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CTBTO PREPARATORY COMMISSION

COMPREHENSIVE NUCLEAR-TEST-BAN TREATY ORGANIZATION

# Lessons learned from conducting radioxenon background measurement campaigns and the need for further data sets

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# Overview

**Summary of noble gas measurement campaigns**

- See companion presentations.

**Important results**

- from analysing data of noble gas background measurement campaigns since 2008.

**What are the problems**

- that need to be solved to enhance radioxenon monitoring?

**Scientific proposals (Reading material)**

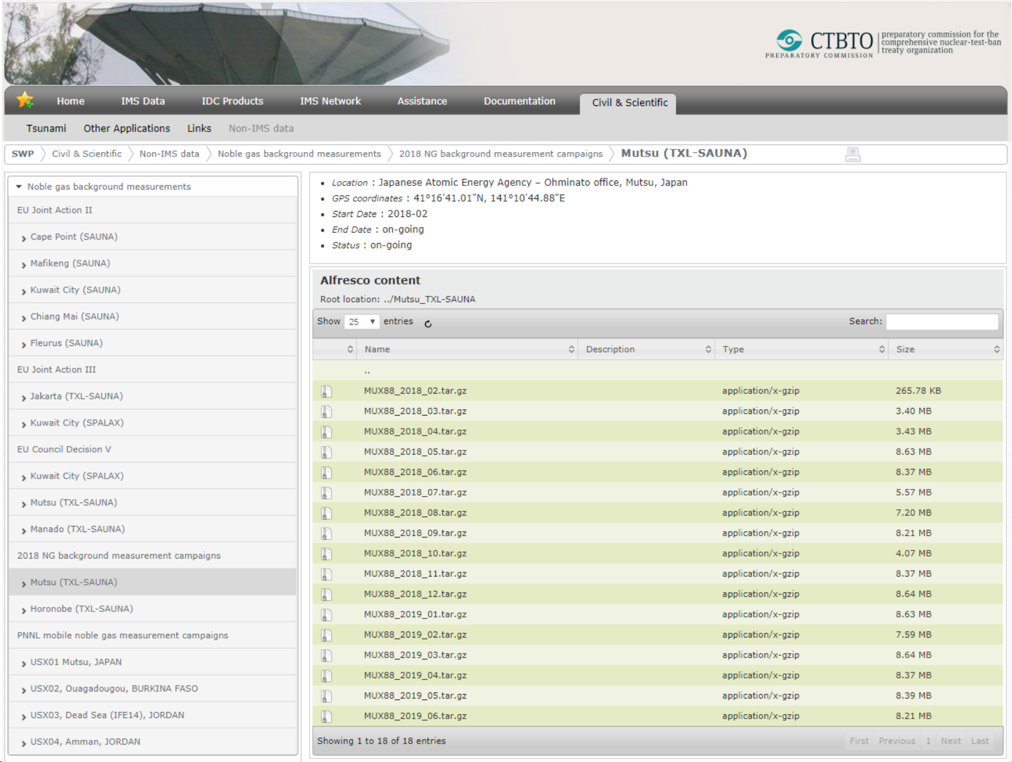
- that aim at enhancing nuclear explosion signal detection.

# Availability of noble gas measurement campaign data

Information about all transportable NG systems is available on the CTBTO Secure Web Portal. This includes the plans, the raw data, analysis results and conclusions.

Access for authorized users designated by States Signatories.

Also available for scientists who have signed a confidentiality agreement to access the virtual Data Exploitation (vDEC) platform.



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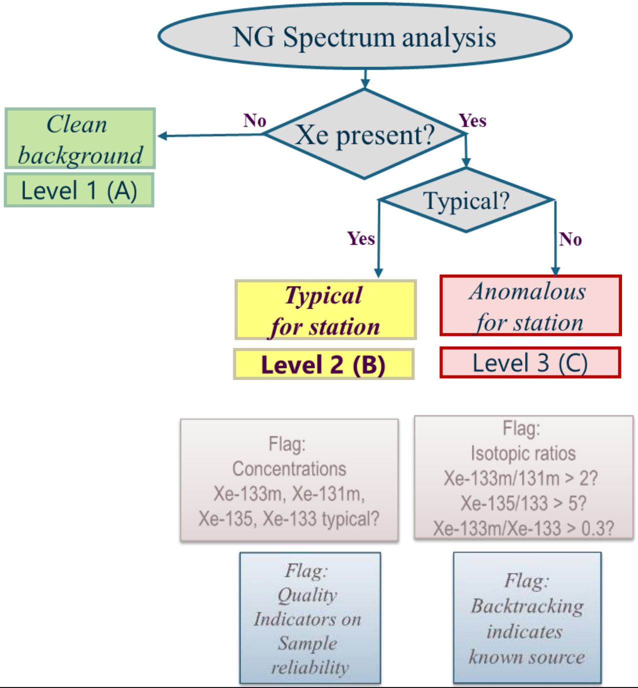
# Important results

Highlights of past findings and conclusions for the IDC categorization scheme are:

- Xe-135 can be observed despite of its short half-live / has to be included in categorization scheme.
- Pure Xe-131m can be observed / bias in isotopic ratios may be caused and requires caution when using ratio screening flags.
- Strong influence from a strong radioxenon source causes very high and strongly fluctuating background / the categorization scheme is robust against these extremes.



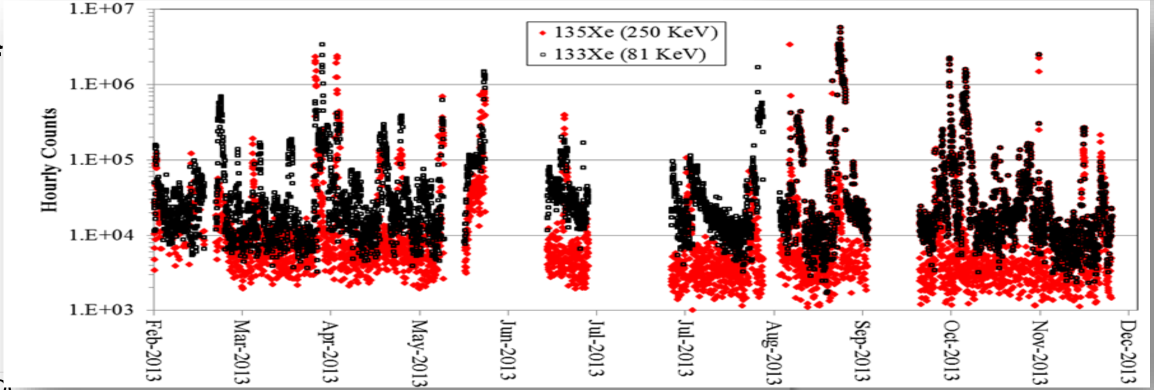
# Important results


## Detector at the stack of PT INUKI (formerly BATEK)

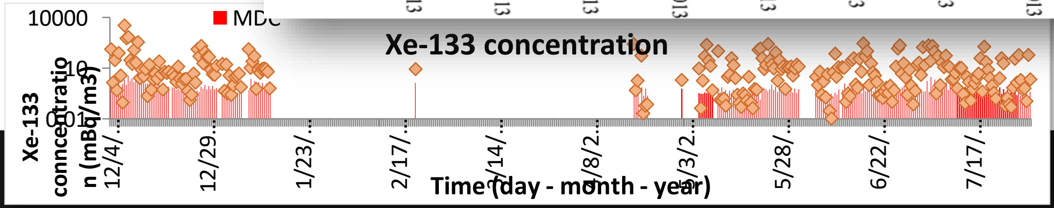
- Installed in 2012 with funding from EU and US CiK
- LaBr3 spectral data every 10 minutes from 3/2013 to 3/2014

## Mobile NG system at Jakarta

- Installed in 2012
- With funding from EU

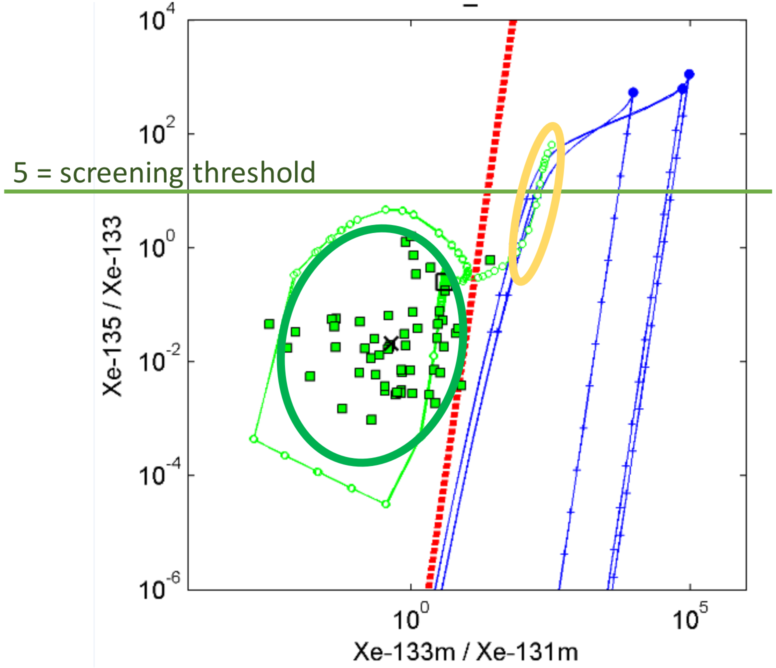



McIntyre et al. (2015)



# Distributions of isotopic ratios

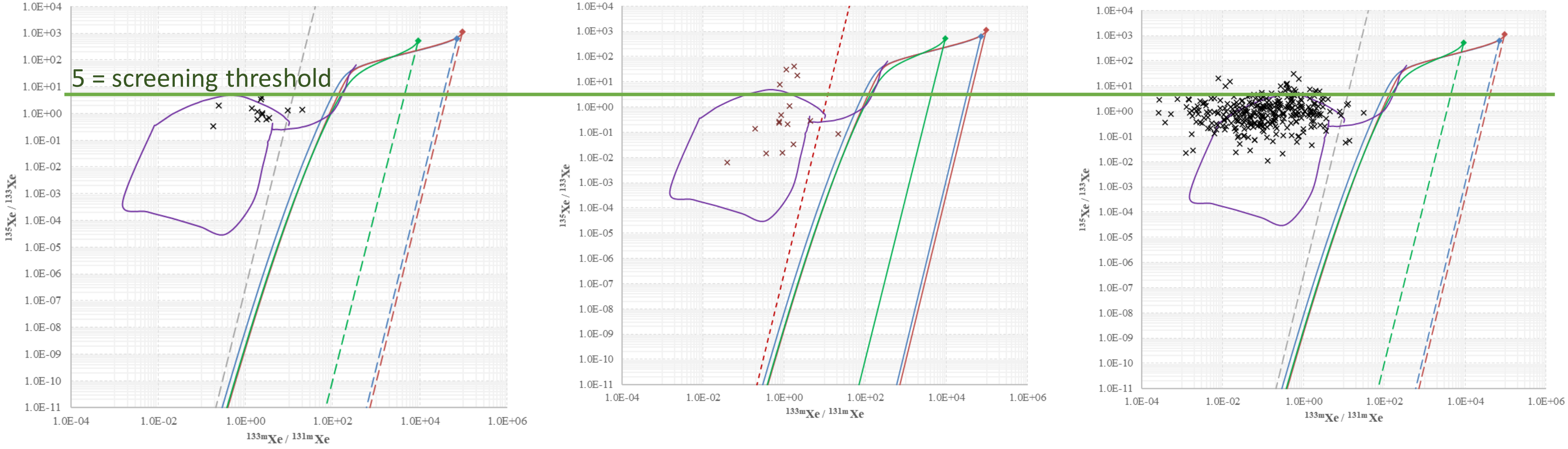
- Nuclear power plants have isotopic ratio of Xe-135 to Xe-133 from fission that are typically well below 5, i.e. below the screening threshold for the nuclear explosion domain (see green horizontal line).
- Medical isotope production is expected to cause observations in the nuclear explosion domain.




Normal observations from fission sources have Xe-135/Xe-133 activity ratios well below the screening threshold of 5.

# Distributions of isotopic ratios

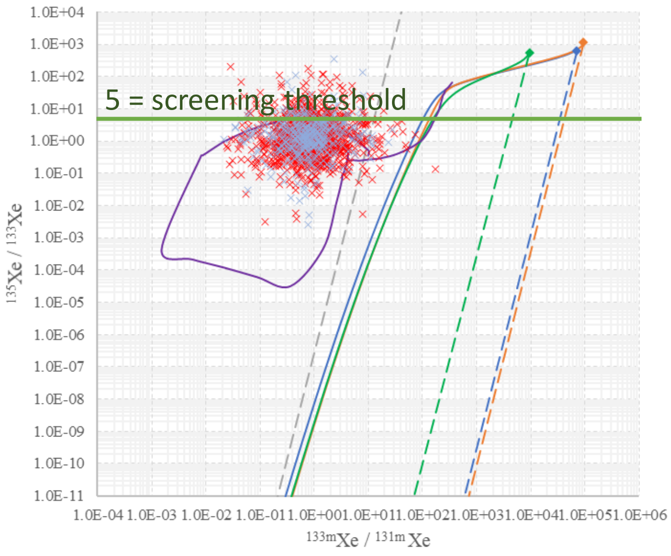
- The surprise was to find observations from medical isotope production in the nuclear reactor domain.
  Confirmed by stack release data to be like this at the source.



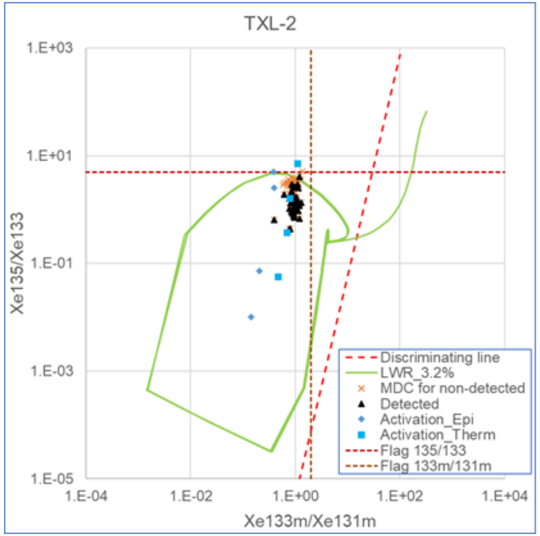

Mafikeng Fleurus Jakarta

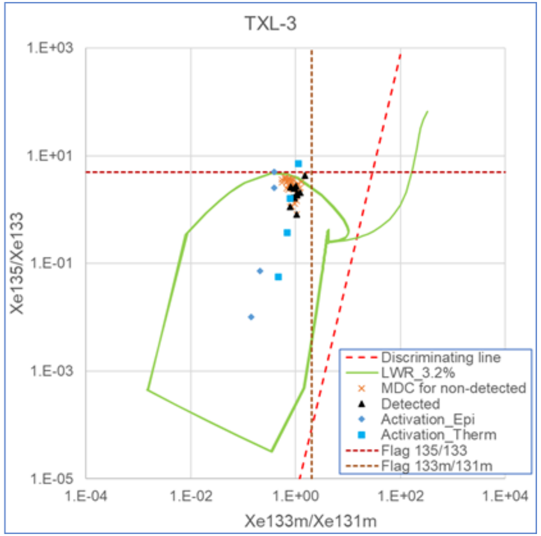
# Distributions of isotopic ratios

- JPX81 (red cross) / MUX88 (blue cross)
- Many real observations of Xe-135




- No isotope production known as source
- Activation rather than fission could explain the ratios.

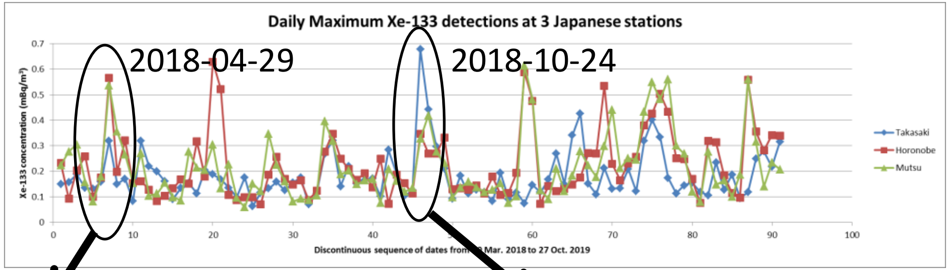


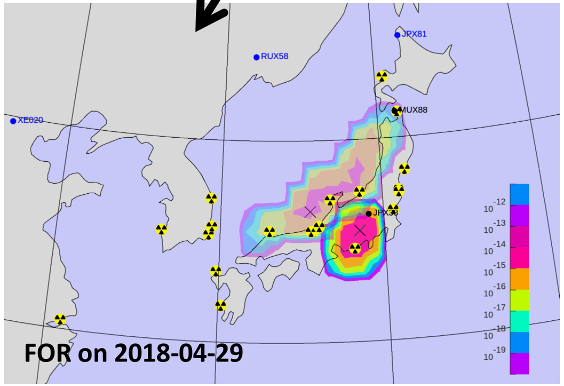



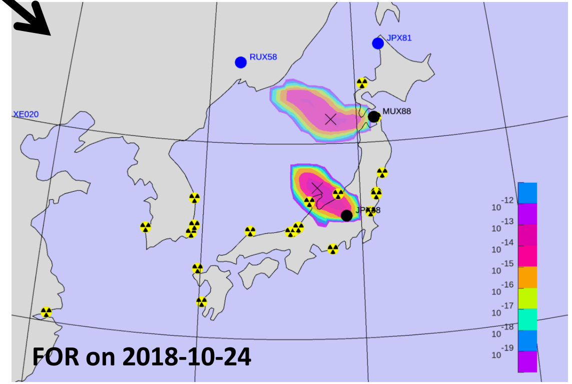
## USING ADDITIONAL MEASUREMENTS TO DEVELOP TOOLS TO ESTIMATE XENON BACKGROUND

A first background estimate (v1) is generated by combining SRS with annual release estimates from NPPs/MIPFs.

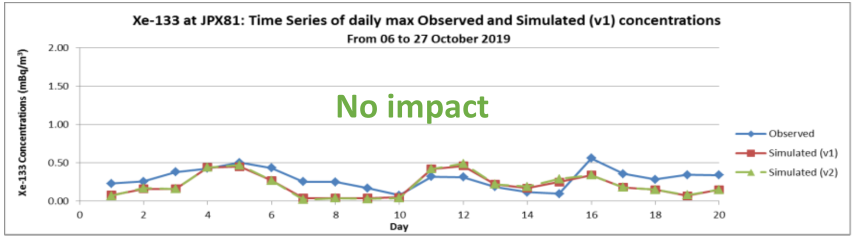
A second estimate (v2) is produced by modifying annual releases for main contributing sources to improve the fit between observed and modelled concentrations.

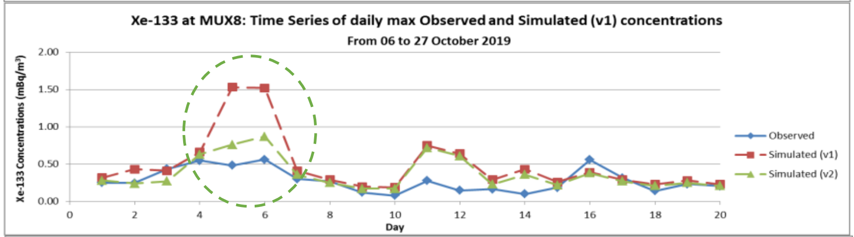


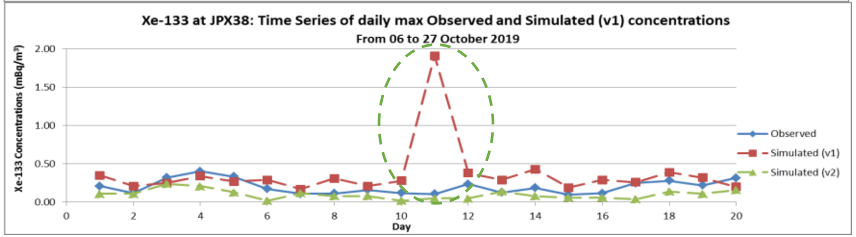



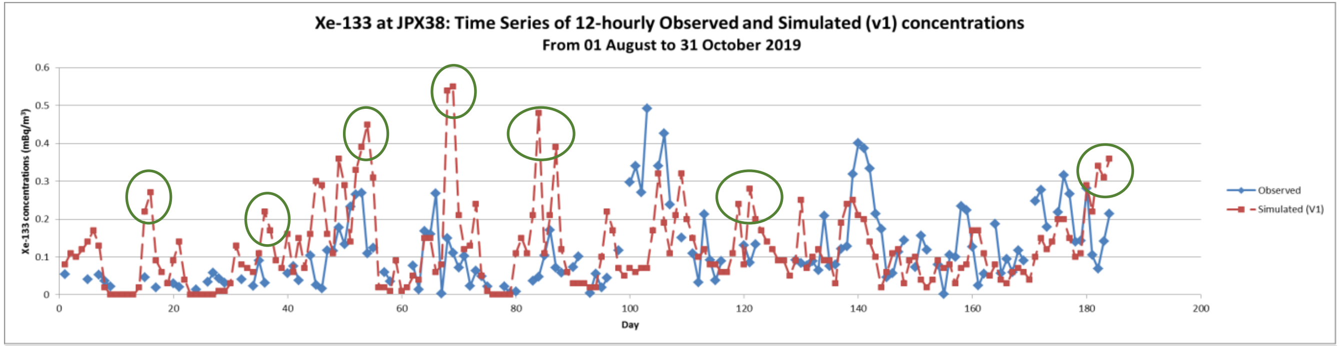
# IMPACT OF MODIFYING ANNUAL RELEASES FROM A FEW SOURCES

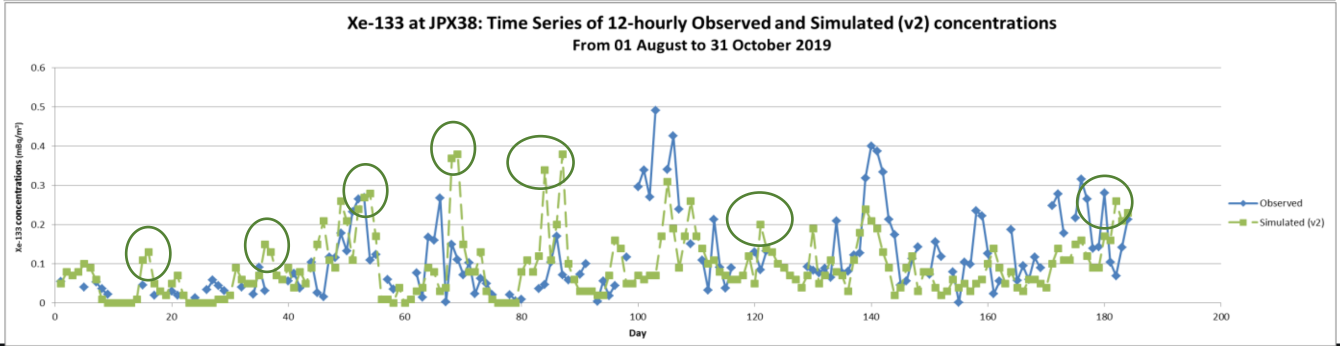


## Testing the two versions over JPX38 on an independent sample from 01 Aug to 31 Oct. 2019



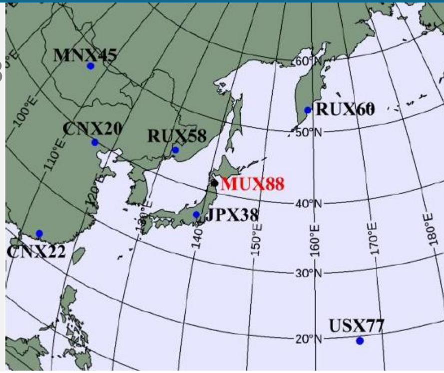




Even over a different period, the overall fit between actual measurements and estimates is better.

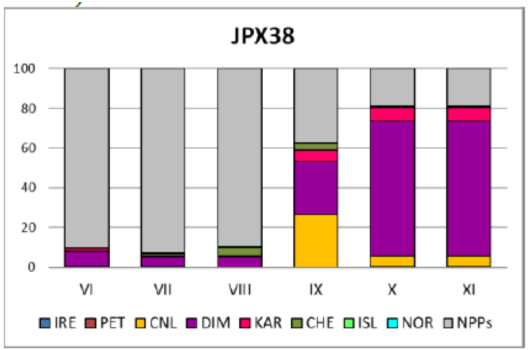
Future background estimators will be more complex, consider more parameters and incorporate algorithms to automatically adjust the parameters.

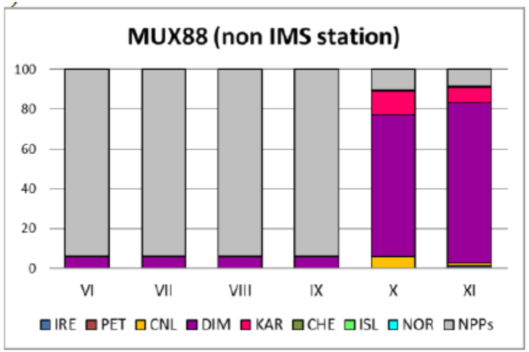
# Important results

The distance between JPX38 and MUX88 is about 584 km, relatively short in comparison to distances between IMS stations.

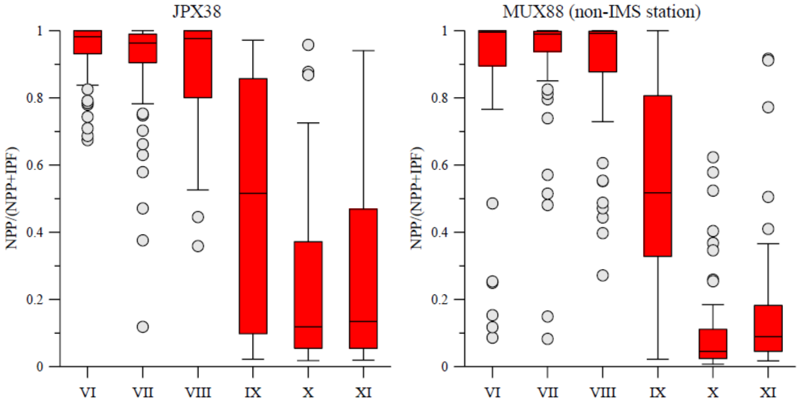



Monthly percentage contributions during the study period of 2014 from individual sources as observed at the IMS station at Takasaki, JPX38, and the transportable system in Mutsu, MUX88.




Monthly changes in the ratio between the contribution from NPPs and the joined contribution from all known NPPs and IPFs.



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**What are the problems**
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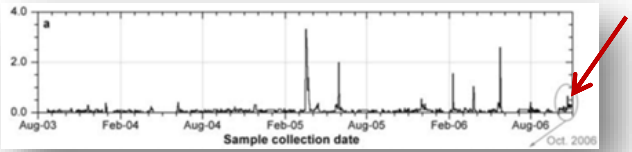
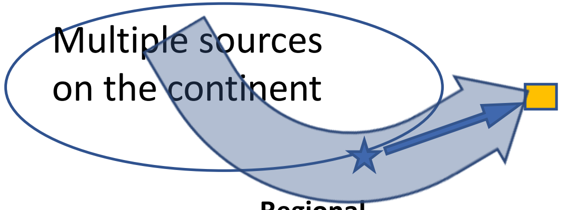
**Scientific proposals (Reading material)**
- that aim at enhancing nuclear explosion signal detection.

# What are the problems that we are trying to solve?

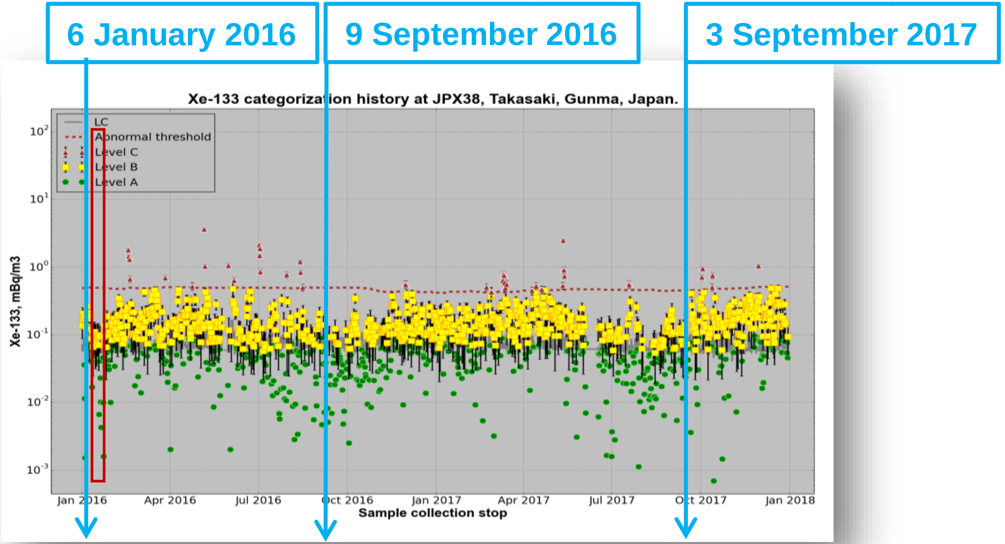
- “Needle in a needle stack”: Xe-133 from nuclear explosion same as from civil facilities.
- Level C every day but still insufficient: every Level B (10,000 per year!) might indicate a nuclear explosion and may still be above 1 $mBq/m^3$ = network design requirement.
- Blinding effect: Small signal from a nuclear explosion may be covered up by large background from civilian sources.
- Hard to relate to a relevant SHI event: Association with close-by source often inconclusive due to further downwind civil sources.



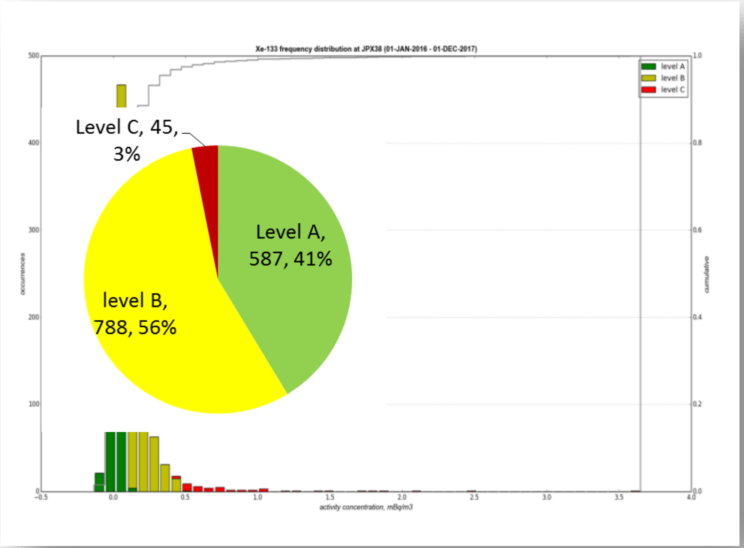



# Which IMS data were not used after DPRK test?

## Observations at JPX38 (Takasaki, Japan) from January 2016- December 2016



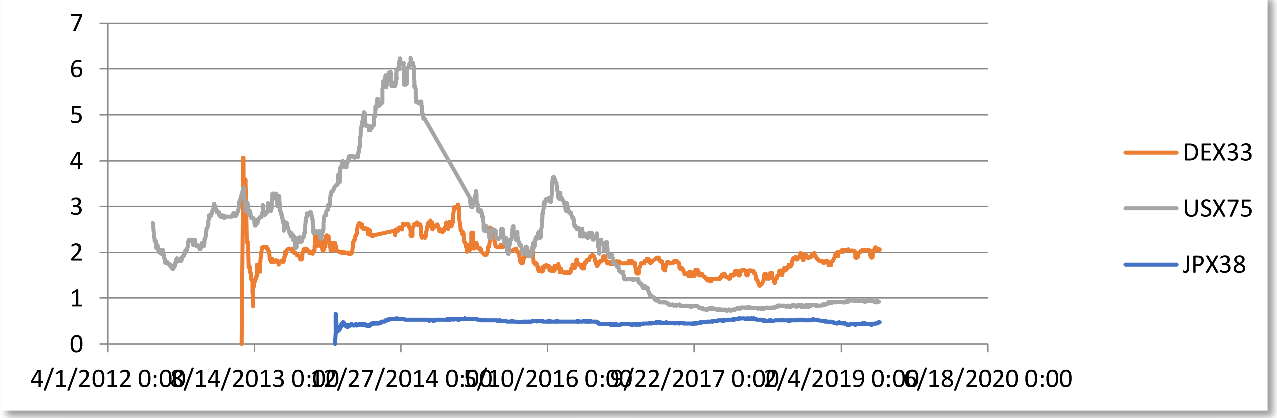

**Xe-133 Categorization History**



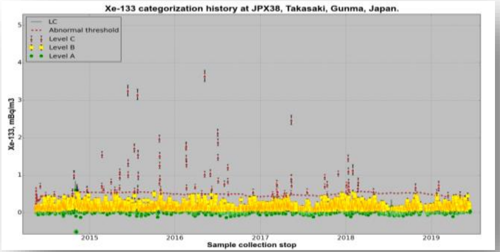

**Xe-133 Frequency Distribution**

De Meutter et al. (2017) used 50 samples (11-23 Feb 2016) of three IMS noble gas systems: JPX38, MNX45, USX77.

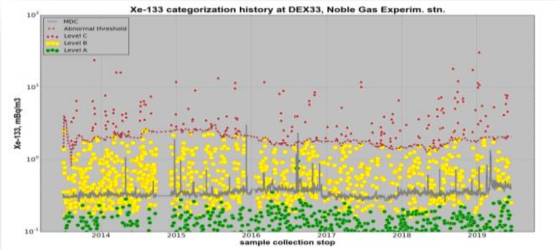
# The IMS sensitivity is easy to fully exploit



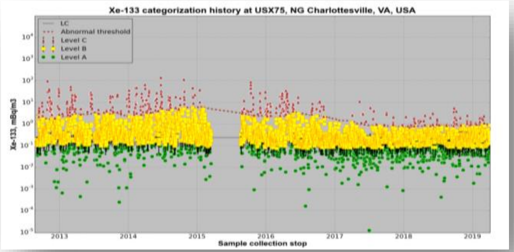

## Xe-133 abnormal threshold for Level C




**JPX38**




**DEX33**




**USX75**

# How to address these problems with IDC analysis methods:

- "Needle in a needle stack": Xe-133 from nuclear explosion is the same as from civil facilities.
- Level C every day but still insufficient: every Level B may be caused by a nuclear explosion (10,000 per year!) and may still be above 1 mBq/m$^3$ = network design requirement.
- Blinding effect: Small signal from a nuclear explosion may be covered up by large background from civilian sources.
- Hard to relate to a relevant SHI event: Association with close-by source often inconclusive due to further downwind civil sources.

- Categorization scheme (Levels A, B, C) and screening flags.
- SSREB*: Multi-sample association and Possible Source Region (PSR).
- Long time series analysis.
- Flag "ATM backtracking to known sources".
- PSR and known sources combined.

* SSREB = Standard Screened Radionuclide Event Bulletin

# How validation data sets could help develop IDC analysis methods:

| | |
|---|---|
| • SSREB: Multi-sample association and Possible Source Region (PSR). | • Get higher number of experimental cases with multiple detections than achievable with sparse network needed to validate PSR. |
| • Long time series analysis. | • Validate ATM models with NG observations in the vicinity of the IMS station. |
| • Flag "ATM backtracking to known sources". | • Learn to distinguish close from far sources at IMS station by observations in the vicinity. |
| • PSR and known sources combined. | • Validate quantitative PSR method. |

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1. Proposal: Method for associating samples to the same release event

2. Proposal: Provide more accurate estimates of the possible location of the source of an event and test the different PSR options

3. Proposal: Developing the screening flag "ATM backtracking to known sources" for ARR and RRR

4. Proposal: Complex terrain
   a. Mountains
   b. Land-sea Breeze

5. Proposal: Use of isotopic ratio measurements for screening

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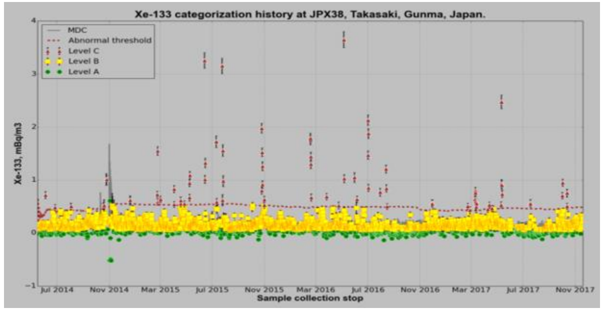
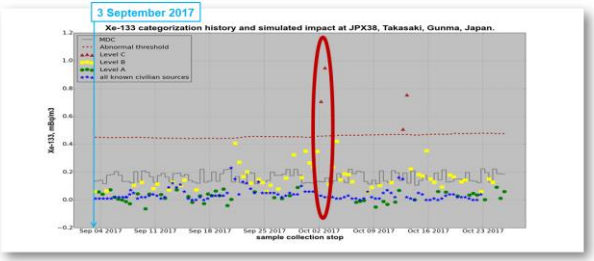
# Proposal 1: Method for associating samples to the same release event

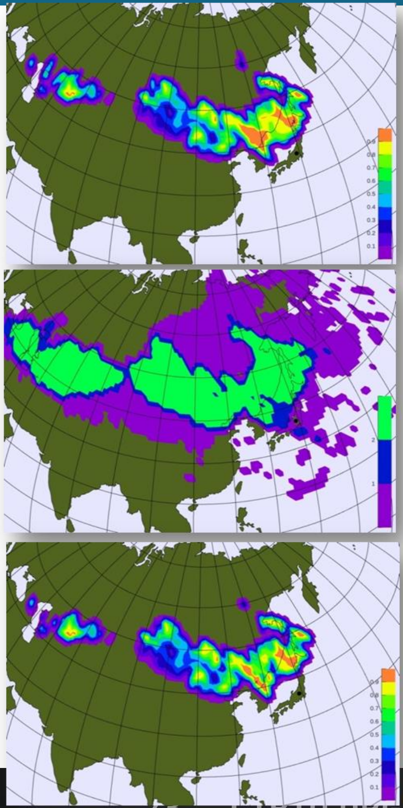
1. **What is the problem to be solved?**
   - The possible source region (PSR) is still missing in the SSREB.
   - PSR for Expert Technical Simulations is based on subjective decisions.
   - One trigger condition for sending samples to CTBT radionuclide lab to be automated.
2. **Which method is to be applied to address the problem?**
   - Alternative mathematical algorithms will be developed and compared to identify the best one.
3. **What is the expected outcome?**
   - A validated method for associating samples. Implementation in the SSREB.
4. **What kind of data is required?**
   - Need multiple detections at different sites from one dominating source. Can best be achieved with a transportable system in the vicinity of an IMS system.
5. **Host region requirements for transportable system (if applicable)**
   - In vicinity of an IMS noble gas system.
   - Downwind from a major emitter (MIPF).



# Proposal 2:
## Provide more accurate estimates of the possible location of the source of an event and test the different PSR options

1. **What is the problem to be solved?**
   - The possible source region (PSR) is based on subjective decisions
   - Different PSR options require testing
2. **Which method is to be applied to address the problem?**
   - Alternative mathematical algorithms will be developed and compared to identify the best one.
   - Optimized ATM parametrization will result in more accurate SRS fields.
3. **What is the expected outcome?**
   - More accurate estimation of the possible location of the source of an event
   - Different PSR options
4. **What kind of data is required?**
   - Additional experimental data collected in different topographical conditions, preferably by two collocated sampling systems operating e.g. at different heights, in a valley versus in a mountain, along a coast versus inland etc
   - ATM simulations to understand detections
5. **Host region requirements for transportable system (if applicable)**
   - In vicinity of an IMS noble gas system.
   - Downwind from major emitters, preferably with well-defined emissions.
   - In areas representing different topographical conditions



# Long Time Series Analysis

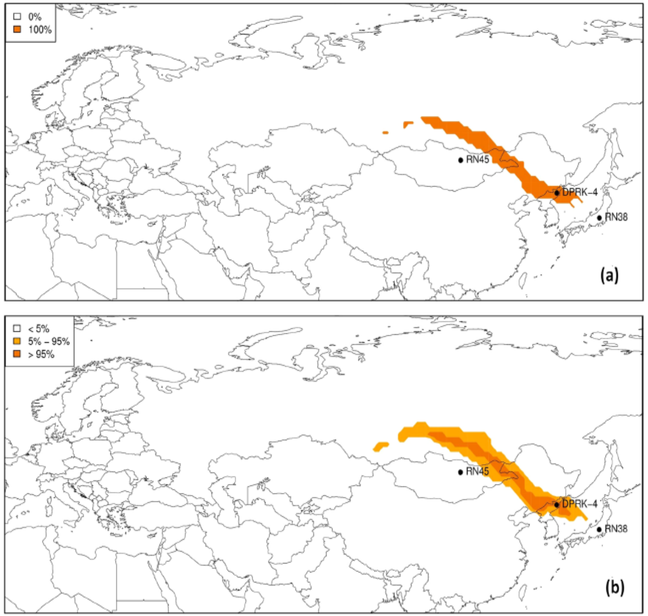


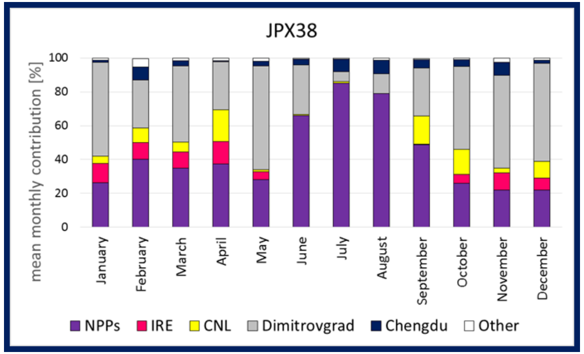

Figure 3. Pointwise probability that a certain grid point is a possible source for (a) the unperturbed simulation (thus fully deterministic) and (b) the full 51 member ensemble. Maps have been generated using ref. 48.

| DPRK announced nuclear test | IMS stations | DPRK test site as source region | Delay after seismic event time | Other potential sources | Conclusion | Confidence |
|---|---|---|---|---|---|---|
| 6 January 2016 | JPX38, MNX45, USX77 | Possible | 6 weeks release delay plausible | Single source excluded | Possible association | **High** |

De Meutter et al. (2017) used 50 samples (11-23 Feb 2016) of three IMS noble gas systems: JPX38, MNX45, USX77.

# Proposal 3: Developing the screening flag "ATM backtracking to known sources" for ARR and RRR

1. **What is the problem to be solved?**
   - More accurate estimation of the source term parameters (localisation, temporal release profile, total amount of radioactivity released) in case of a nuclear test.
2. **Which method is to be applied to address the problem?**
   - Different mathematical techniques applied to data set consisting of detections from the IMS and transportable NG systems and SRS fields.
3. **What is the expected outcome?**
   - Estimation of the radioxenon contribution from known sources to every sample collected by noble gas systems at IMS stations
   - The screening flag "ATM backtracking to known sources" for ARR and RRR
4. **What kind of data is required?**
   - Additional experimental data collected in different topographical conditions (different heights, in a valley versus in a mountain, along a coast versus inland etc)
   - ATM simulations to understand detections
5. **Host region requirements for transportable system (if applicable)**
   - In vicinity of an IMS noble gas system.
   - Downwind from major emitters ( e.g. MIPFs, NPPs), preferably in areas heavily influenced by emissions from non-treaty activities.
   - In areas representing different topographical conditions




*Mean monthly contribution of Xe-133 emissions from individual sources as observed at IMS stations. The results are based on operationally produced ATM results (backward modelling) using meteorological data from ECMWF.*

# Roadmap for using noble gas release data

**Research and development stages towards a possible implementation**

Done
Now
Next

1. **Situation analysis phase:** Published information for scientific studies to understand impact of MIPF releases on IMS stations.
2. **Proof-of-principle phase:** Few historic data for developing and testing methodologies, e.g. ATM challenge
3. **Method development phase:** Systematic historic (2014) and increasingly continuous near real-time data for scientific research into sound algorithms for network performance, contribution to sample concentrations, and source attribution
4. **Demonstrate operationalization phase:** Continuous near real-time data for demonstration of being able to put it in operations

# Proposal 4a: Complex terrain - Mountains

**1. What is the problem to be solved?**

- Understand the effects of turbulence around mountainy IMS stations to be able to interpret ATM results.
- Verify the representativity of the IMS locations in mountainy locations.

**2. Which method is to be applied to address the problem?**

- Applying a sensitivity study of input and output parameters with ATM and comparing the results with measurements (spatial variability).
- Fine tuning of ATM.

**3. What is the expected outcome?**

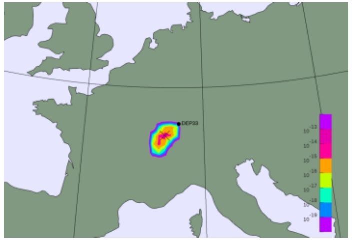
- Observed and modelled concentrations should show a similar frequency distribution.
- Improvement of final ATM products, specifically in ETA. Depending on results, might also influence RRR and ARR.

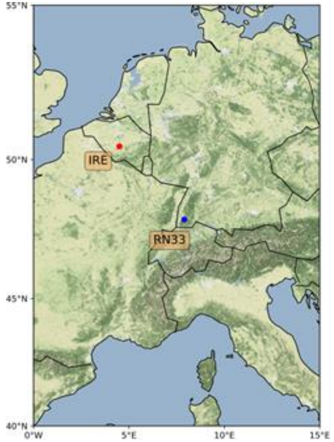
**4. What kind of data is required?**

- Multiple sources in a close range of the IMS station and at varying heights at significant locations of the complex region.

**5. Host region requirements for transportable system (if applicable)**

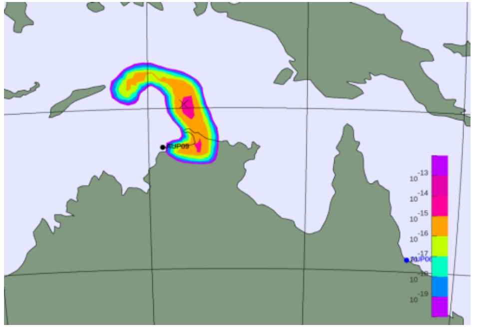
- Region with an IMS station in a mountainy region where emissions from nearby sources are frequently detected. Additional stations should be located around IMS station at various heights, preferably in more open areas, at mountain slopes and a mountain face.

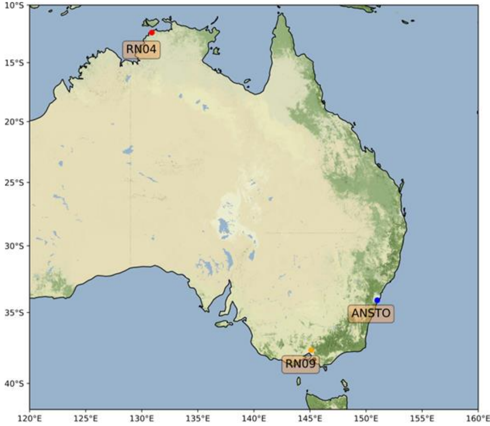




# Proposal 4b: Complex terrain – Land-sea breeze

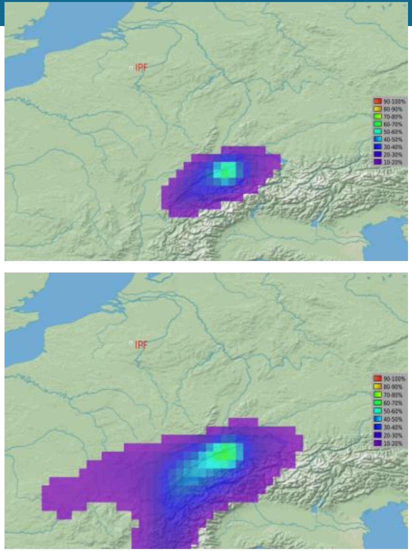
1. **What is the problem to be solved?**
   - Understand the effects of turbulence and influences of land-sea breeze on measurements of IMS stations to be able to interpret ATM results.
   - Verify the representativity of the IMS located near the coast.
2. **Which method is to be applied to address the problem?**
   - Applying a sensitivity study of input and output parameters with ATM and comparing the results with measurements (spatial variability).
   - Fine tuning of ATM.
3. **What is the expected outcome?**
   - Observed and modelled concentrations should show a similar frequency distribution.
   - Improvement of final ATM products, specifically in ETA. Depending on results, might also influence RRR and ARR.
4. **What kind of data is required?**
   - Multiple measurements at close range of the IMS station and at significant locations varying in distance from the coast.
   - Campaign should last at least for a year to capture all seasons.
5. **Host region requirements for transportable system (if applicable)**
   - Region with IMS station close to the coast and experiencing land-sea breeze, preferably a location with complex terrain and a nearby source (e.g. MIPF).
   - Possibility to add transportable systems scattered around IMS station and at varying distances from the coast. Maybe also in different terrains.





# Proposal 5: Use of isotopic ratio measurements for screening

1. **What is the problem to be solved?**
   - Even though multiple radioxenon isotopes are often observed at IMS stations, the methods of using isotopic ratios for discriminating between known sources and possible signals from nuclear tests are insufficient.
2. **Which method is to be applied to address the problem?**
   - Kernel density estimates of probability distributions for radioxenon concentrations at IMS stations from known sources.
3. **What is the expected outcome?**
   - Derive probability distributions of isotopic ratios at IMS stations from known sources to adjust and validate analysis methods of isotopic ratios for event screening flags, expert technical analysis and special studies.
4. **What kind of data is required?**
   - Statistically relevant large data set of radioxenon observations caused by known sources are missing. Due to the short half-life of Xe-135, ratios with this isotope are rarely observed at IMS NG systems (see figures).
5. **Host region requirements for transportable system (if applicable)**
   - Locations where well-defined emissions can be observed, such as IRE and ANSTO.




Examples of the Network Coverage for DEX33 in winter 2020. **Upper Panel:** Xe-135; **Bottom Panel:** Xe133. The red sign indicates IPF in Fleurus (IRE) . The color-coded percentage indicates the area monitored by DEX33 with sufficient sensitivity to trigger detection.

# Summary

This presentation describes possible scientific projects to develop and enhance IDC analysis methods for radioxenon samples with different objectives:

1. Further enhancements in standard IDC products, including
   - Screening flag “ATM backtracking to known sources” in Automatic/Reviewed Radionuclide Reports
   - and associating multiple samples to the same radionuclide release event as foreseen in the SSREB (Standard Screened Radionuclide Event Bulletin).
2. Enhancing ATM output
   - Identifying the most precise method for the Possible Source Region
   - Correcting for errors due to complex terrain (mountains, land-sea breeze)
3. Sufficiently characterize the radioxenon background at IMS noble gas system
   - Among others by optimizing the use of isotopic activity ratios.

Appropriate validation data sets will make sure that scientific methods and software tools for radioxenon monitoring can be significantly enhanced.

# Summary

**Summary of noble gas measurement campaigns**

- See companion presentations.

**Important results** of temporary noble gas measurement campaigns

- knowledge crucial for the development of the noble gas categorization scheme,
- new insight into background features, partially still unexplained,
- data sets for monitoring method validation.

**What are the problems** of radioxenon monitoring?

- Four methodological areas are identified that can be significantly enhanced

**Scientific proposals** **(Reading material)** that aim at enhancing nuclear explosion

- Need validation data sets for signal detection and event source characterization methods.

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