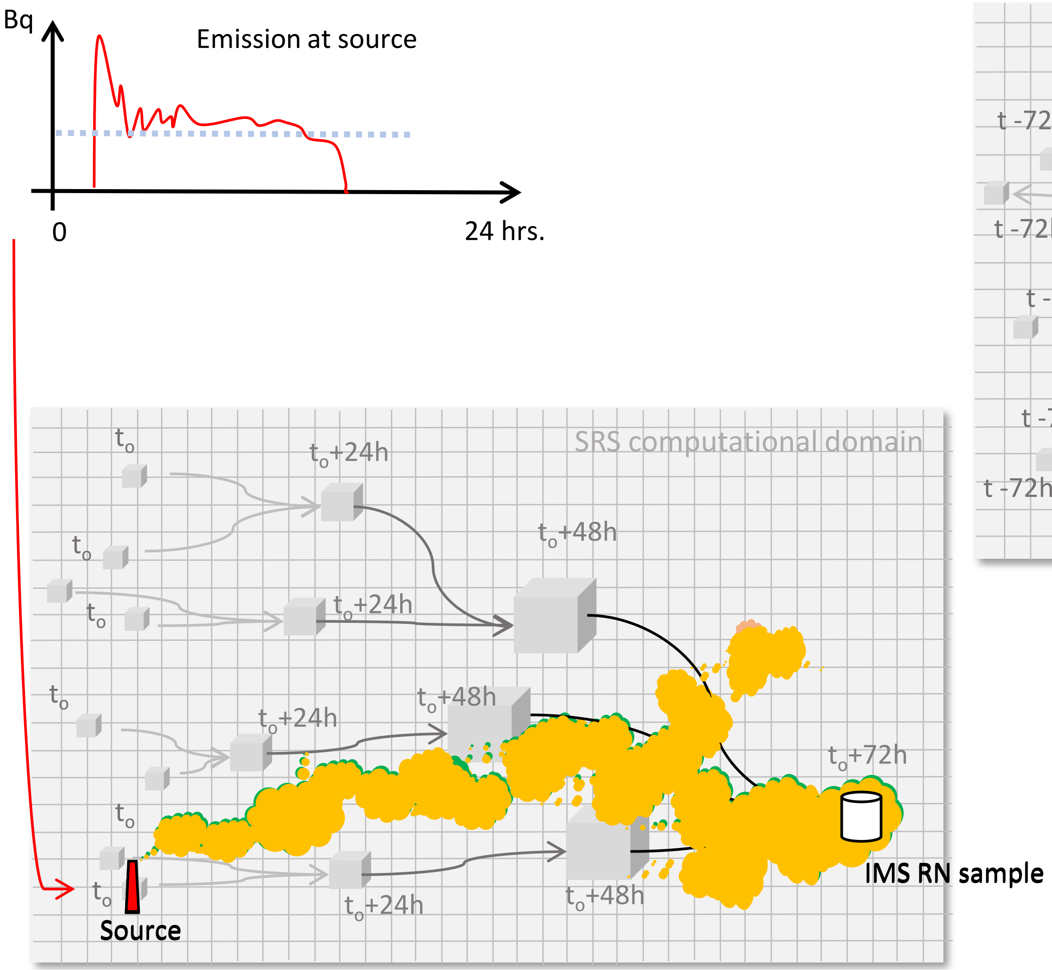
Monte Carlo methods

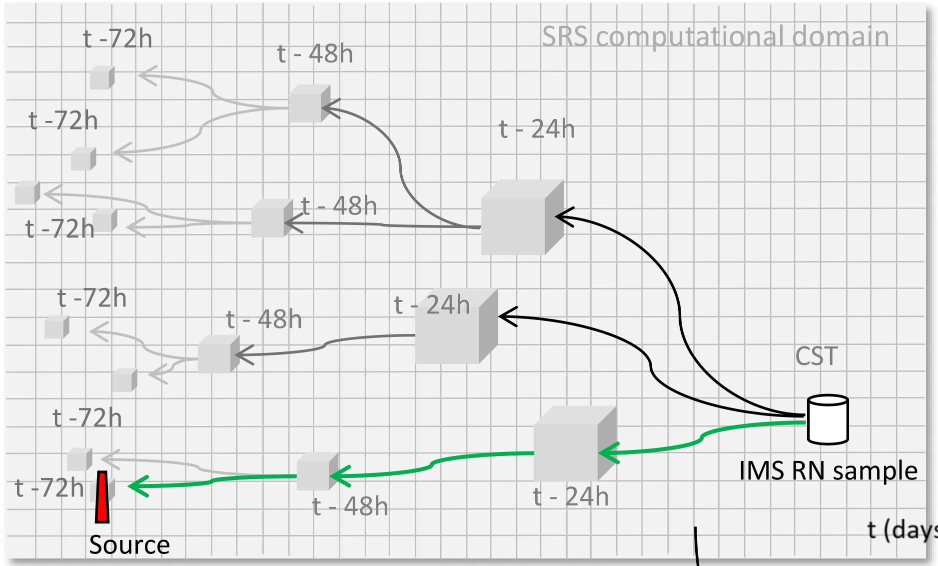
Stochastically obtaining numerical results for optimization, numerical integration, or generating draws from a probability distribution.

We compute the probability density of the ATM predicted activity concentration for one sample by generating daily draws from an emission probability density function and scaling them by deterministic source-receptor sensitivity values over a 14-day transmission window.

✓ **Joshua Kunkle, et al.**, *Evaluation of methodologies for forming a global view of radionuclide release events and their application to the data fusion pipeline at the CTBTO*, WOSMIP IX 2023.

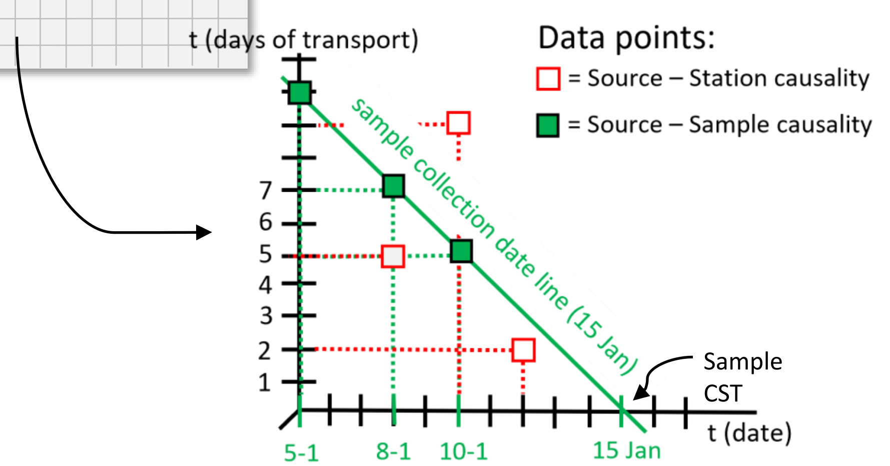
✓ **Yuichi Kijima, et al.**, *Investigating the radioxenon probability density function at IMS stations using a Monte Carlo approach for background estimation*, WOSMIP IX 2023.



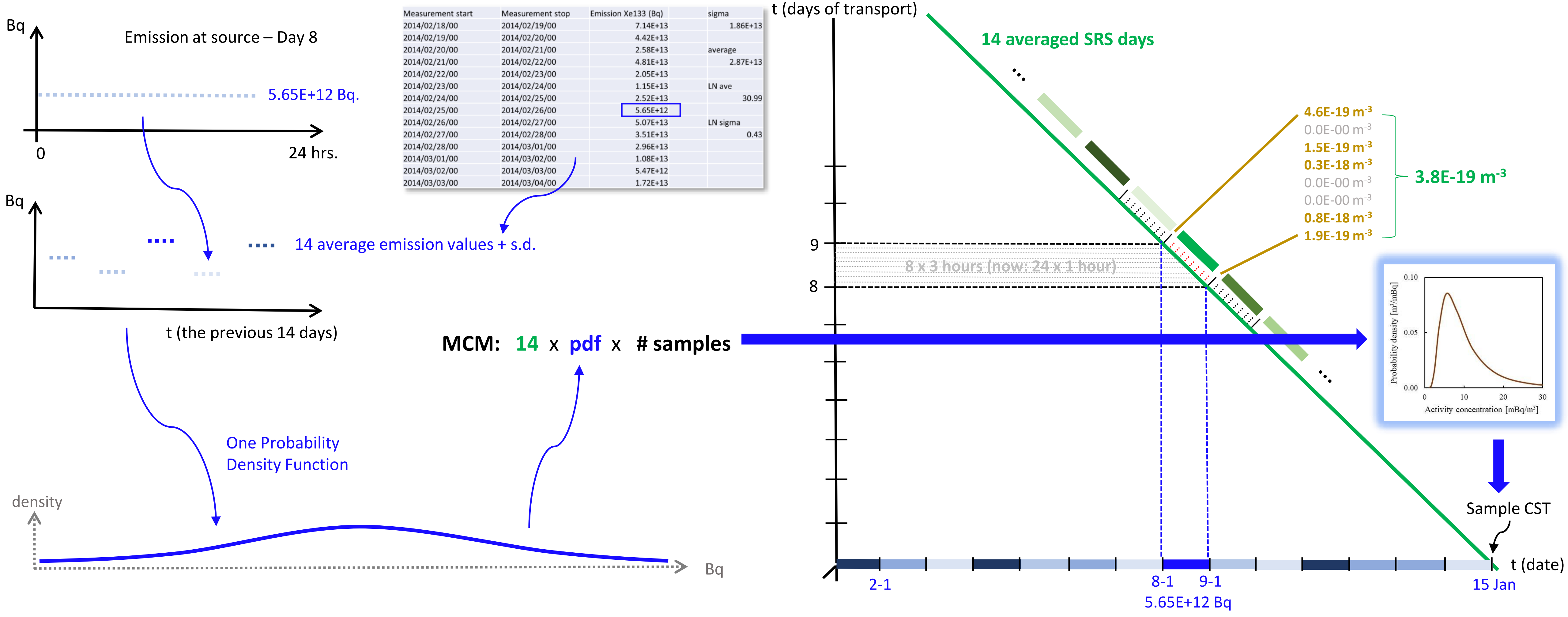


ATM in backward mode is used to **identify the origin of the associated air masses** if an IMS station detects an elevated level of radionuclides in a particular day and station.

Standard IDC product:
14-day backward SRS



Measurement start	Measurement stop	Emission Xe133 (Bq)	sigma
2014/02/18/00	2014/02/19/00	7.14E+13	1.86E+13
2014/02/19/00	2014/02/20/00	4.42E+13	
2014/02/20/00	2014/02/21/00	2.58E+13	average
2014/02/21/00	2014/02/22/00	4.81E+13	2.87E+13
2014/02/22/00	2014/02/23/00	2.05E+13	
2014/02/23/00	2014/02/24/00	1.15E+13	LN ave
2014/02/24/00	2014/02/25/00	2.52E+13	30.99
2014/02/25/00	2014/02/26/00	5.65E+12	
2014/02/26/00	2014/02/27/00	5.07E+13	LN sigma
2014/02/27/00	2014/02/28/00	3.51E+13	0.43
2014/02/28/00	2014/03/01/00	2.96E+13	
2014/03/01/00	2014/03/02/00	1.08E+13	
2014/03/02/00	2014/03/03/00	5.47E+12	
2014/03/03/00	2014/03/04/00	1.72E+13	



Frontend layer *(GUI)*:

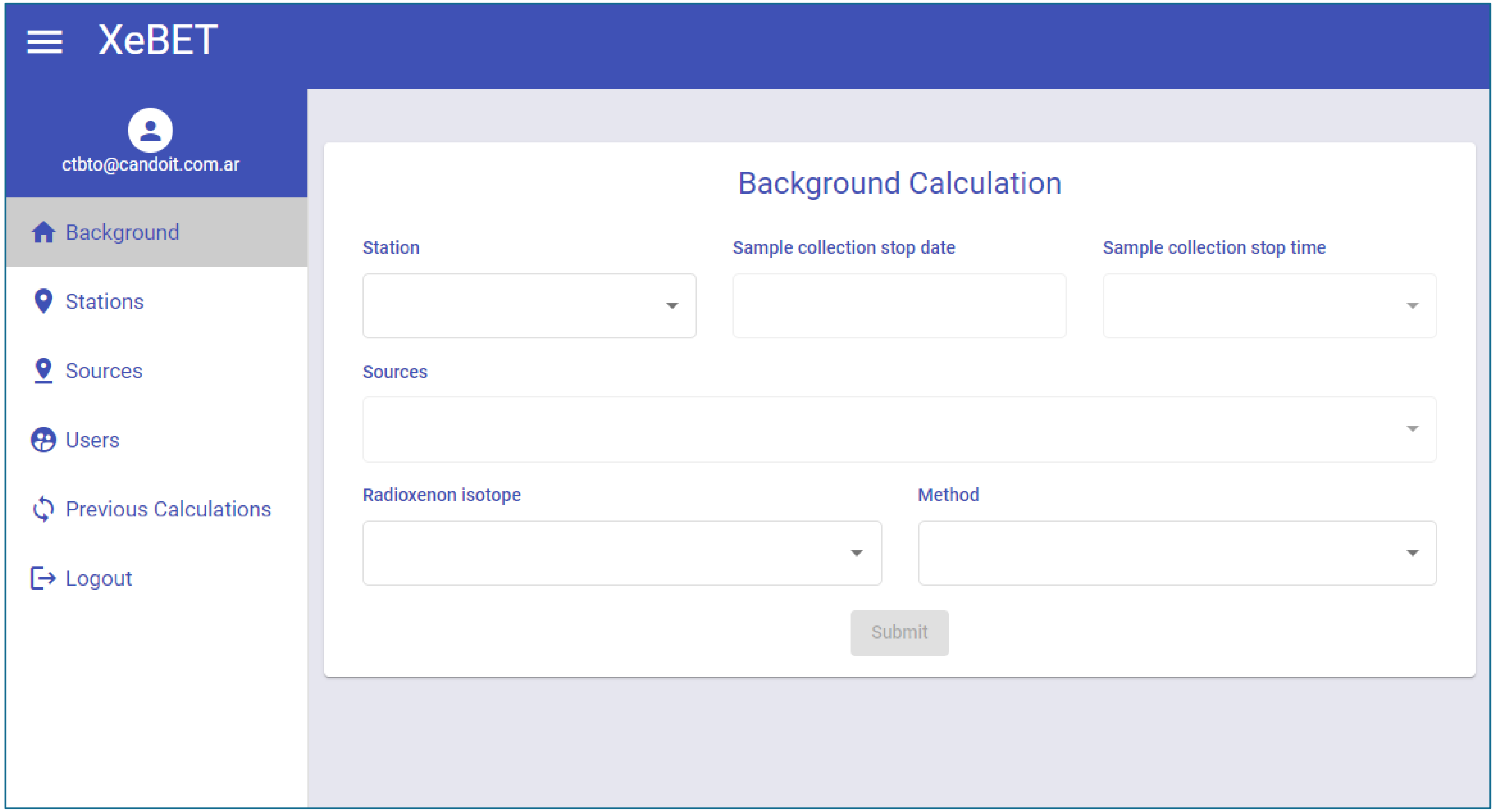
- **Station and sample**: *date/time*
- **Known source(s)**: for 14-day prior
- **Emission strength**: *PDF (time)*
  - ✓ *2014 data set*
- **Radioxenons**
- **Method**

Functional layer *(methods)*:

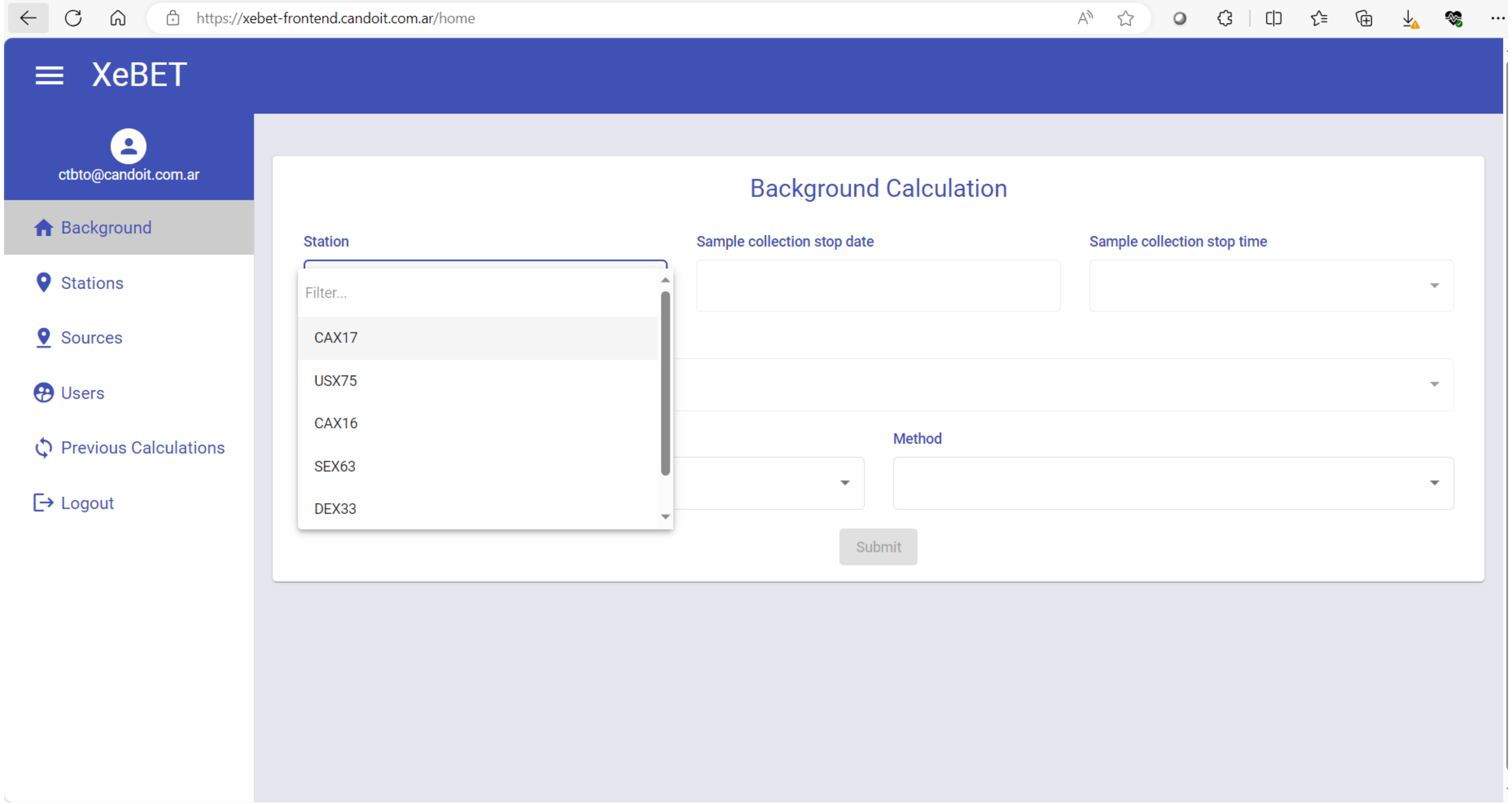
- Monte Carlo method**

Backend layer *(data)*:

- IMS RN (NG) detections database
- ATM SRS files
- Any emission data available



* **XeBET**: Xenon Background Estimation Tool
** **Kijima, Y. et al.**, *Using a Monte Carlo Approach to Determine the Radioxenon Probability Density Function at an IMS Station for Background Estimation,* WOSMIP IX 2023.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Background
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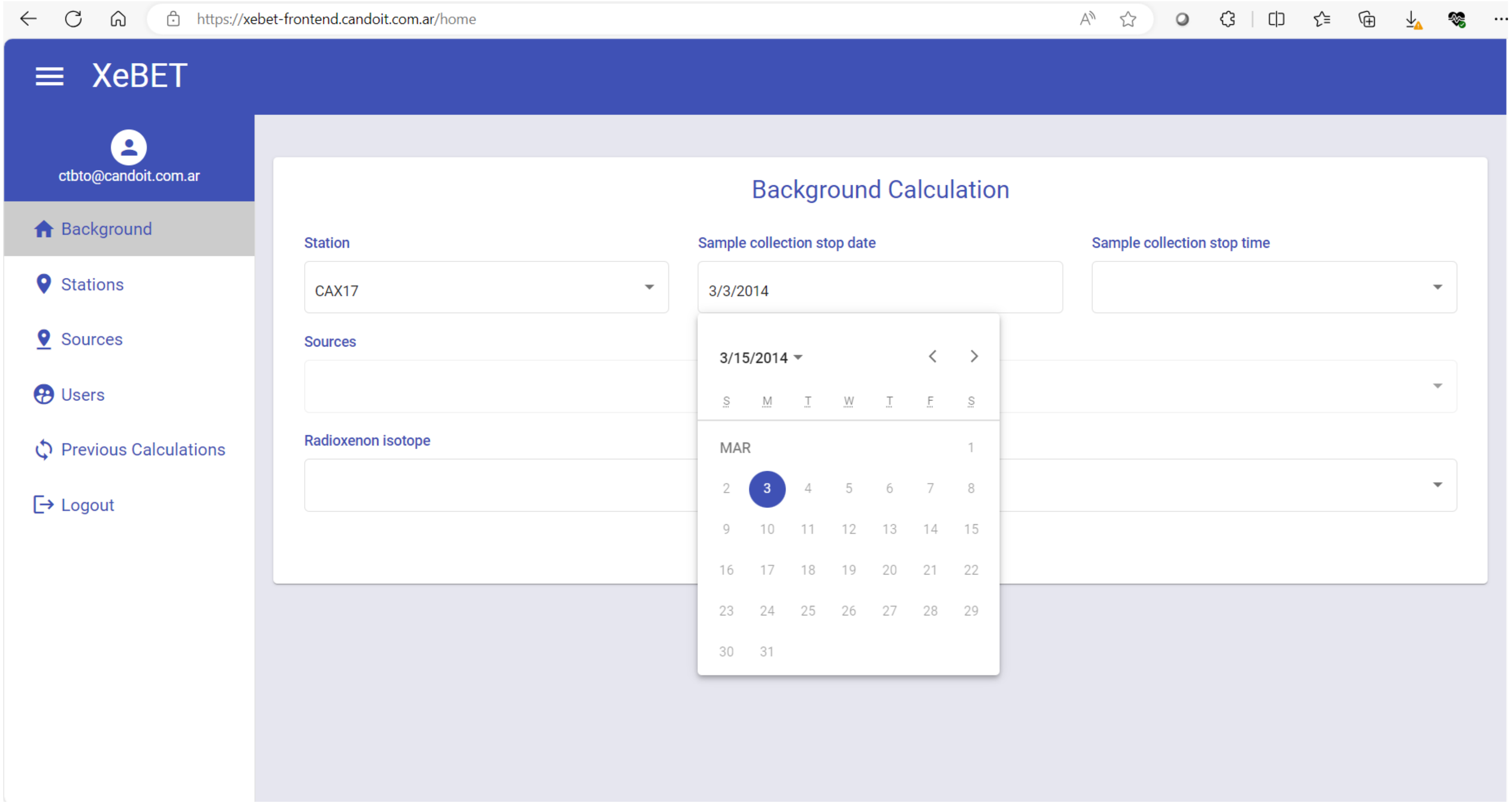
Sample collection stop time
Filter...
CAX17
USX75
CAX16
SEX63
DEX33
Method
Submit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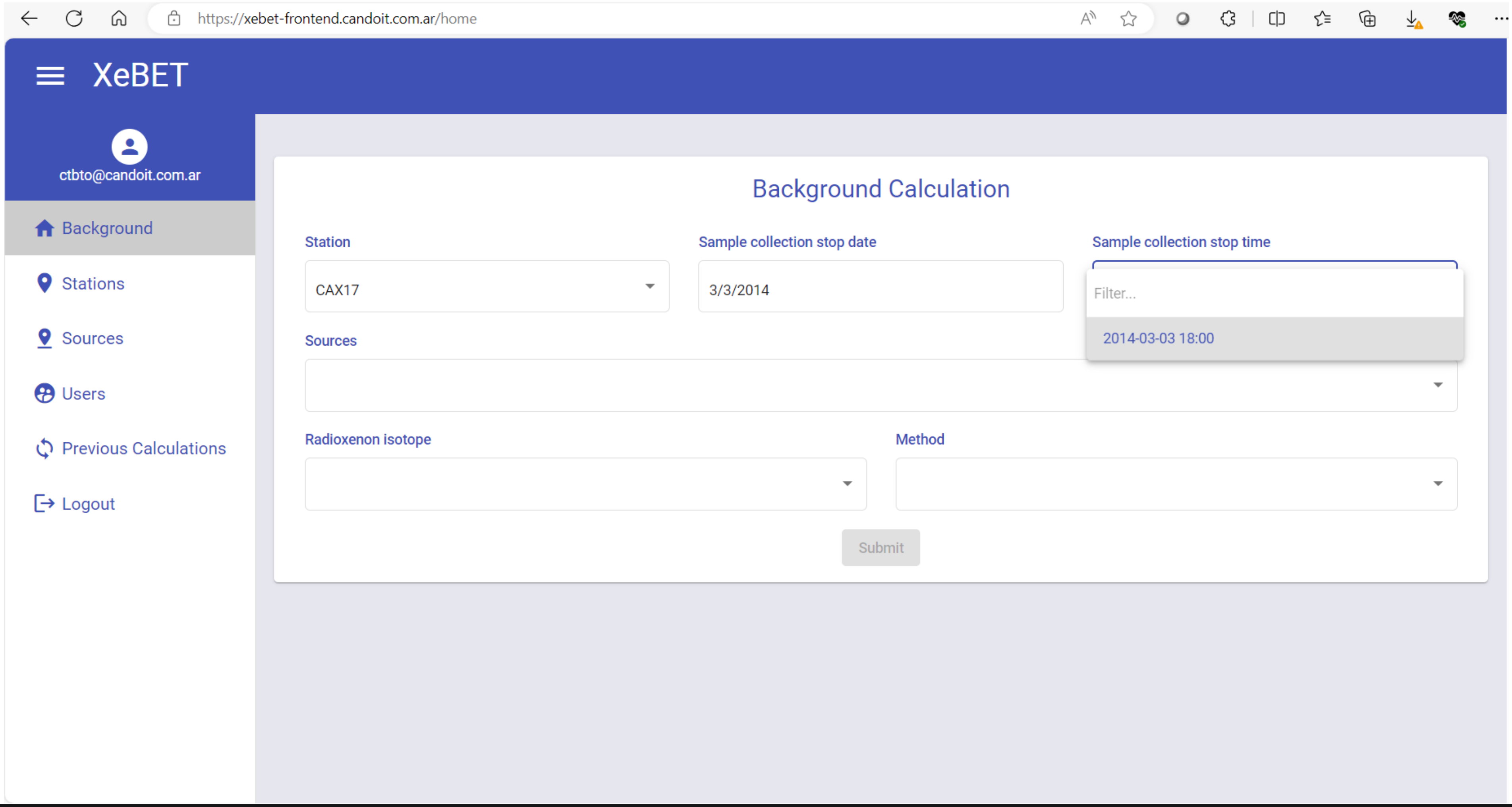
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Radioxenon isotope
Method
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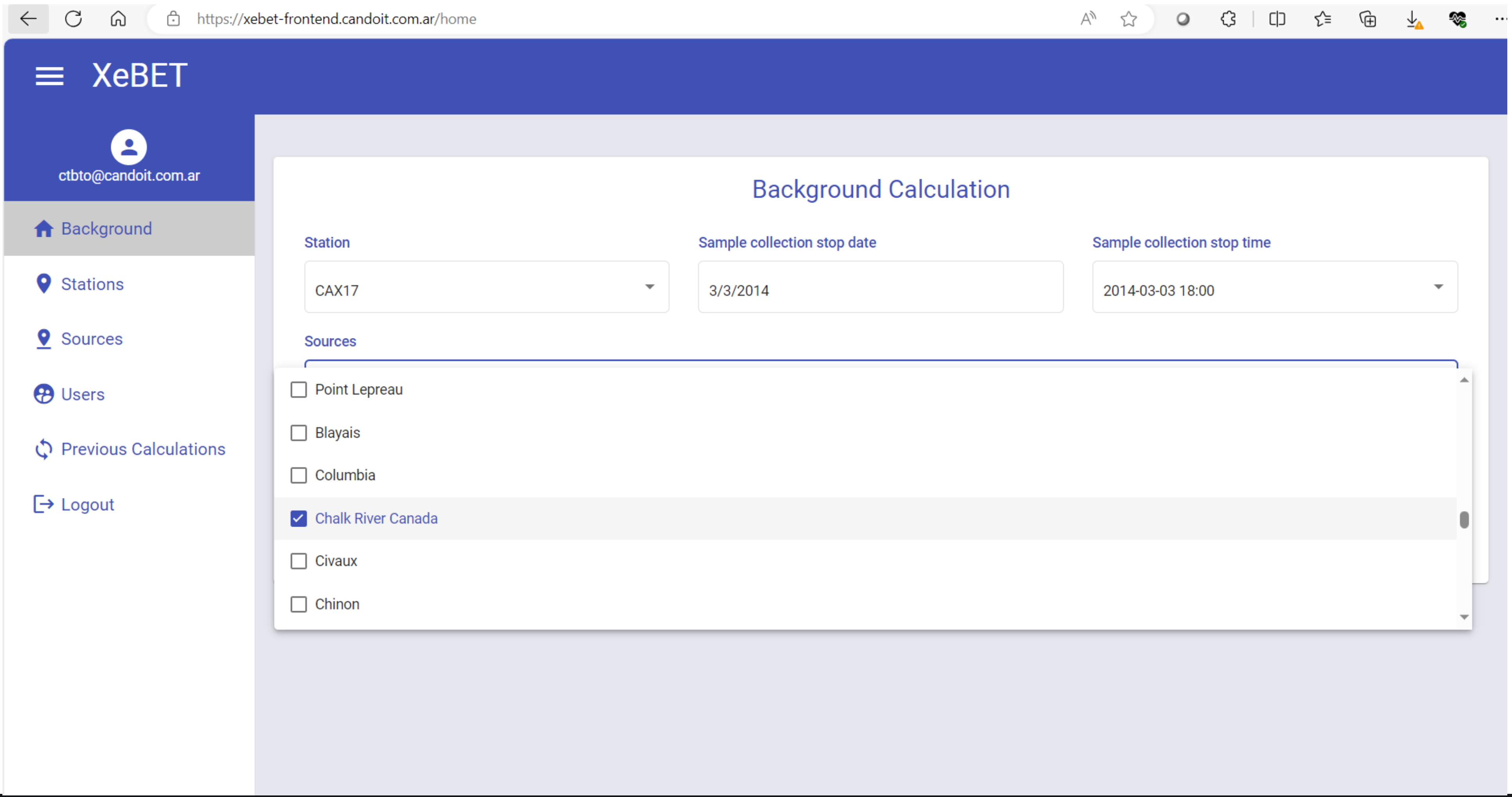

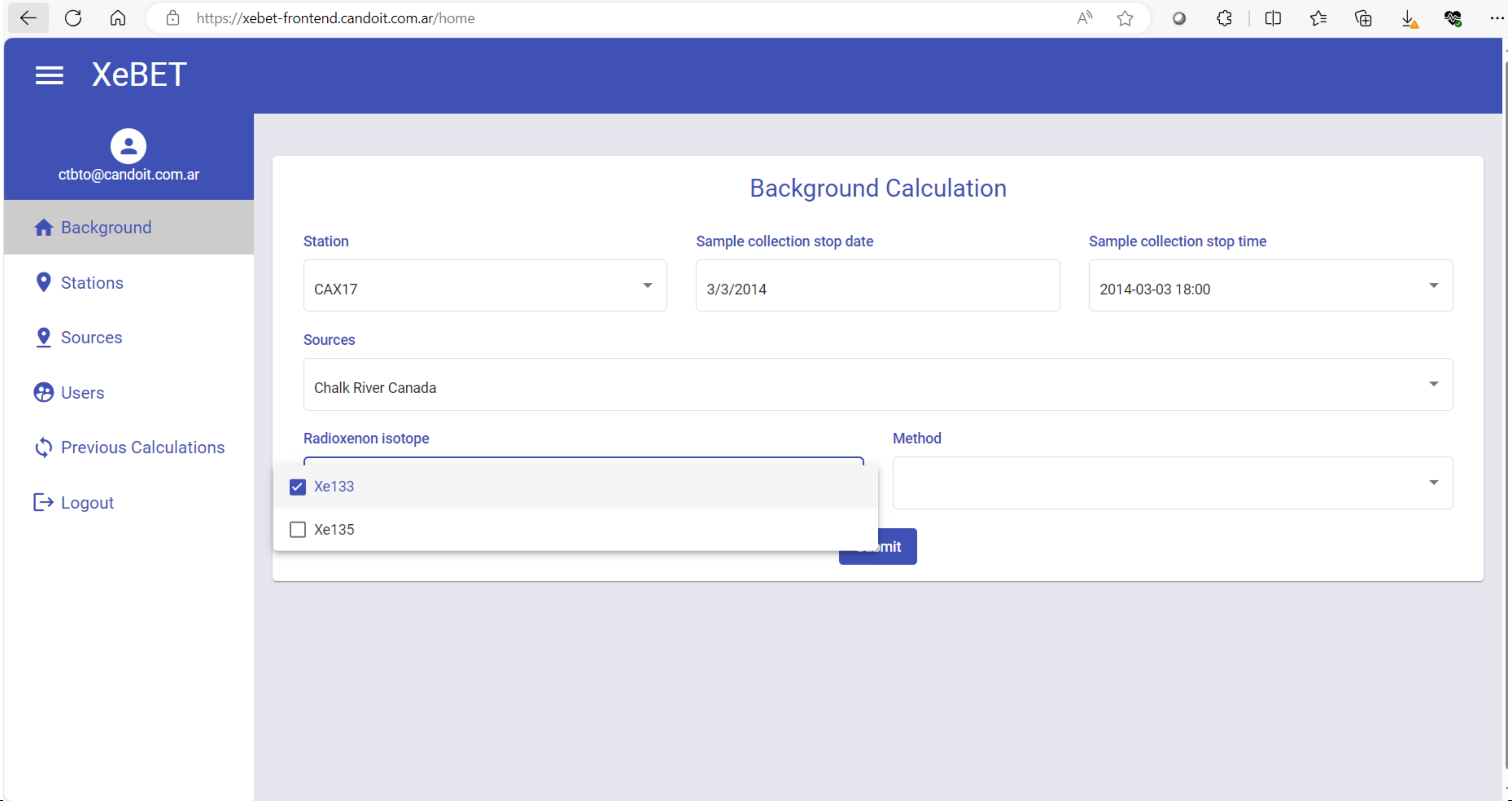
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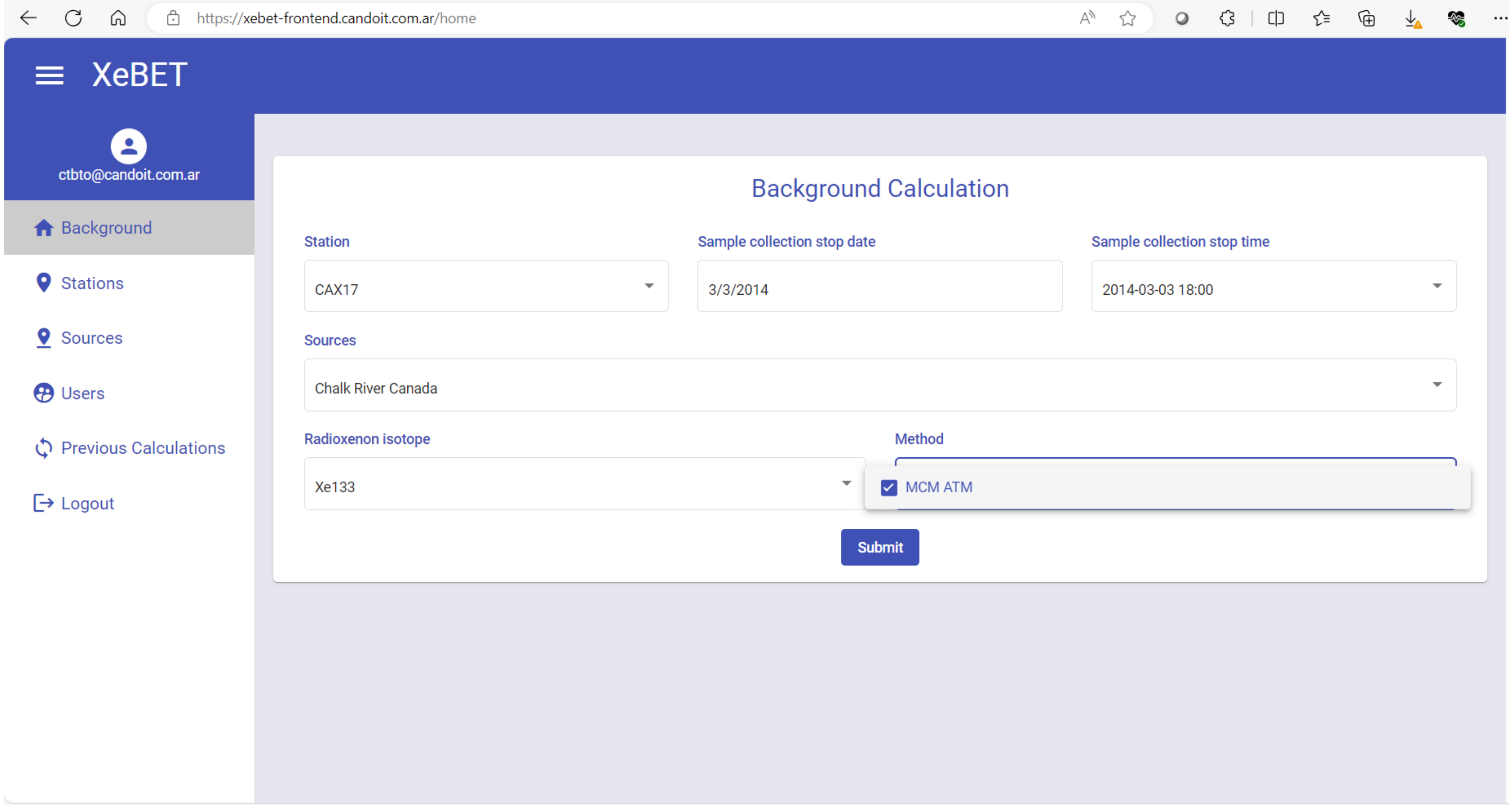
Chalk River Canada
Radioxenon isotope
Xe133
Xe135
Method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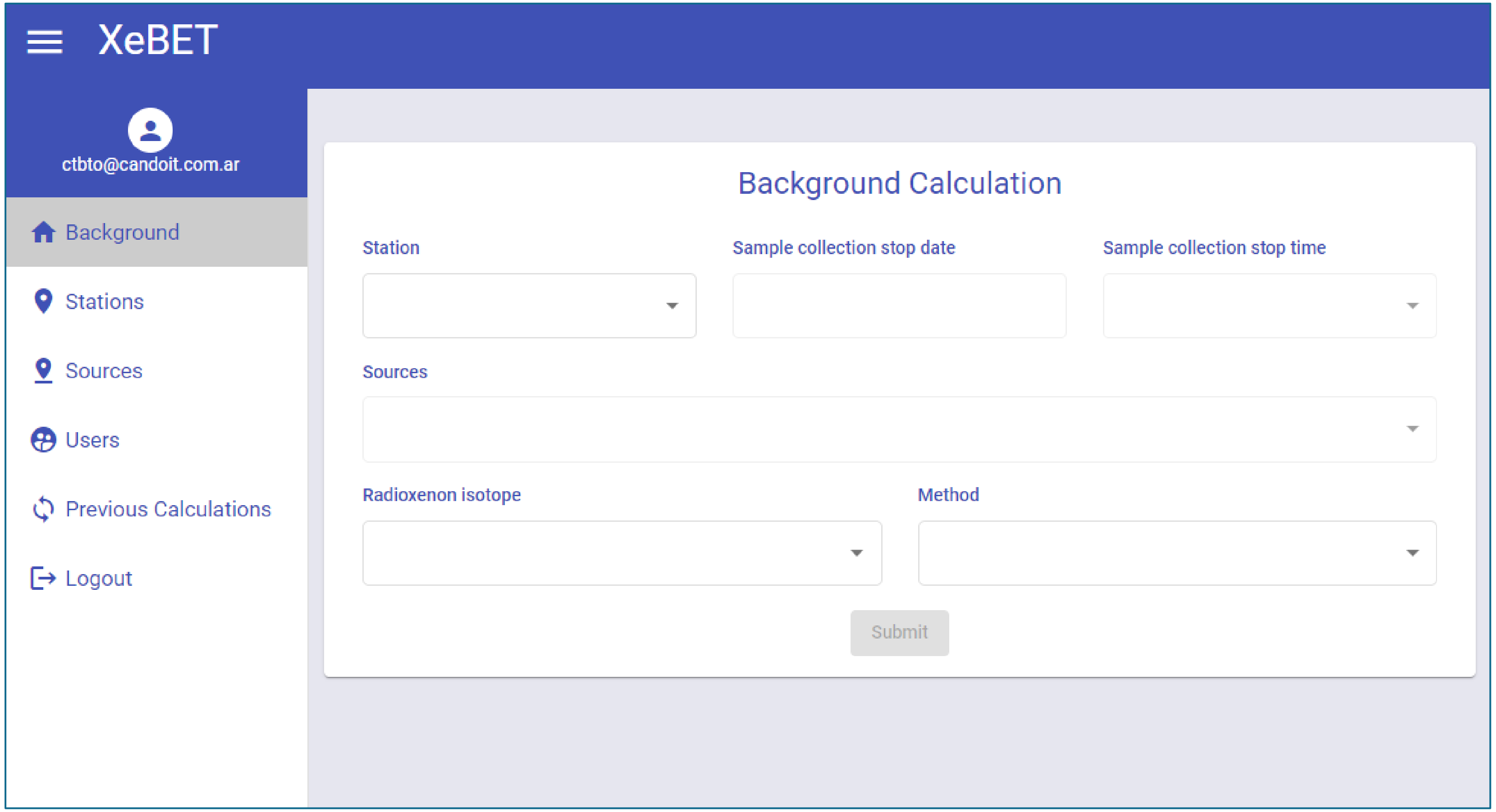
Sample collection stop date
3/3/2014
Sample collection stop time
2014-03-03 18:00
Sources
Chalk River Canada
Radioxenon isotope
Xe133
Method
MCM ATM
Submit

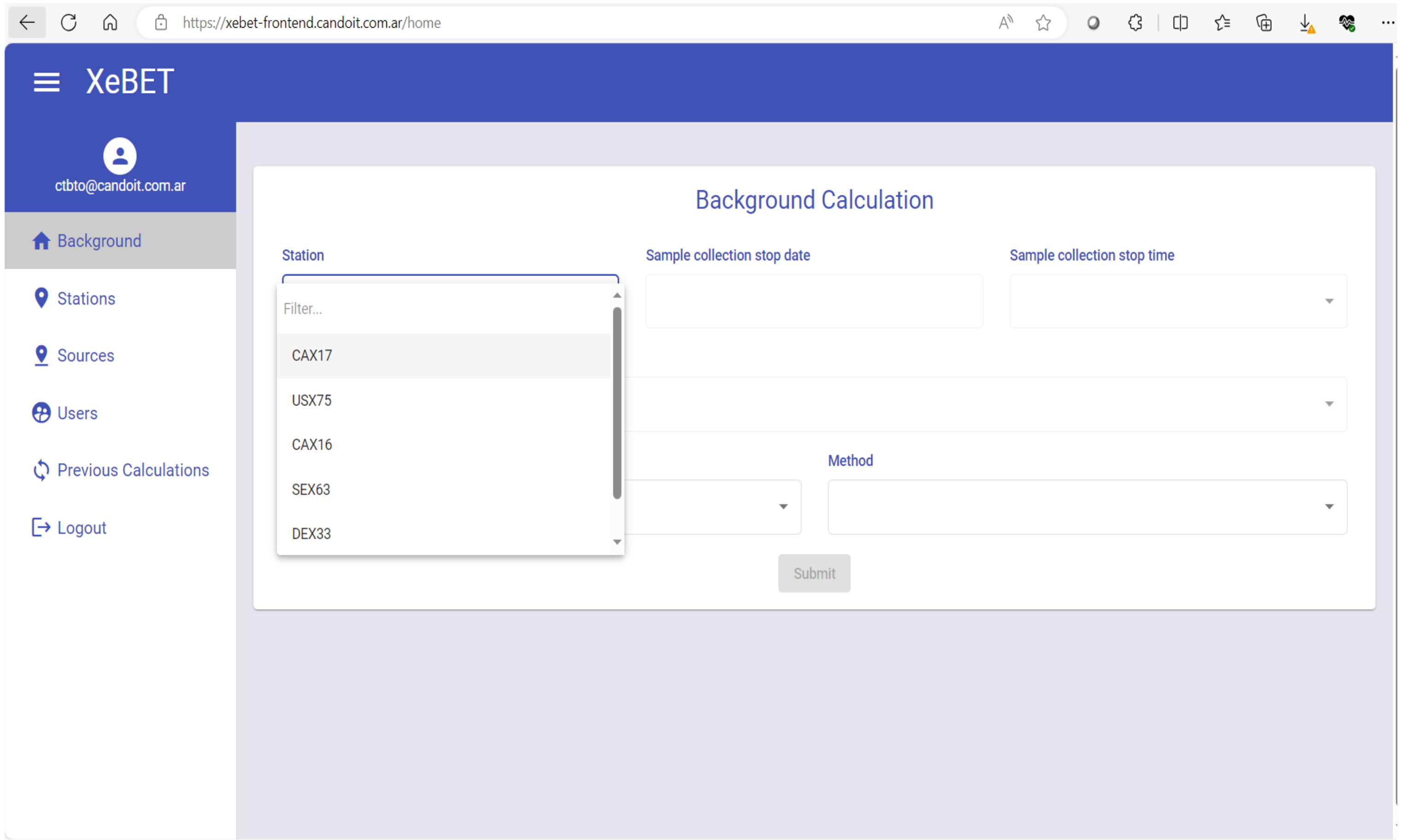
Demo

Use case 1[*]: 3 March 2014
One source contribution to CAX17:
- Chalk River (CNL)

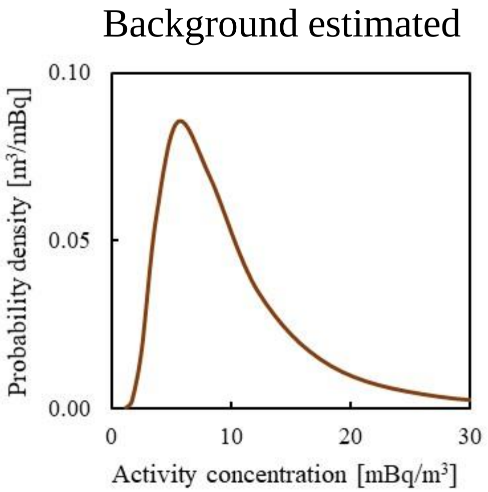
Use case 2[*]: 26 January 2014
Multiple source contributions to USX75:
- Chalk River (CNL)
- LaSalle County Generation Station
- ?



[*] **Kijima, Y. et al.**, *Using a Monte Carlo Approach to Determine the Radioxenon Probability Density Function at an IMS Station for Background Estimation*, WOSMIP IX 2023.



Use case 1[*]



* *"The mean value of the background for CAX17 (in St. John's, Canada) on 3 March 2014 is 7.3 mBq/m3. On the other hand, the measured activity concentration is 8.3 mBq/m3."*

[*] **Kijima, Y. et al.**, *Using a Monte Carlo Approach to Determine the Radioxenon Probability Density Function at an IMS Station for Background Estimation*, WOSMIP IX 2023.

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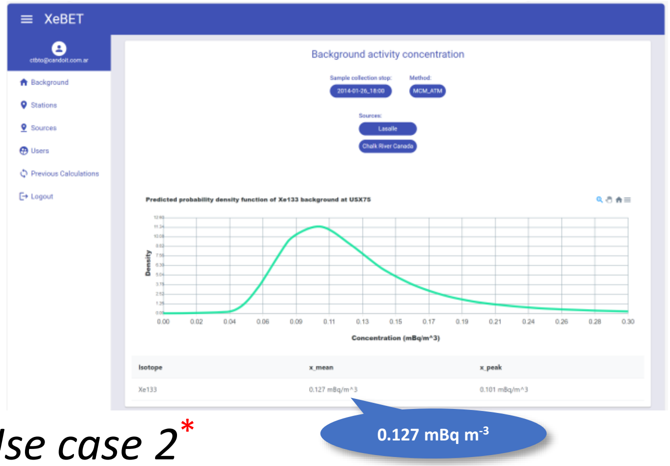
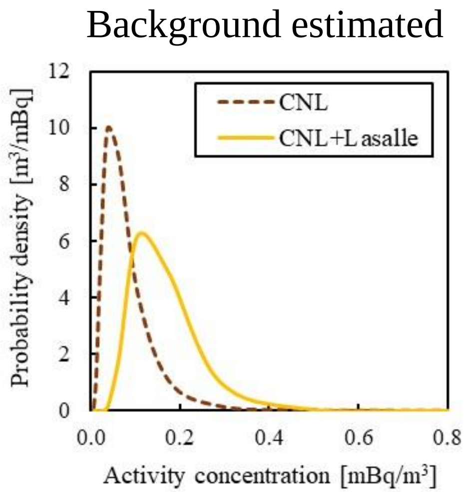


+ ? + ?

*Use case 2**



* *"The mean value of the background only CNL for USX75 (in Charlottesville, USA) at 23:00 on 26 January 2014 is 0.06 mBq/m3 and that of both CNL and Lasalle is 0.14 mBq/m3. On the other hand, the measured activity concentration is 0.41 mBq/m3."*

* **Kijima, Y. et al.**, *Using a Monte Carlo Approach to Determine the Radioxenon Probability Density Function at an IMS Station for Background Estimation*, WOSMIP IX 2023.

<u>Near future</u> efforts at the IDC for background estimation

Common denominator: UQ (uncertainty quantification)

- Identification and assessment of prospective data-driven scientific methods.
- Development of an uncertainty quantification related to each prospective scientific method (and combinations thereof).

Data and methodologies

- IMS RN data : ✓
- Emission data : Fragmented, we use what's available . . . as a prior to optimization
- ATM data : <u>Focus!</u>
  - ✓ Ensemble prediction (UQ prospect)
  - ✓ High-resolution ATM
  - ✓ Other: current SRS file utilization (spatio-temporal nudging of emission database to best fit IMS observations, …)

2024 - 2026

Background estimation ('XeBET-2', …) — UQ inside

Ensemble prediction ('ATM EPS', …) — UQ inside

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