



# UK NDC Analysis of IMS Radionuclide Events Near to North Korea

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Introduction



Modelling the Radioxenon background



UK NDC Event Analysis



Flagged 'Events' at JPX38



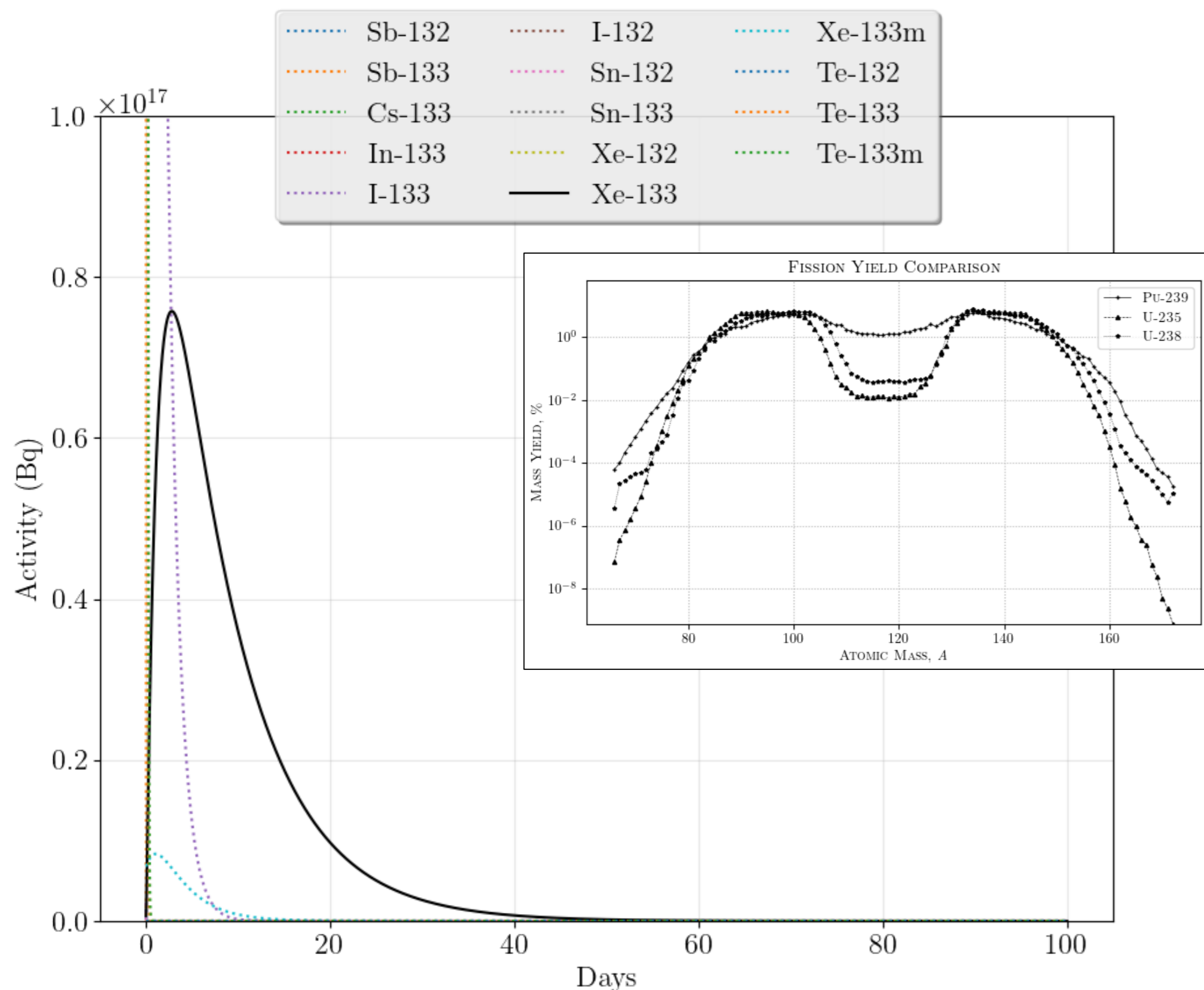
The next steps in event analysis...



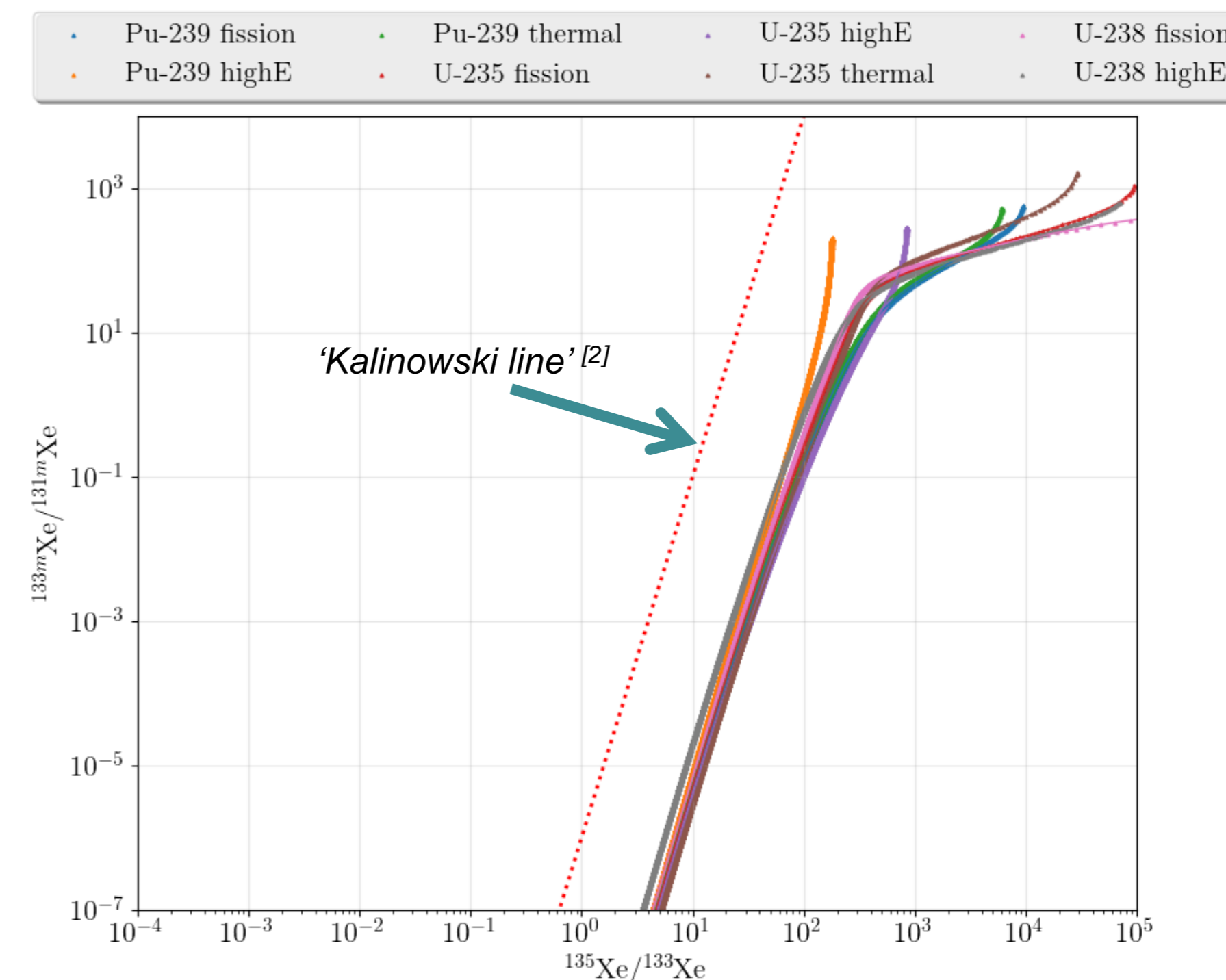
- AWE operates the UK CTBT Radionuclide Laboratory (GBL15), which has two primary certified operations:
  - Gamma spectrometry of high volume air filters, collected at IMS stations
  - Beta-Gamma coincidence spectrometry of xenon samples, collected at IMS stations
  
- As well as operating the laboratory, GBL15 scientists operate the UK National Data Centre (NDC)
  - Independent analysis of the International Monitoring System (IMS) radionuclide data, which is used to advise the UK MoD of any possible violations to the Treaty.



# Measuring Signatures of Nuclear Weapons Testing



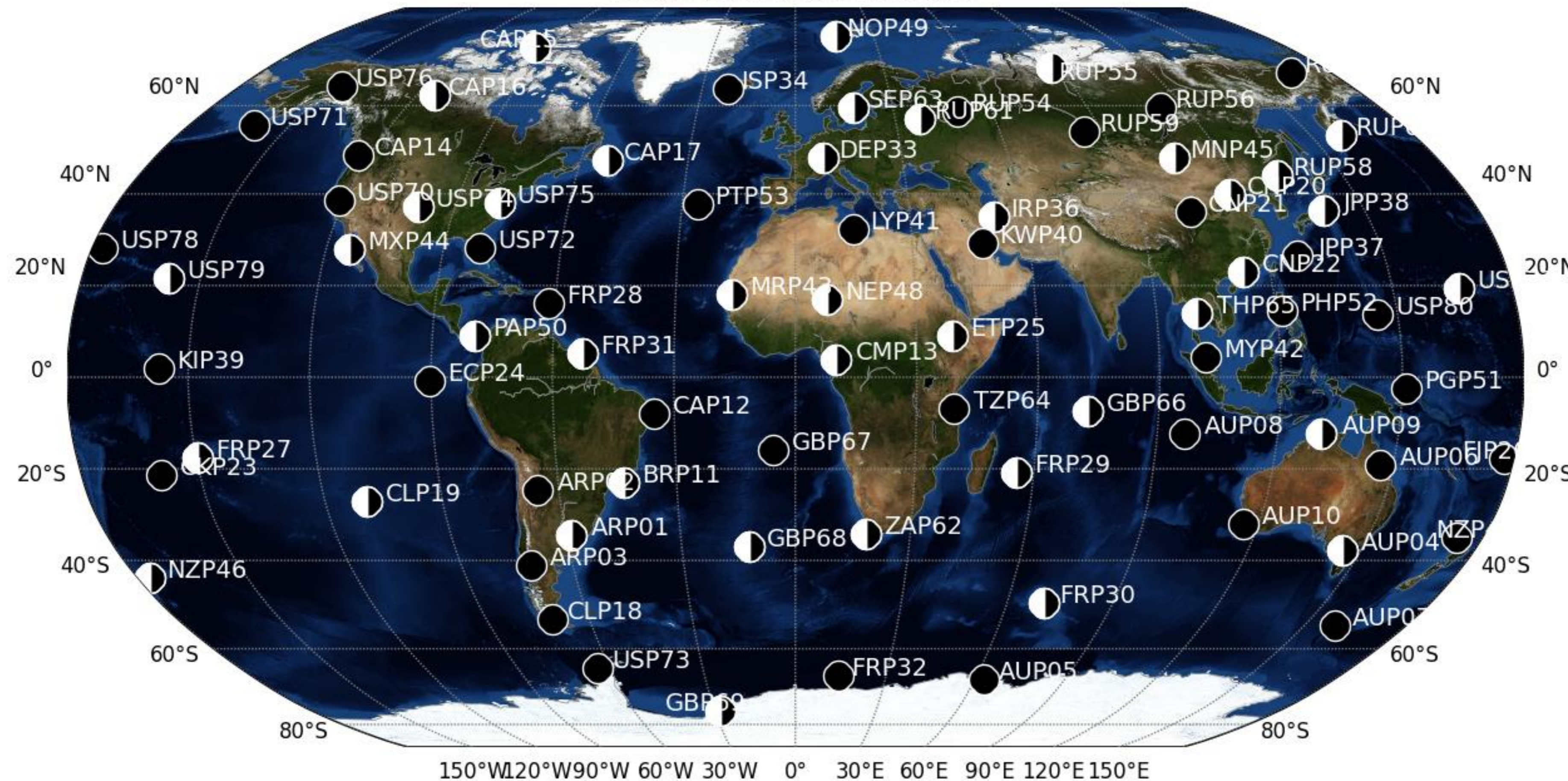
*Fig 0b. (below)  
 Modelled Radioxenon ingrowth / decay from a 10 Kt UGT using 14 MeV neutrons on  $^{235}\text{U}$ , vented slowly from a cavity. Presented as the '4 isotope plot'*



*Fig 0a. (above)  
 Modelled Xe-133 decay chain from a 10 Kt nuclear explosion using 14 MeV neutrons on  $^{235}\text{U}$   
 (inset) Fission split comparison of common fuels. FY data from [1]*



### IMS Radionuclide Network



- RN Particulate Station
- ◐ RN Particulate & Noble Gas Station

*Fig 1. International Monitoring System (IMS) Radionuclide stations with and without Noble Gas technology installed*



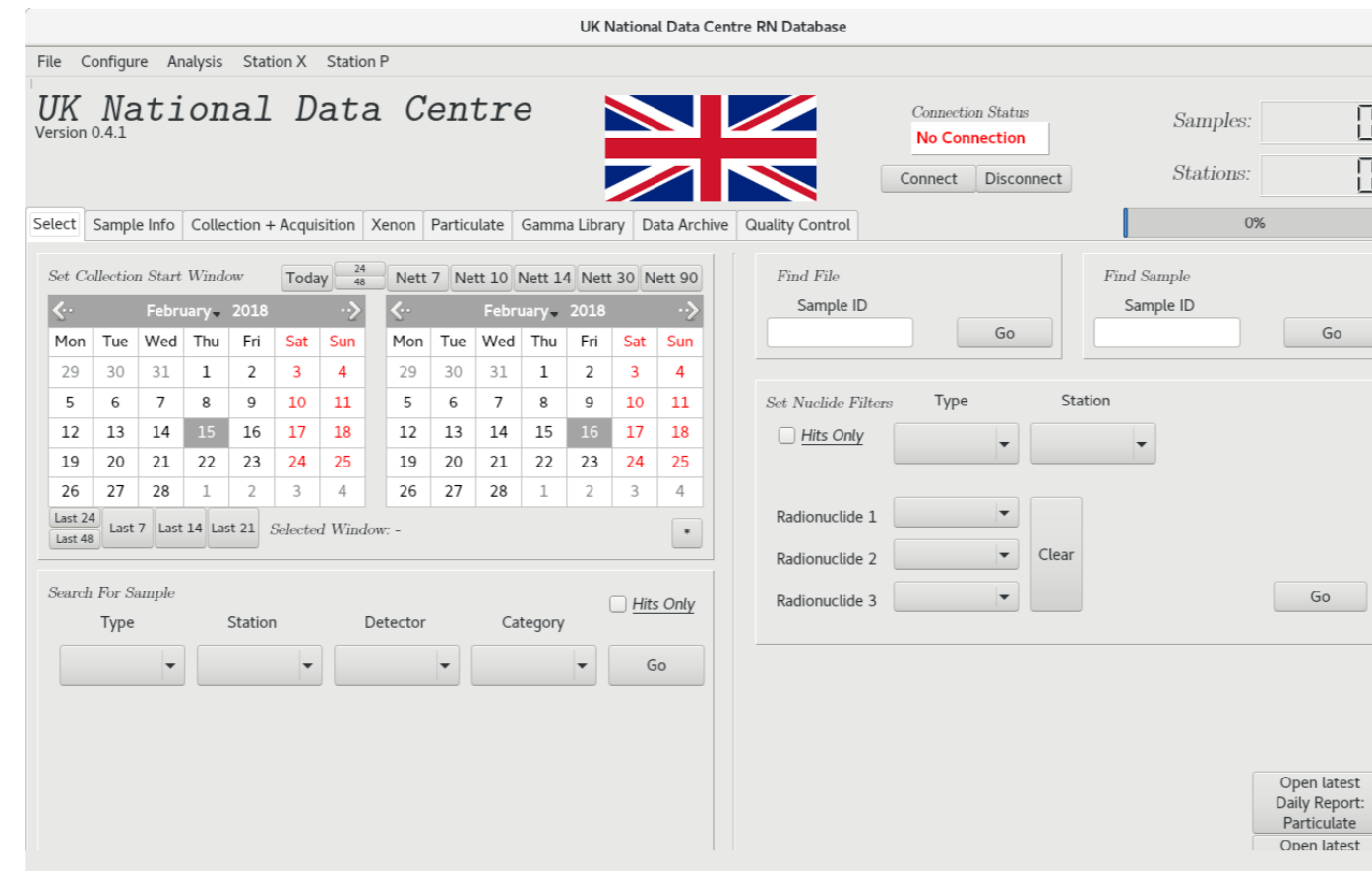
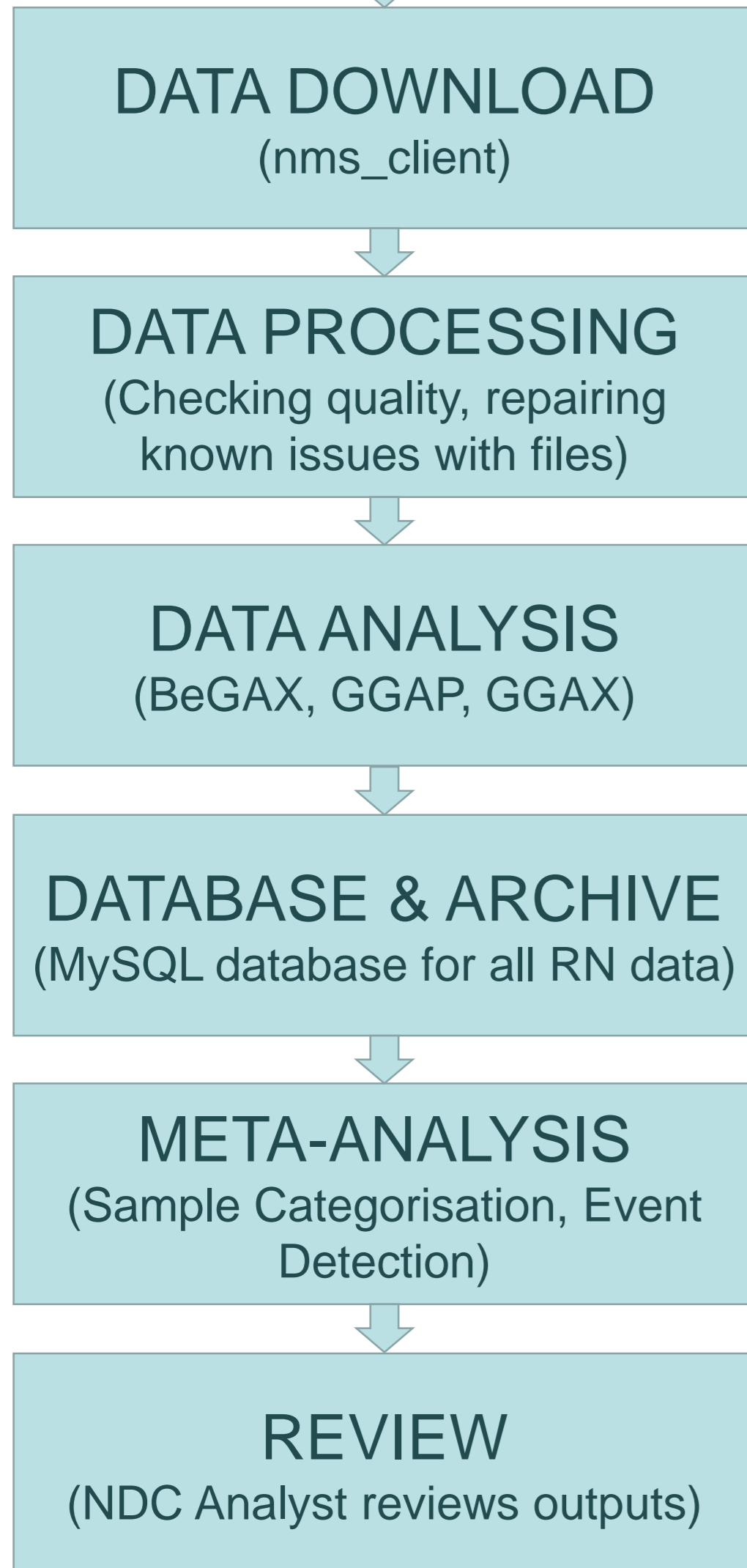
# Automated Analysis

- Continued development of in-house systems
  - Full transparency of algorithms / logic used on the raw data
  - Growth takes place at our own rate
  - Develop UK national RN capability
- Modular in design and implementation
  - It is possible to adapt individual fragments of the pipeline, without a major update to the main codes
  - Duplication is possible, we often run several iterations of the pipeline in parallel, when testing new ideas or checking performance
  - Modern, interpreted programming language: Python
- Discuss ideas with other NDCs (NDC workshop etc.)
- A quick overview of the automated processes...

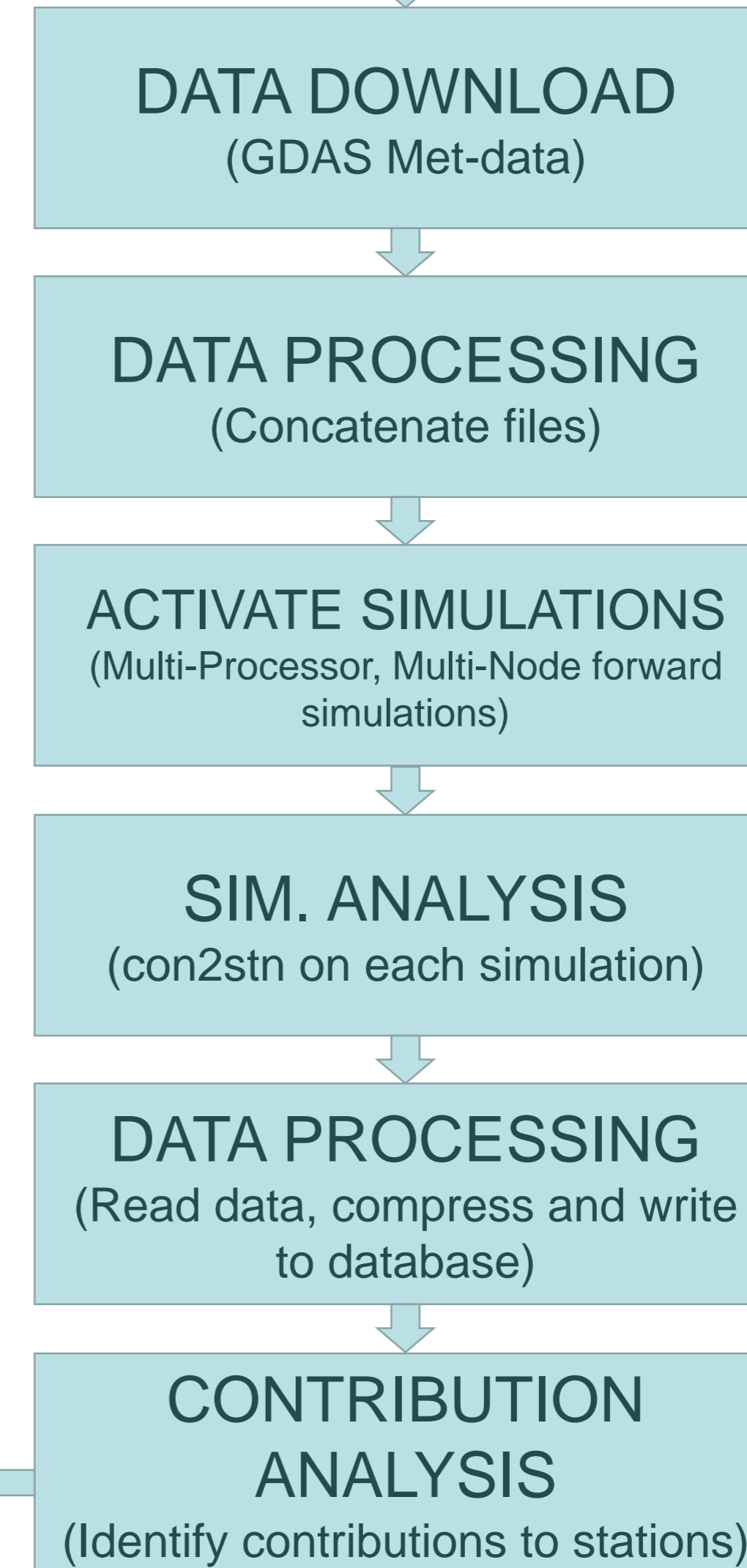


# UK NDC Automated Analysis Pipelines

RN PIPELINE



ATM PIPELINE

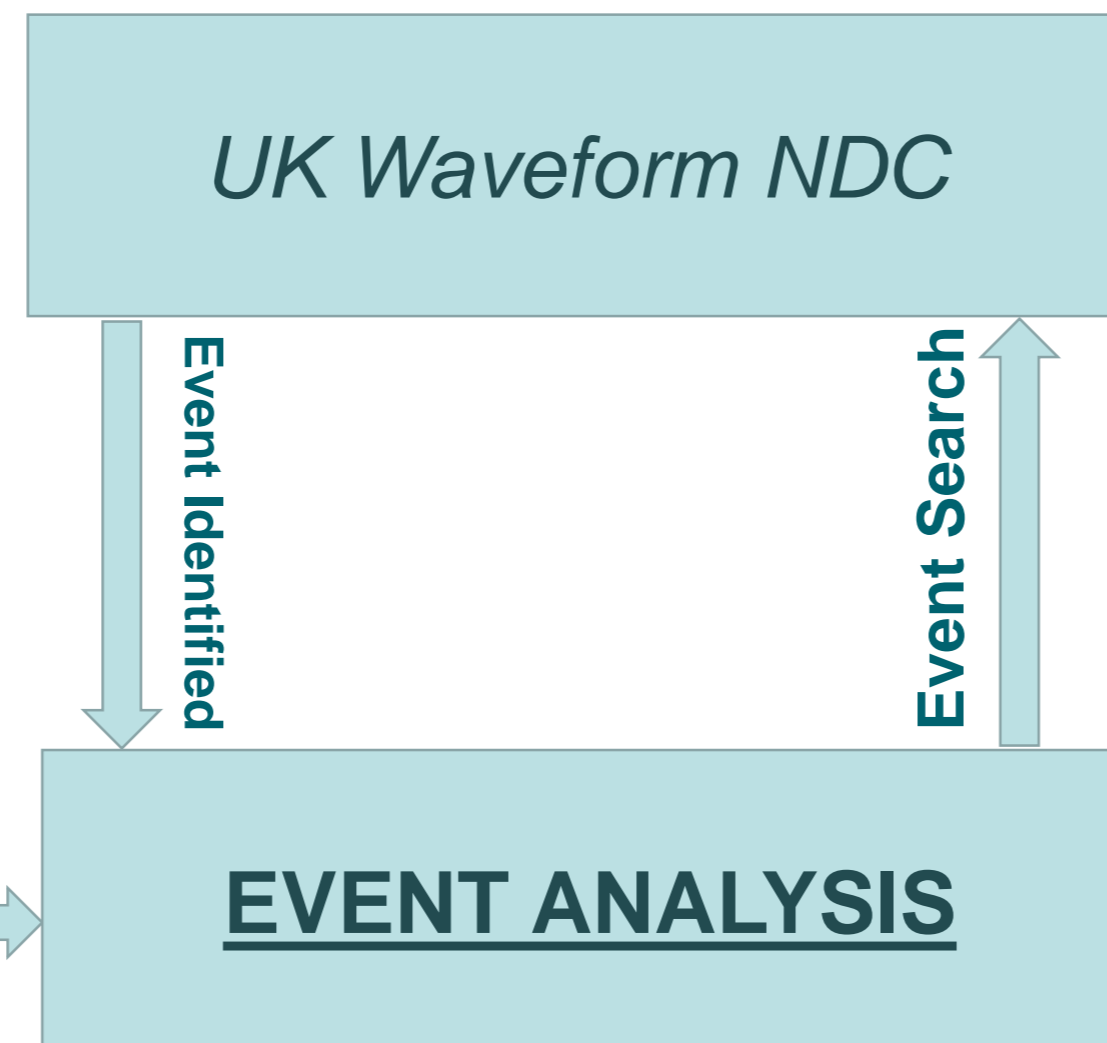
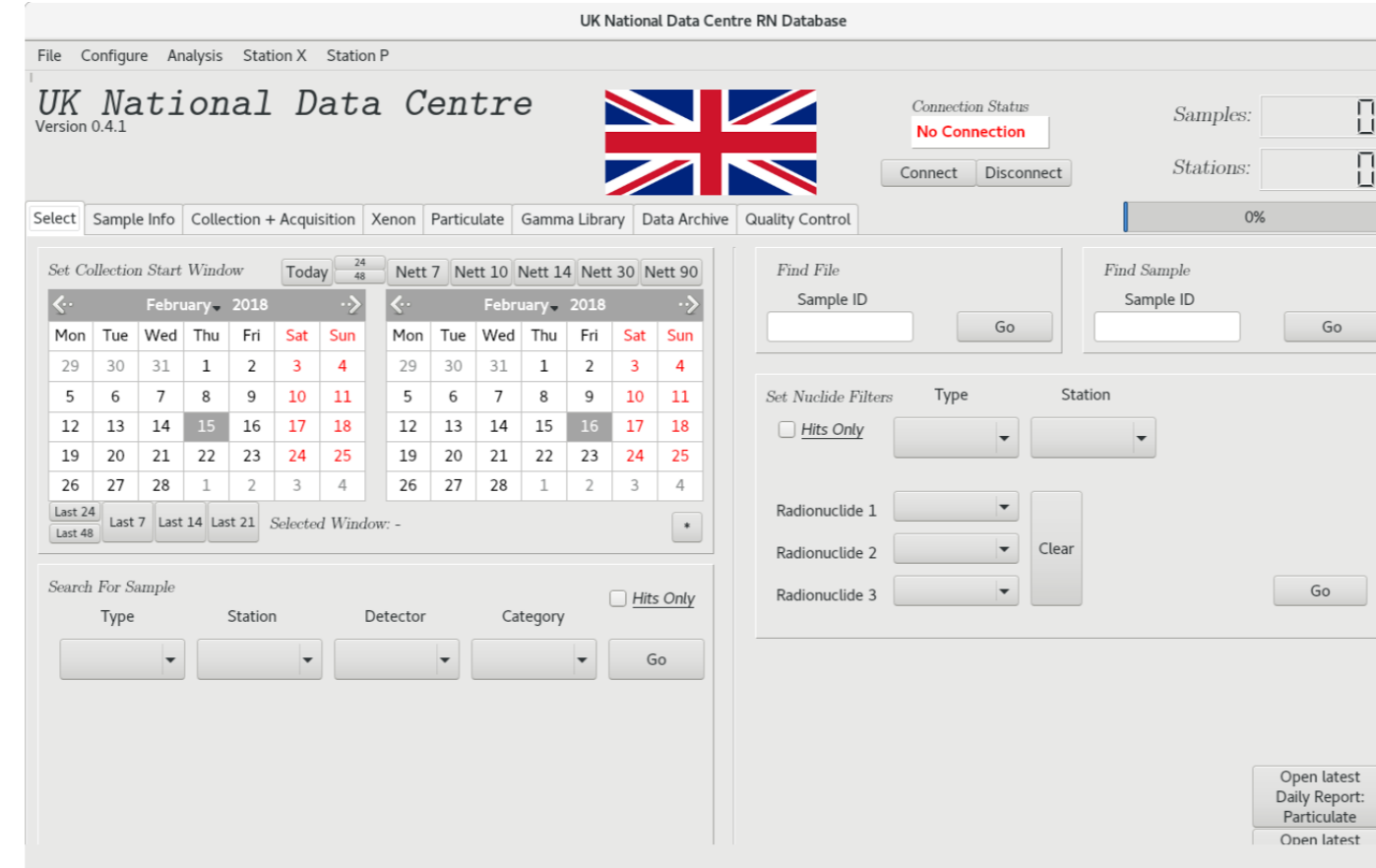
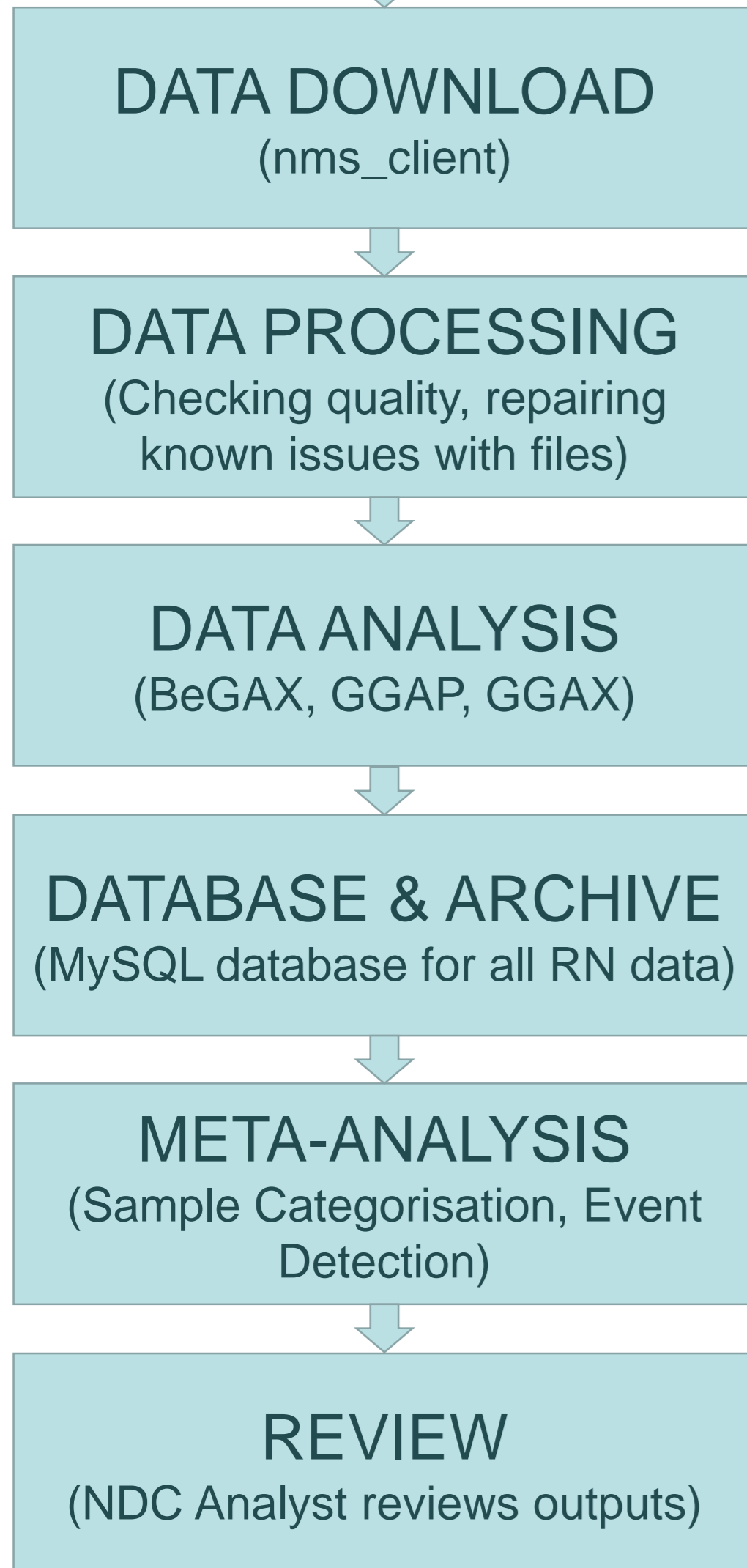


**EVENT ANALYSIS**

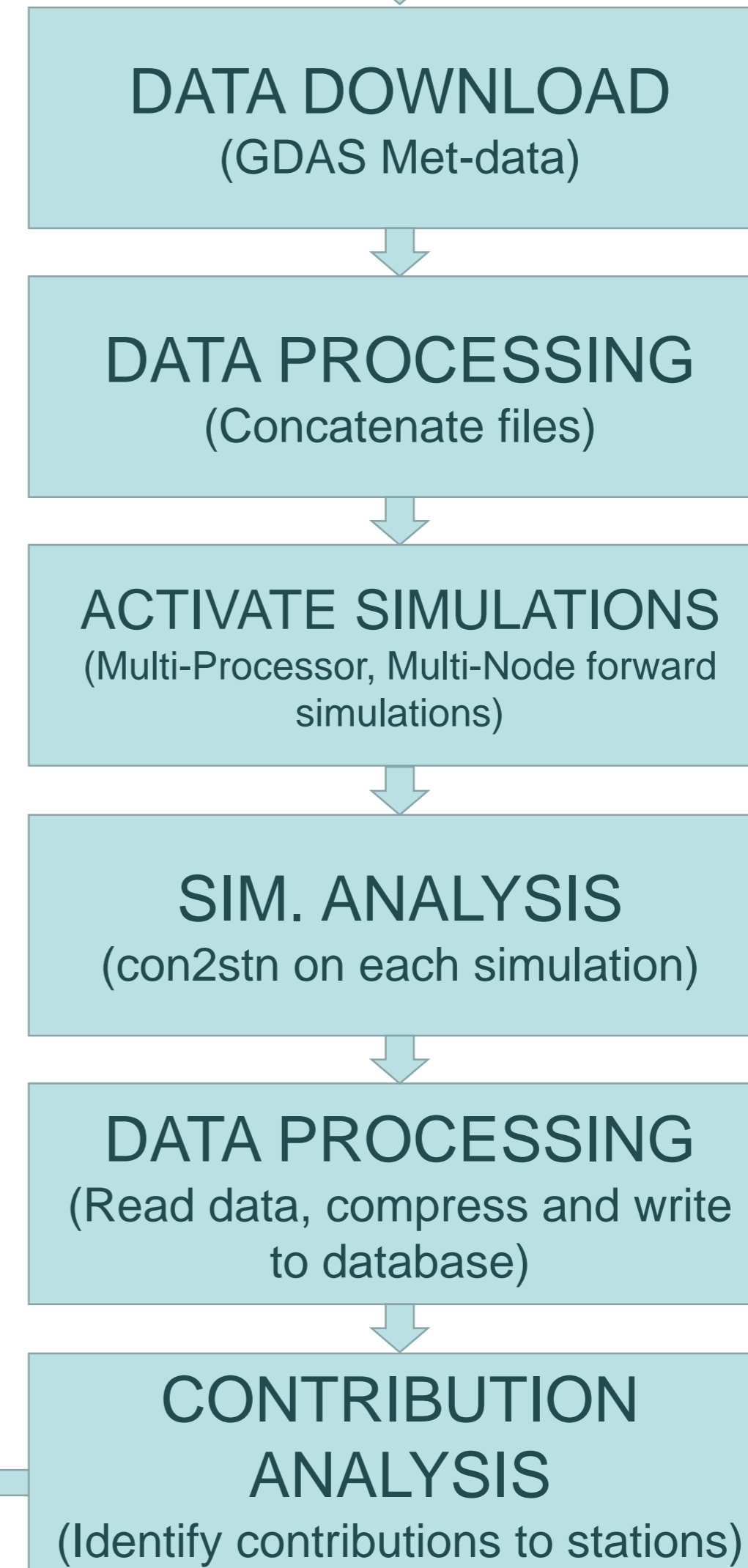


# UK NDC Automated Analysis Pipelines

RN PIPELINE



ATM PIPELINE





# ATM Pipeline

- HYSPLIT simulations, from multiple locations, multiple times every day.
- Contribution to all IMS sites assessed.
- Designed to identify contributions to the IMS from known / possible sources of radioxenon
- Further simulations can be run with more specific variables, on an ad-hoc basis

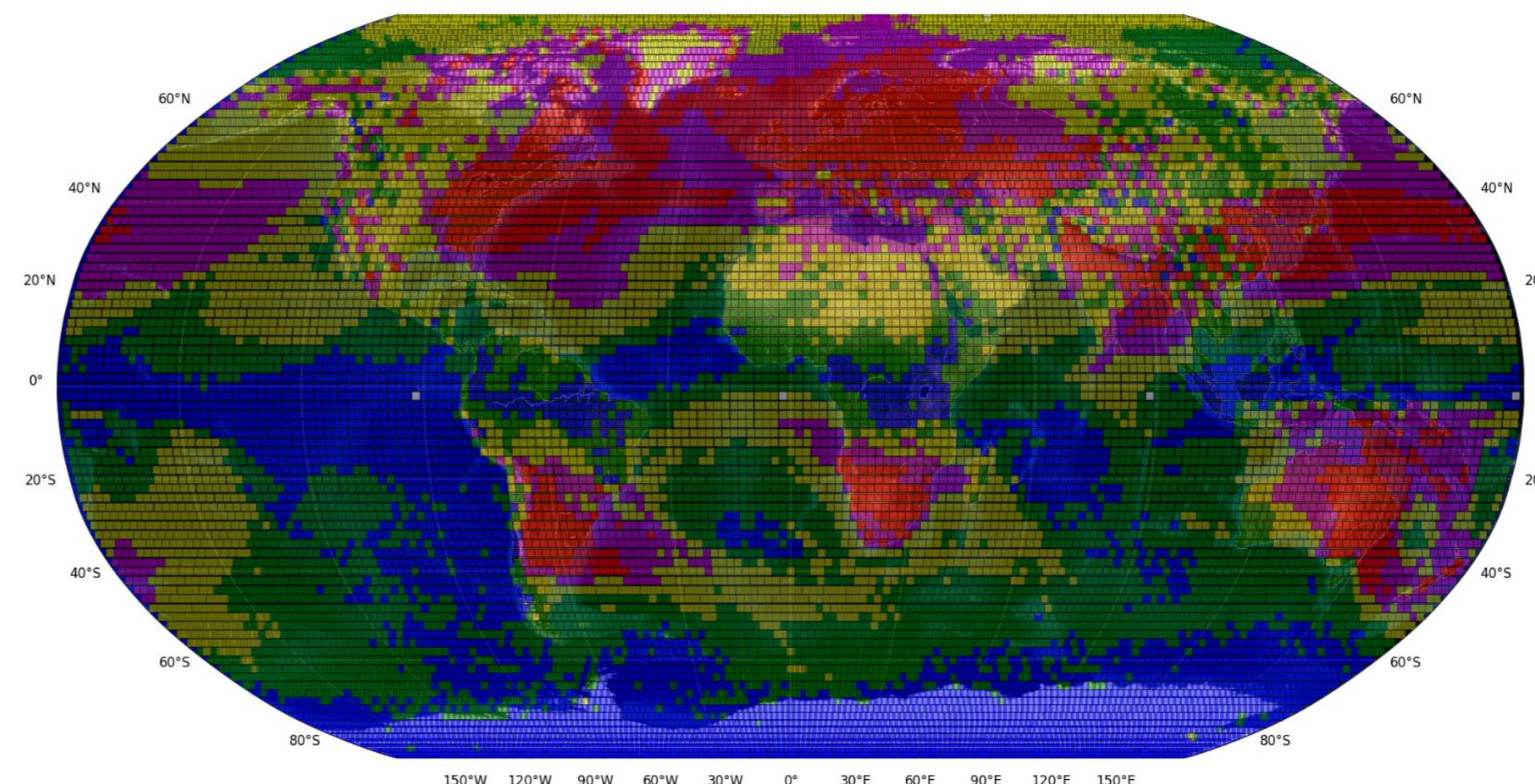
*Table 1. ATM Pipeline HYSPLIT variables*

Variable Name	Value	Units
N particles / release	100,000	
Max particles	100,000	
Rate	0.5	Units/hour
Release duration	2	Hours
Stack height	40	m
Wet deposition	OFF	
Dry deposition	OFF	
Half-life	5.2	Days
Emission releases	0300, 0900, 1300, 2100	hrs
Max ATM Height	10000	m
Sampling Layer	0-200	m
Sampling Resolution	0.5	Degrees
Sampling Resolution	1	Hours
Metrological Resolution	0.5	Degrees
Metrological Resolution	3	Hours



# North Korea Area of Interest

- Multiple sites contributing to the radioxenon background near to North Korea
- Medical Isotope Production Facilities (MIP), Nuclear Power Plants (NPP) and other facilities (Yongbyon)
- Yongbyon is of particular interest, given proximity to the North Korean test site
- A (changing) number of 'local' sources (NPPs) in Japan
- MIP facilities emit large volumes of radioxenon to the atmosphere.



*Fig 2. (top) Modelled radioxenon background based on ATM Pipeline simulations. (Bottom) Radionuclide Area of Interest around North Korea.*



# Radoxenon Background

Emitter ID	Emitter Name	Emitter Desc	Latitude	Longitude	Status
1	SA1	Pelindaba SA (NTP)	-25.480	27.560	1
2	BE1	IRE Belgium	50.270	4.320	1
3	PK1	PINSTECH Pakistan	33.390	73.150	1
4	AU1	ANSTO Australia	-34.050	150.980	1
5	CA1	Nordion Canada	45.340	-75.910	1
6	AR1	CNEA Argentina	-34.820	-58.580	1
7	CN1	HFETR China	29.750	103.670	1
8	RU1	Karpov Institute Russia	55.750	37.650	1
9	DPRK	DPRK Test Site	41.290	129.110	1
10	CARR	CARR China (RIAR)	39.440	116.030	1
11	IBAM	Marrinckrodt US	38.660	-90.190	1
12	NK1	DPRK reactor Yongbyon	39.790	125.750	1
13	SE1	Forsmark Sweden	60.403	18.167	1
14	JP1	Ikata Japan	33.490	132.310	1
15	JP2	Sendai Japan	31.820	130.190	1
16	JP3	Takahama Japan	35.520	135.500	1
17	JP4	Tomari Japan	43.040	140.510	1
18	JP5	Oma Japan	41.510	140.910	1
19	CH1	Hongyanhe China	39.790	121.480	0
20	CH2	Tianwan China	34.690	119.460	0
21	CH3	Qinshan China	30.430	120.950	0
22	SK1	Hanbit South Korea	35.410	126.420	0
23	SK2	Wolseong South Korea	35.710	129.480	0
24	SK3	Hanul South Korea	37.090	129.380	0
25	SK4	Kori South Korea	35.320	129.290	0

- Database flag activates pipeline emissions.
- Emitter type defines simulation length.
- Sites can be added / removed from the table at any point and back-filled to compare emissions
- Table compiled using [2]






# Batch Xe-133 Simulations

- We need to understand what is being detected at JPX38, so we are using our tools to model the contribution from possible sources...
- Model emissions from each site of interest and MIP facility, every day for a several years
- Assess the contribution to JPX38 for *all* collection periods
- Given estimated emission magnitude, calculate probability of JPX38 detection
- One emission can contribute to multiple collection periods
- JPX38 SAUNA system runs on a 0700 – 1900 hrs cycle
- Huge variation in average contribution (to be expected)



# Radoxenon Background

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	MIP
	Local NPP
	Site of Interest



# Batch Radioxenon Simulations

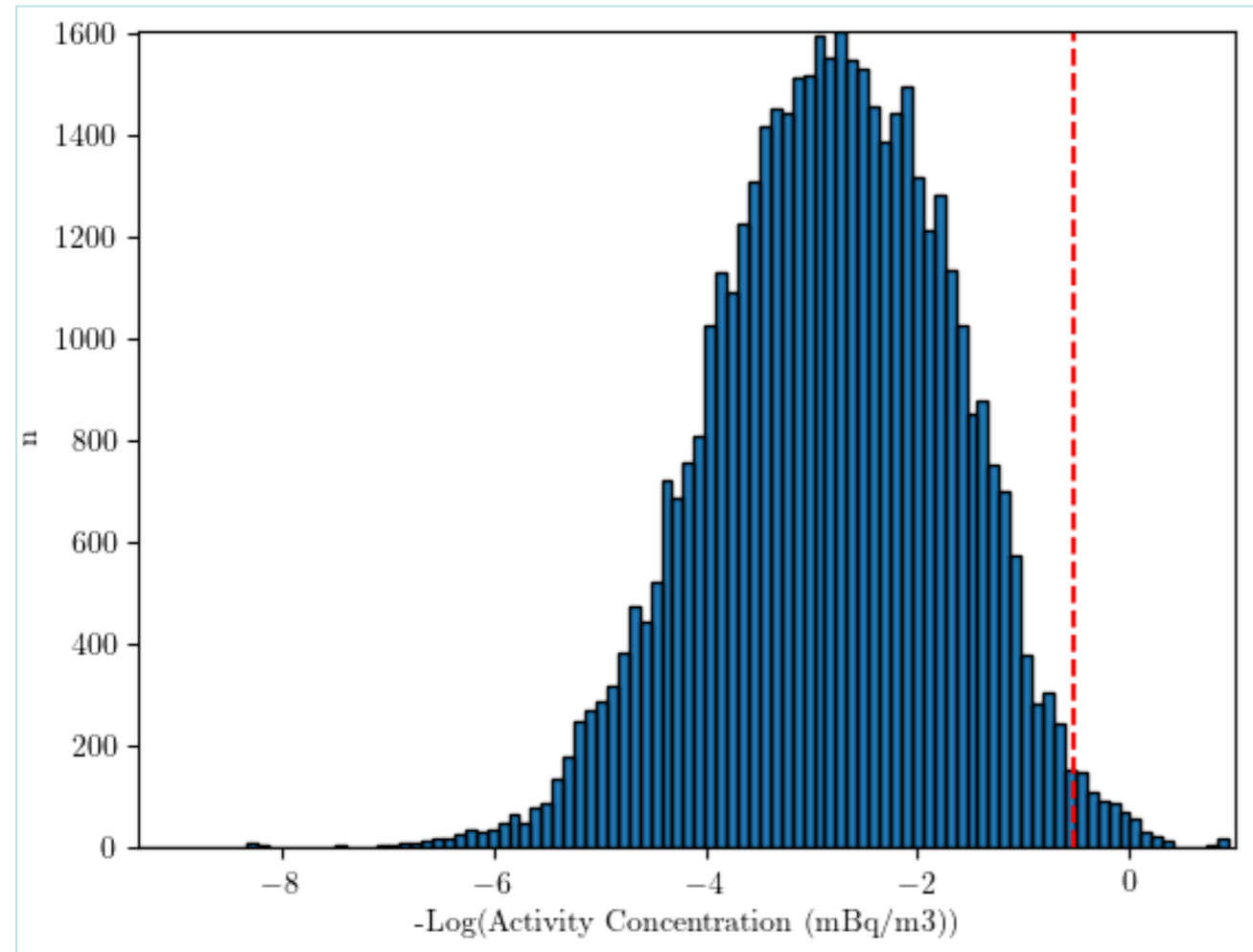


Fig 3a. Emissions of  $1E14$  Bq from CARR,

Multiple emissions from sites of interest, the average concentration ( $mBq.m^{-3}$ ) is calculated at JPX38 in any given collection period (0700/1900 clock)

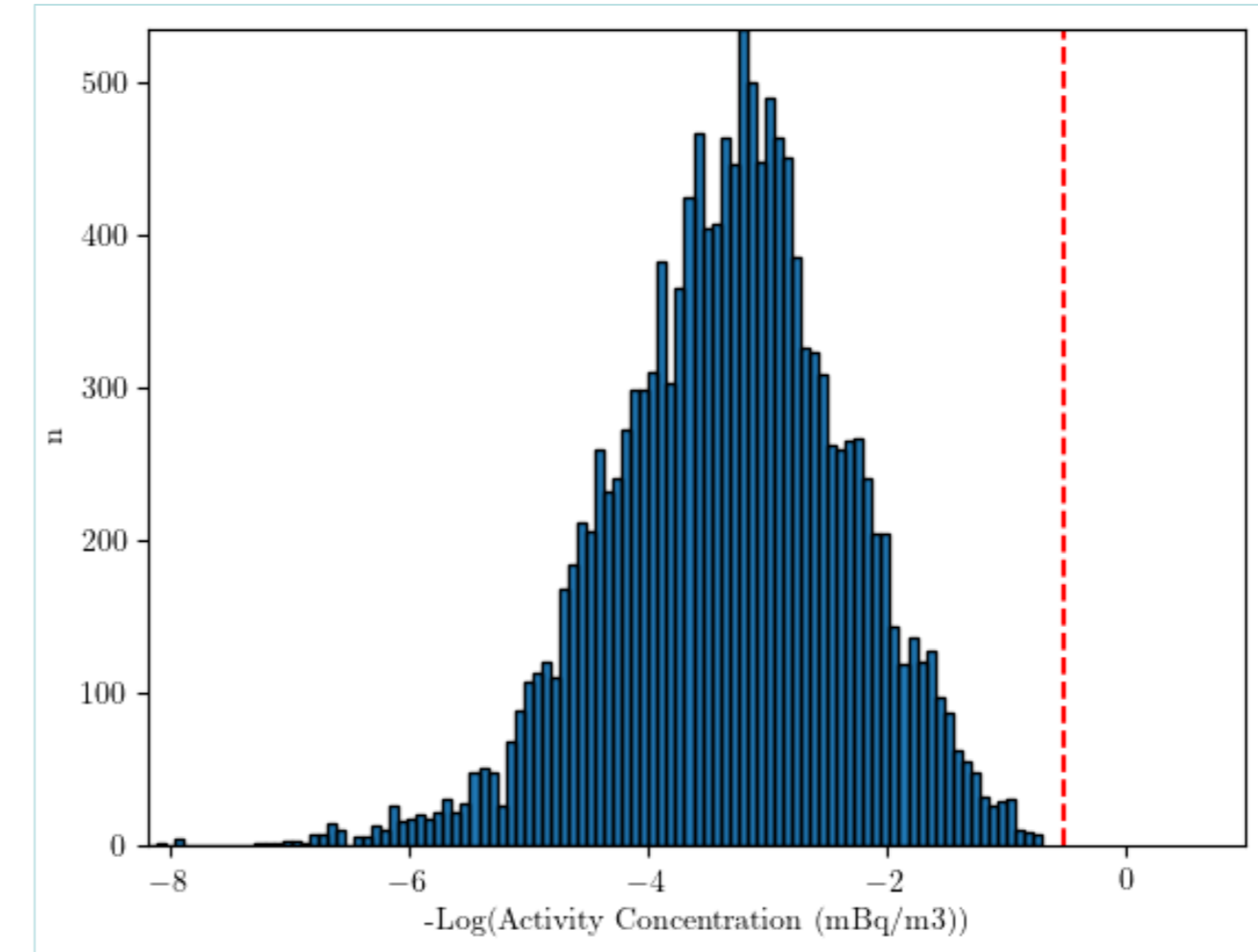


Fig 3b. Emissions of  $1E14$  Bq from HFETR, China

Warning:  
Log<sub>10</sub> scale  
x-axes!

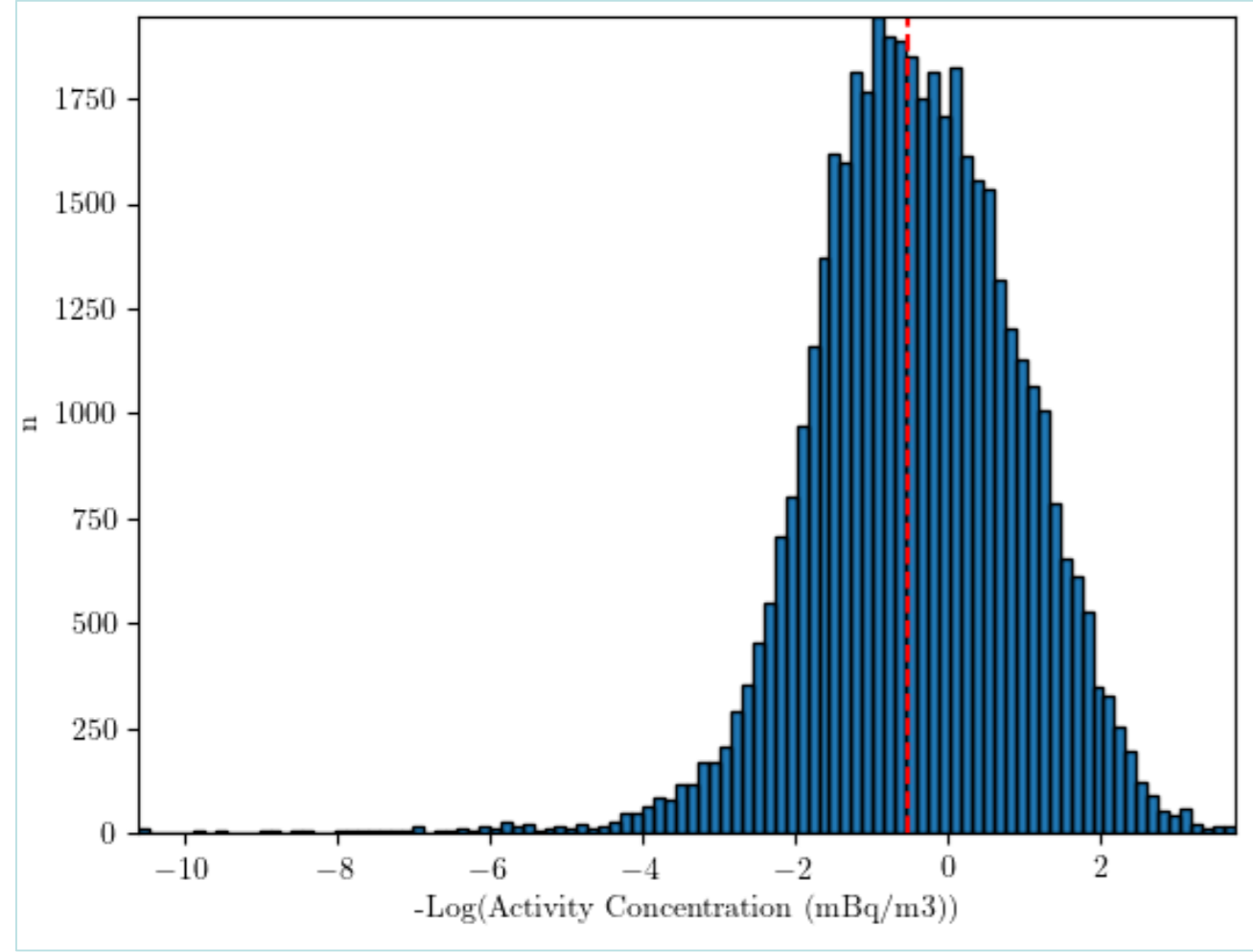


Fig 3c. Emissions of  $1E15$  Bq from North Korean Test Site

Analysis of events identified in 2018 led us to believe that YB is emitting more radioxenon than 'expected'. [3]

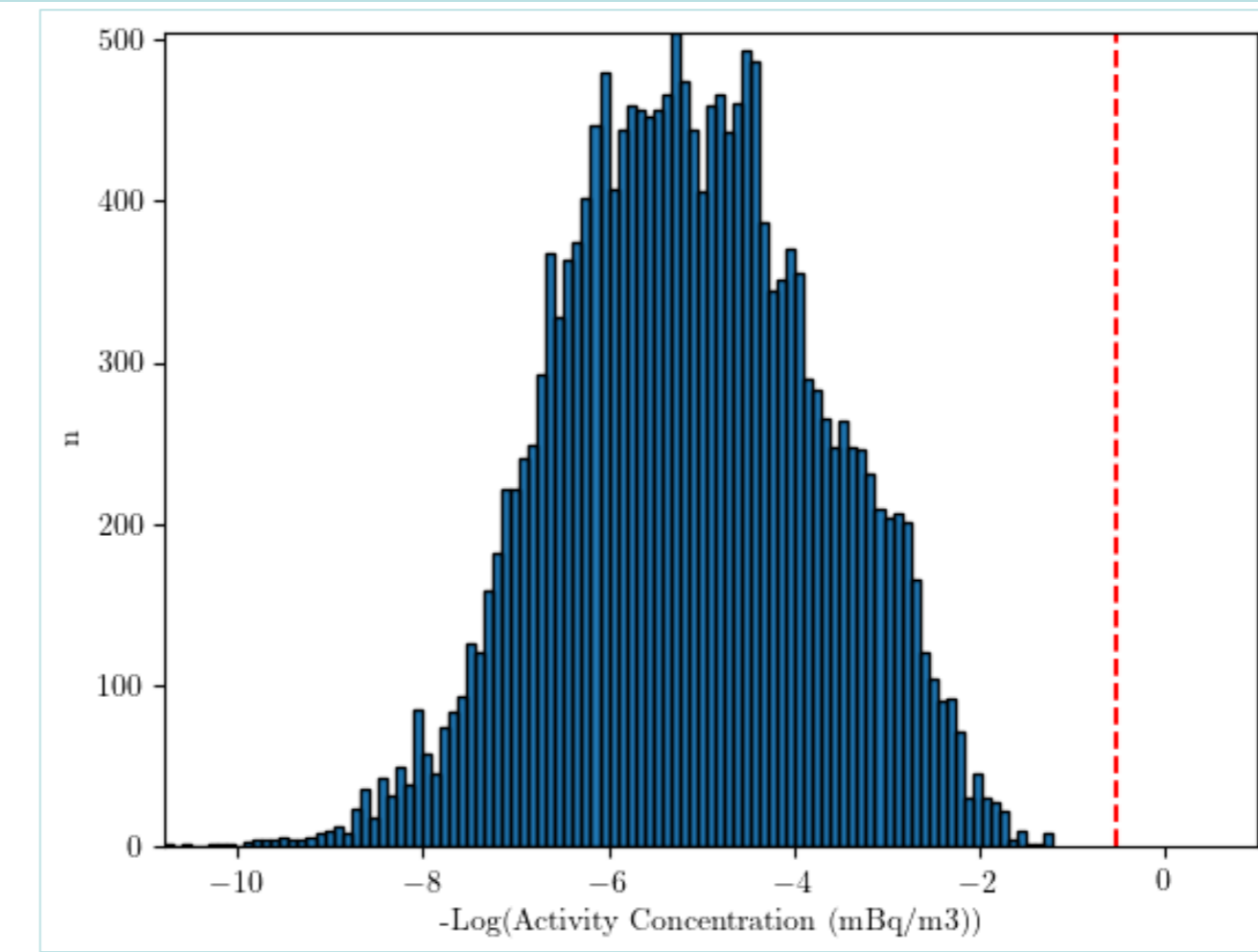


Fig 3d. Emissions of  $1E10$  Bq from Yongbyon Test Reactor



# 2018 JPX38 Detections

- Multiple 'events' considered and emissions modelled to simulate the detections. Calculated source terms used to adjust YB emissions. Some example 2018 events are:

*Table 2. Possible Yongbyon detections at JPX38 in 2018*

Collection Start	AC (mBq.m <sup>-3</sup> )	Mean Contribution Factor (m <sup>-3</sup> )	Source Term (Bq)
01-01-2018 0700	0.165		
01-01-2018 1900	0.336	7.11E-16	4.73E+11
02-01-2018 0700	0.426	1.20E-15	3.54E+11
02-01-2018 1900	0.487		

Collection Start	AC (mBq.m <sup>-3</sup> )	Mean Contribution Factor (m <sup>-3</sup> )	Source Term (Bq)
05-02-2018 0700	0.271	5.50E-15	4.92E+10
05-02-2018 1900	0.183	3.51E-16	5.22E+11
06-02-2018 0700	0.462	5.78E-16	7.99E+11
06-02-2018 1900	0.242	1.35E-17	

Average source term: 4.36E+11 Bq



# Yongbyon adjusted emissions

- Emissions at  $4E+11$  Bq explain more likely contributions to JPX38
- Circumstantial – this is based on many emissions, with no knowledge of actual release times or profiles
- None-the-less this helps us understand the likely contributors to JPX38

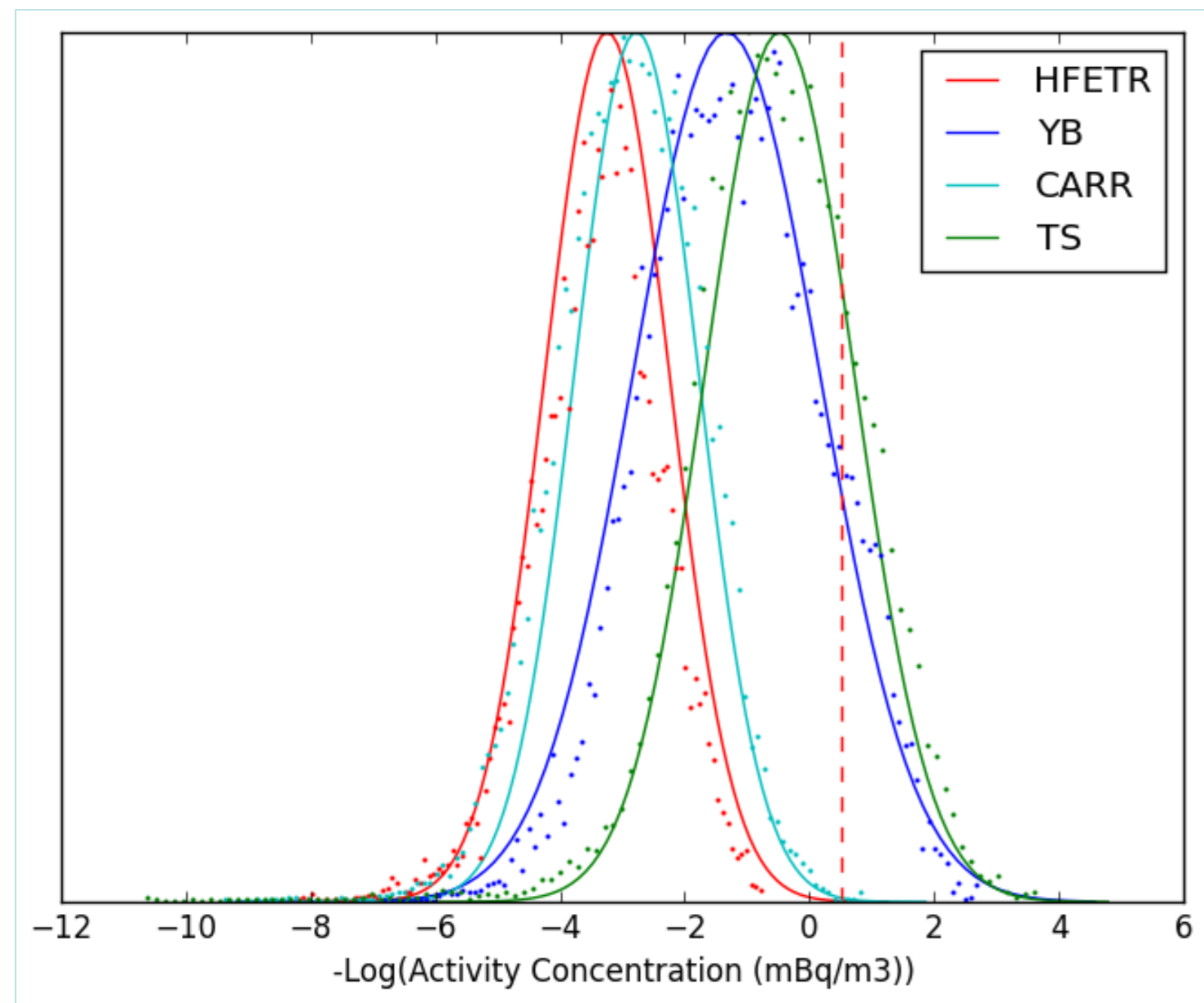


Fig 4. Showing all contributors makes it possible perceive relative likelihood of a given simulation contributing to JPX38

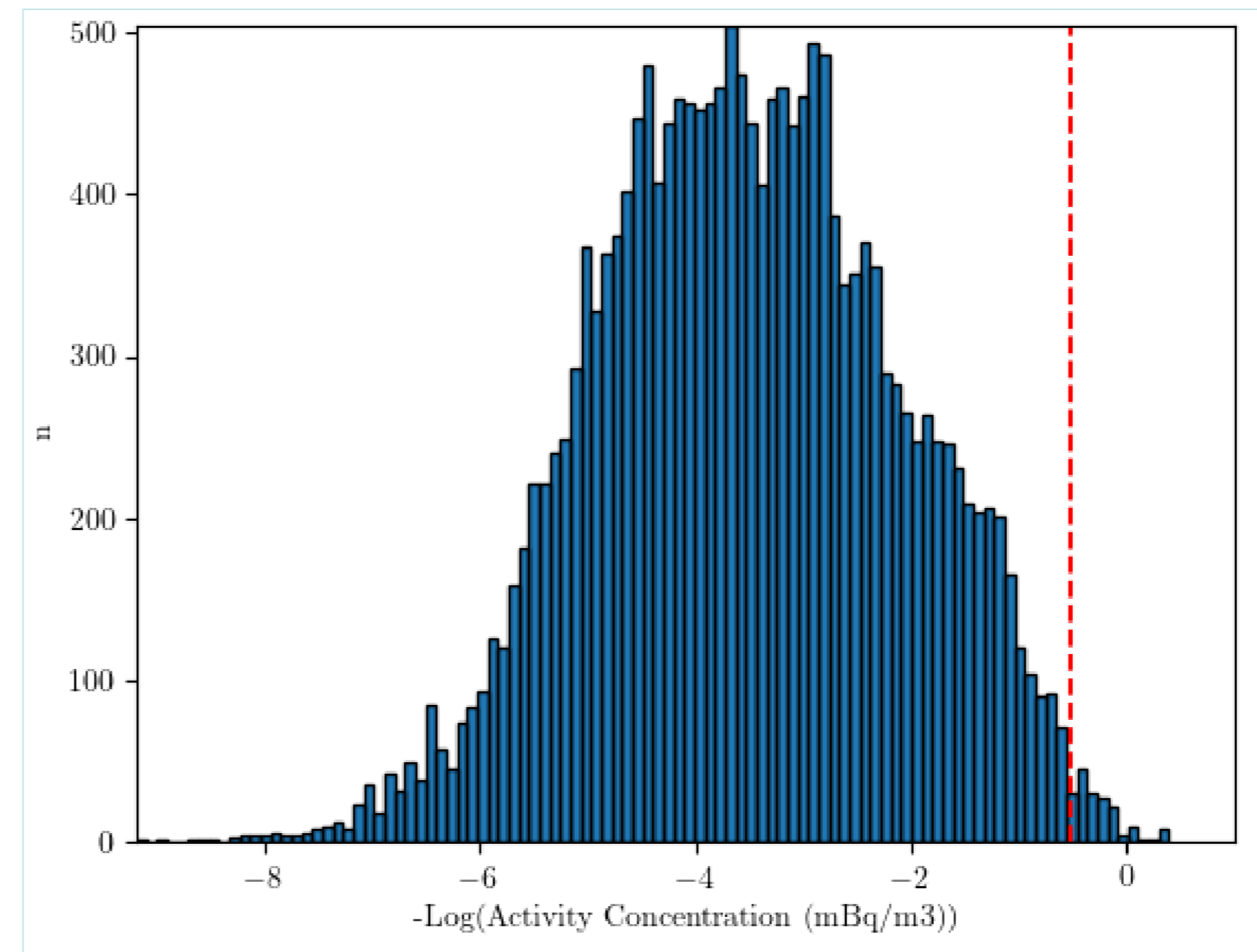


Fig 5. Yongbyon emissions at  $4E+11$  Bq contributing to JPX38



# Identifying 'Events'

- UK NDC flagging system automatically highlights events of interest, based on logic we have built
  - We add to this to try and refine the events
  - Machine Learning may be the future, based on 'events' we have been interested in previously
  - Automation is key, based on current workloads
- 'Event' identification is the RN *needle in a haystack*
- The 'critical' part of the RN IMS Verification Process
- From an NDC perspective, an 'event' is dependent on location and surroundings.
- Hence we rely on a certain level of 'intelligence' to be able to evaluate events fully. We need to know what to *expect*
- CLX19 (Easter Island, the middle of the Pacific Ocean) has detected  $^{135}\text{Xe}$  regularly. They are highly unlikely to be real, therefore event analysis must account for false positive detections.



# IMS Radionuclide 'Events' – What to consider

(with consideration to radioxenon detections)

- Identification
  - Which radionuclides have been identified in the sample?
- Magnitude
  - What are the activities of the identified radionuclides?
- Ratios
  - Of the radionuclides quantified, what are the *relative* activities?
- Station History
  - What else has been identified/quantified at this station previously
  - This could include particulate detections
- Correlated events
  - For example, detections of Iodine radionuclide parents at co-located particulate station
- Additional Information
  - Other IMS technology can be used to 'tip off' RN event analysis
  - What is happening in this part of the world, at this time?



# What does an 'Event' look like?

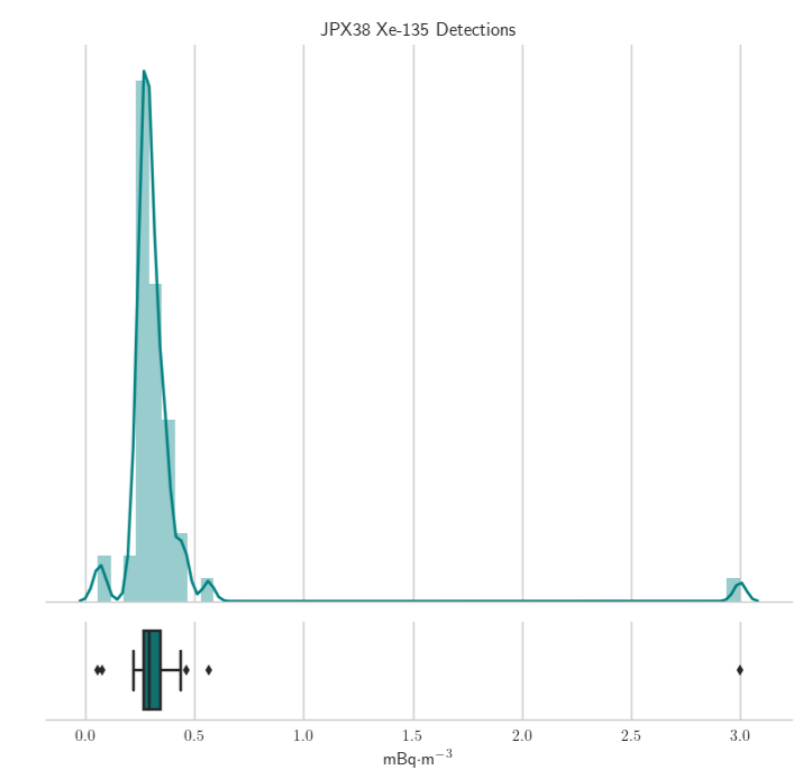
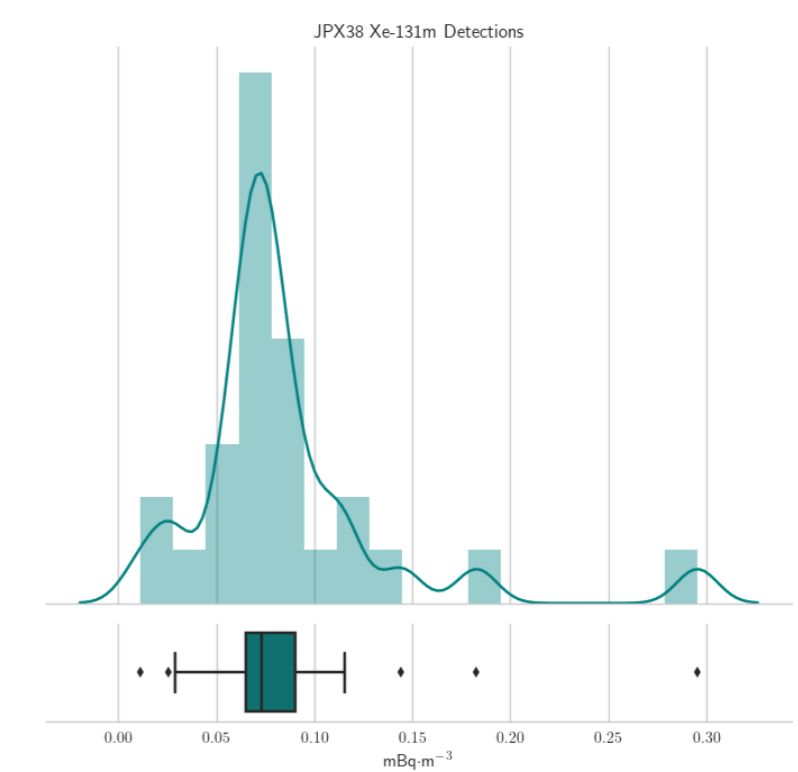
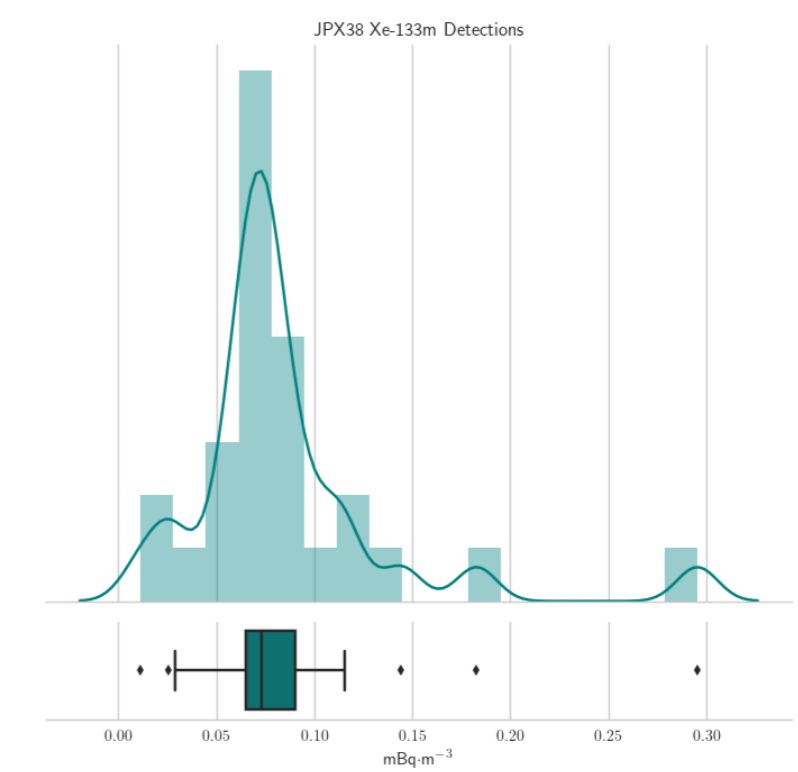
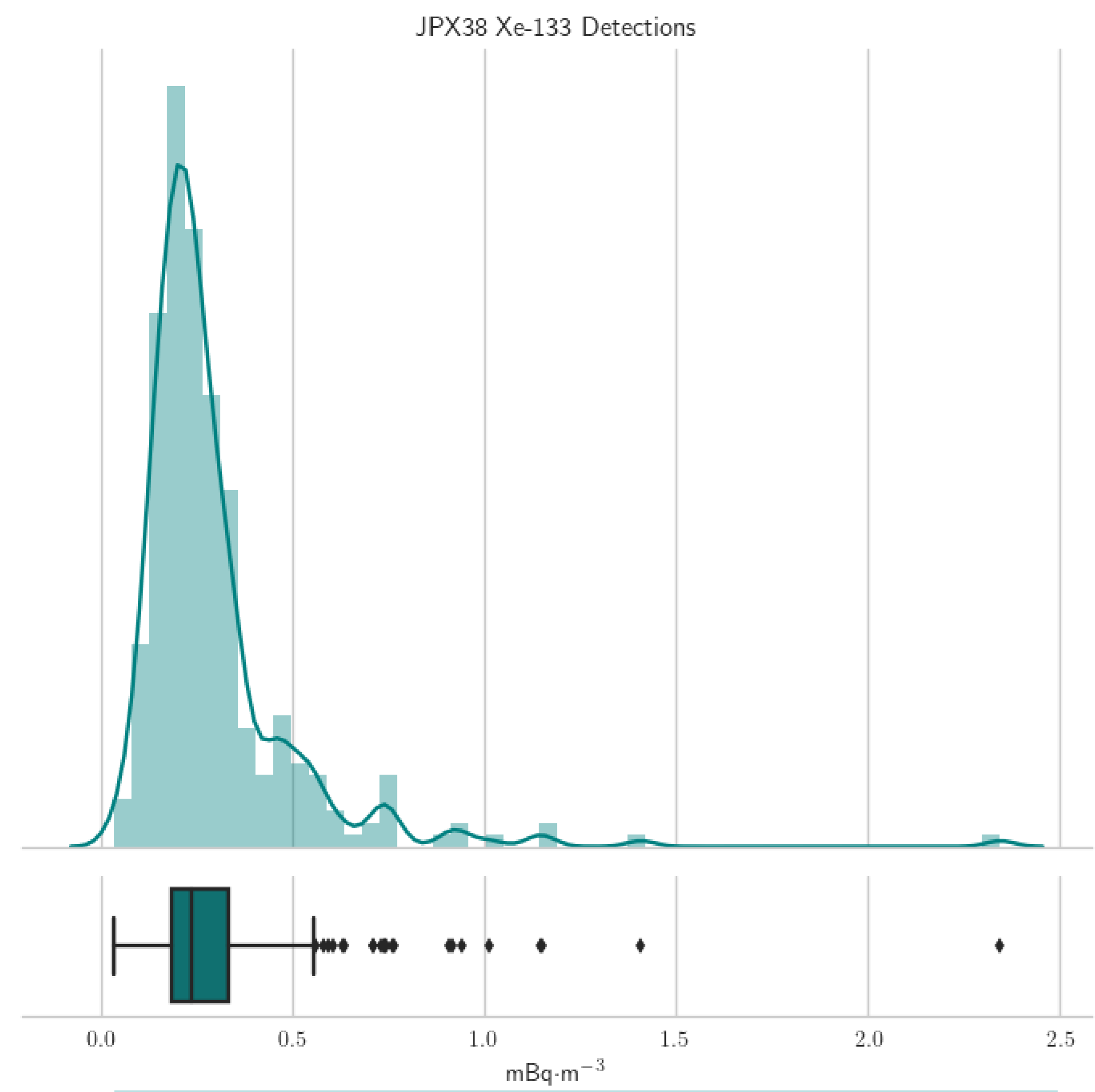


Fig 6. Radioxenon detection histogram / boxplots for JPX38



# What does an 'Event' look like?

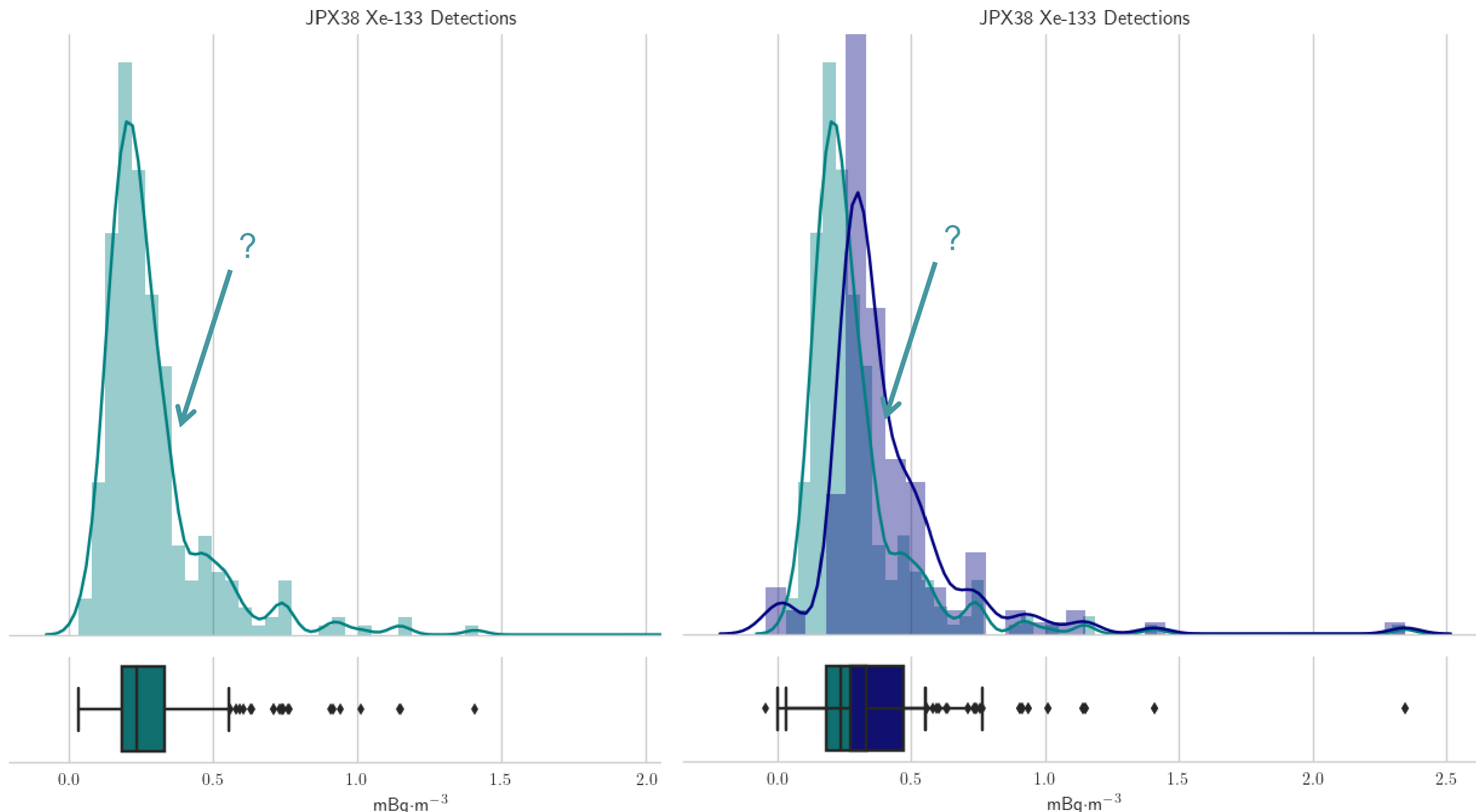


Fig 7. (Right) Xe-133 detections (above MDC – indigo) histogram and boxplots



# Flagged Events

- A series of ‘events’ have been identified at JPX38, which are to be investigated
- Two detections could be from North Korea

*Table 3. Flagged ‘events’ of interest at JPX38 in 2019 (so far)*

Event ID	Est. Start <sup>1</sup>	Est. End <sup>1</sup>	No. Detections <sup>2</sup>	Comment
2019-01	22-01-2019	25-01-2019	5	Clean Xe-133
→ 2019-02	31-01-2019	01-02-2019	3	Clean Xe-133
2019-03	12-03-2019	13-03-2019	3	Clean Xe-133
→ 2019-04	05-04-2019	07-04-2019	5	Xe-133, Xe-135
2019-05	15-04-2019	17-04-2019	6	Clean Xe-133
2019-06	01-05-2019	06-05-2019	7	Xe-133, Xe-135
2019-07	26-05-2019	26-05-2019	7	Xe-133, Xe-131m

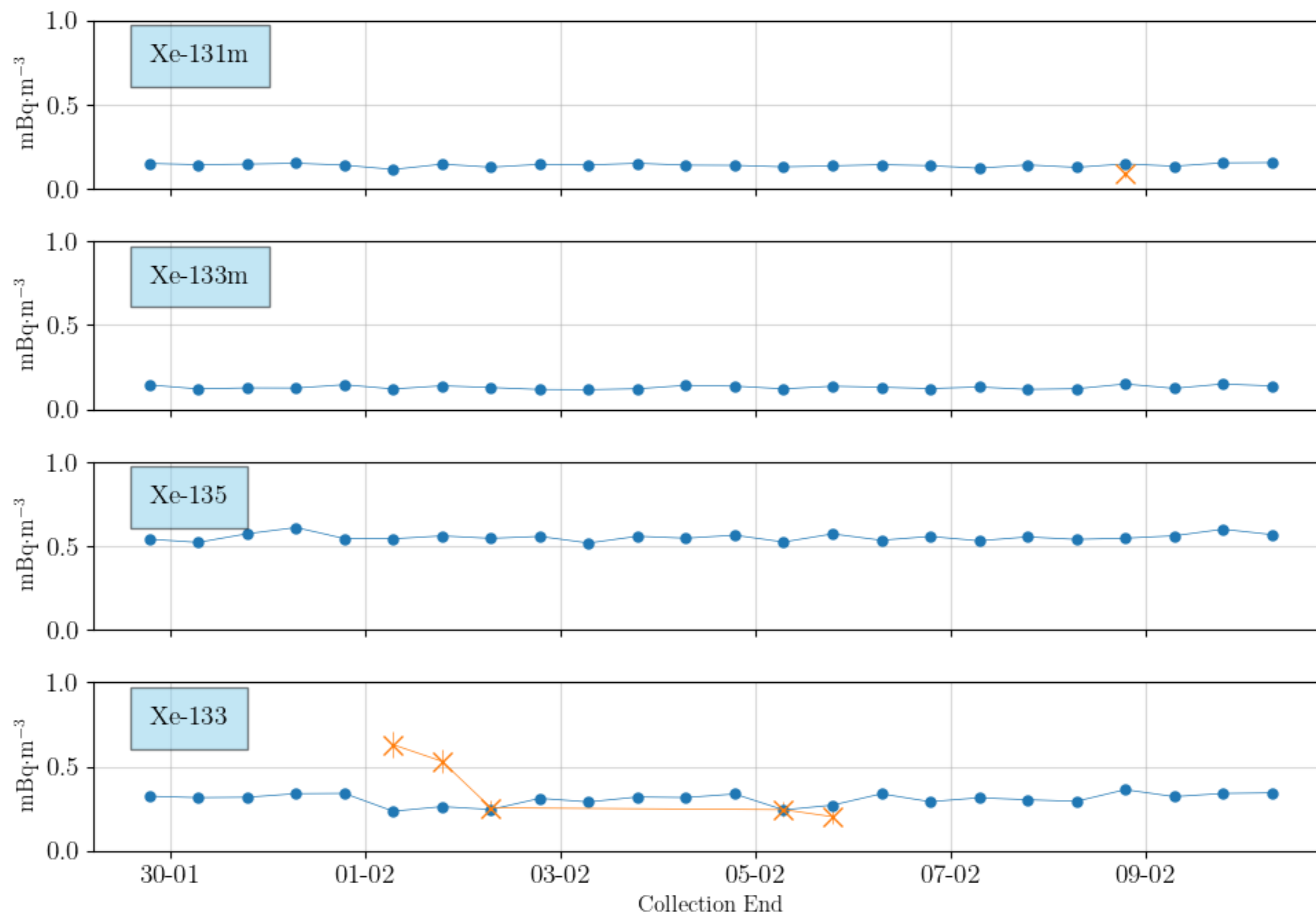
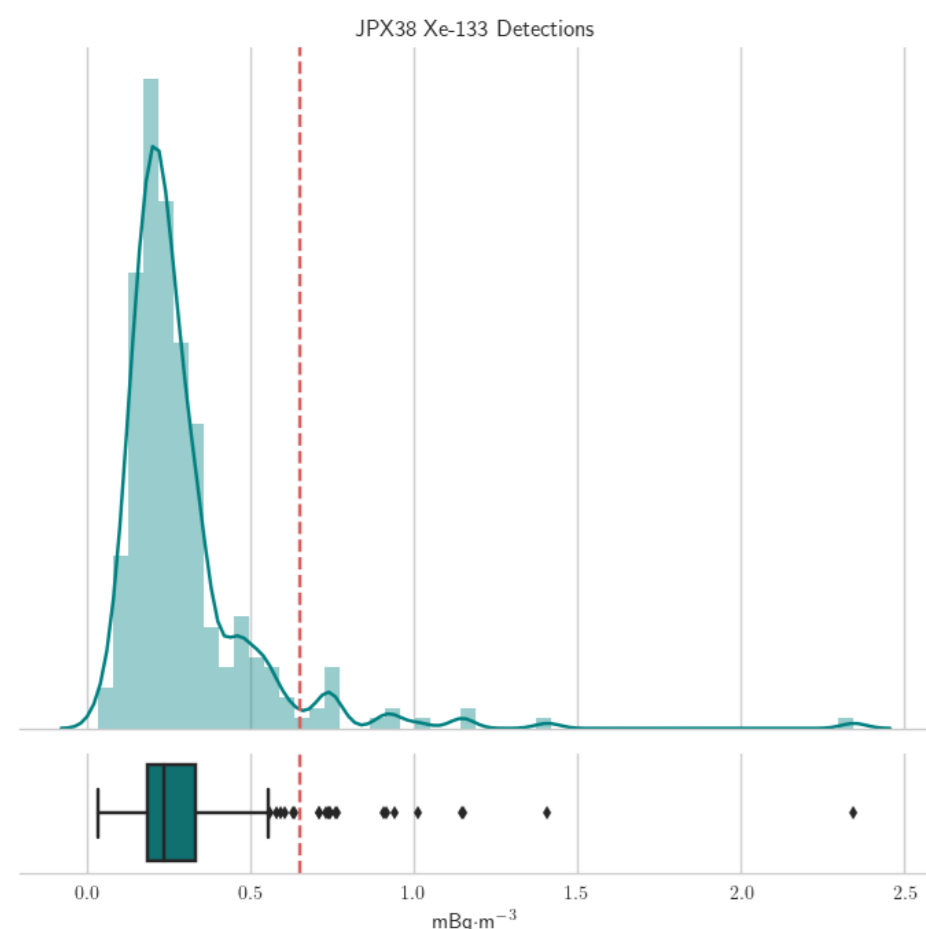
- Events chosen as local emitters were considerably less likely to contribute during these events identified with a red arrow.

<sup>1</sup> Estimated start/end of event refers to the earliest and latest times of the ‘event’ identified by the event search algorithm.

<sup>2</sup> Number of detections considered to be relevant to the ‘event’



# Event 2019-02



Activity Concentration X

MDC ●

Fig 9. Radioxenon detections at JPX38



# Event 2019-02

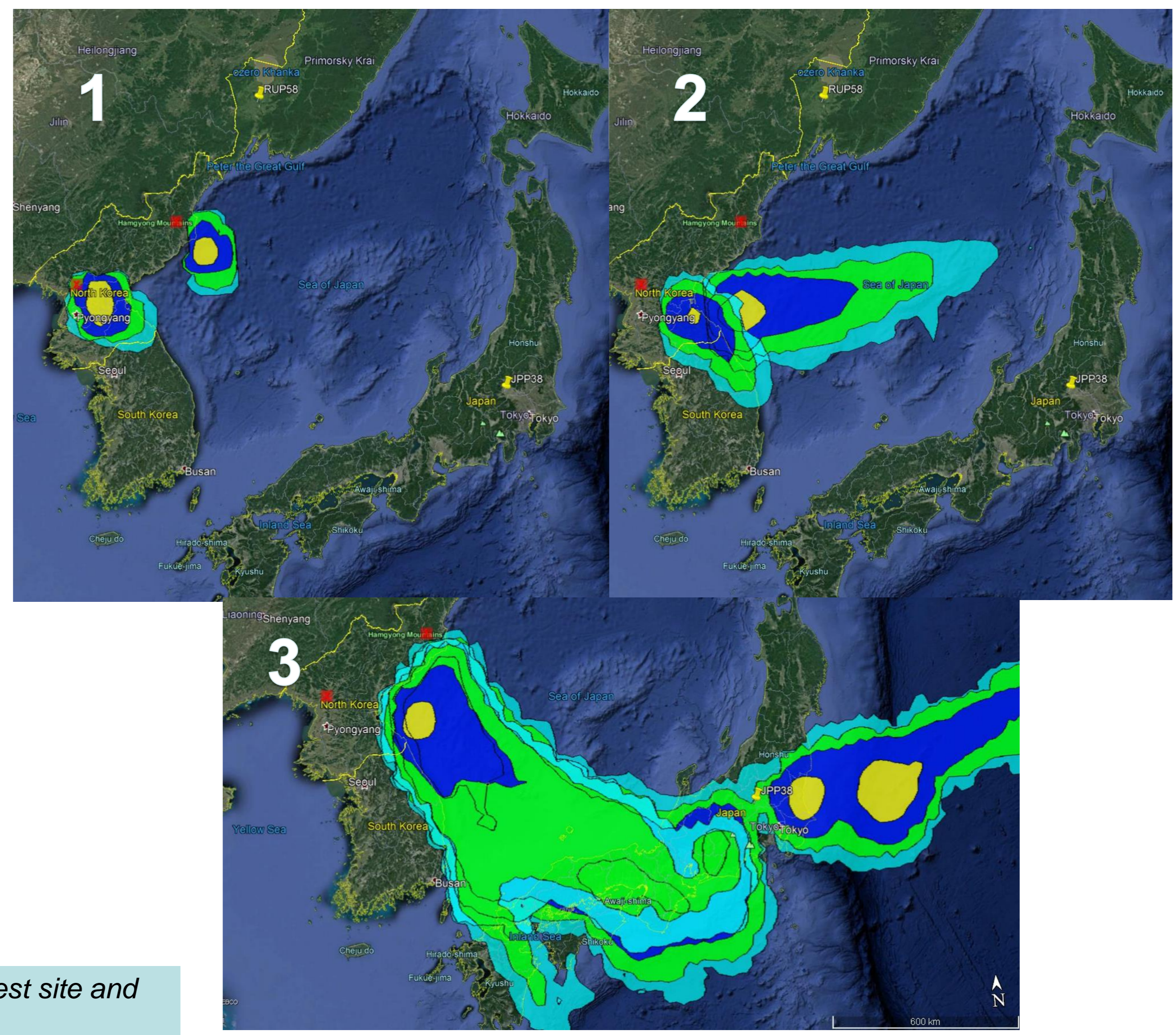


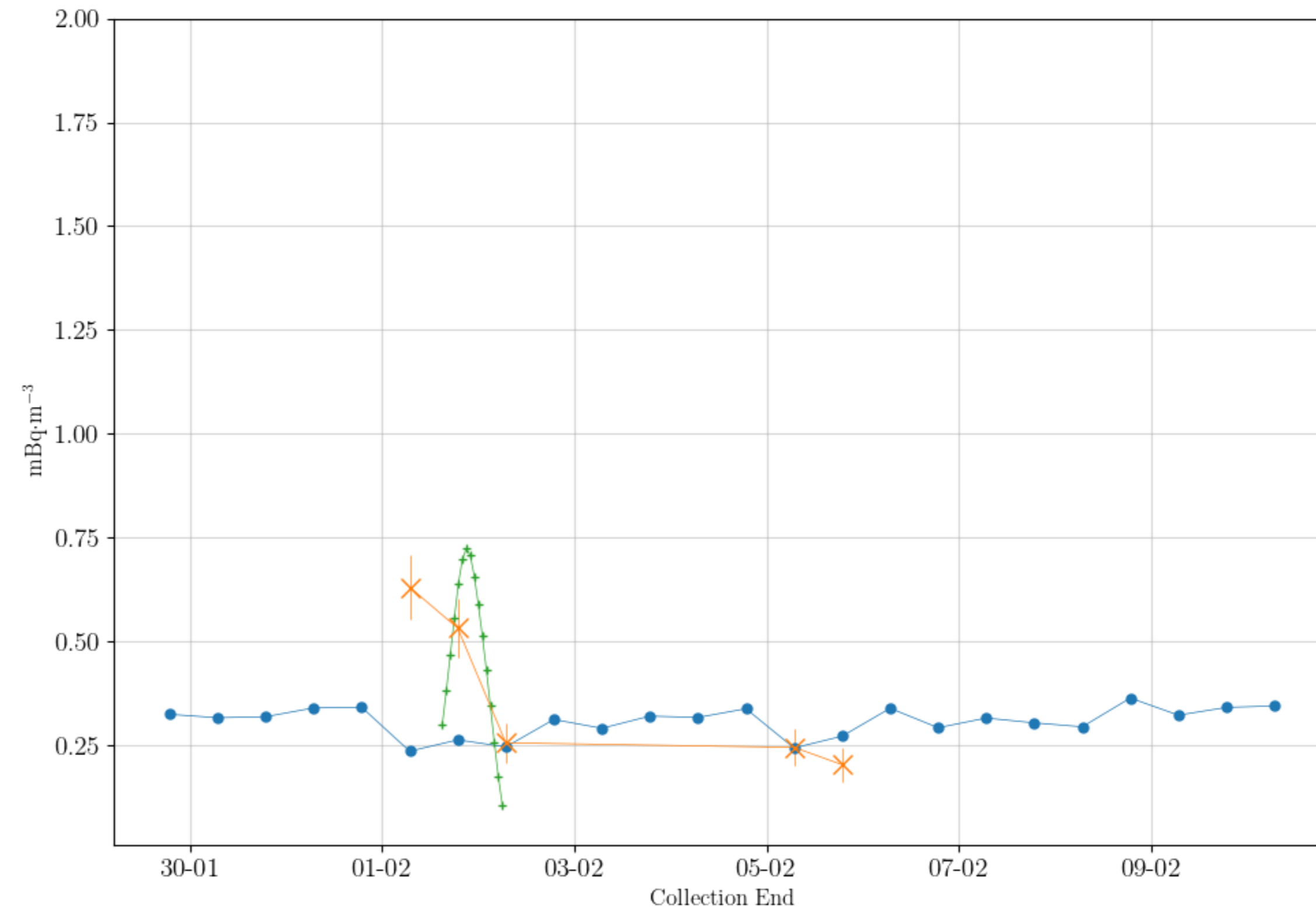
Fig 10. Modelled simulation from DPRK Test site and Yongbyon facility



# Comparing RN data & ATM Simulations

- Yongbyon emission of  $8E+11$  Bq on 30-01-2019 0900 Hrs
- Emission ID: 46020

Met data can only offer 3 hours resolution  
Temporal offset with data.



Activity Concentration X

MDC ●

ATM +

Fig 11. Comparing the ATM Pipeline modelled contribution with the RN Pipeline data



# Comparing RN data & ATM Simulations

- North Korean Test Site emission of  $3E+11$  Bq on 30-01-2019 0900 Hrs
- Emission ID: 46016

Met data can only offer 3 hours resolution  
Temporal offset with data.

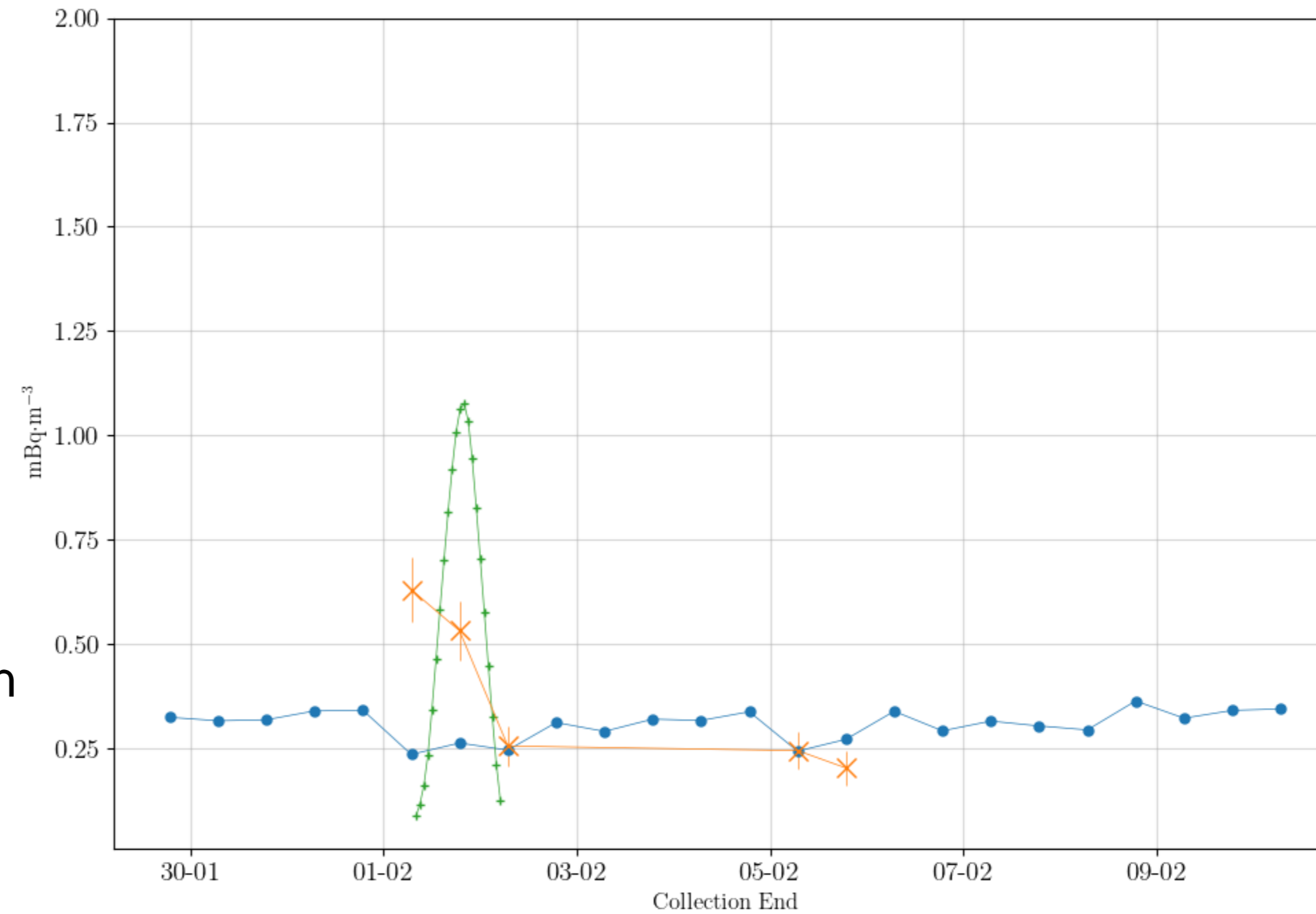


Fig 12. Comparing the ATM Pipeline modelled contribution with the RN Pipeline data

Activity Concentration X

MDC ●

ATM +



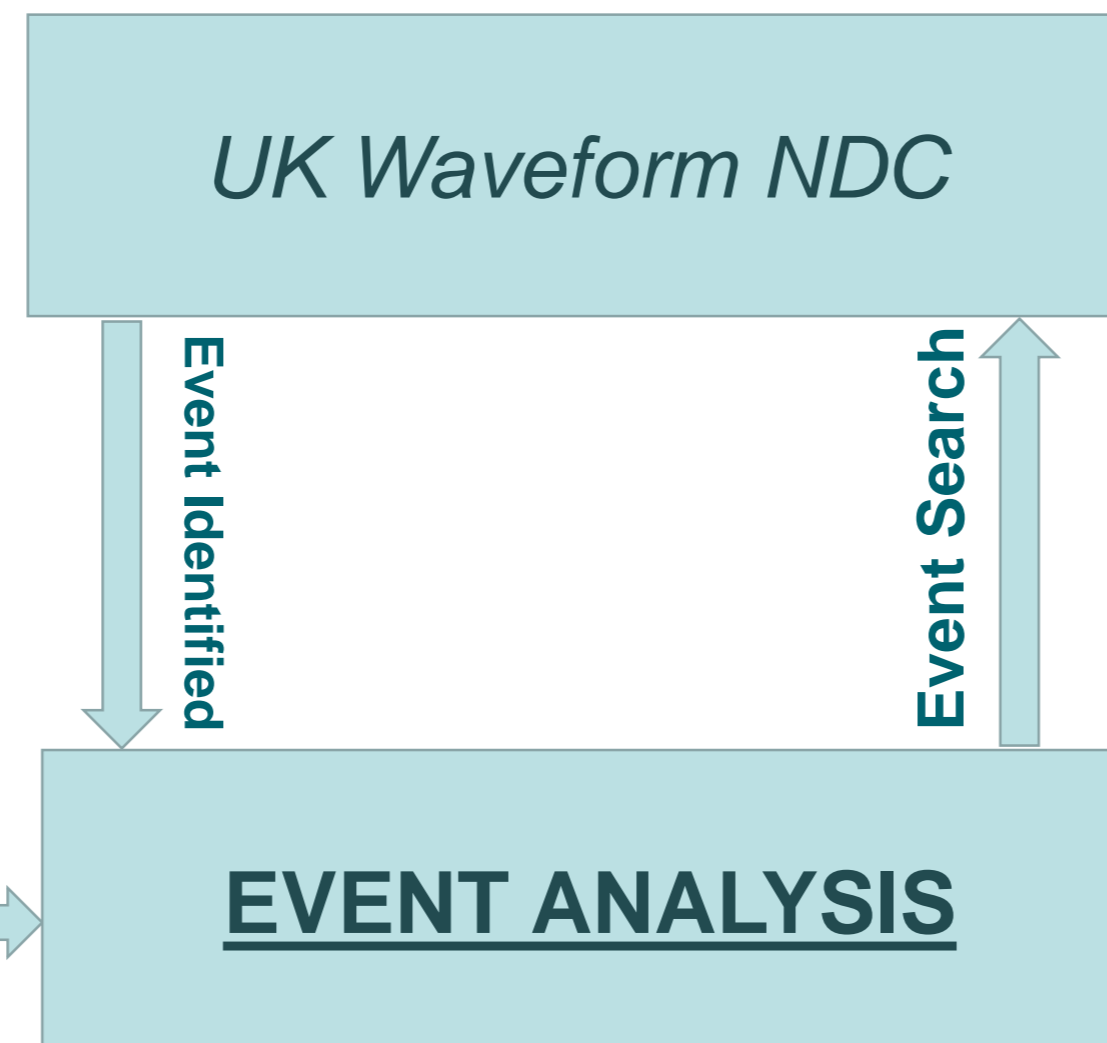
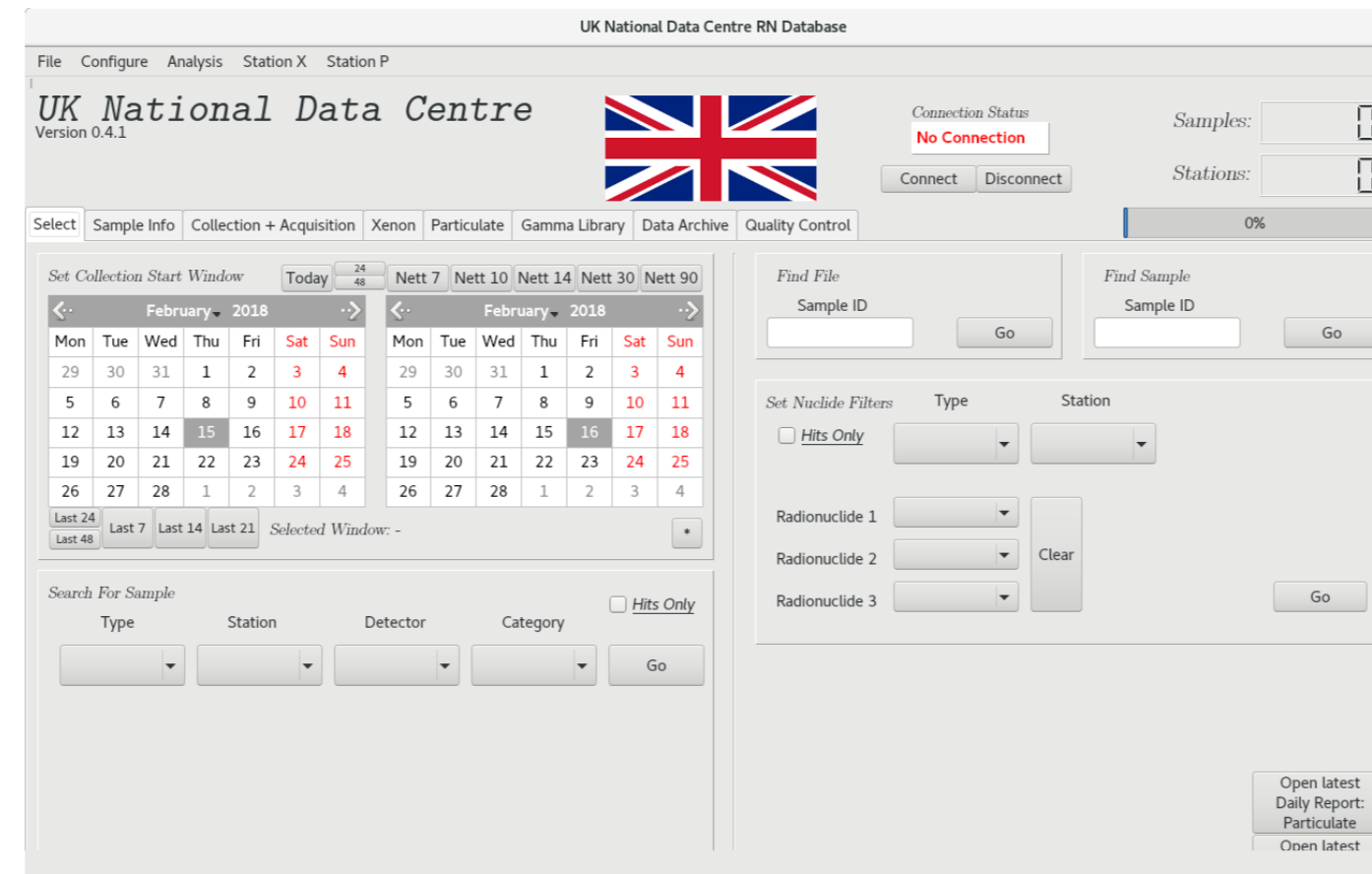
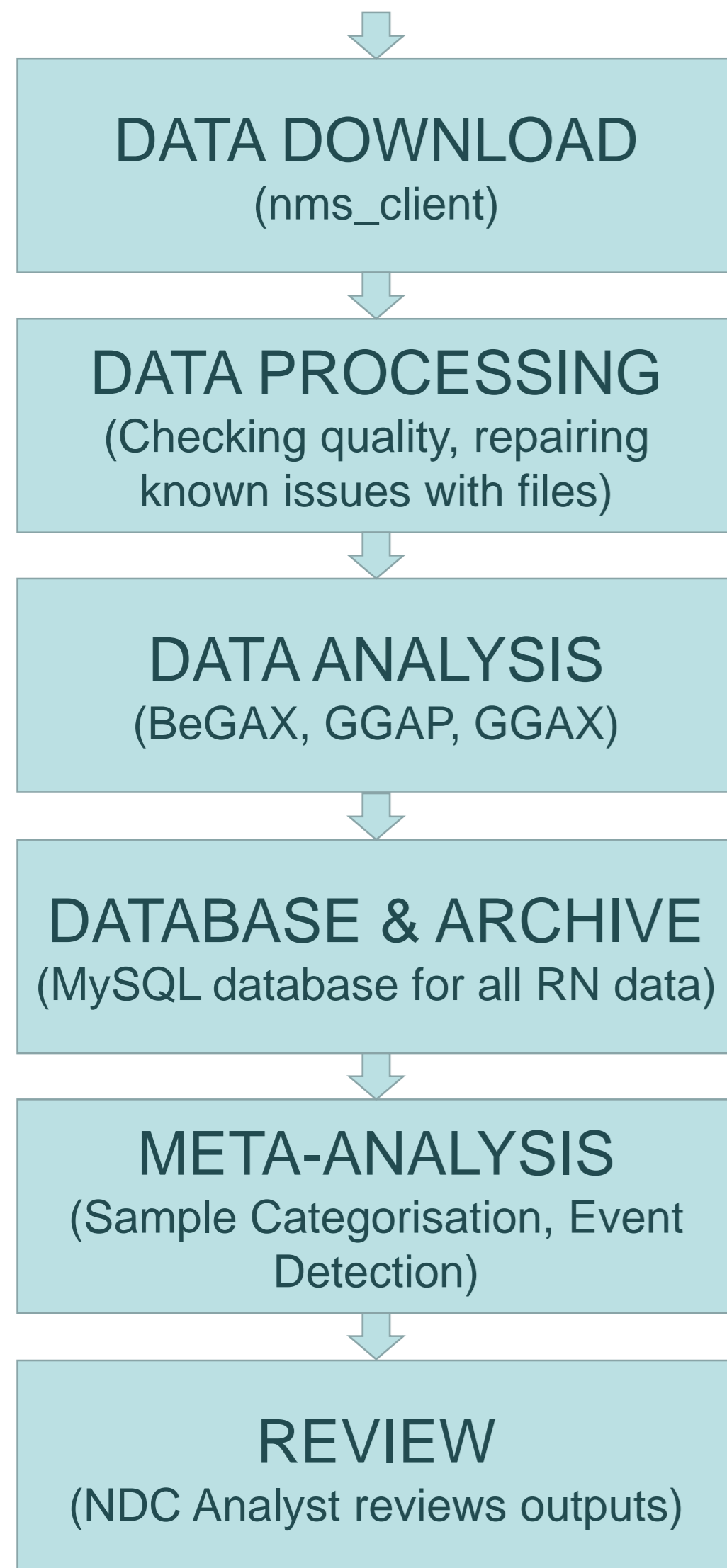
# Conclusions

- This work highlights the **difficulties** associated with event analysis, based on current IMS capability.
- A number of emissions have been identified at JPX38 that are of **significant interest** to NDCs – some *possibly* from North Korea
  - *The IMS is detecting interesting events – NDCs must continue to work to assess each one*
- ATM simulations are helping to build a bigger picture of what we should expect at JPX38, and other IMS stations.
- RN Analysis is still an issue – False positives are making it more difficult to identify ‘events’ – *the needle in the RN haystack*
- The UK NDC will continue to develop the ATM capability to aid radionuclide event analysis
- Seismo-radionuclide-ATM automated data fusion is the aim – giving analysts the biggest possible picture on an event-by-event basis
- **Validation?**

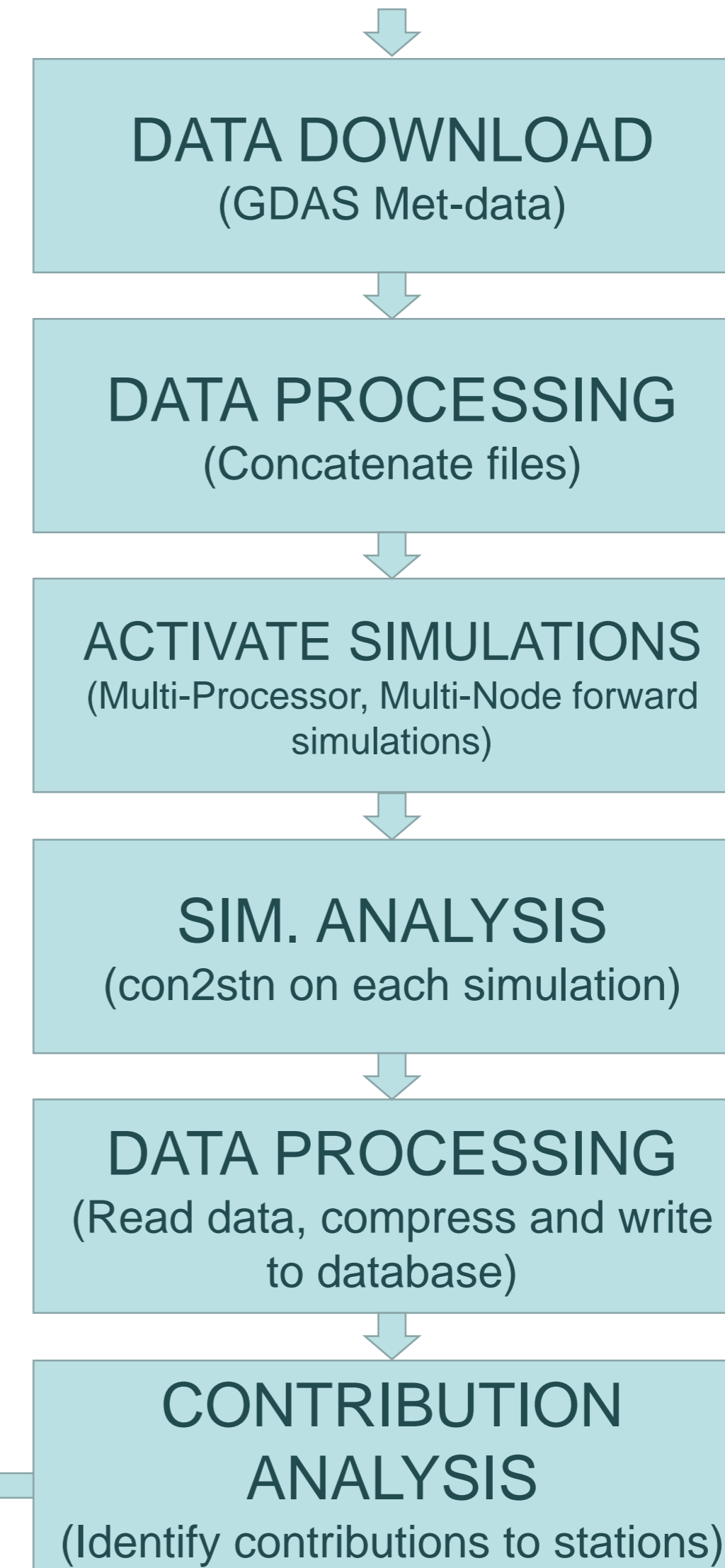


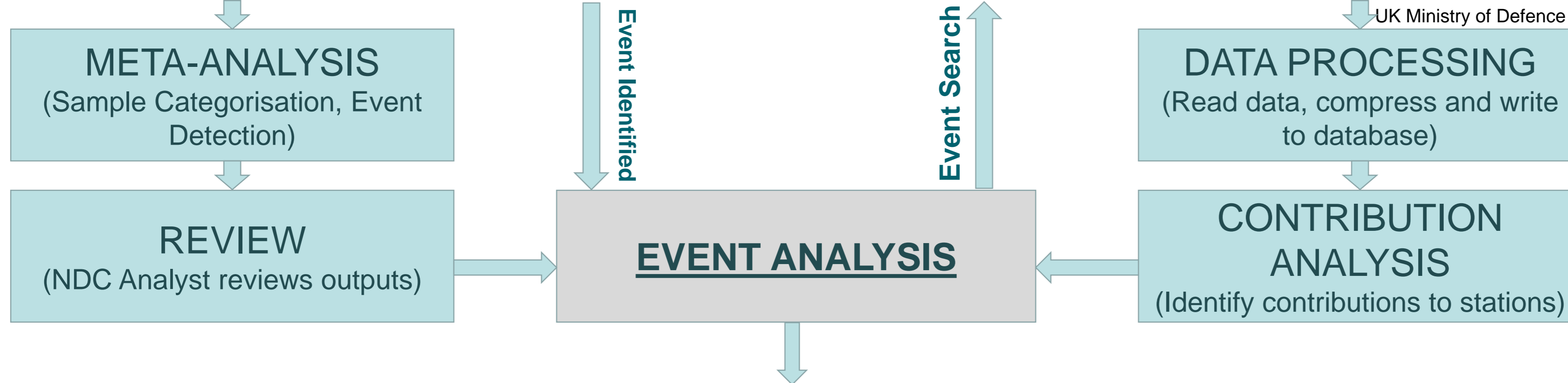
# UK NDC Automated Analysis Pipelines

RN PIPELINE



ATM PIPELINE





How can we improve our *event analysis*?

- More comprehensive modelling: A full time ATM modeller?
- Backward Modelling - Virtual source locations [4]
- Automated flagging of co-located detections
- Event categorisation – working with RN Treaties Community, such as Experts meeting on RN Event Analysis
- Data Science may take over where Radiometrics can do no more (currently)
- Embrace new approaches / technology – Machine Learning may have a greater role to play in the NDC
- Incorporate non-IMS facilities to this analysis
- Further understanding what constitutes an ‘Event of Interest’
- Continue to batch-model contributions to each station, but for more emitters and with more radionuclides calculated. How do we combine this data?
- Ensemble analysis [5]
  - Use averages of multiple emissions to best model station contributions
- Non-detects



# Plugs

## Posters from Colleagues at the UK RN NDC

- Goodwin *et al.* Developing a Laboratory Based Beta-Gamma Coincidence Detection System: Progress Update (T 3.2 P2)
- Goodwin *et al.* Developing a Deployable, Flexible, Radionuclide Pipeline (T3.5 P26)
- Davies *et al.* How the UK NDC Utilises Stack Monitoring Data in Support of Comprehensive Nuclear Test Ban Treaty (T2.4 P29)
- Britton *et al.* Hypersensitive Gamma Spectrometry: Approaching the Ultimate Limit (T3.1 P22)



**Any questions?**





# Supplementary Slides



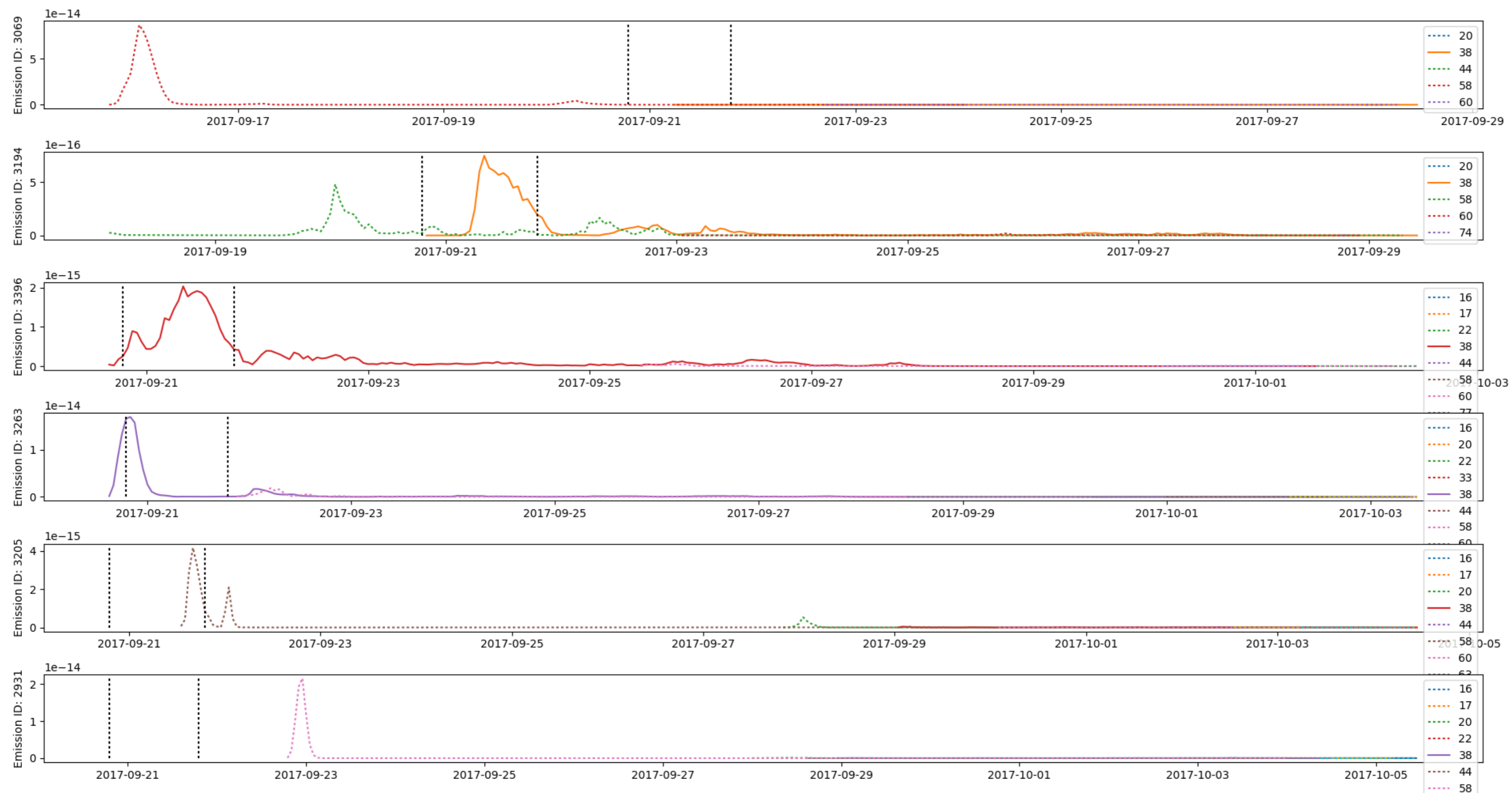


# References

1. England, T. R. and Rider, B. F., (1994) *Evaluation and compilation of fission product yields, 1993*, ENDF-349, Los Alamos National Laboratory LA-UR-94-3106
2. *IAEA Report NEA/SEN/HLGMR(2017)*
3. Kalinowski M. “*Discrimination of Nuclear Explosions against Civilian Sources Based on Atmospheric Xenon Isotopic Activity Ratios*”. *Pure Appl. Geophys.* 167 (2010), 517-539
4. AWE-FOI Discussions at collaborative NDC meeting, October 2018
5. Eslinger P.W. *et al.* “*International challenge to predict the impact of radioxenon releases from medical isotope production on a comprehensive nuclear test ban treaty sampling station*”, *Journal of Environmental Radioactivity* 157 (2016) 41-51

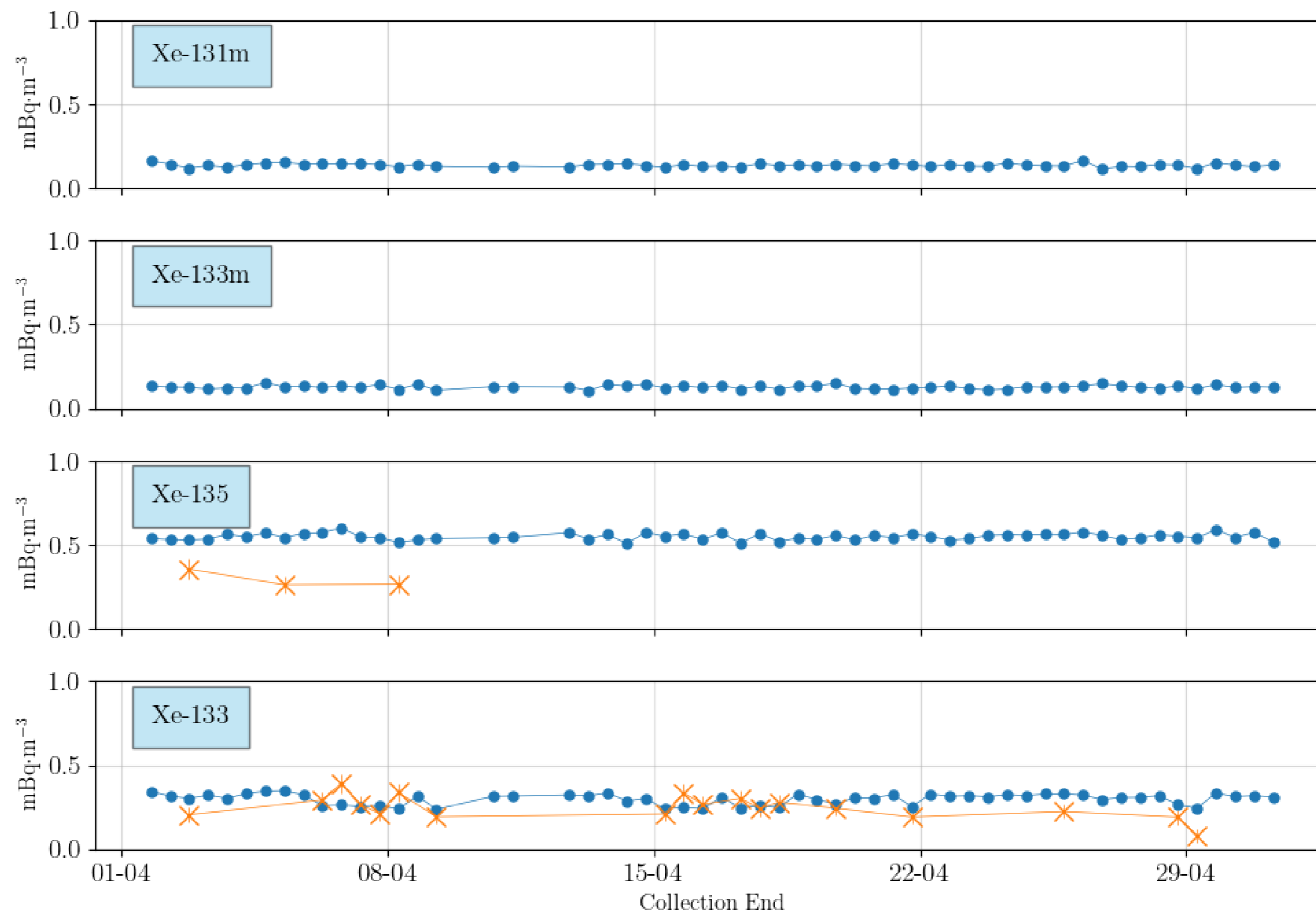


# Discriminating Non-detects





# Event 2019-04 & 2019-05



Activity Concentration X

MDC ●

Fig. Radioxenon detections at JPX38



# Event 2019-04

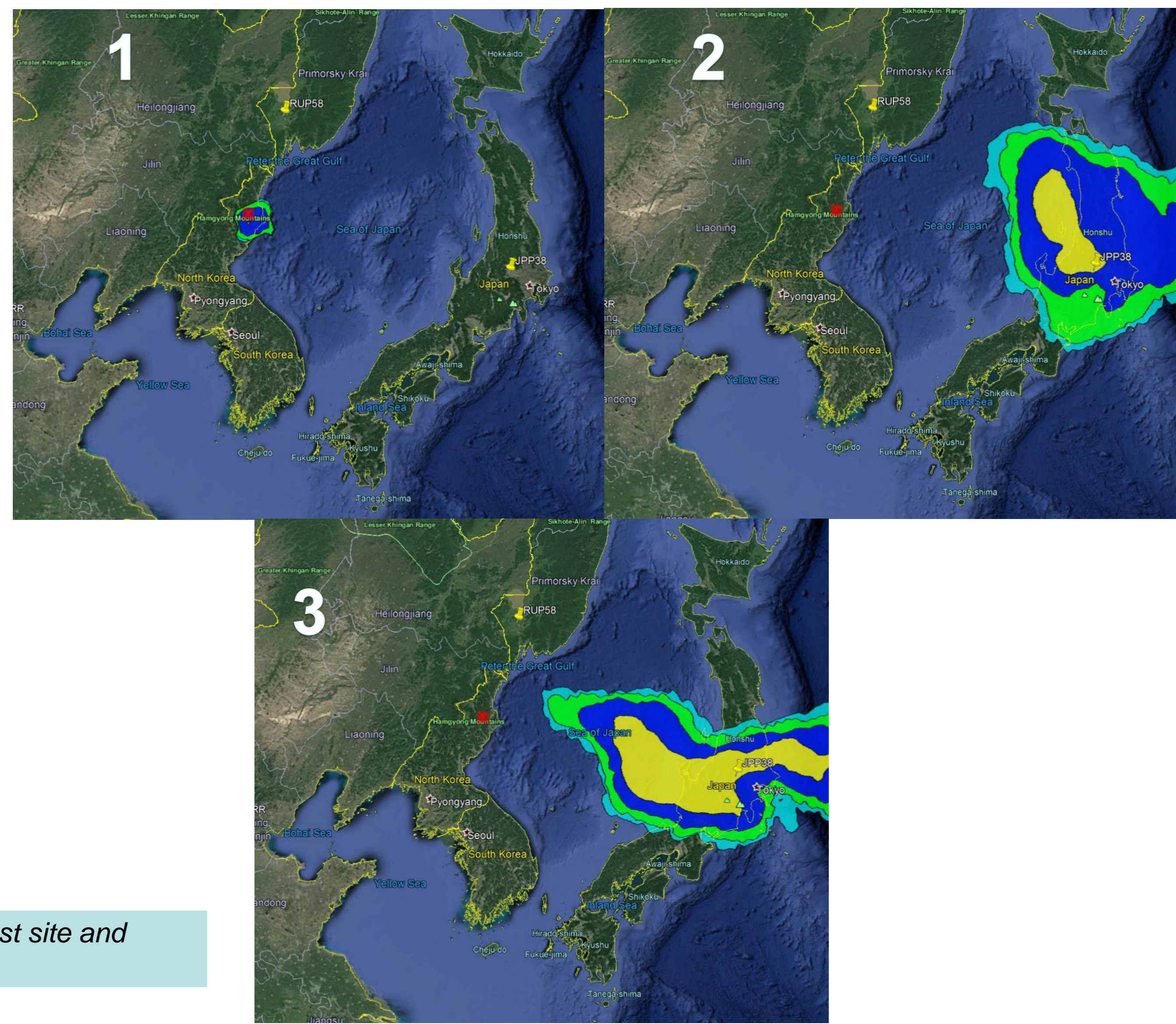


Fig. Modelled simulation from DPRK Test site and Yongbyon facility



# Measuring Radioxenon

- There are a number of radioxenon isotopes of interest:  
 $^{133}\text{Xe}$ ,  $^{131\text{m}}\text{Xe}$ ,  $^{133\text{m}}\text{Xe}$ ,  $^{135}\text{Xe}$
- Beta-gamma coincidence measurements allow for the selection of specific decay paths / de-excitations

Energy (keV)	Relative Probability (%)
30.6254	13.54
30.9731	25.0
34.9197	
34.9873	
35.252	7.31
35.822	
35.907	
35.972	1.78

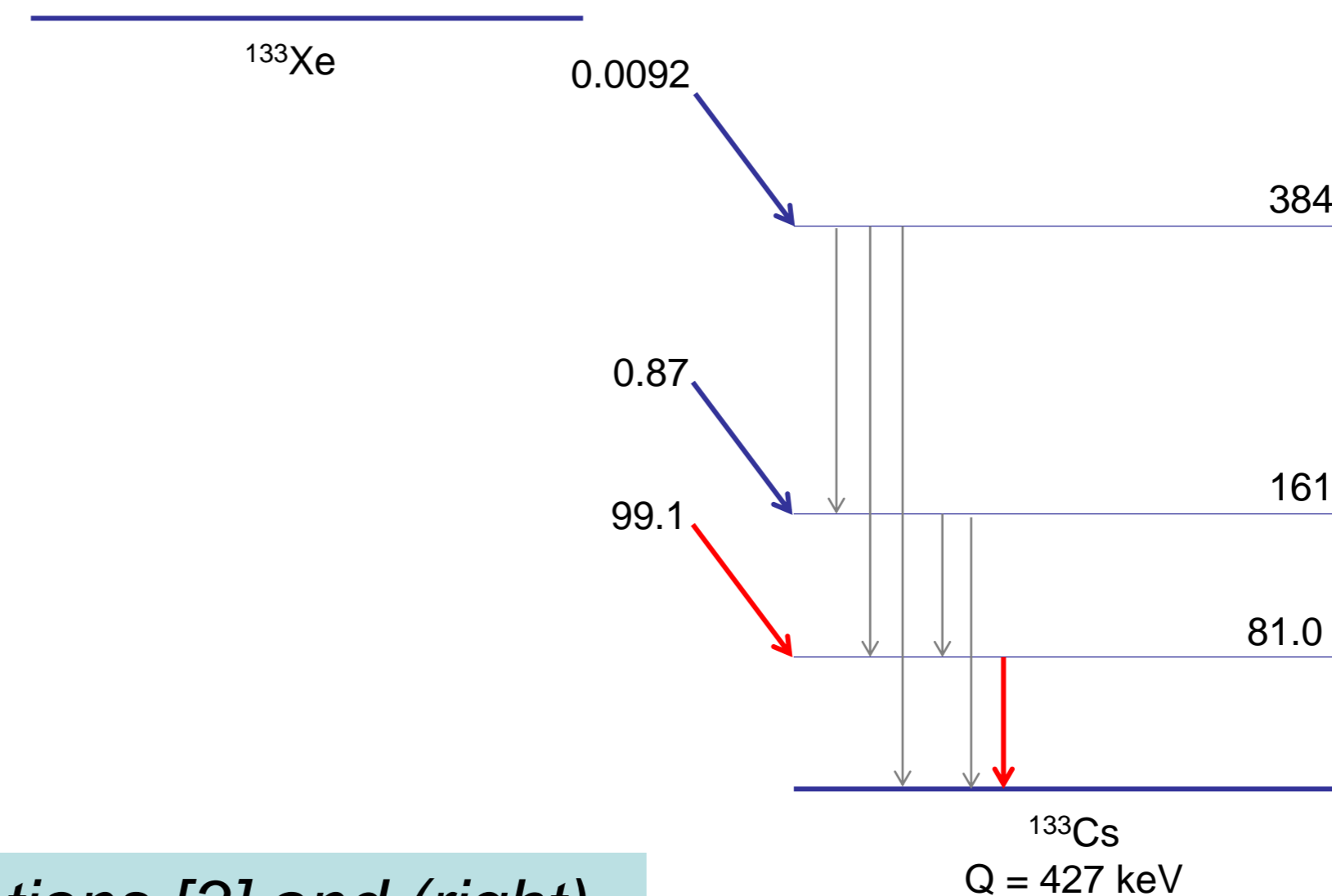


Fig. (left)  $^{133}\text{Xe}$  X-radiations [3] and (right) Nuclear decay scheme for  $^{133}\text{Xe}$

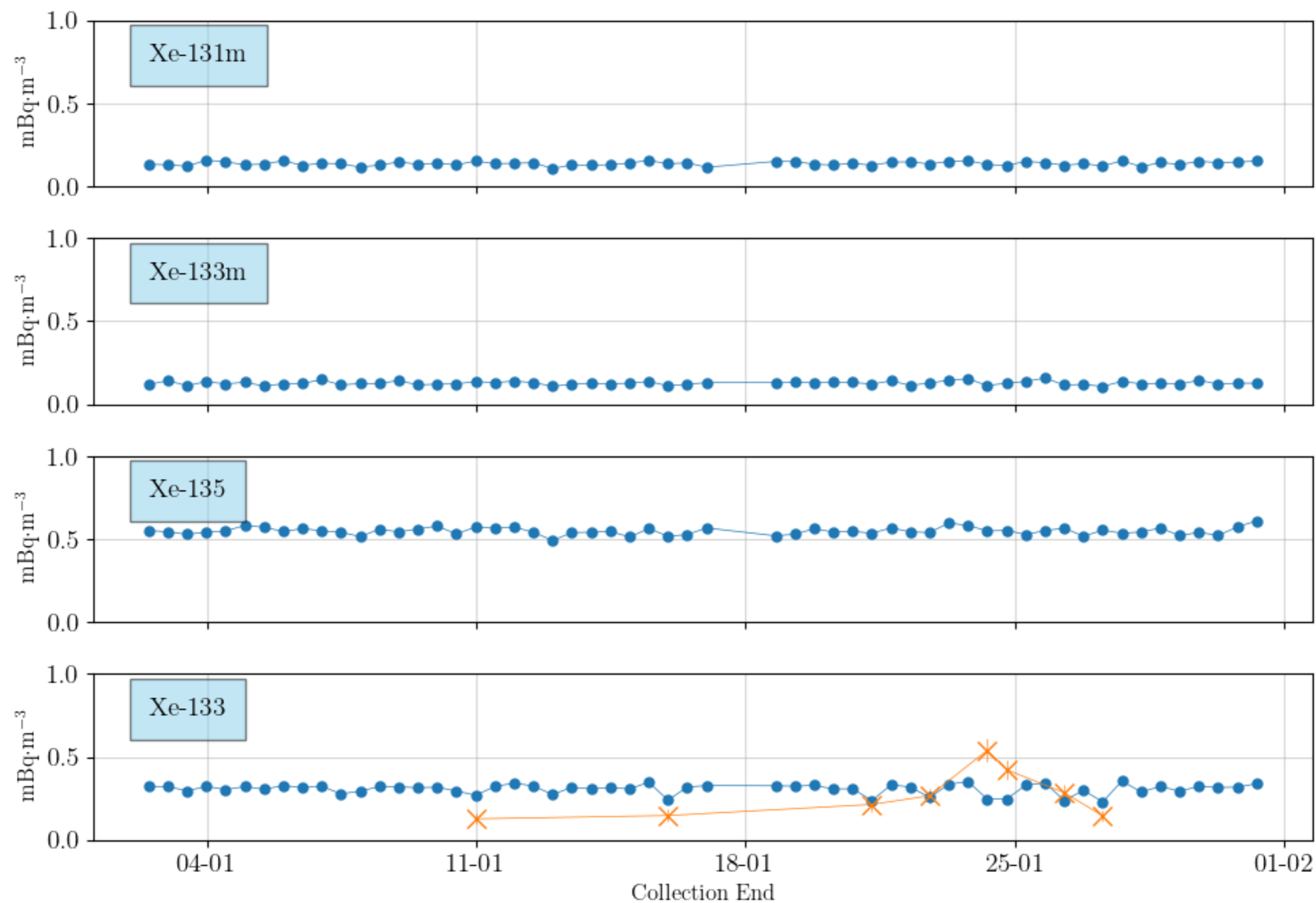
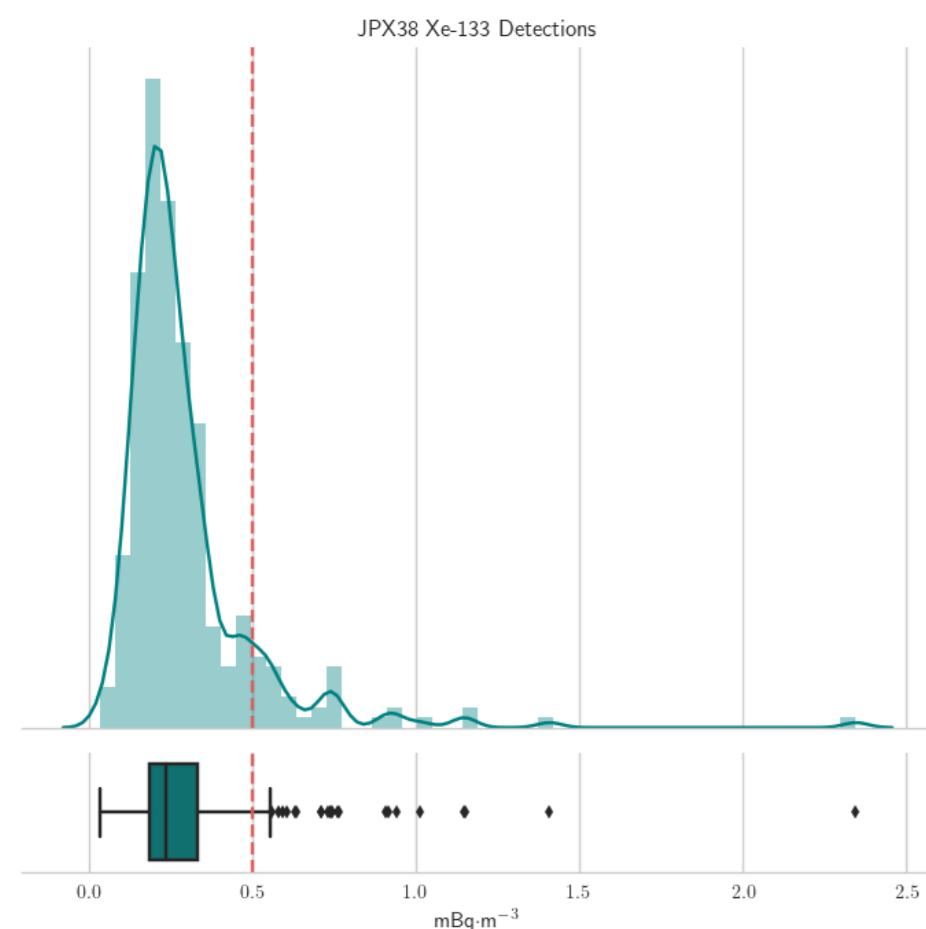


# GBL15 Technologies

- **IMS particulate filter analysis:**
  - HPGe
  - Cosmic Veto Suppression
- **Research technologies and other systems:**
  - Compton Suppression Systems (9" NaI(Tl) veto detectors (with plug) around BEGe & Co-axial HPGe)
  - SAGe Well System
  - $\gamma$ - $\gamma$  coincidence system (BEGe 6530 with cosmic veto, and IDM200 mobile system)
- **IMS Noble Gas analysis:**
  - $\beta$ - $\gamma$  (NaI(Tl) with coated BC404)
- **Research technologies and other systems:**
  - PIPSBox setup ( $\beta$ - $\gamma$  with HPGe)
  - New collaborative PhD studentship with the University of Surrey and NPL



# Event 2019-01



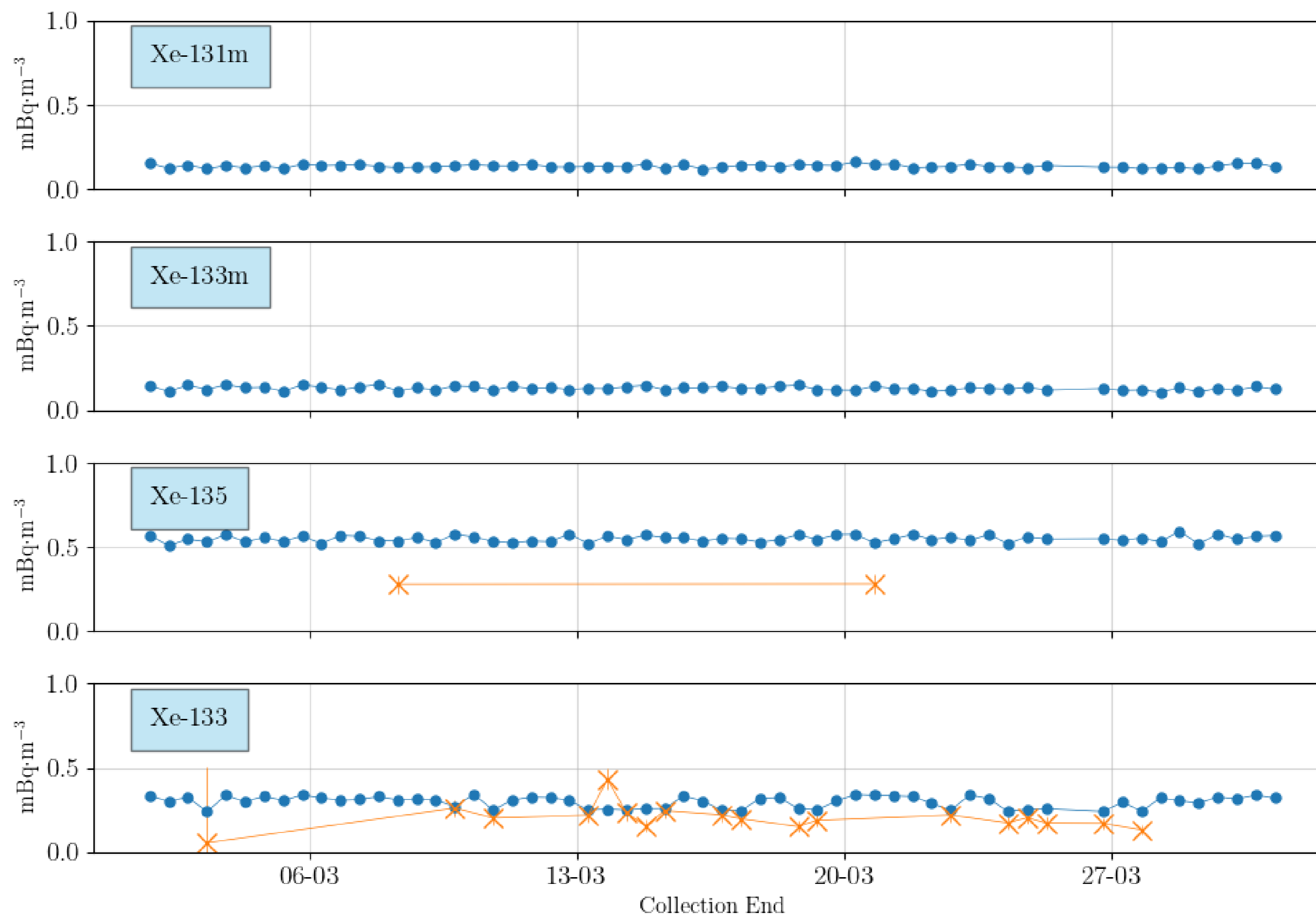
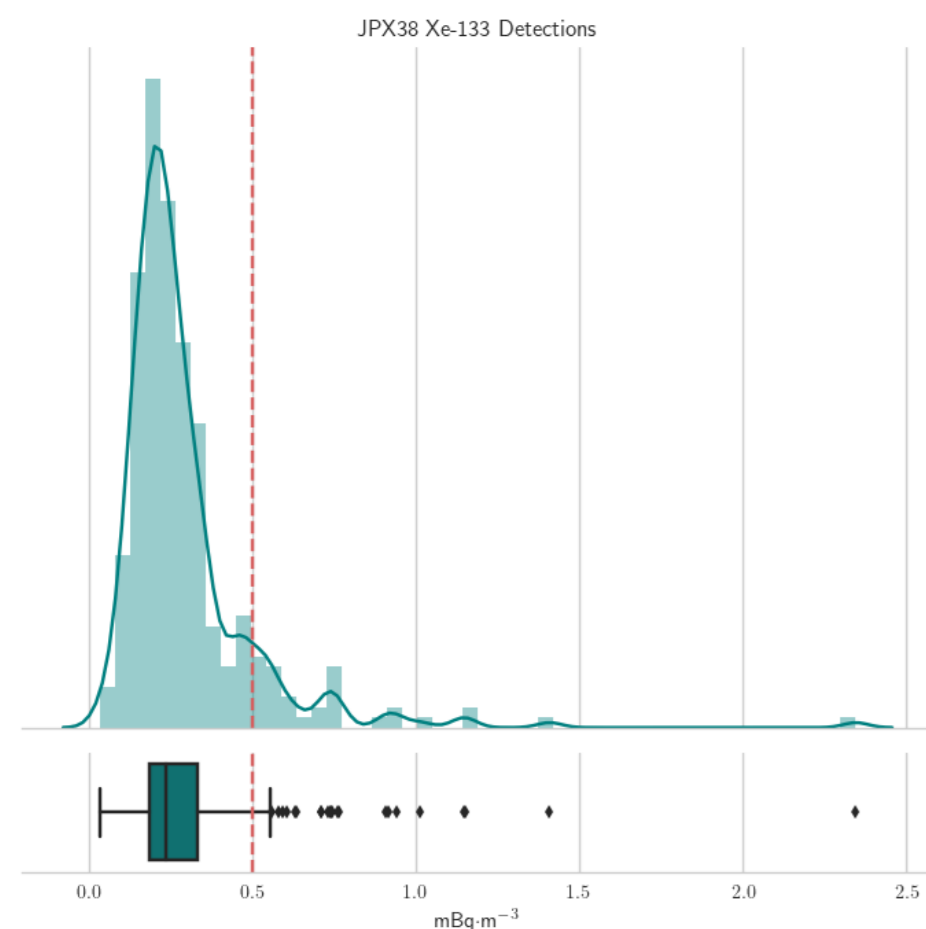
Activity Concentration X

MDC ●

Fig. Radioxenon detections at JPX38



# Event 2019-03



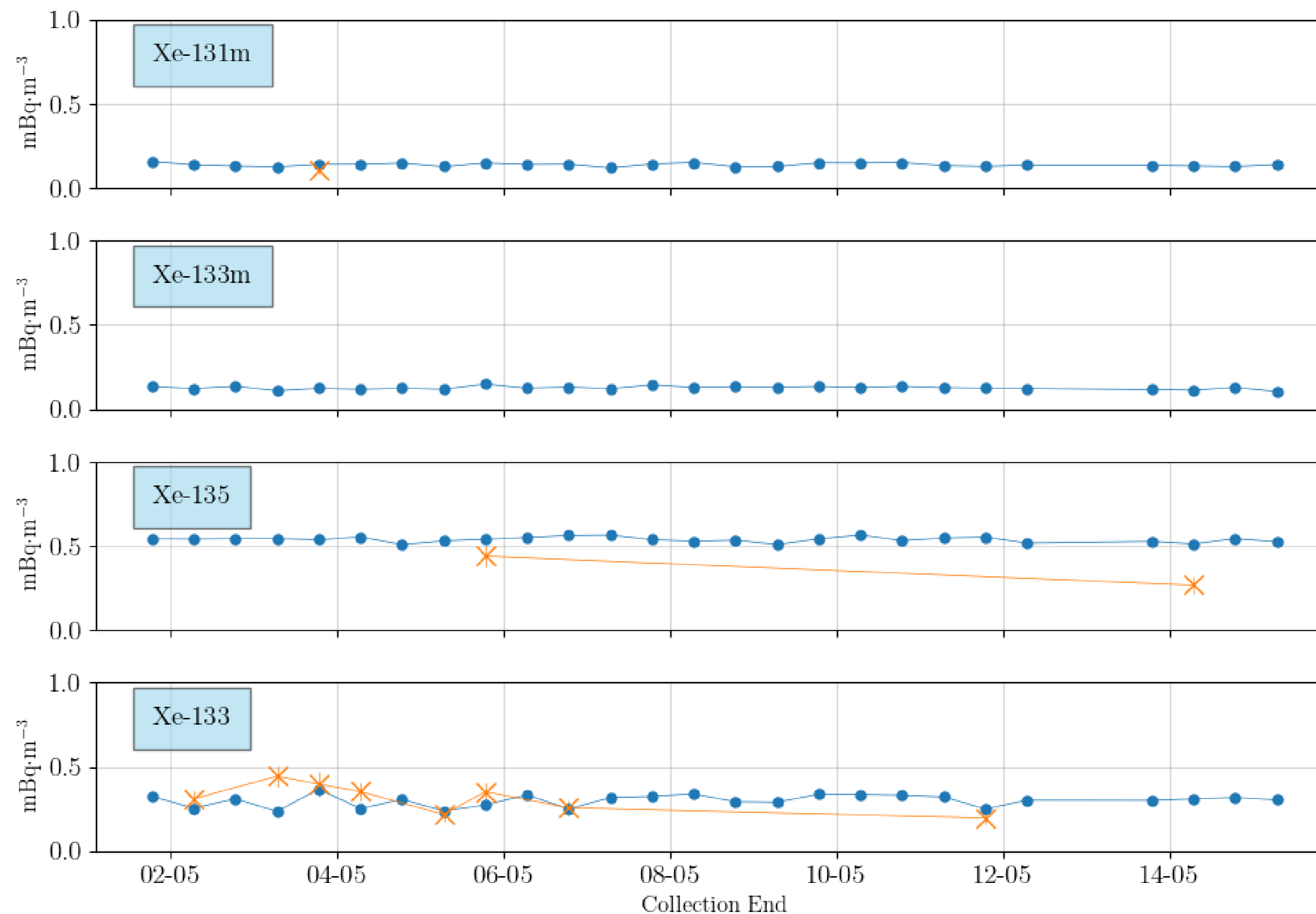
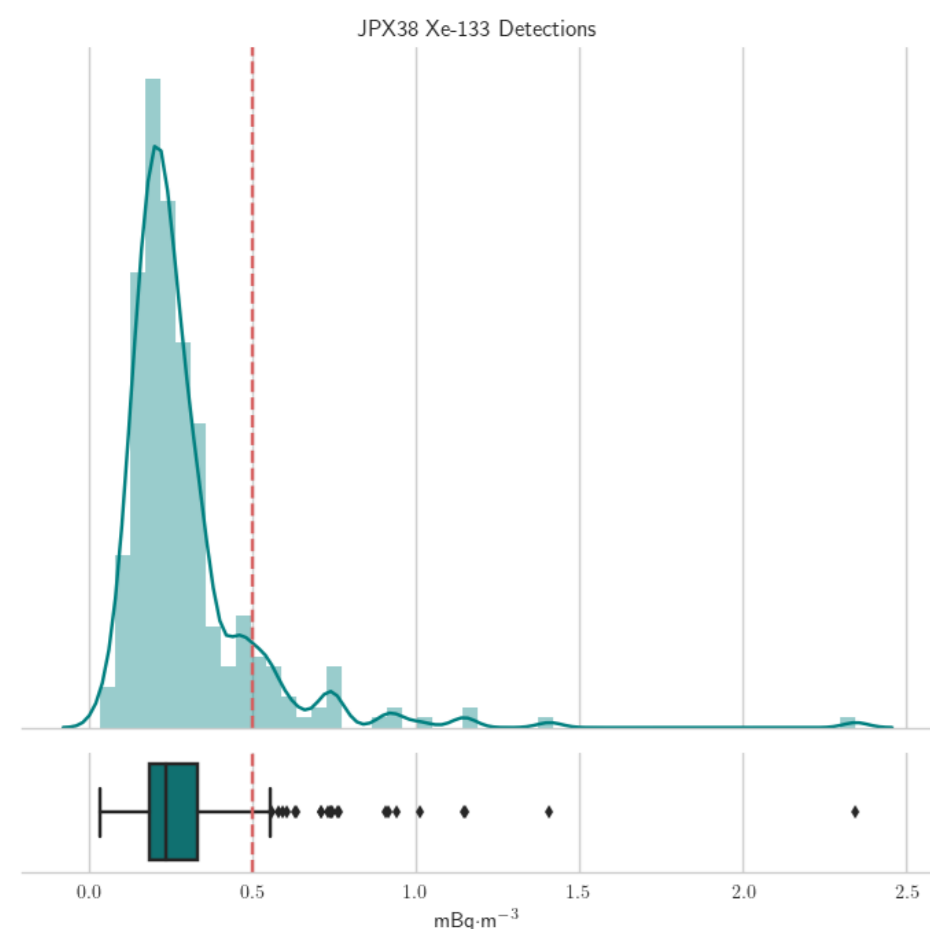
Activity Concentration X

MDC ●

Fig. Radioxenon detections at JPX38



# Event 2019-06

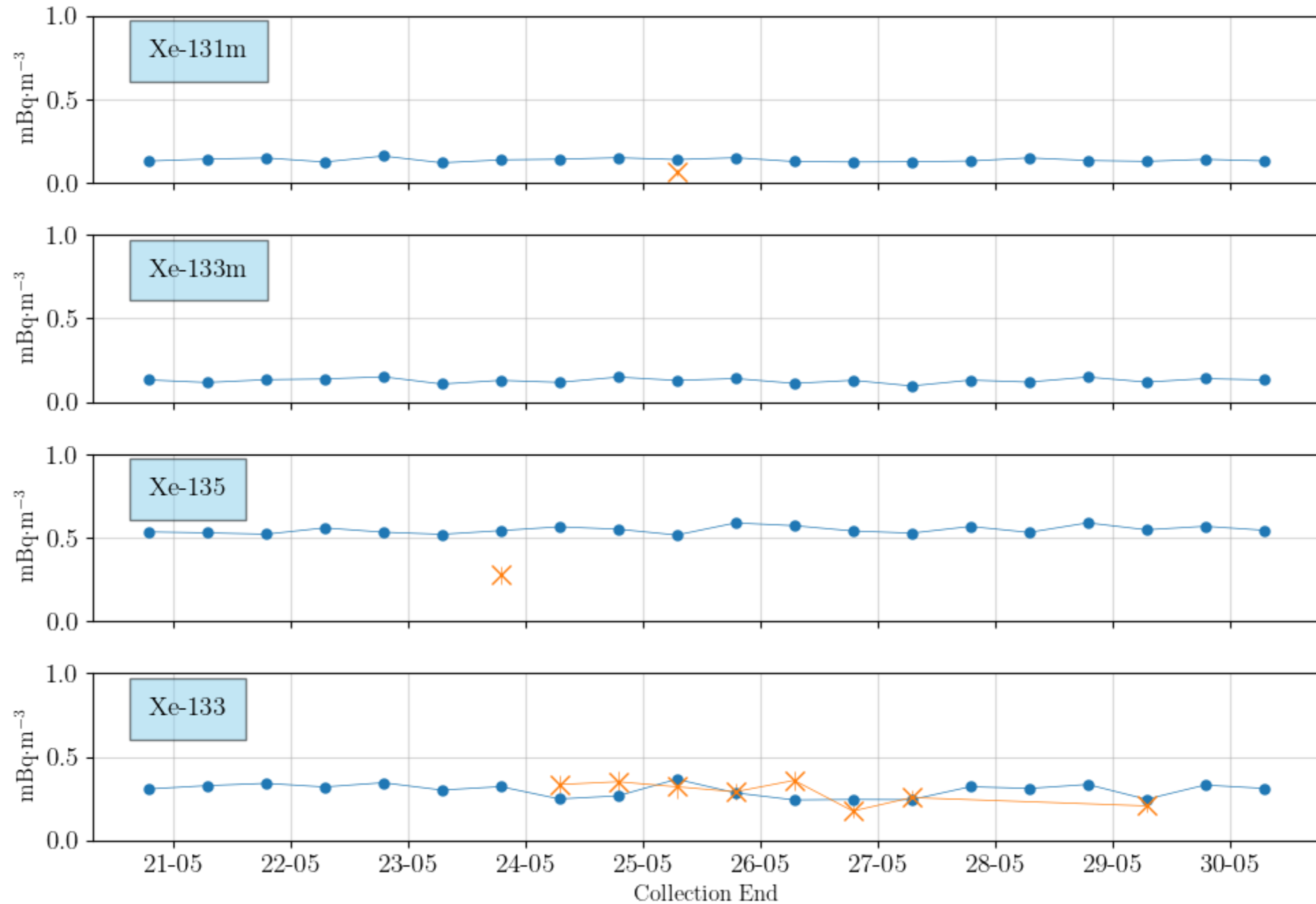


Activity Concentration X

MDC ●



# Event 2019-07



Activity Concentration X

MDC ●



# Comparing RN data & ATM Simulations

## Event 2019-04

Met data can only offer 3 hours resolution  
Temporal offset with data.

Activity Concentration **X**

MDC **●**

ATM **+**

