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WOSMIP Workshop on Signatures of Man-made Isotope Production

WOSMIP IX | December 4 - 7, 2023

InterContinental Santiago Hotels & Resorts | Av. Vitacura 2885, 7550023 Las Condes Region Metropolitana, Chile

Pacific Northwest NATIONAL LABORATORY

CTBTO PREPARATORY COMMISSION

COMPREHENSIVE NUCLEAR-TEST-BAN TREATY ORGANIZATION

The Problems of Backgrounds at the CTBTO PrepCom

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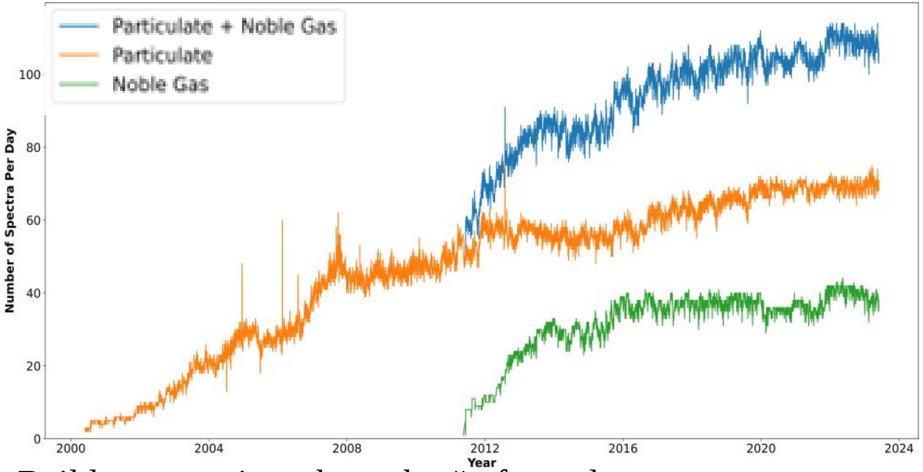
The radionuclide component of the IMS network

The noble gas technology in the IMS network

- 40 out of 80 radionuclide stations will have noble gas monitoring technology. In addition: 16 radionuclide laboratories.
- The global monitoring system for atmospheric xenon radioactivity is a unique and high-quality network.

Current status of the NG network:
- **Certified: 26**
- **Installed: 6**
- **Under construction: 2**
- **Planned: 6**
- **Total: 40**

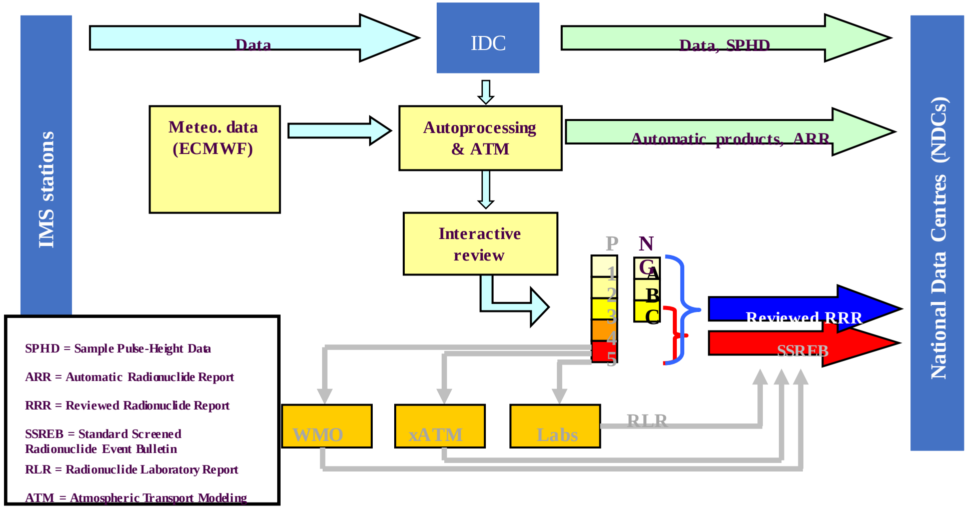


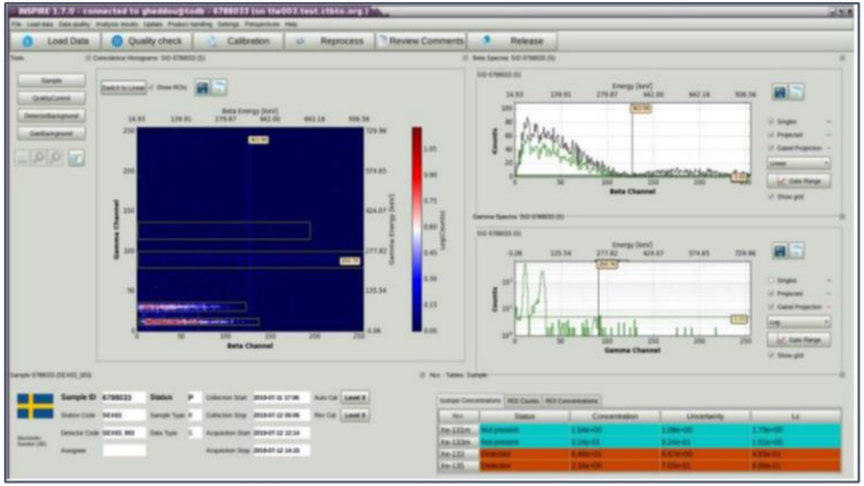
Build-up over time shown by # of samples.

In 2023: daily 60 particulate, 40 NG samples.

IDC data processing pipeline and generation of analysis reports

- The new generation NG systems enhance time resolution from 12 or 24 hours to 6, 8 or 12 hours.
- This results in more than 2-fold increase in the number of daily samples to be processed.
- All spectra are processed automatically at the IDC to generate the Automatic Radionuclide Report (ARR).
- Interactive review by radionuclide data analysts generates the Reviewed Radionuclide Report (RRR).





Event categorization

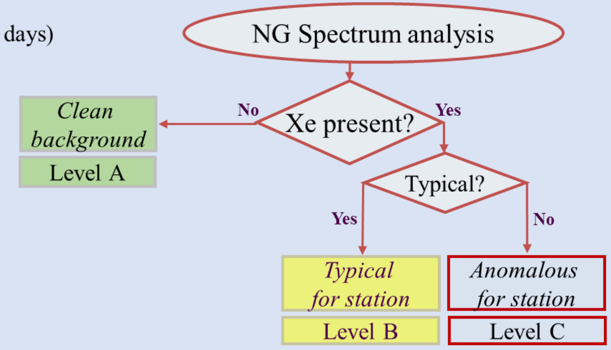
The three-level scheme categorizes each noble gas sample by its potential interest based on the observed concentrations.

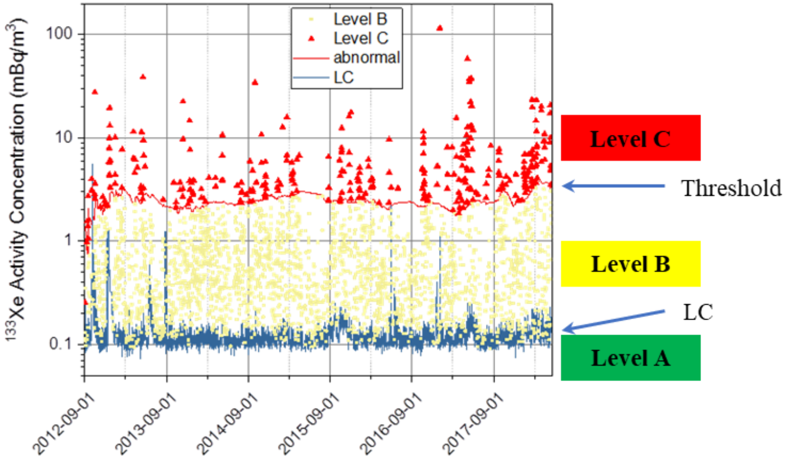
Concept of the NG categorization scheme

- Categorization scheme based on activity concentration levels
  - **Level A**: no xenon present in the spectrum
  - **Level B**: xenon detection within the typical range of the station
  - **Level C**: anomalous xenon detection
- The category of the 4 isotopes / isomers is determined individually using the flow chart
  Highest isotope / isomer category = spectrum final category
- Typical for a station?
  Based on a long-term trend (365 moving days)

Screening flags on isotopic ratios:
Xe-133m/131m > 2?
Xe-135/133 > 5?
Xe-133m/Xe-133 > 0.3?

Screening flag on ATM Backtracking to known sources:
not yet implemented



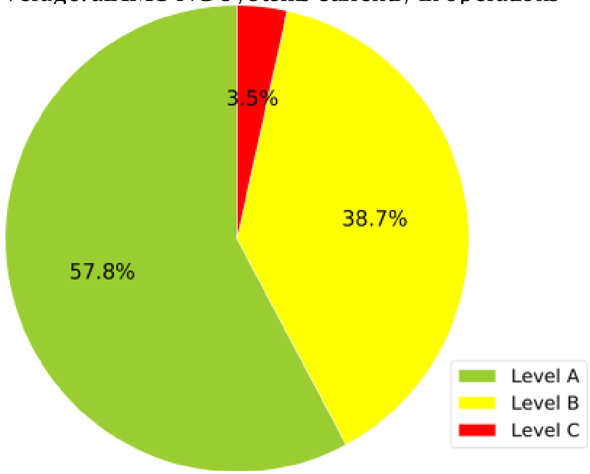


Overall picture of noble gas categorization results

Spectra categorization results (RRR)

Reporting period: 1 Sep. 2012 – 31 May 2023

Coverage: all IMS NG systems currently in operations



- **Level A:** no xenon detected
- **Level B:** xenon detection, typical for the station
- **Level C:** xenon detection, not typical for the station site

For the period 1st September 2012 - 15th of November2023:

- 141,459 quality-controlled and reviewed sample spectra
- Radioxenon was observed in 58,732 (41.5%) spectra

Xenon detections were observed in about 42% of reviewed samples *(Level C + Level B)*

- 53,898 (38.1%) categorized as level B
- 4,834 (3.4%) as level C

Challenge for explosion monitoring:
Each of these observations could indicate a nuclear explosion

- Currently, 45 level C per month.
- With new NG systems, there will be 90 per month, i.e. **3 Level C samples per day.**

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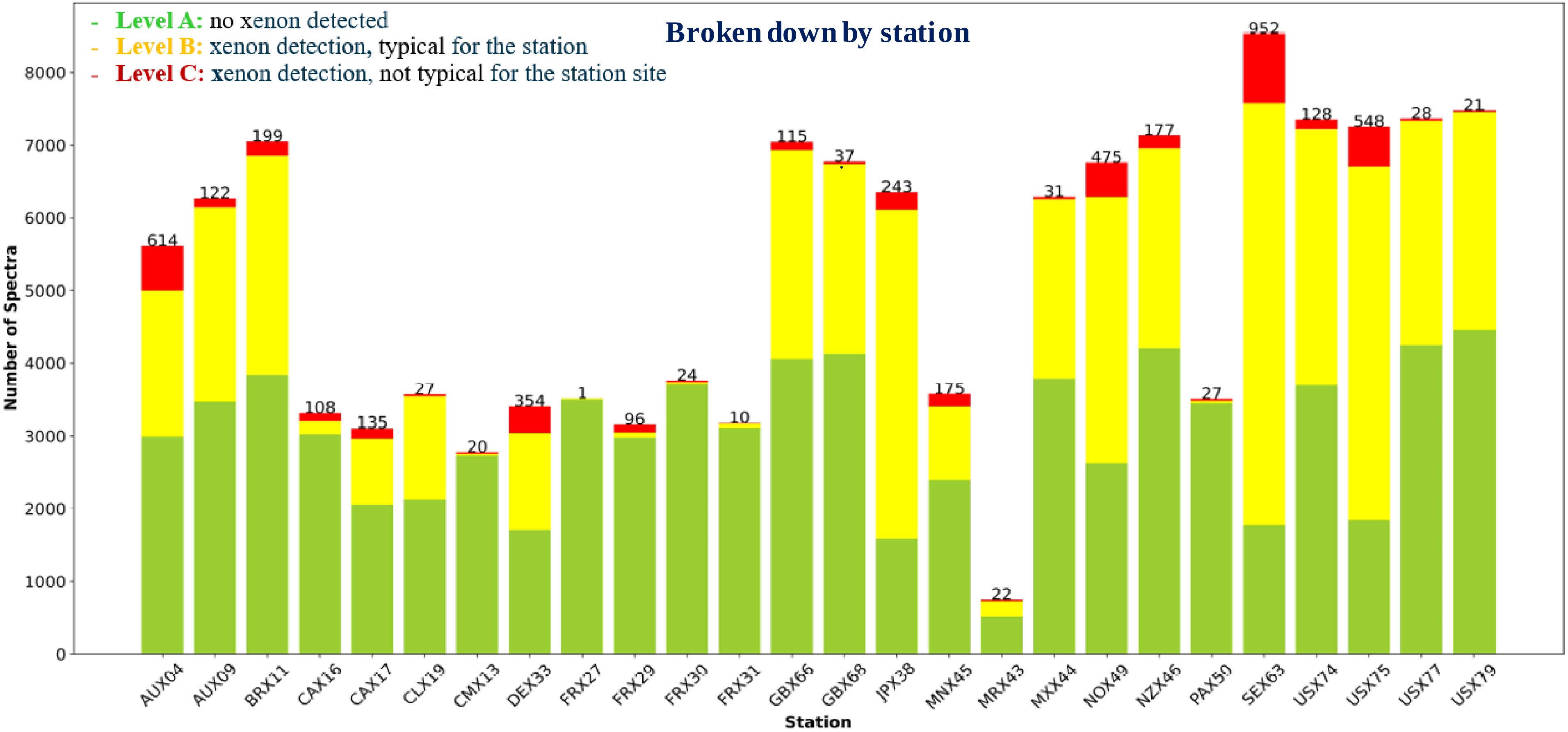
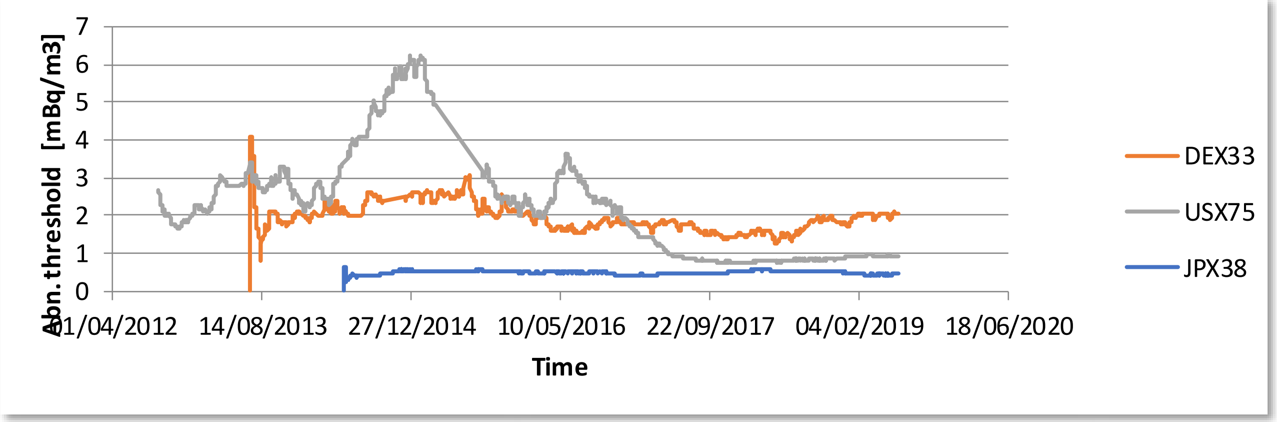
Overall picture of noble gas categorization results



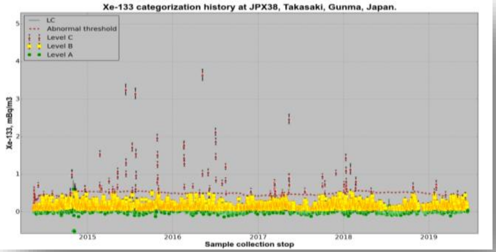
Xe-133 abnormal threshold for Level C



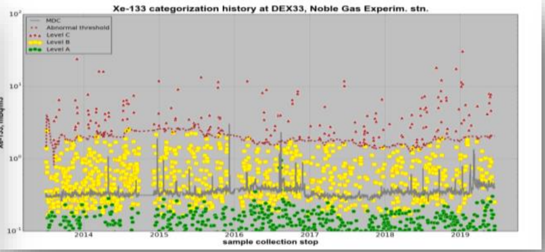
The NG systems' sensitivity is much better than required (MDC = 1 mBq/m^3).

But the abnormal threshold may be higher due to atmospheric background. In such a case, relying solely on Level C samples is not sufficient to meet the requirement.

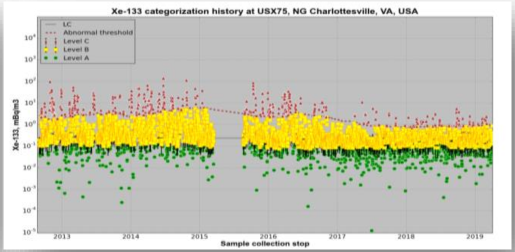
The only remedy is to be able to explain the signal by known sources. This is a big challenge.



JPX38

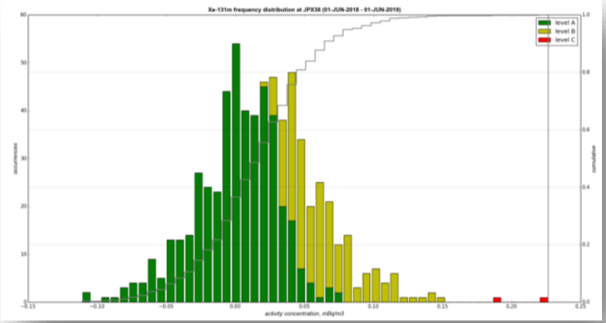


DEX33

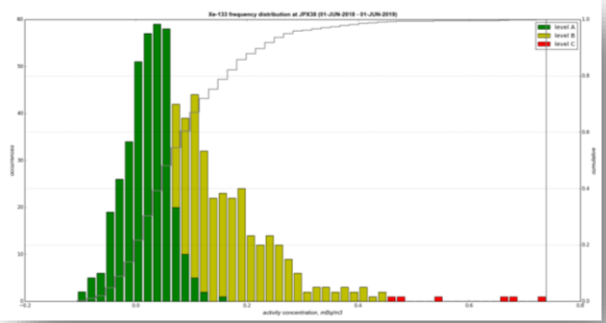


USX75

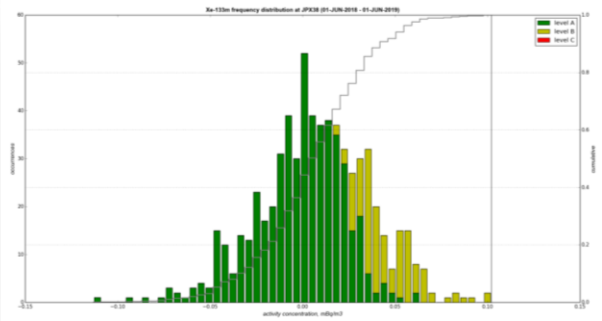
JPX38 (June 2018- June 2019)



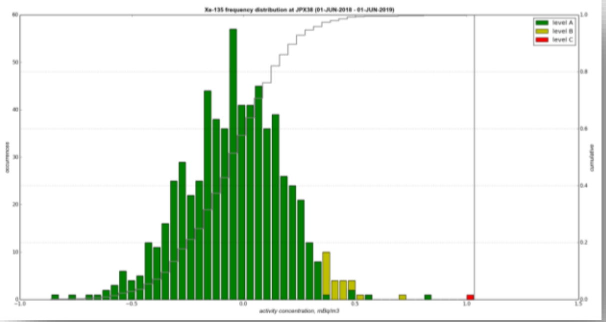
Xe-131m



Xe-133



Xe-133m

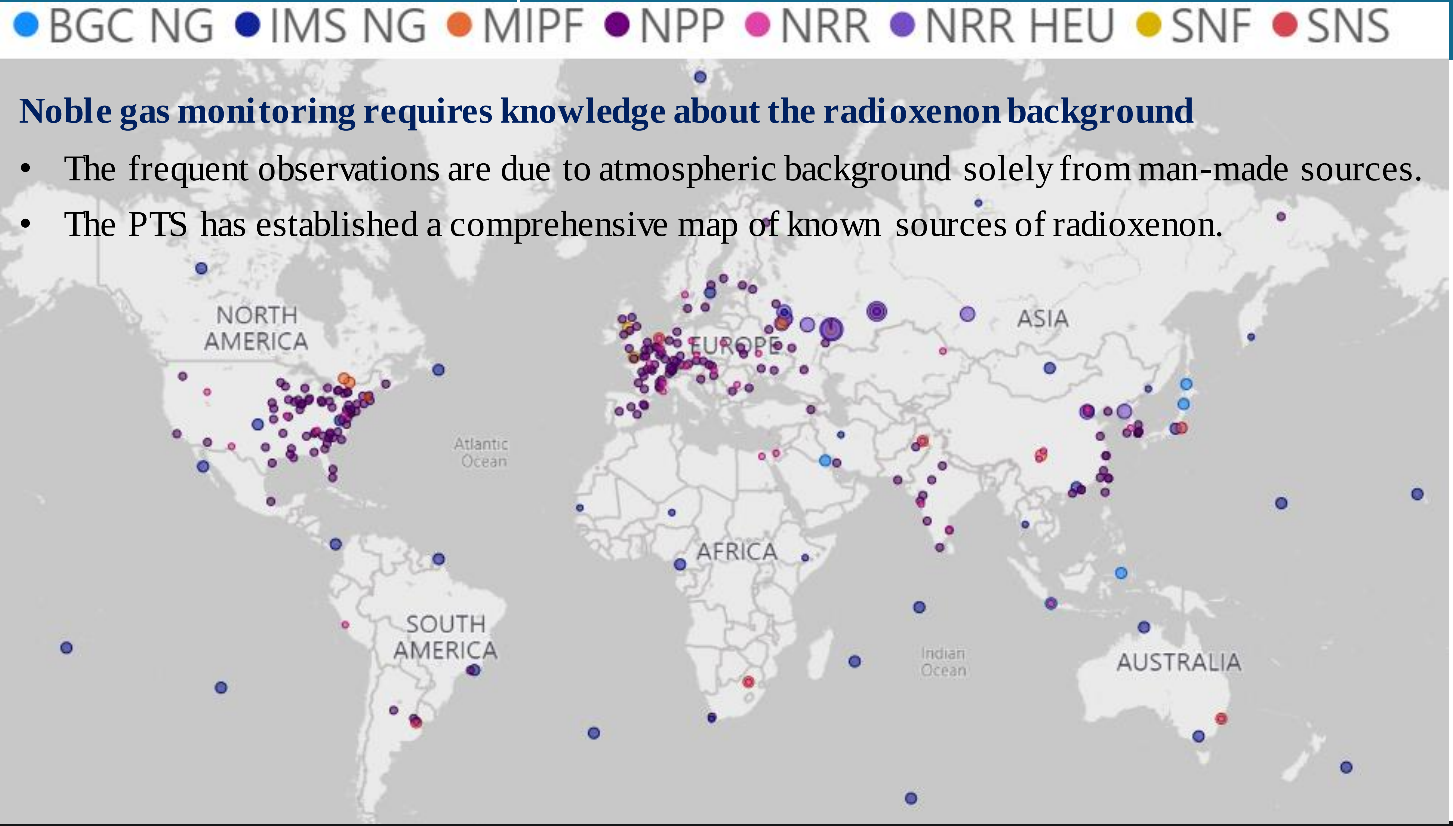


Xe-135

Radioxenon sources

Noble gas monitoring requires knowledge about the radioxenon background

- The frequent observations are due to atmospheric background solely from man-made sources.
- The PTS has established a comprehensive map of known sources of radioxenon.

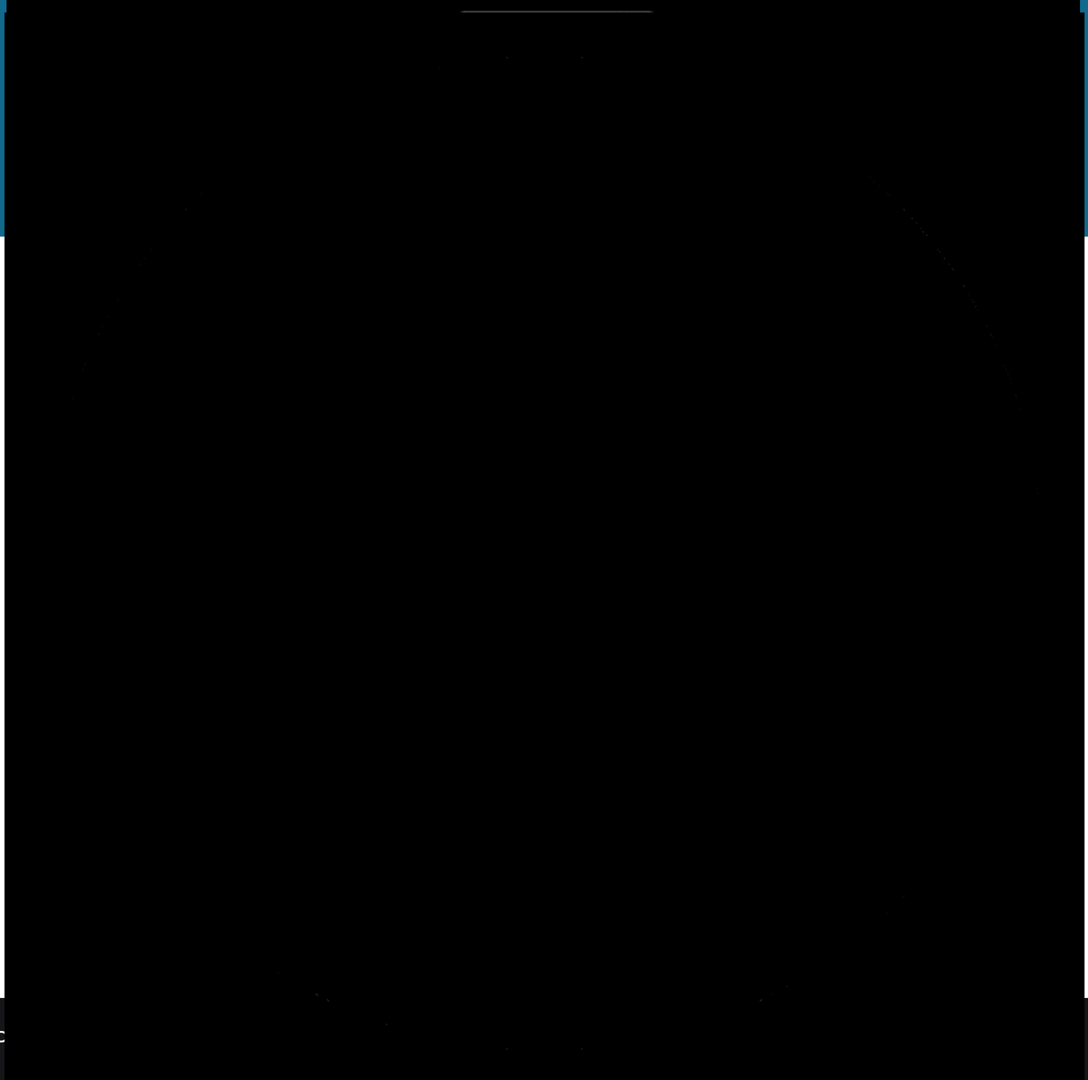


But:

- *Unknown sources*
- *Sources change*
- *Variable releases*
- *Still not fully understood*

Text displayed for 30 seconds before the animation starts:

The animation visualizes how the radioxenon emissions from the selected civil nuclear facilities in the Northern Hemisphere quickly mix with each other. This mix creates the atmospheric background before reaching IMS stations. Therefore, any release from an unknown source, e.g. a nuclear test, would be difficult to identify.



- 14 days of plume dispersion is shown.
- Different plume colours are used to visualize the effect of mixing. However, there is no physical difference of ^{133}Xe from different sources.

Civilian sources of radio-xenon causing an atmospheric background

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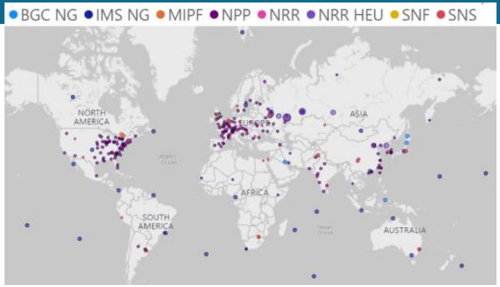
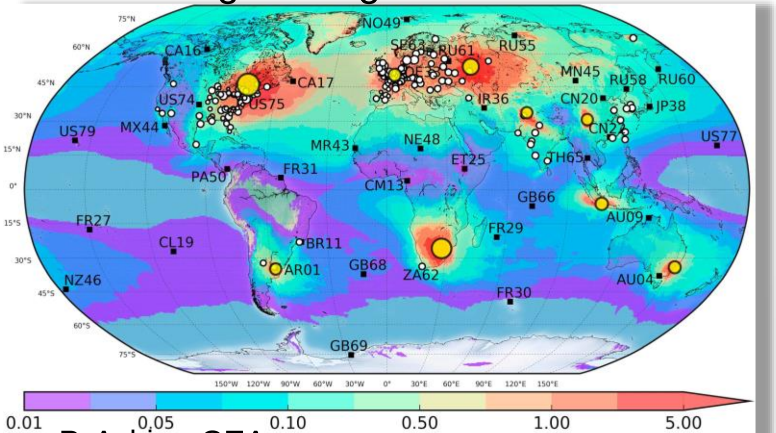


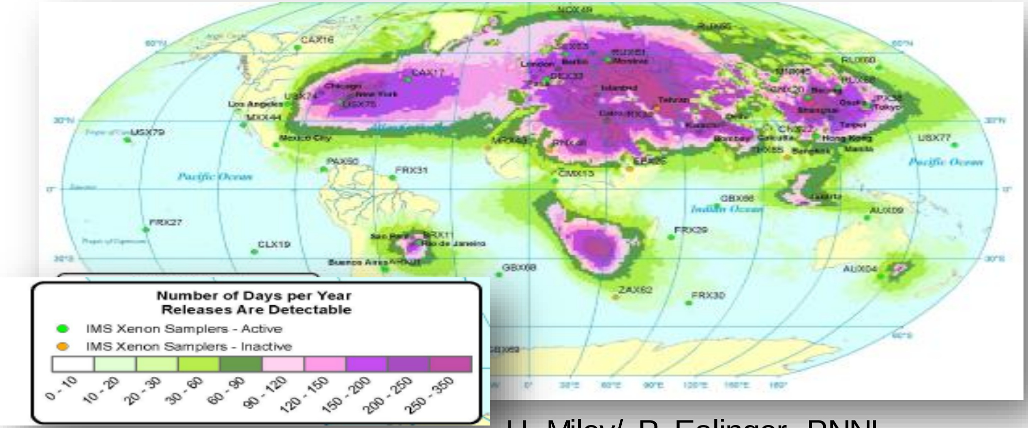
Source information used to simulate the impact on observations at IMS stations.

Average background of Xe-133



P. Achim, CEA

"Hit rate" above detection limit

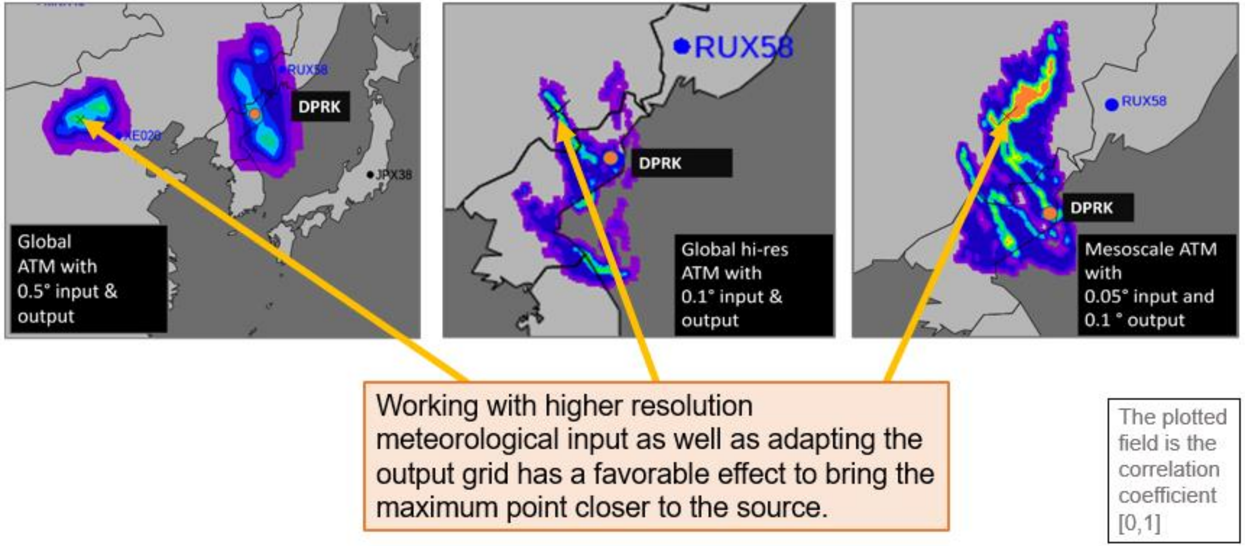


H. Miley/ P. Eslinger, PNNL

Atmospheric Transport Modelling (ATM)

ATM crucial for source location

- The PTS has implemented two ATM capabilities: a global model (Flexpart) and a high-resolution model (Flexpart/WRF)
- International ATM intercomparison exercises have repeatedly proven the operational IDC software of being of highest quality.
- High Resolution Atmospheric Transport is shown with DPRK-2013 as case study of bringing the maximum point closer to the source.

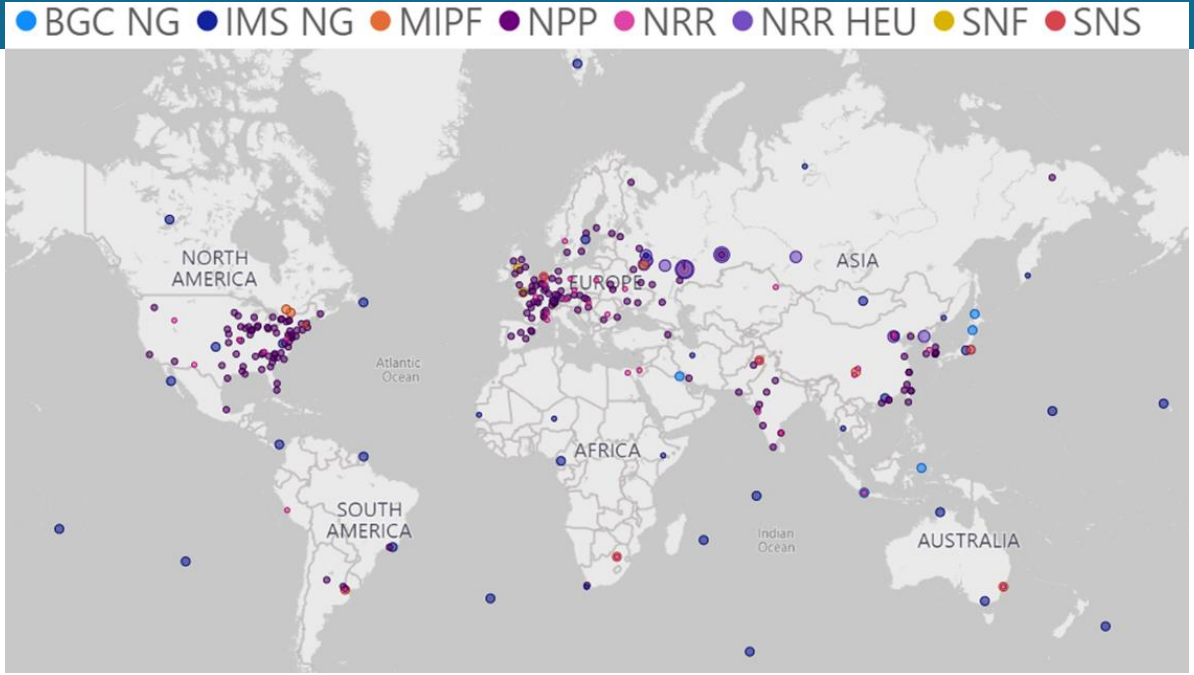


Global emission inventory 2014

Global emission inventory of ^{131m}Xe, ^{133}Xe, ^{133m}Xe, and ^{135}Xe for 2014 (Kalinowski, 2023)

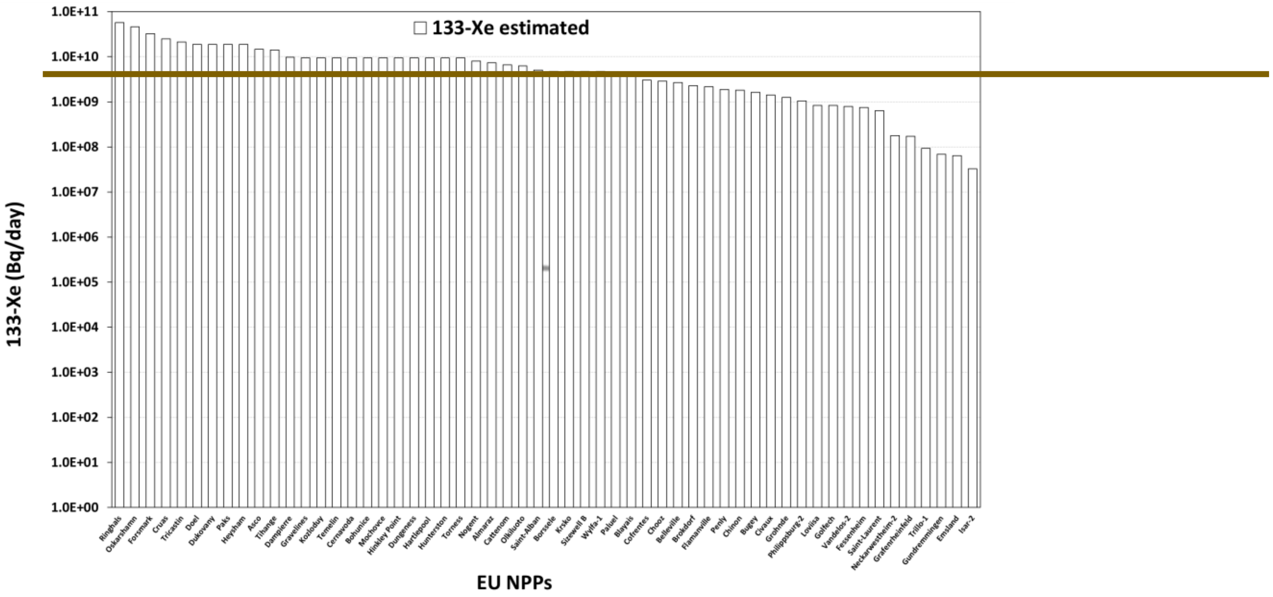
Used for the 1st Nuclear Explosion Signal Screening Open Inter-Comparison Exercise

1. Medical isotope prod. facilities
2. Nuclear power plant sites
3. Nuclear research reactors
4. Spallation neutron sources
5. SNF reprocessing facilities



Daily emissions of NPPs

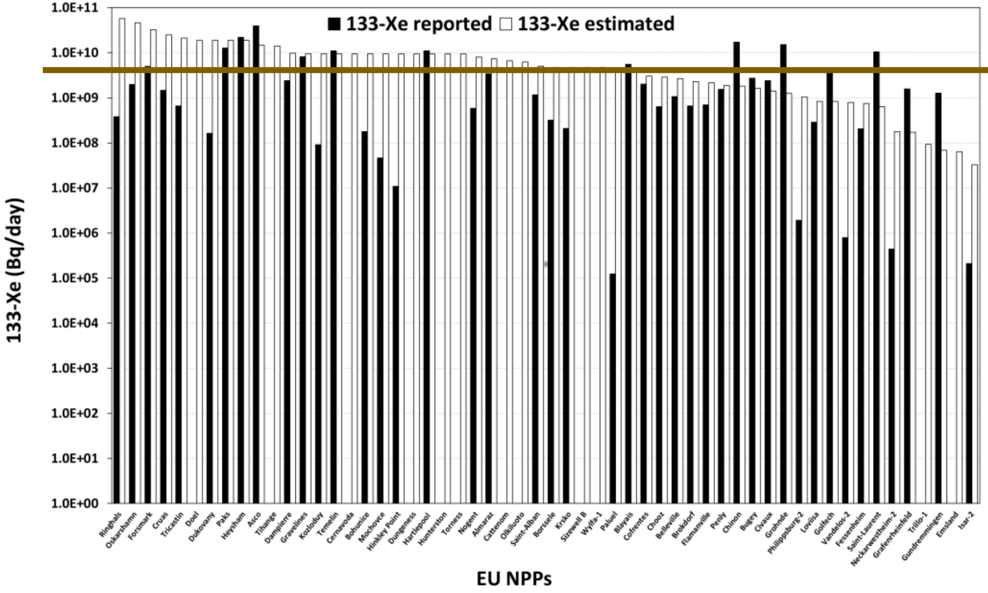
Estimated daily emissions of European NPPs (Kalinowski/Tuma, 2009)



5 GBq/d: value below which impact on IMS stations is very low (Bowyer et al., 2013)

Annual variability of daily average NPP emissions

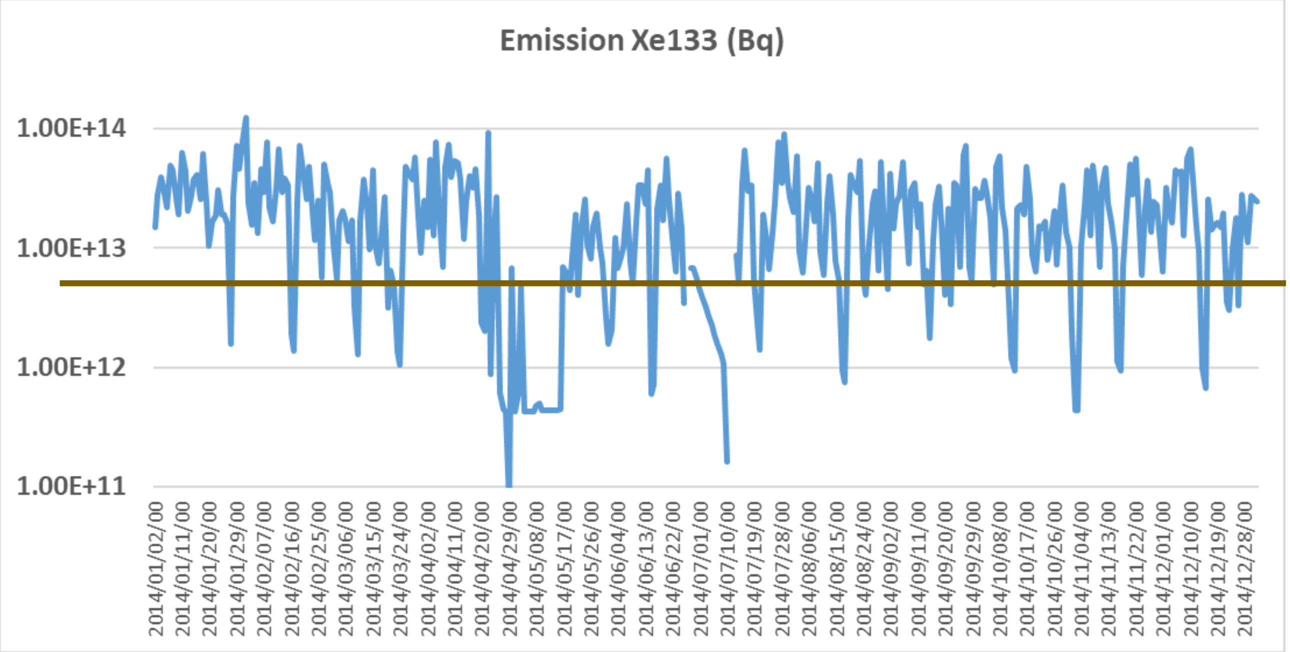
A value for a generic year (Kalinowski/Tuma, 2009) is not representative for a specific year (Kalinowski/Tatlisu, 2021)



- Release values cannot be extrapolated from one year to another.

Daily variability of MIPF emissions

Canadian Nuclear Laboratories



Variability over time

- At least daily resolution required to estimate concentrations at IMS stations
- Higher resolution even better

Summary on source data

- The global radioxenon emission inventory is useful for global network studies
- Release data of one year (e.g. 2014) are not representative for any other year
- Annual total release data don't have a sufficient time resolution for event analysis

- More work needed, e.g. on deciphering background noise that appears like a nuclear explosion signal.

Data Fusion: SHI geo-localisation + RN observations + ATM

DPRK announced tests served as quality check

- ^{133}Xe from the test in 2006 was discovered at Yellowknife, Canada.
- The test in 2013 was more challenging because the radioxenon release was delayed by about 50 days. The detections at Takasaki and Ussuriysk were confirmed by the simulation of isotopic ratios as a function of time.

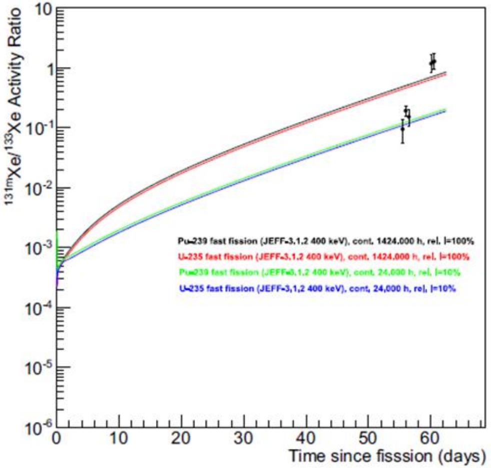


Fig. 17. Calculated ^{131m}Xe/^{133}Xe ratios as a function of time since fission for four different nuclear explosion scenarios (solid lines). The black markers are the observed ratios. Uncertainties are at the 1σ level. The two upper curves assumes full ingrowth of all precursors until release, and fits best to samples 4 and 5, while the two lower curves assumes separation of xenon and 10% of the iodine inventory after 24 h.

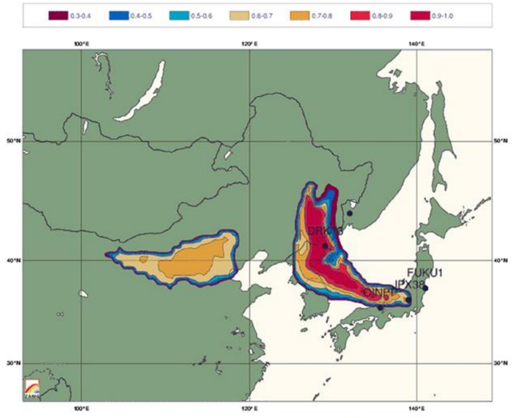
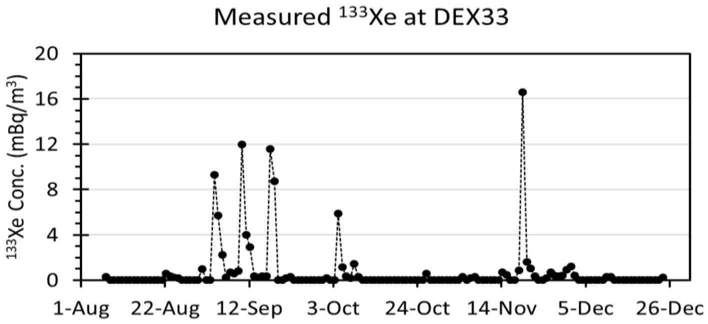


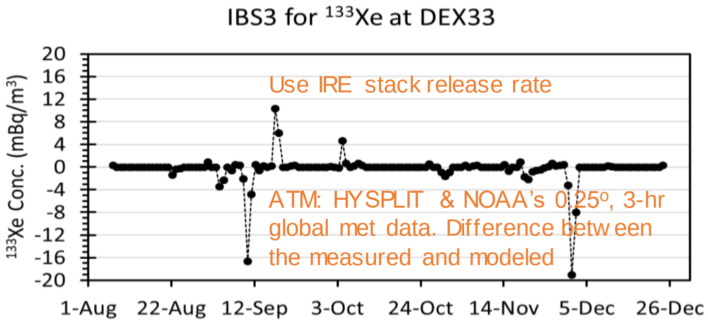
Fig. 13. Possible source regions (correlation maxima) calculated using the extended scenario described in Section 5.2. The point "DPRK13" denotes the DPRK event location, "FUKU1" the location of the Fukushima Daiichi NPP, and "OINPP" the location of the NPP Ohi, the only NPP in operations in Japan during the time of the DPRK event in 2013.

Ringbom, A. et al. (2014)

Data Fusion: SHI geo-localisation + RN observations + ATM

But: Other DPRK tests may also have been detected at IMS stations and some studies have given evidence of this.



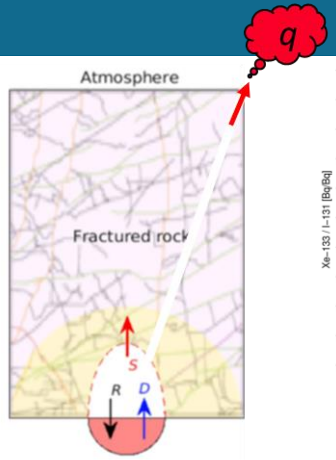


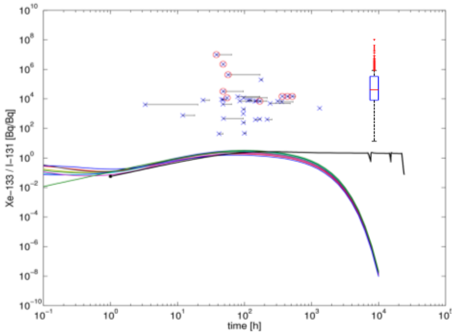
- The use of data collected at known facilities may prove useful to remove the effect of these sources.
- For example, using data from IRE, one may subtract off its affect at DEX33.
- Many detections at IMS could be screened out.

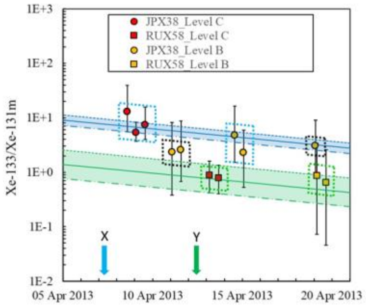
PNNL

Ongoing R&R

- Global analysis of radioxenon background by data assimilation to simulate best estimate of concentrations at IMS stations.
- New NG systems with shorter sampling time.
- Enhanced knowledge about all sources.
- Comprehensive knowledge on nuclear explosion source term.
- Bayesian source estimation for release time, duration, strength and location.
- Complementing sample categorization with a suite of screening methods (see e.g. isotopic ratio screening flags, ATM backtracking to known sources)
- Integration of radionuclide sample information into source location, e.g. by sample association and event timing.







Availability of data for scientific purpose / vDec

- There are significant scientific and technological opportunities that are promising to make a giant leap,
- using the tremendous asset of more than 10 years of IMS noble gas data plus background campaign data.

- Authorized users have access to the IMS data and those from background measurement campaigns
- Other scientific establishments can get access to the data through the virtual Data Exploitation Centre (vDEC) by signing a zero-cost confidentiality agreement.

Conclusions

- The IMS noble gas systems form a unique and high-quality network.
- The global monitoring of atmospheric radioxenon is a complex task.
- For each sample to determine whether the source could be an explosion, it requires sufficient understanding of the atmospheric background created by hundreds of man-made sources.
- Sources still need to be even better known.
- Solutions to the remaining challenges of noble gas monitoring can be achieved by strong cooperation of the international scientific and technological community like here at WOSMIP IX.

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