Analysis of high time-resolution observations of radioxenon releases from BWRs compared to stack data and reactor operation parameters

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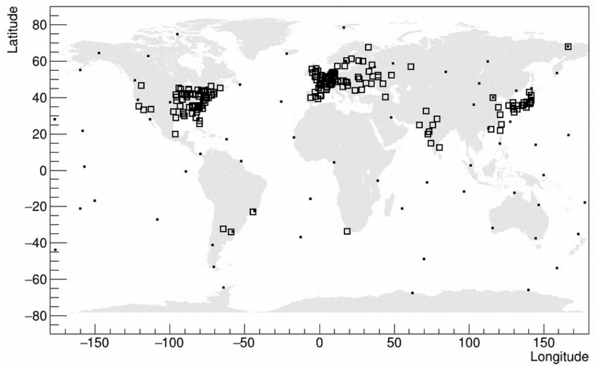
Outline

- Why do we need to understand radioxenon emissions from nuclear power plants?
- The Forsmark NPP
- Analysis of stack data from the Forsmark NPP.
- Analysis of 6 and 12 h - resolution radioxenon observations in Stockholm vs. stack data:
  - Ratios
  - ATM using “Pello” - a regional dispersion model.
- Conclusions and outlook

Power reactors and radioxenon

- Typically ”weak” sources of radioxenon, but…
  - There are many
  - They contain and could emit (and occasionally have emitted) quite sizeable amounts of radioxenon
  - Some reactors are close to IMS-stations
- Operational signatures typically different from fresh NE, but
  - We cannot always expect fresh NE radioxenon
  - Surprisingly many exceptions from ”typical” operations
- We need to know as much as possible about reactor radioxenon emissions



Power reactors and radioxenon

- Radioxenon comes from contaminated fuel rods or cracks in cladding.
- It is mitigated using delay lines (*e.g*. sand/charcoal beds)
- Mitigation system are not always fully functional, or has to be by-passed in certain operational modes.
- Increased emissions and changed isotopic ratios can be an indicator of fuel damage and/or startup/shutdown.

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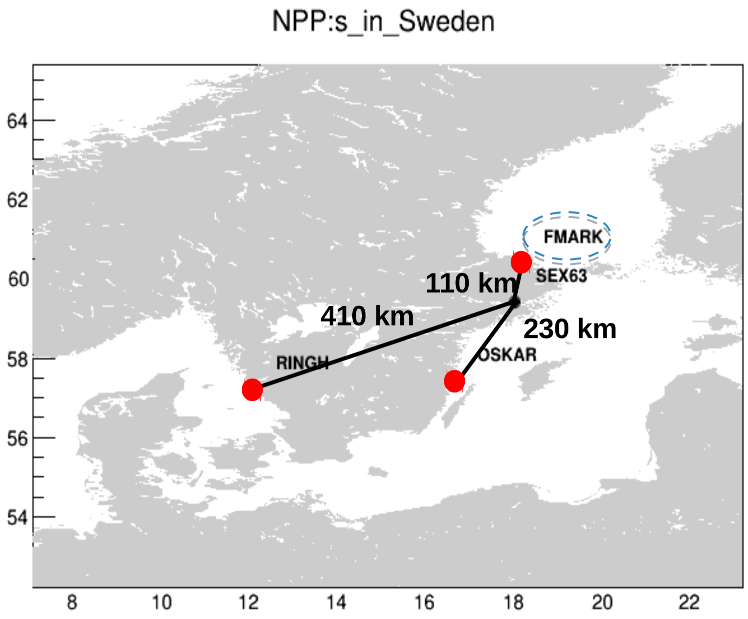
Operating NPPs in Sweden

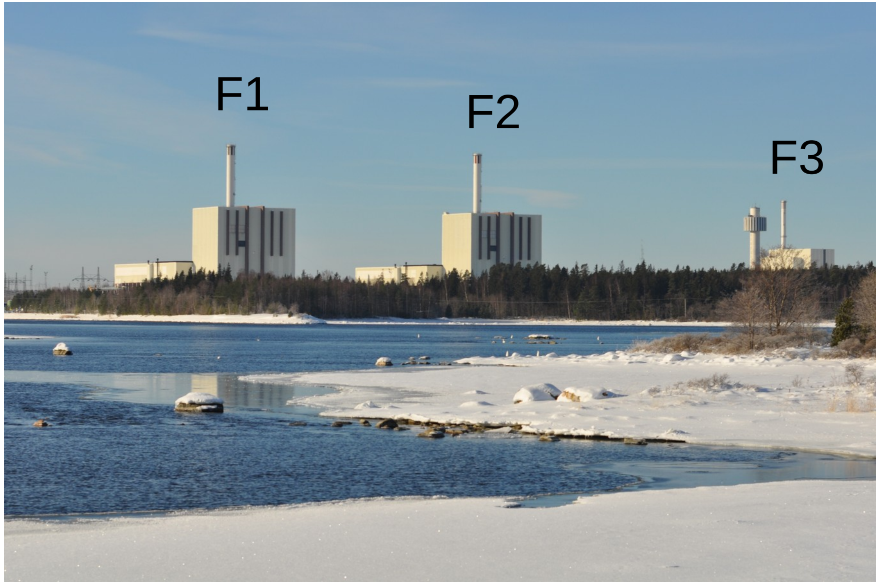


Name	Reactor type	Operating Reactors	Total Power (MW)
Ringhals	PWR	4	3730
Oskarshamn	BWR	1	1200
Forsmark	BWR	3	3276
Total		**8**	**8206**

The Forsmark NPP

Closest NPP to the Swedish radioxenon systems in Stockholm is Forsmark with three BWRs.

Stack height 100 m. Diameter 3.5-3.6 m.



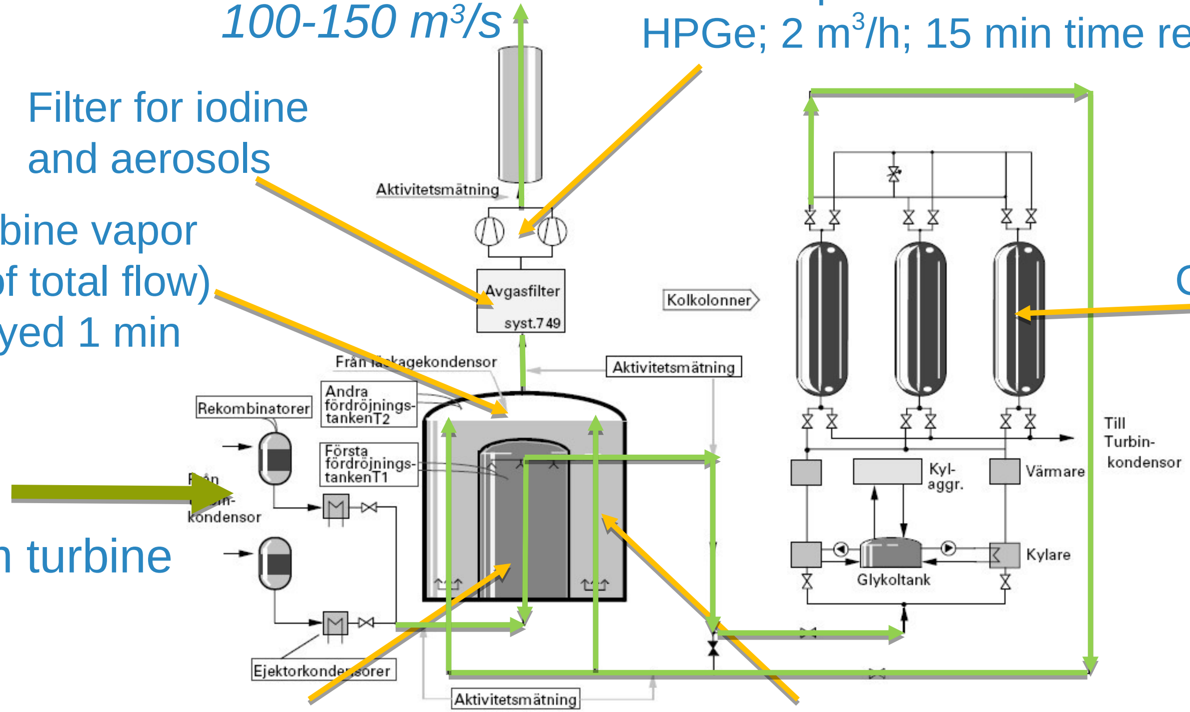
The Forsmark NPP exhaust system

100-150 m³/s

Nuclide specificic measurement;
HPGe; 2 m³/h; 15 min time resolution

Filter for iodine
and aerosols

Some turbine vapor
(1/1000 of total flow)
only delayed 1 min



Charcoal columns

Xe backflushed
Effective delay time can
be hundreds of hours

From turbine

Sandbed 1 (15-20 h)

Sandbed 2 (15-20 h)

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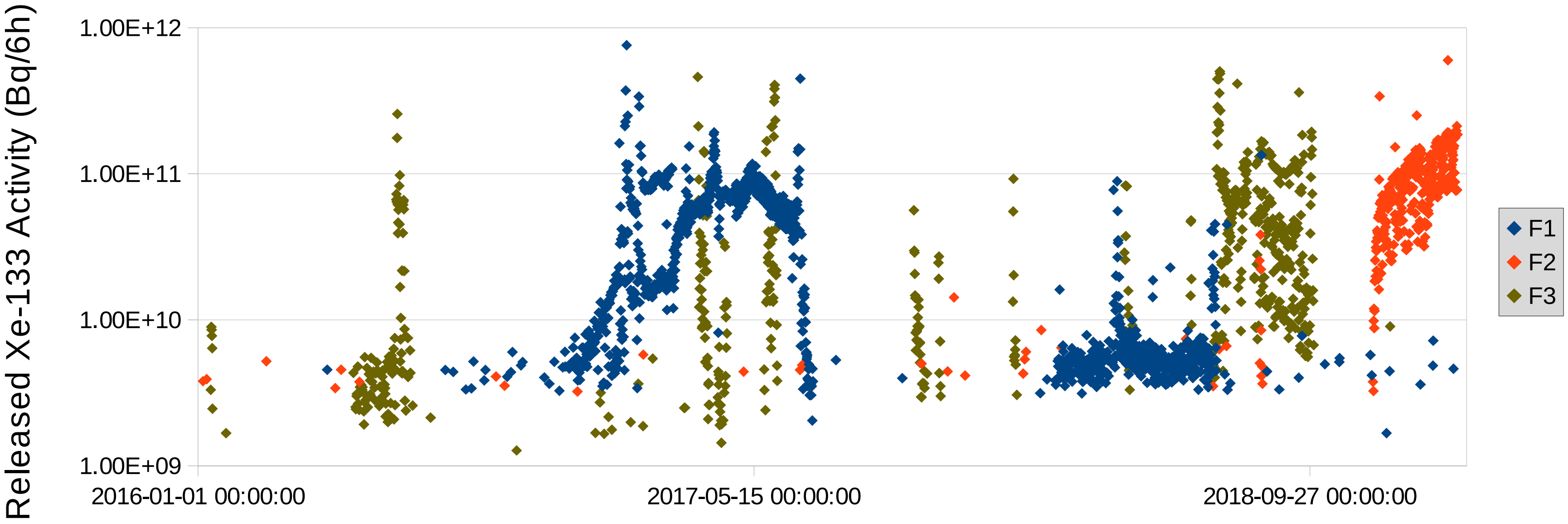
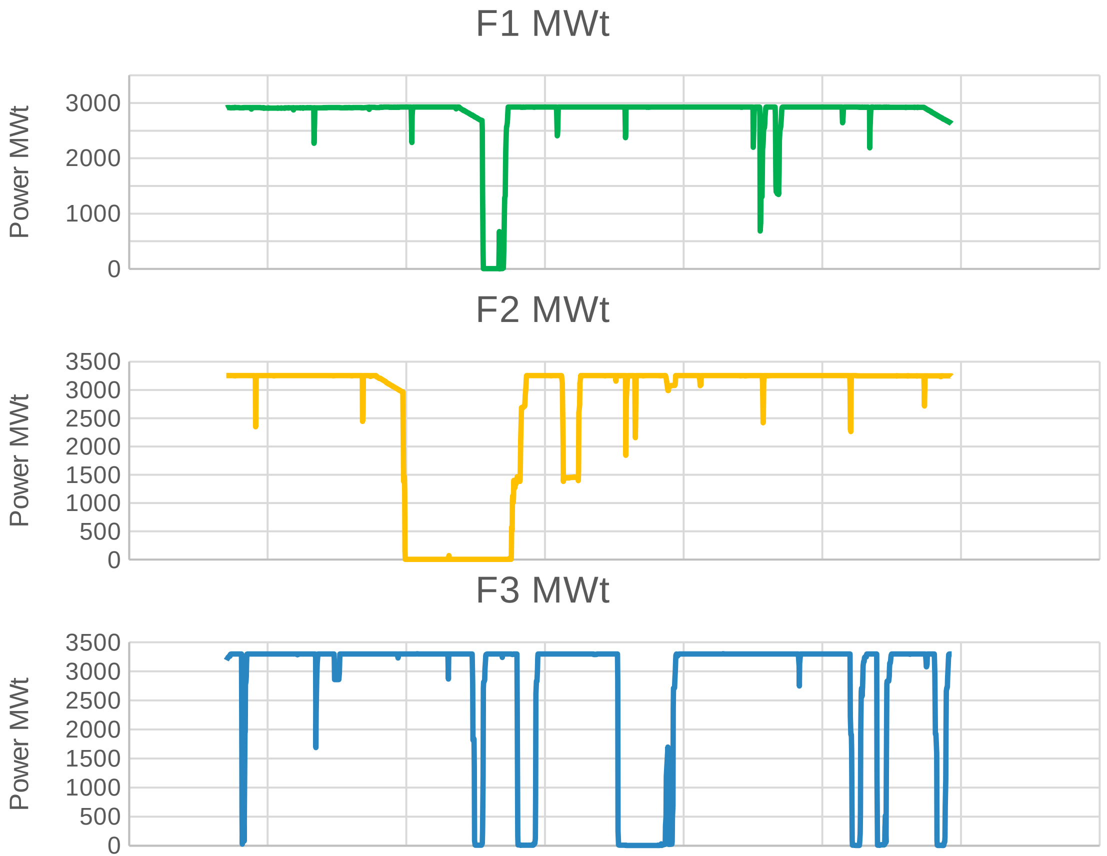
Forsmark ^{133}Xe release data 1/1 2016 – 13/2 2019



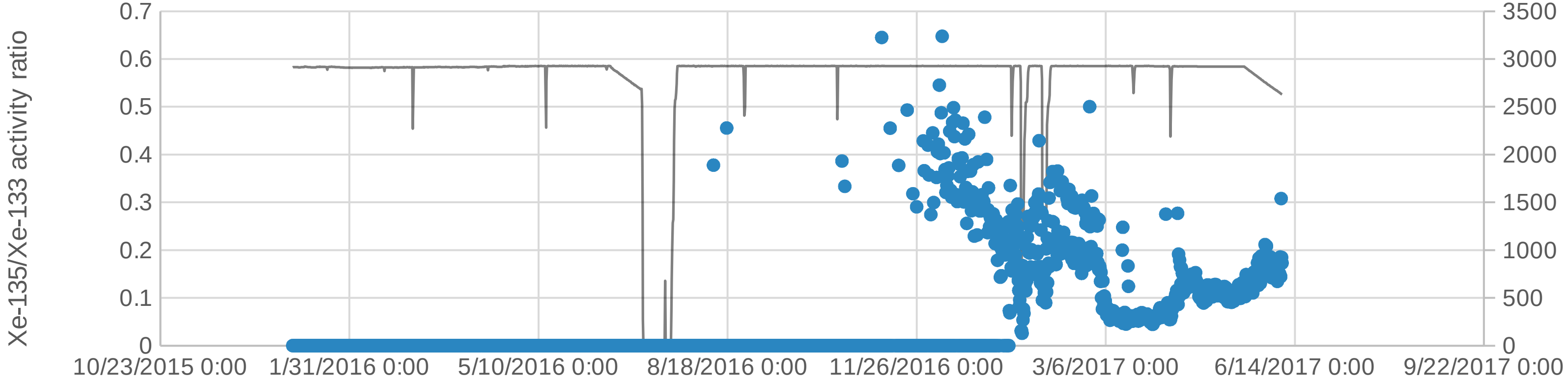
- Damaged fuel in F1 and F3 for this time period.
- F3 more damaged than F1,but F3 mitigation systems more efficient.
- At the end of the period, also releases from F2 (fuel damage).

Power history 2016-01 – 2017-06

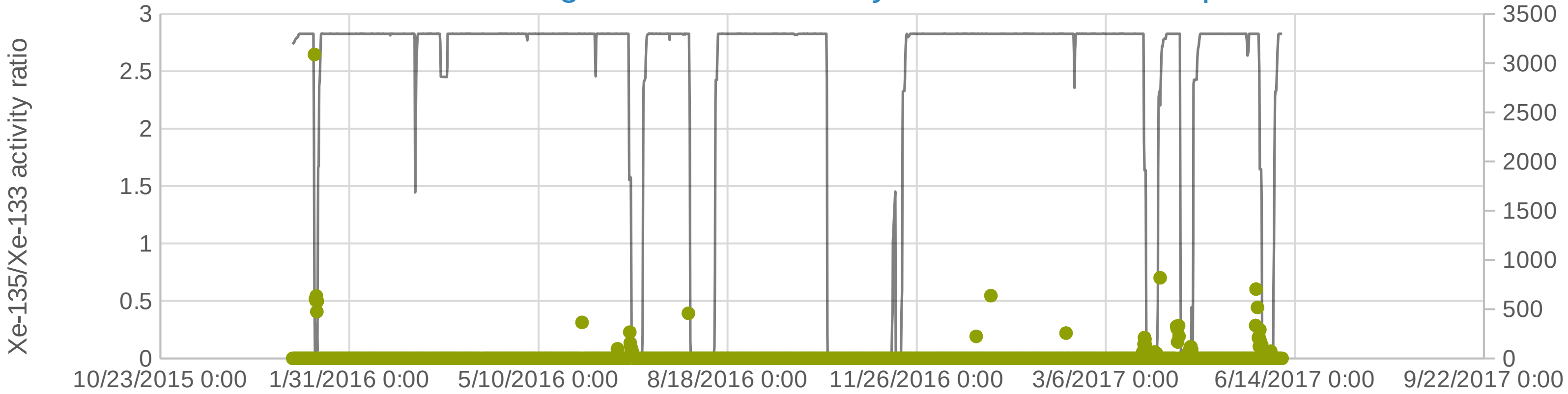


Stack release data (detected ^{135}Xe/^{133}Xe ratios) vs. reactor power

Reactor 1 – fuel damage. Mitigation system less efficient compared to F3.



Reactor 3 – fuel damage. Releases mainly at shutdown/startup



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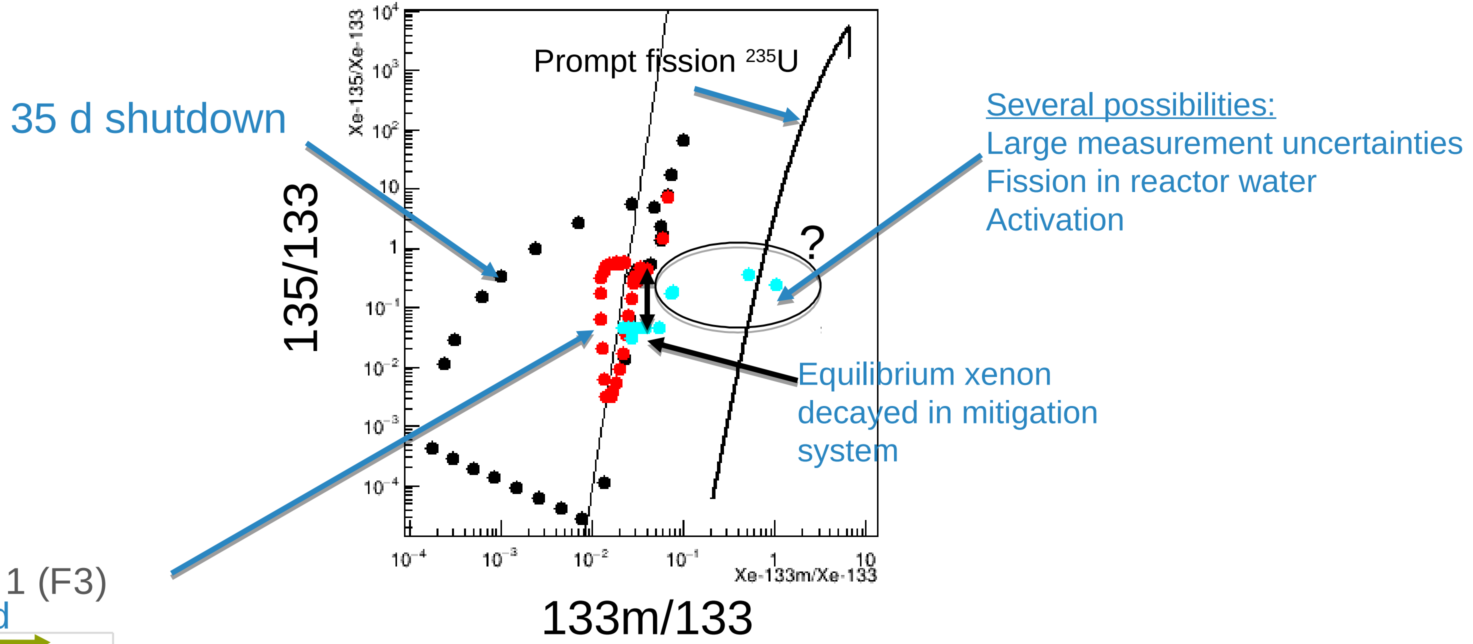
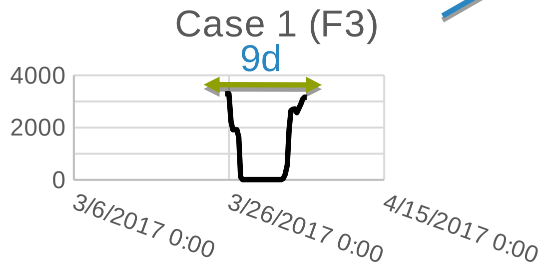
F3 shutdown/startup in Mar-Apr 2017

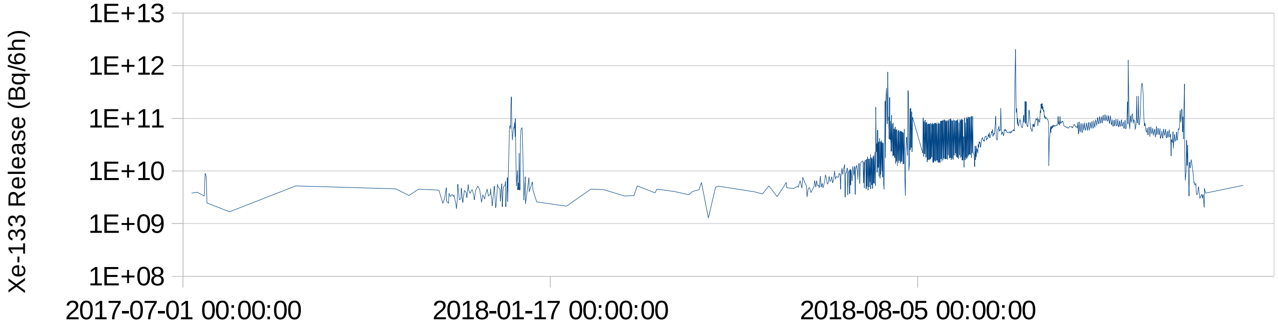




Data set: 2017-07-01 – 2019-01-31

Source: F1+F2+F3

6h stack measurements
The three stacks added

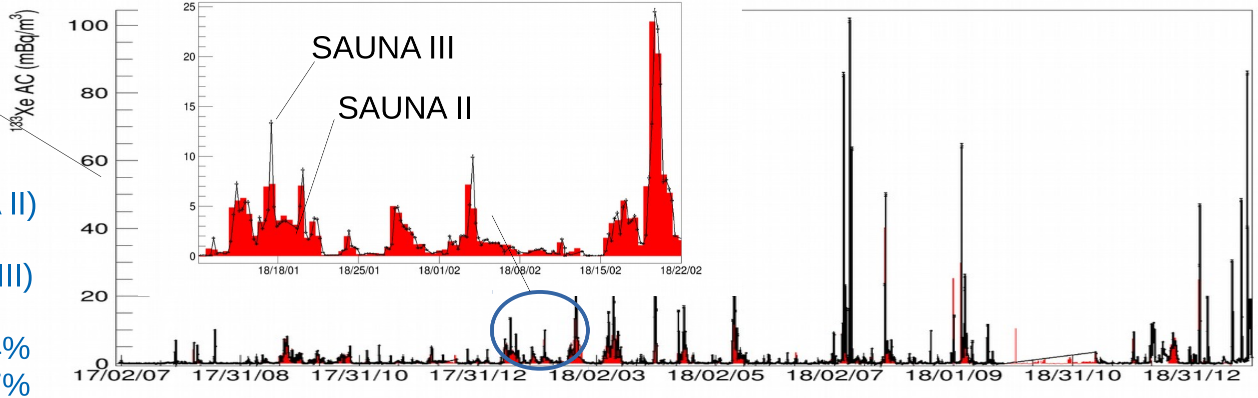


2 NG systems

1115 12 h – measurements (SAUNA II)

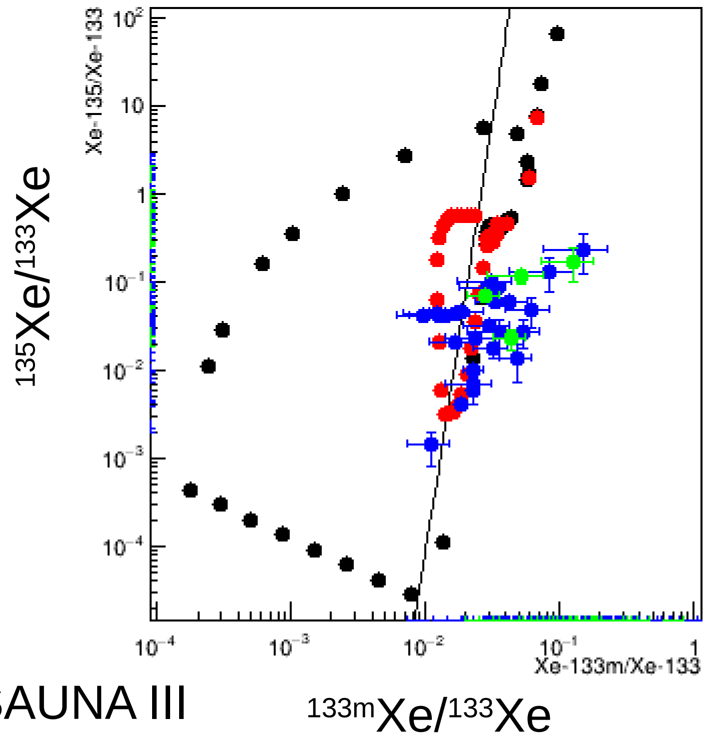
2072 6 h – measurements (SAUNA III)

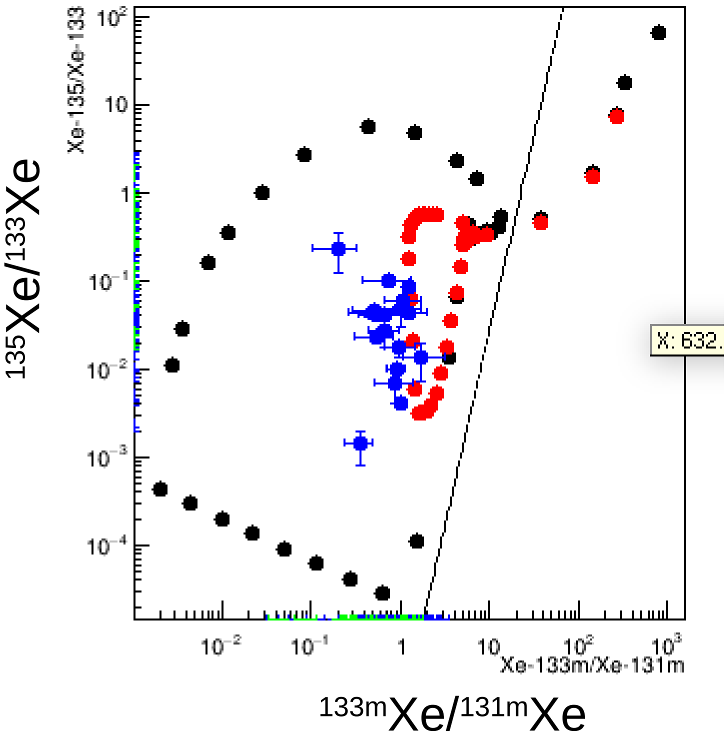
Detections:		
	^{131m}Xe	34%
	^{133}Xe	77%
	^{133m}Xe	13%
	^{135}Xe	12%



Analysed using the new BGM-method (see T3.5-P2)

Observed ratios (99% conf.) in Stockholm vs. NPP scenarios

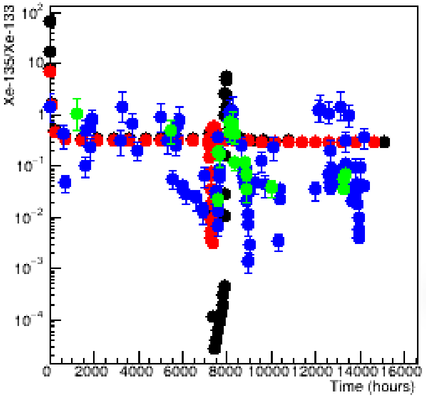




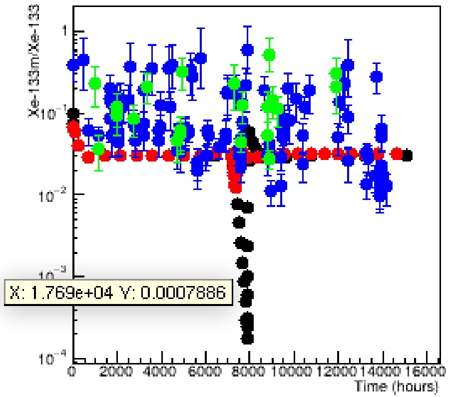
- SAUNA III
- SAUNA II

Observed ratios (99% conf) in Stockholm vs NPP scenarios

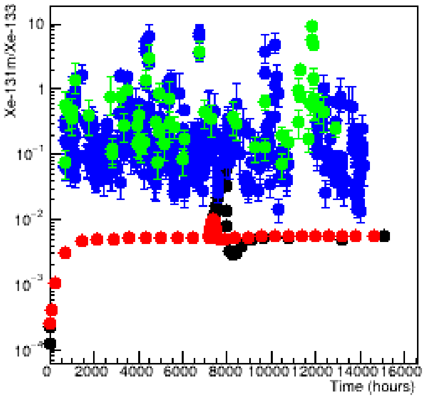
$^{135}Xe/^{133}Xe$



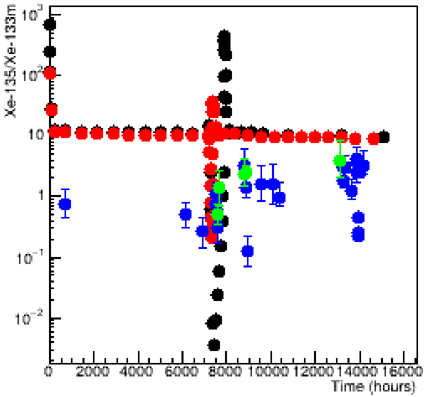
$^{133m}Xe/^{133}Xe$



$^{131m}Xe/^{133}Xe$

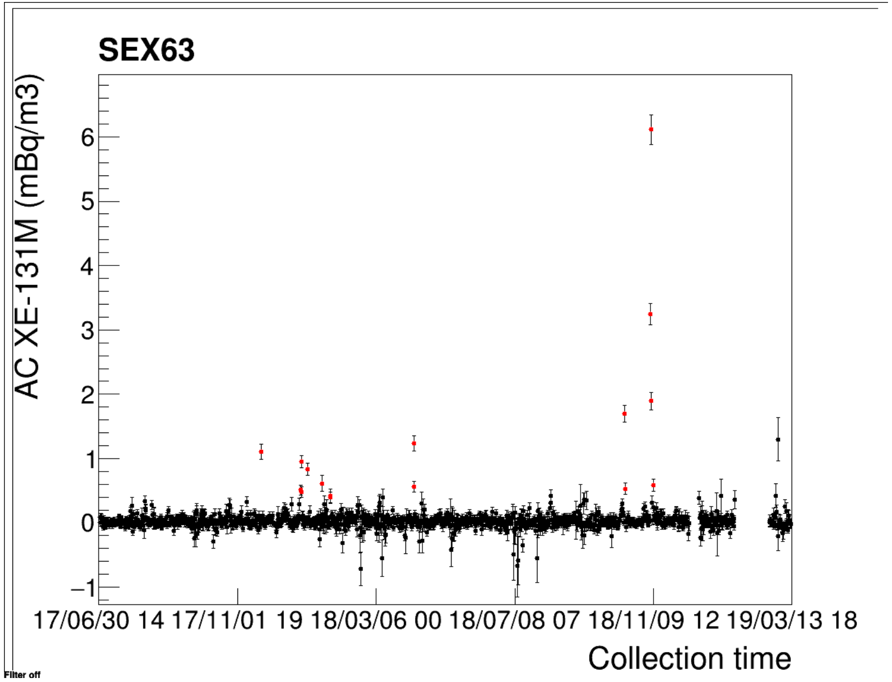


$^{135}Xe/^{133m}Xe$



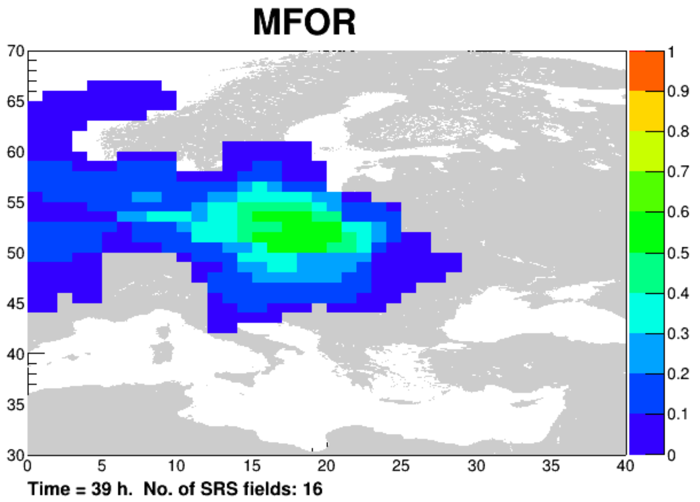
- SAUNA III
- SAUNA II

Source of most ^{131m}Xe detections most likely located in central Europe



Combined FOR for the 16 strongest SEX63 samples

High 131m/133 ratio (between 1 and 10).



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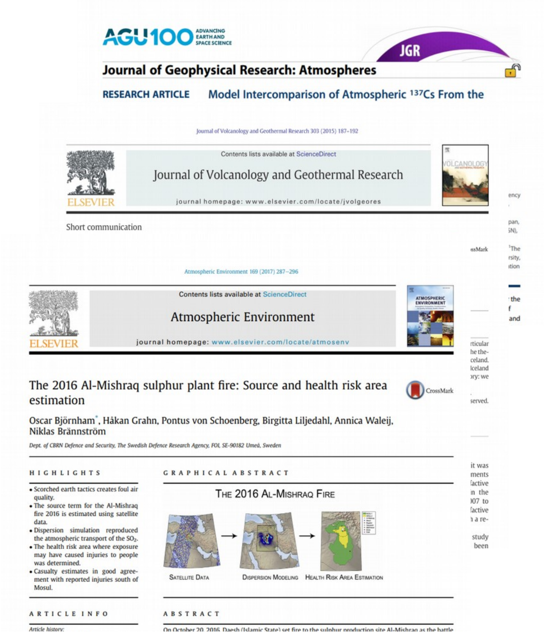
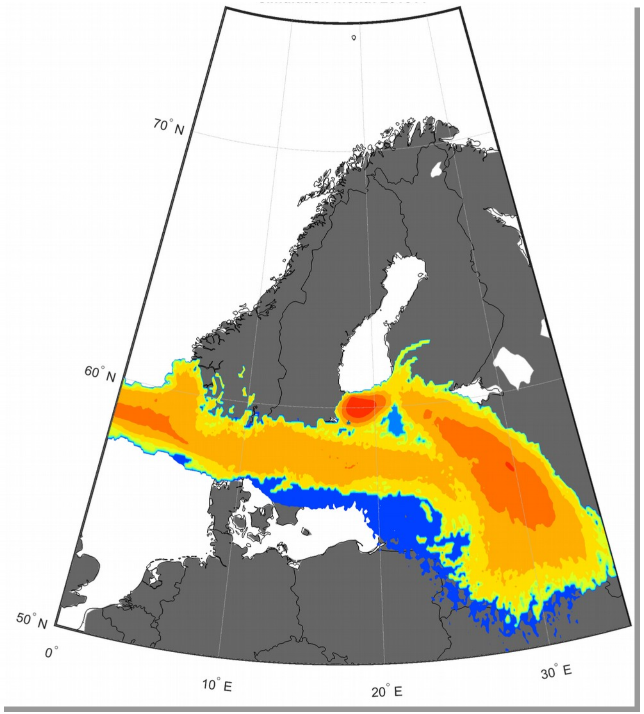
PELLO – Lagrangean Particle Dispersion Model

- **PELLO - P**article model in an **E**tha **L**at **LO**n coordinate system
- Lagrangean Particle Disperison Model (LPDM) developed at FOI
- Regional to global scale
- Model particles with unique properties are tracked in the air flow
  - Size, sedimentation velocity
  - Moved by mean wind and random step representing turbulence
- Weather data from NWP (Numeric weather prediction model)
  - ECMWF – European Centre for Medium-Range Weather Forecasts
  - SMHI – Swedish Meteorological and Hydrological Institute
- Dispersion of gas or particles
- Used for
  - Swedish Armed Forces
  - Swedish Radiation Safety Authority

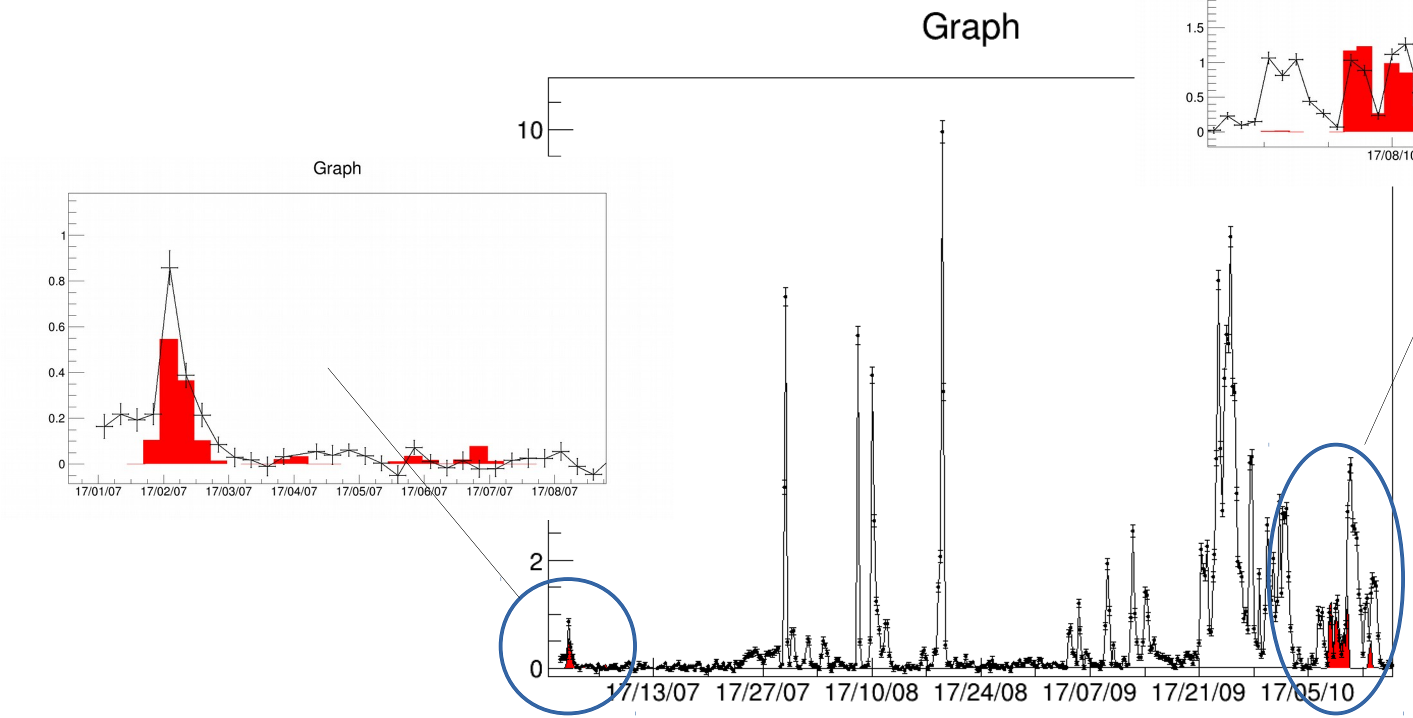


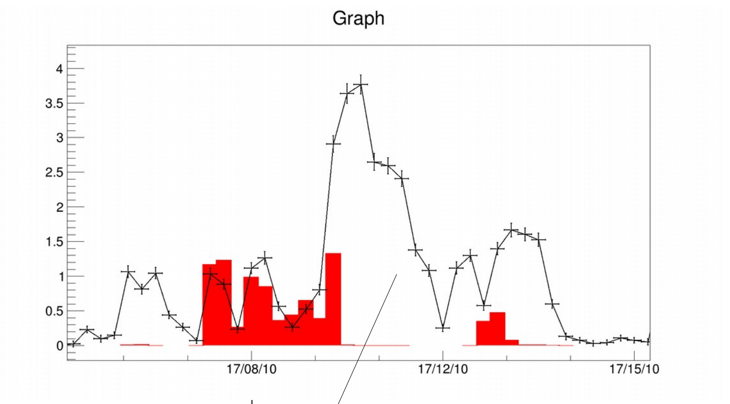
PELLO – model data

- Weather forecast ECMWF
  - Resolution: 0.1x0.1 degrees
  - Boundaries: 45° - 65° latitudes 0 – 40° longitude
  - Forecast lengt 6 and 12 hours
- Source release
  - Xenon-133 according to measurements at Forsmark
  - Plumerise calculation with respect to current weather (Briggs formalism)
  - 10 model particles/second
- Simulation time
  - 2017-07-01 – 2019-03-09
- Output
  - One concentration field every 6 hour

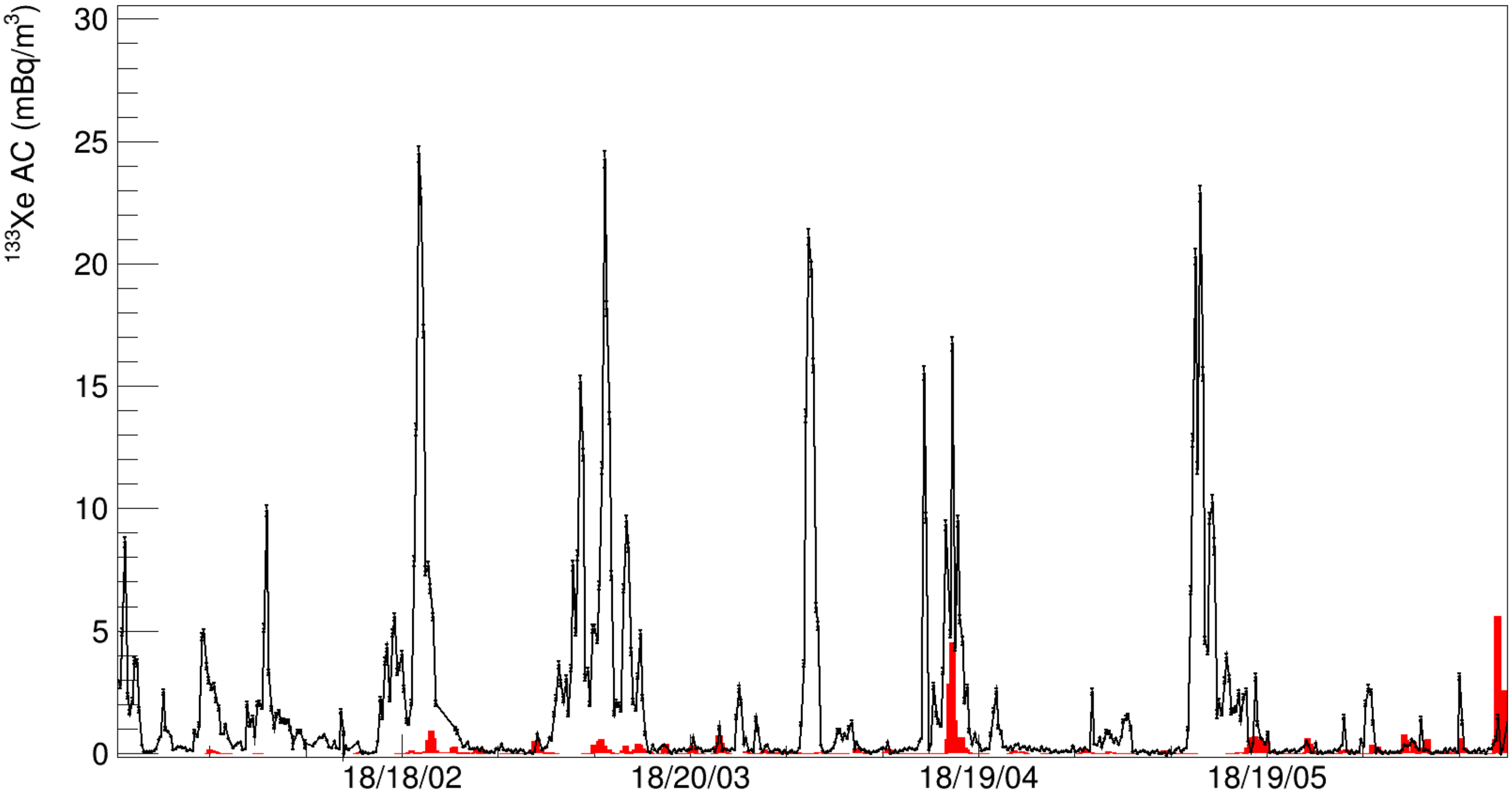


Results June – Dec 2017

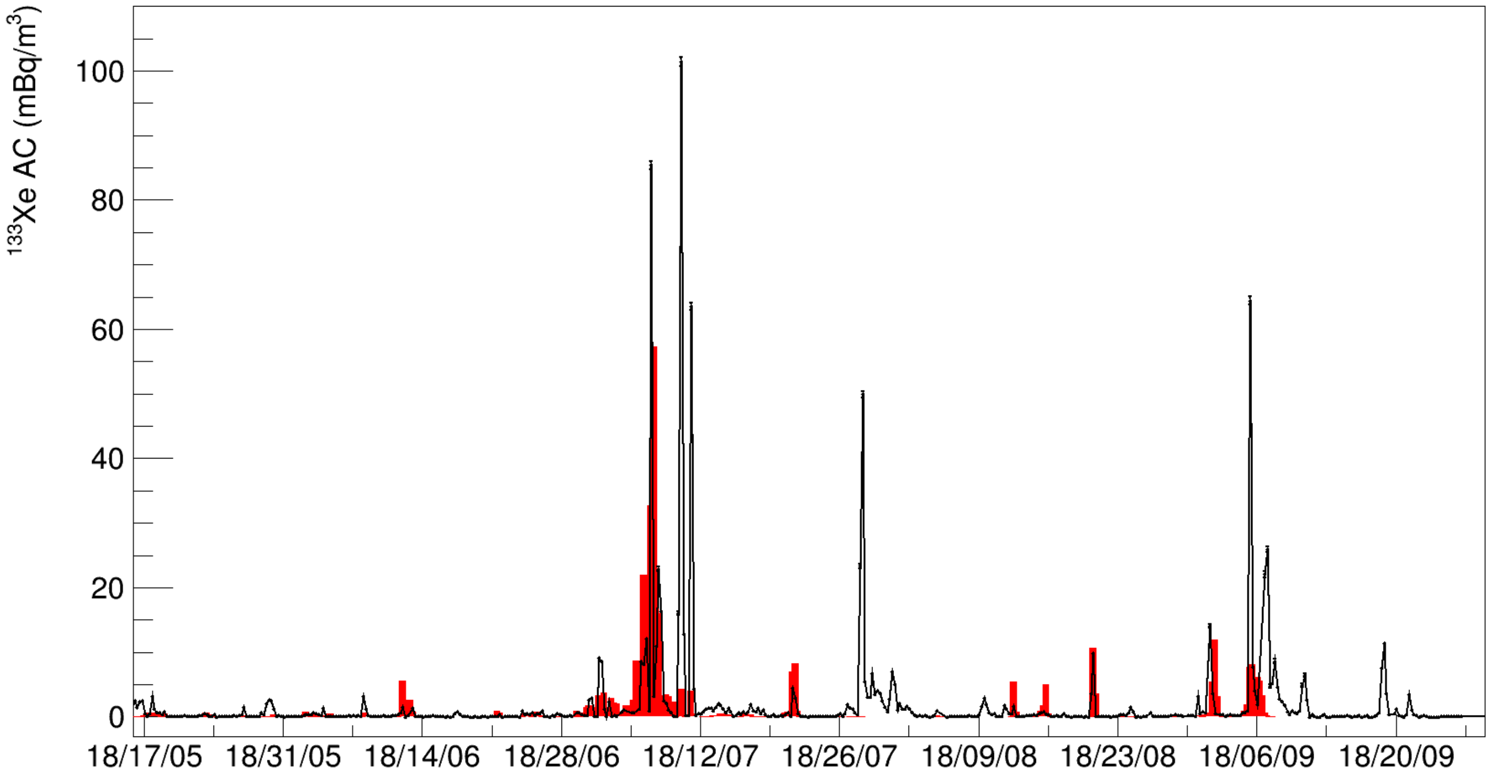




Results Jan-June 2018



Results Jun – Sep 2018



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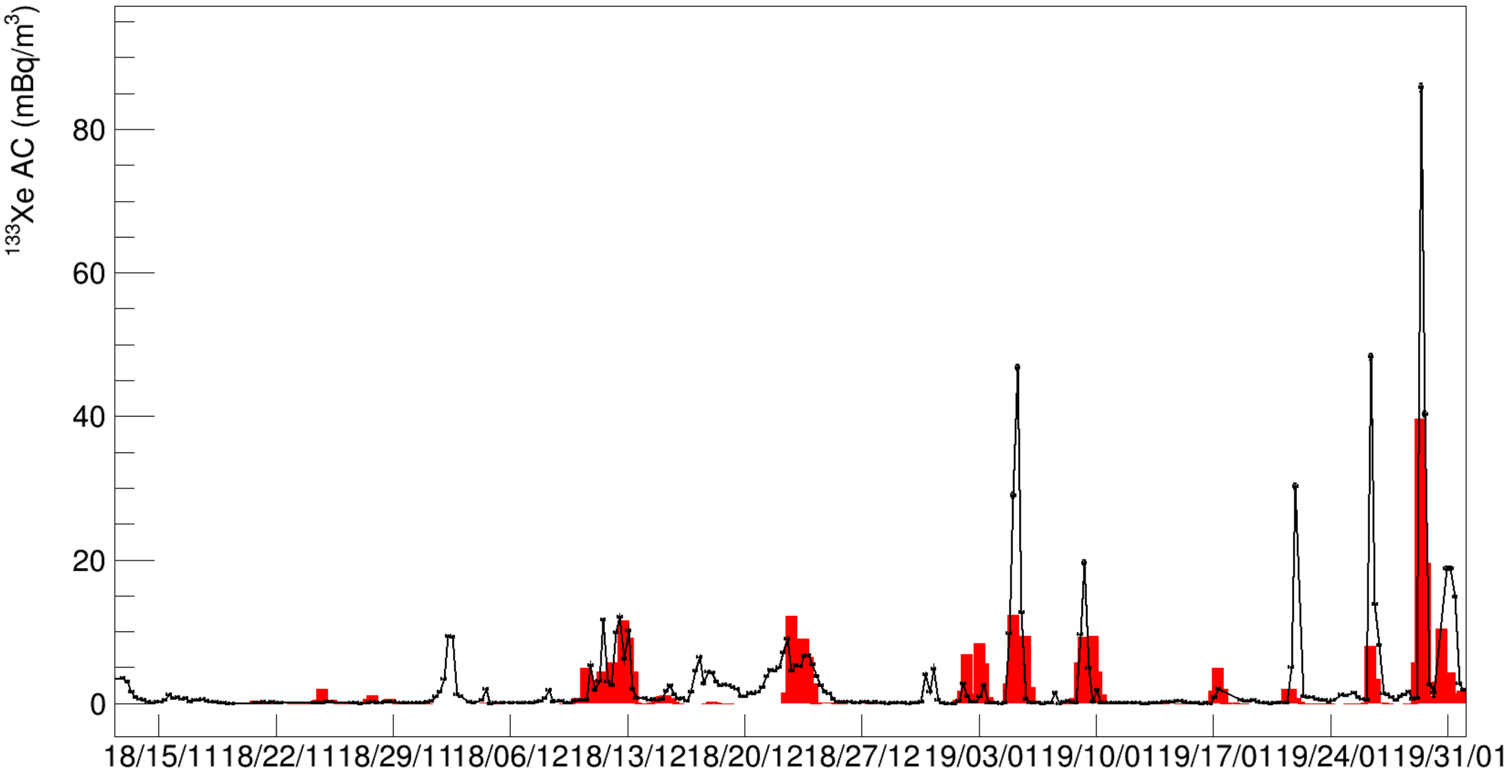
Results Oct 2018 – Jan 2019



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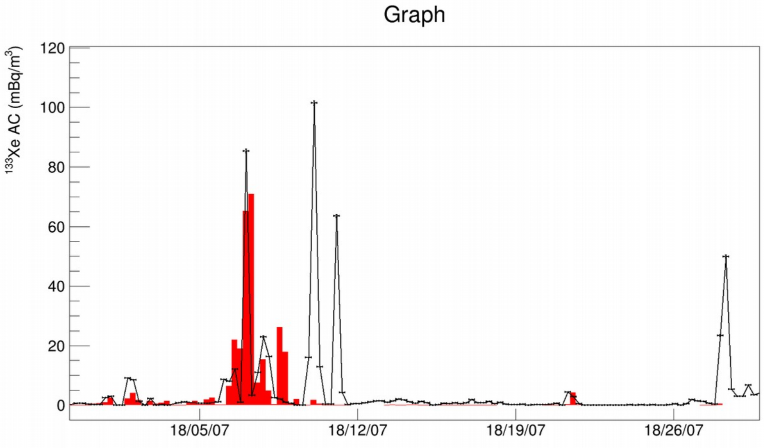
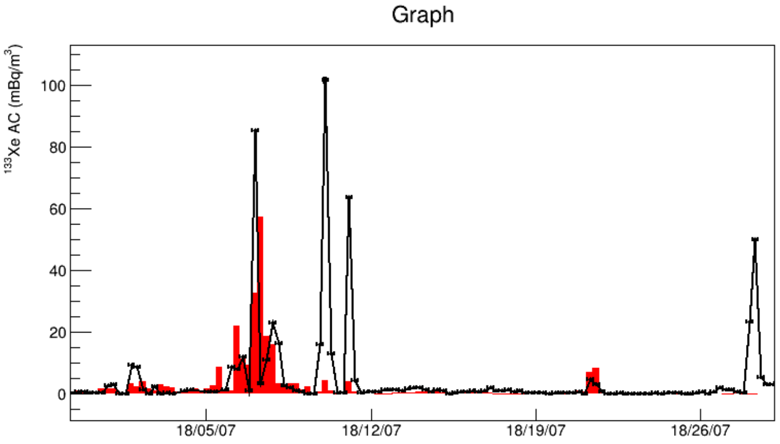
Hysplit vs Pello, July 2018



Hysplit



Pello

Qualitative agreement

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Summary and conclusions

- The most extensive data set of observed releases from a NPP reported to date has been analysed together with stack measurements.
- Isotopic ratios are compatible with models of reactor cycling, with the exception of $^{133m,131m}Xe/^{133}Xe$ ratios, which sometimes are higher than expected.
- Stack data show correlation between releases and start-up shut-down.
- The results show that more refined models of reactor operation are needed in order to explain the observations.
- A regional ATM model (Pello) agree well with observed peaks.
- The results show the power of the new generation NG-systems, resulting in an increased range of measurable isotopic ratios, as well as a higher number of observations for a given time period.
- It is crucial to have good communication with the NPP:s in order to gain more insight into radioxenon observations in IMS.

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