

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

Anders Ringbom\*, Anders Axelsson\*, O. Björnham\*,  
N. Brännström\*, Tomas Fritioff\*, H. Grahn\*, Mattias Olsson\*\*,  
Staffan Hennigor\*\*

\*Swedish Defence Research Agency (FOI)

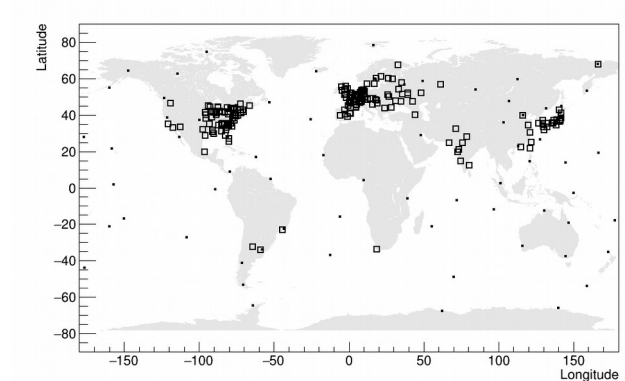
\*\*Forsmarks Kraftgrupp AB

# Outline

- Why do we need to understand radionuclide emissions from nuclear power plants?
- The Forsmark NPP
- Analysis of stack data from the Forsmark NPP.
- Analysis of 6 and 12 h - resolution radionuclide 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

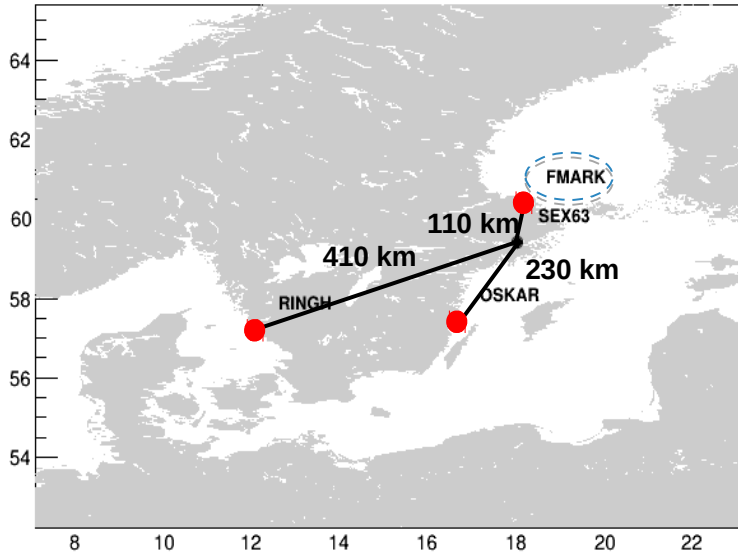


# Power reactors and radioxenon

- Radioxenon comes from contaminated fuel rods or cracks in cladding.
- It is mitigated using delay lines (*e.g.* sand/charcoal beds)
- Mitigation systems are not always fully functional, or have 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.

# Operating NPPs in Sweden

NPP:s\_in\_Sweden

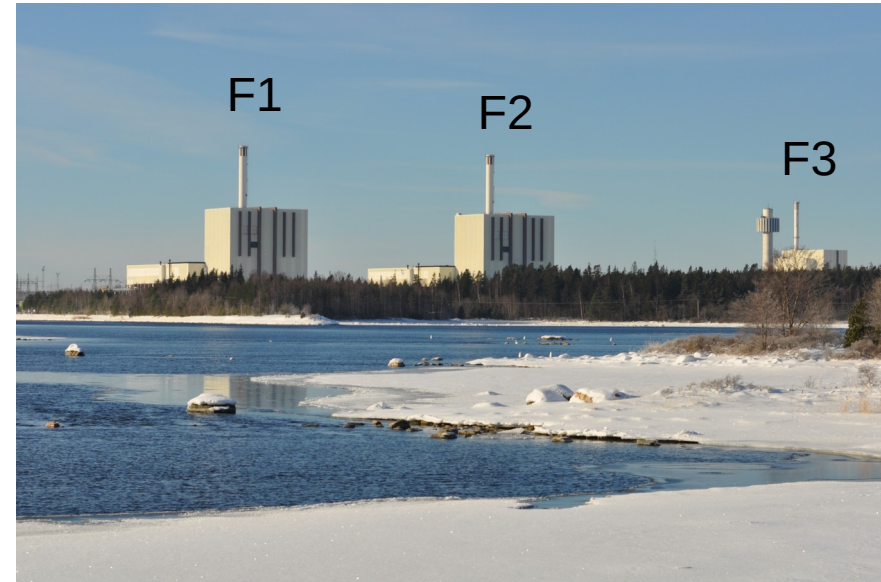


Name	Reactor type	Operating Reactors	Total Power (MW)
Ringhals	PWR	4	3730
Oskarshamn	BWR	1	1200
Forsmark	BWR	3	3276
<b>Total</b>		<b>8</b>	<b>8206</b>

# 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

Nuclide specific measurement;  
HPGe; 2 m<sup>3</sup>/h; 15 min time resolution

100-150 m<sup>3</sup>/s

Filter for iodine  
and aerosols

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

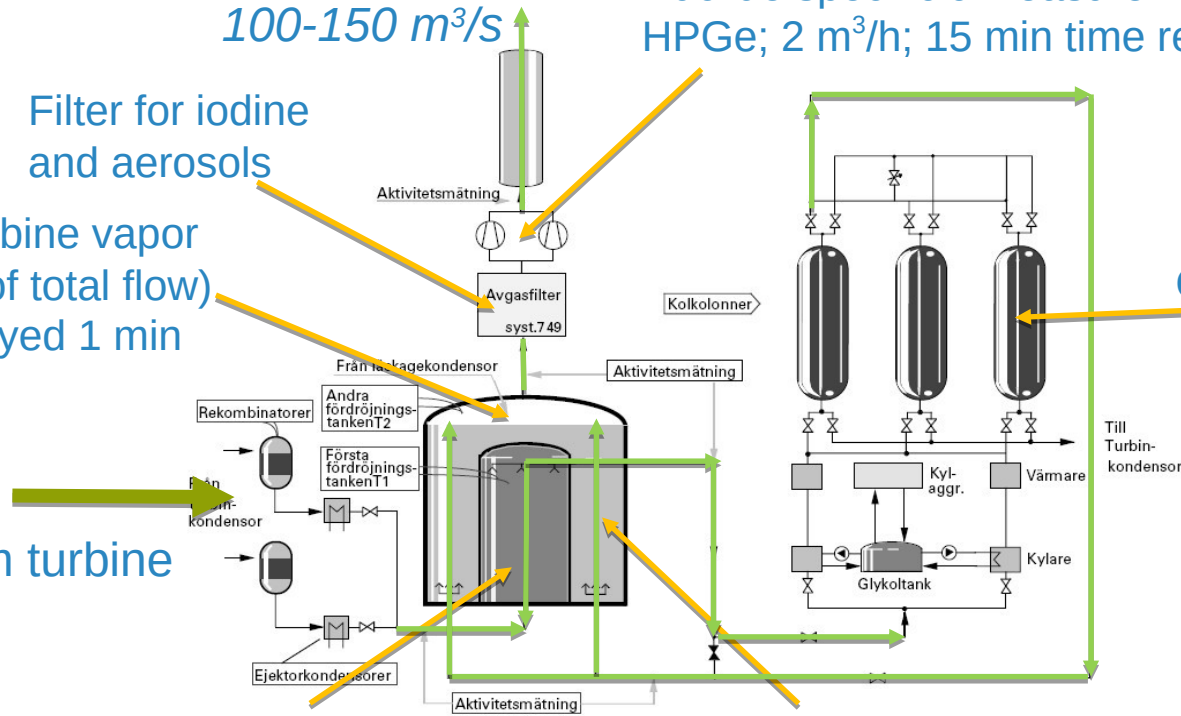
Charcoal columns

Xe backflushed  
Effective delay time can  
be hundreds of hours

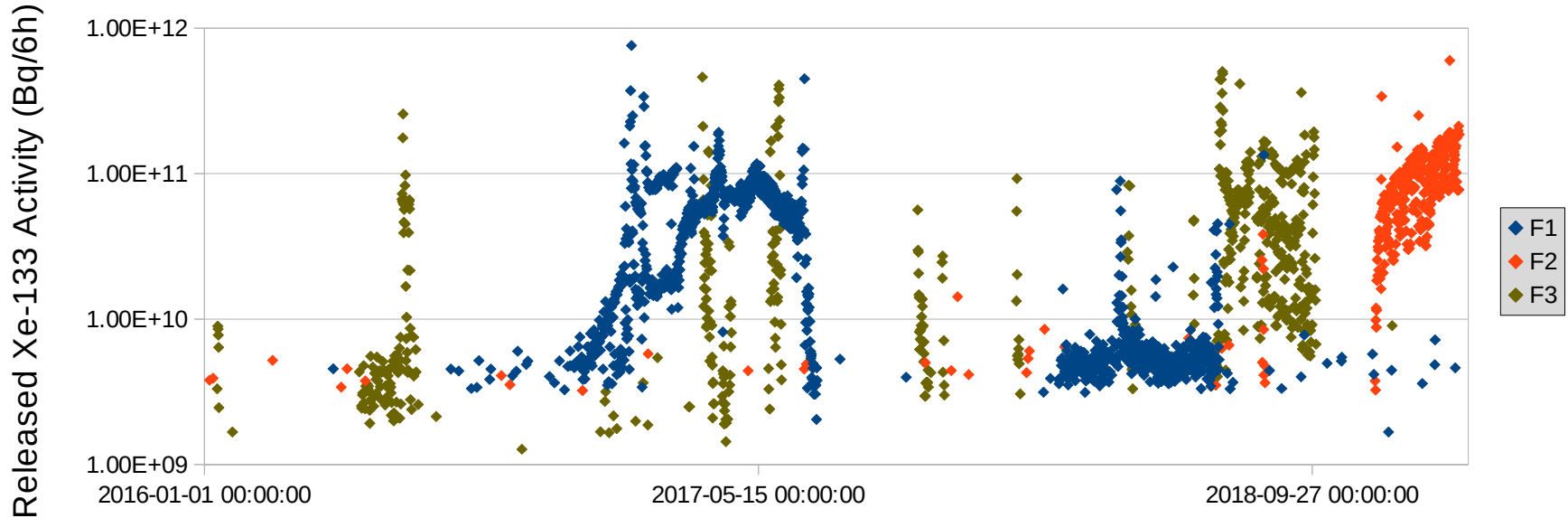
From turbine

Sandbed 1 (15-20 h)

Sandbed 2 (15-20 h)



# Forsmark $^{133}\text{Xe}$ release data 1/1 2016 – 13/2 2019



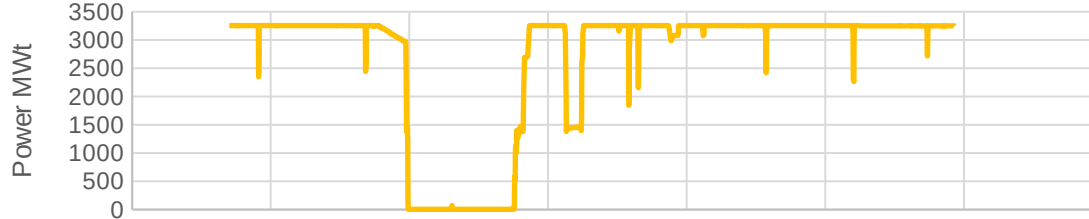
- Damaged fuel in F1 and F3 for this time period.
- F3 more damaged than F1, but F3 mitigation systems more efficient.
- At the end of the period, also releases from F2 (fuel damage).

# Power history 2016-01 – 2017-06

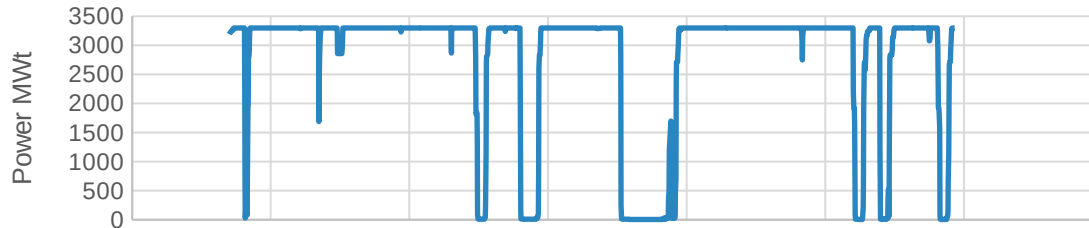
F1 MWt



F2 MWt

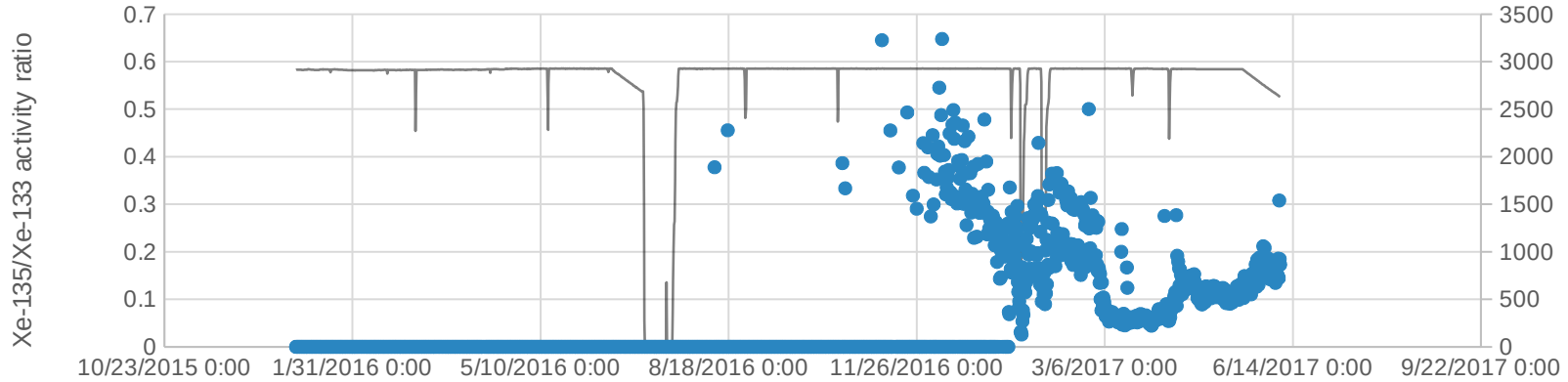


F3 MWt

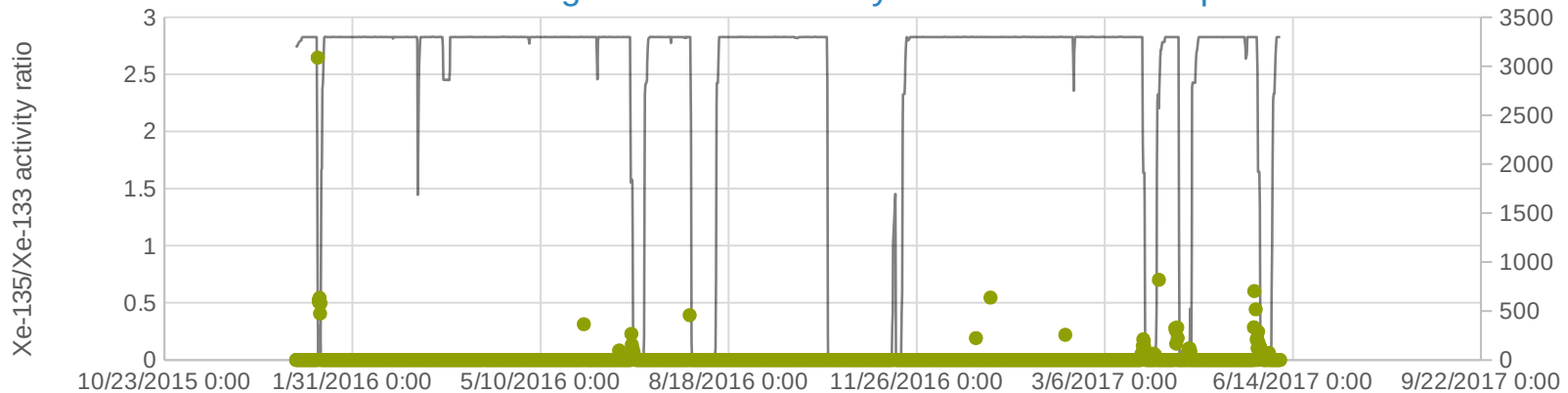


# Stack release data (detected $^{135}\text{Xe}/^{133}\text{Xe}$ ratios) vs. reactor power

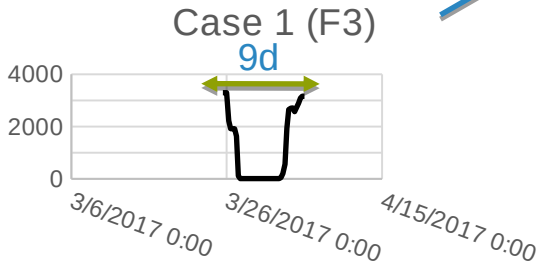
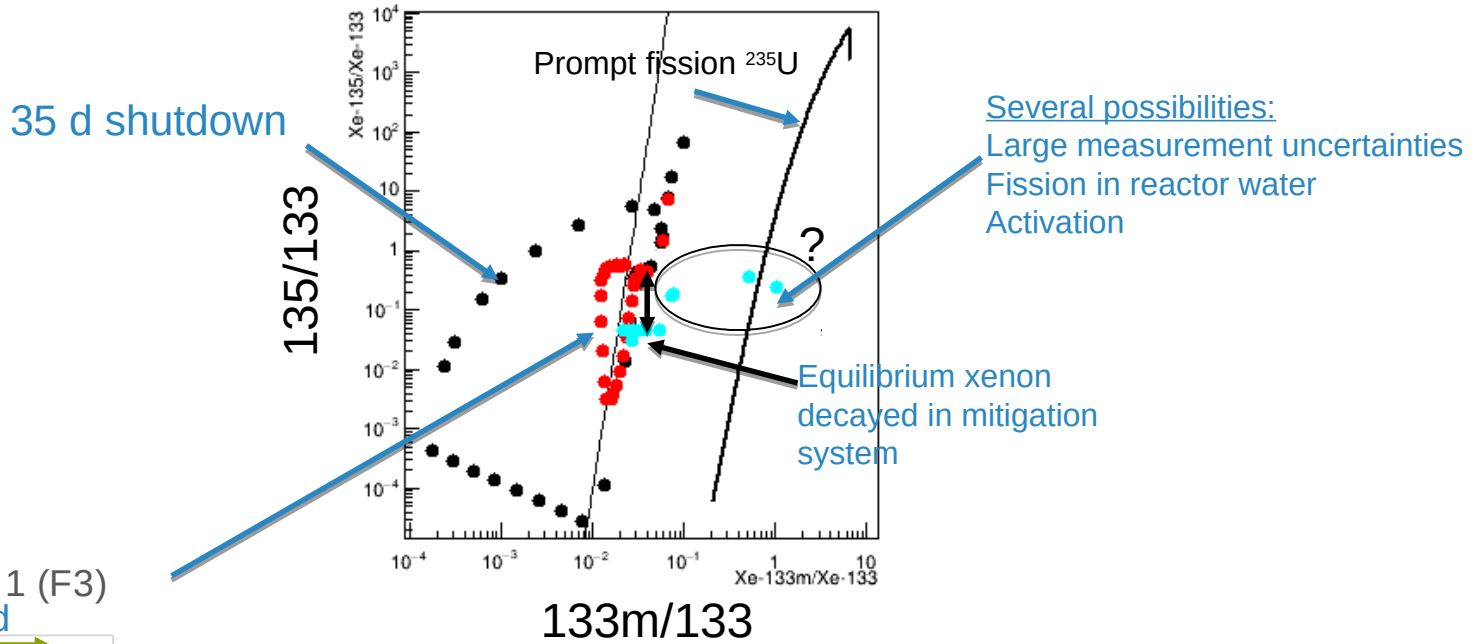
Reactor 1 – fuel damage. Mitigation system less efficient compared to F3.



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

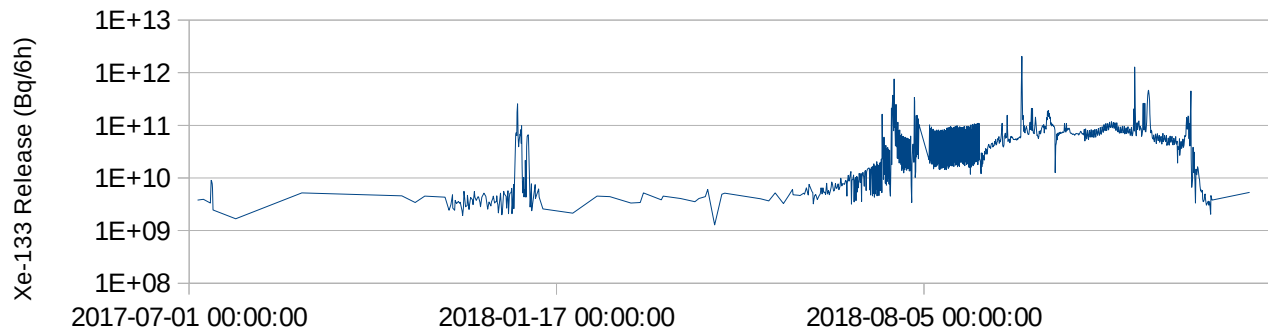


# F3 shutdown/startup in Mar-Apr 2017



# Data set: 2017-07-01 – 2019-01-31

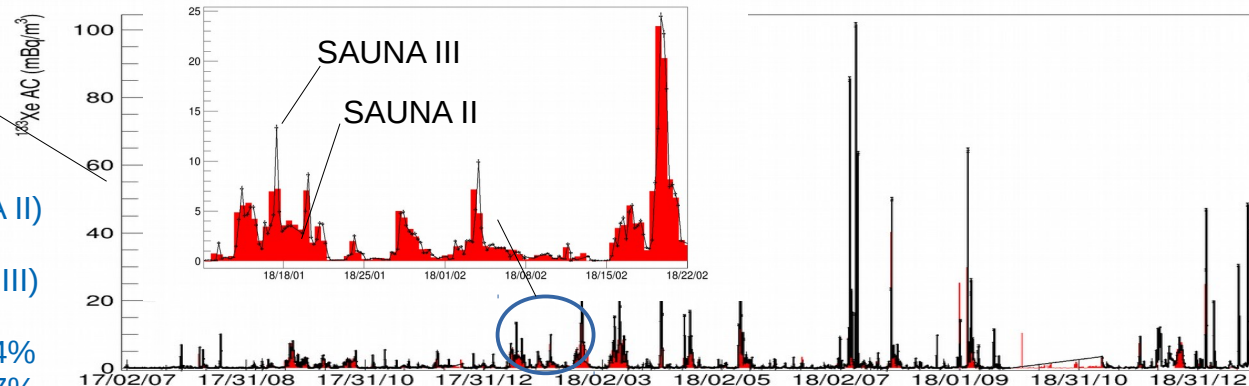
Source: F1+F2+F3  
6h stack measurements  
The three stacks added



2 NG systems

1115 12 h – measurements (SAUNA II)

2072 6 h – measurements (SAUNA III)

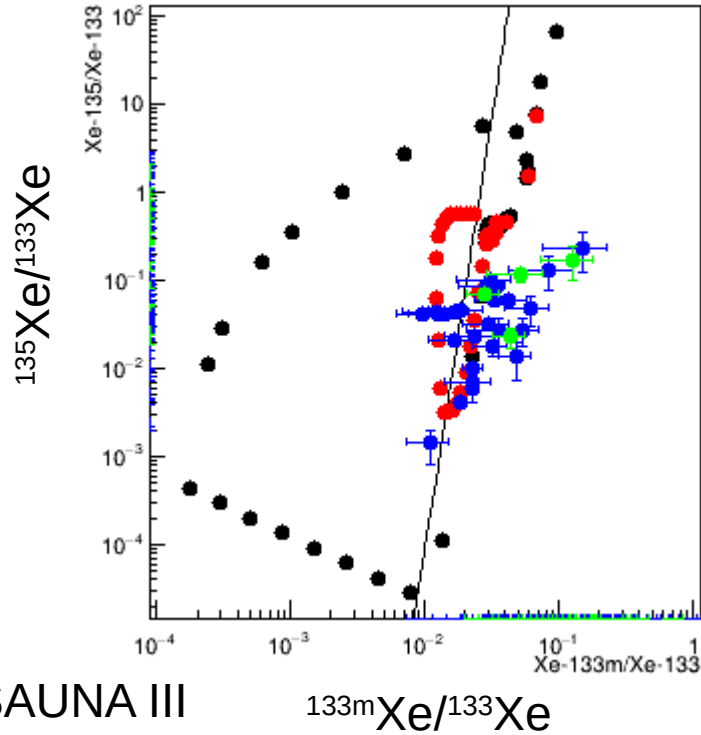


Detections:

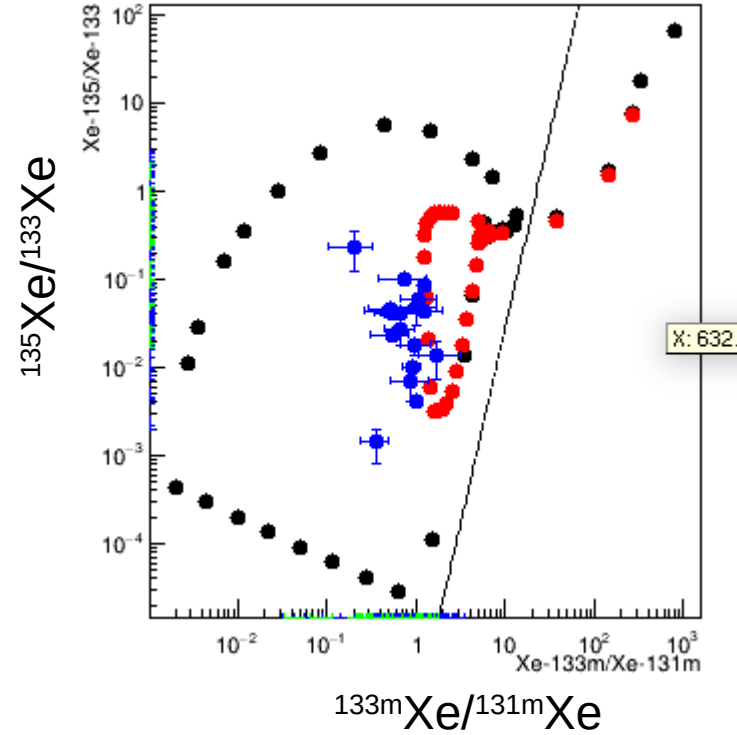
$^{131}\text{mXe}$	34%
$^{133}\text{Xe}$	77%
$^{133\text{m}}\text{Xe}$	13%
$^{135}\text{Xe}$	12%

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

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

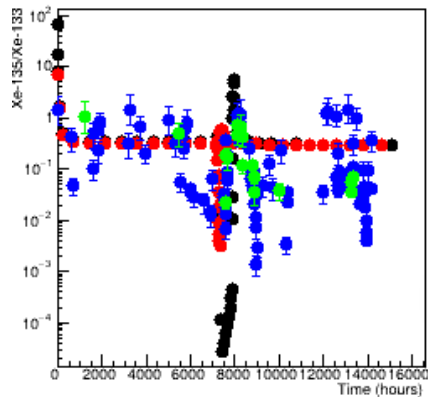


- SAUNA III
- SAUNA II

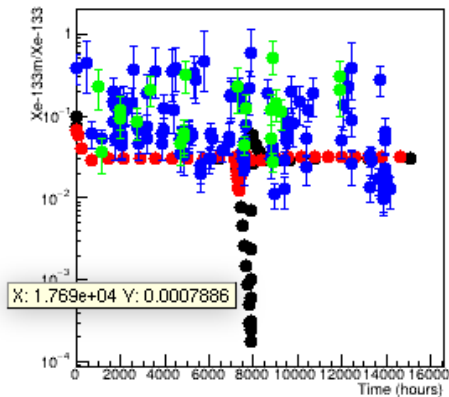


# Observed ratios (99% conf) in Stockholm vs NPP scenarios

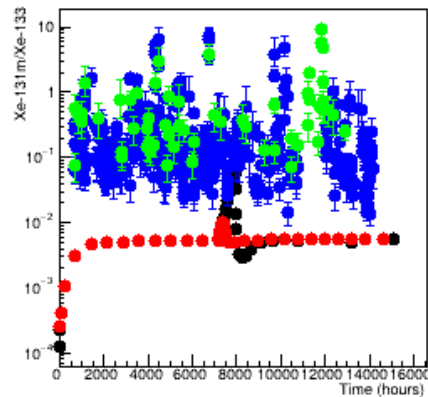
$^{135}\text{Xe}/^{133}\text{Xe}$



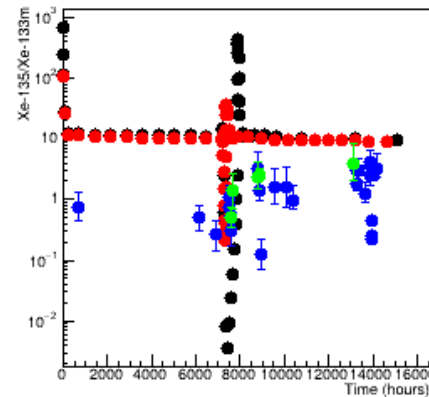
$^{133m}\text{Xe}/^{133}\text{Xe}$



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

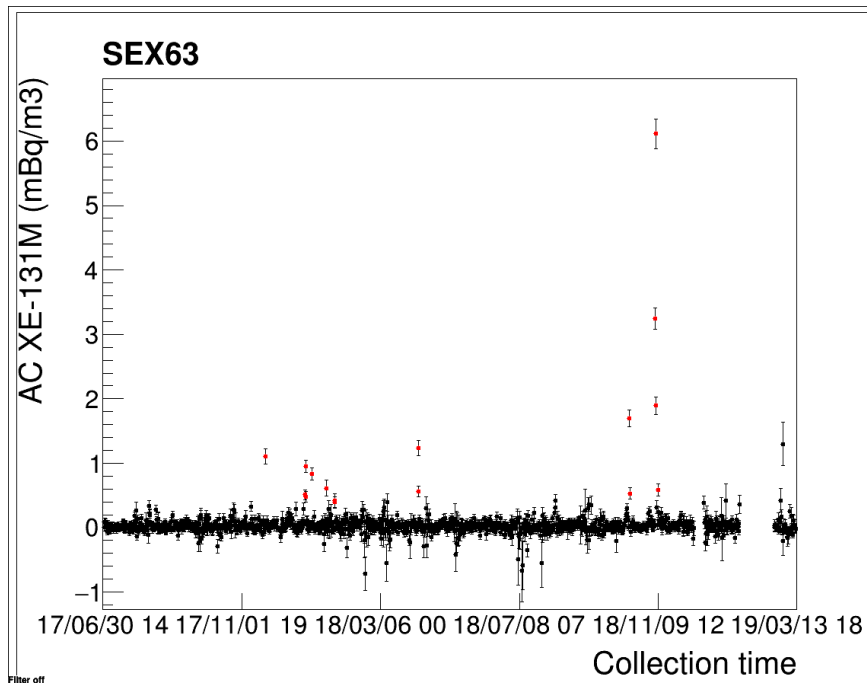


$^{135}\text{Xe}/^{133m}\text{Xe}$

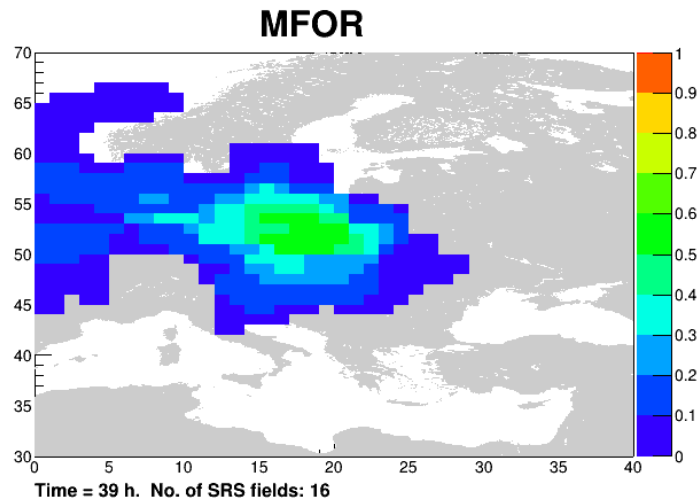


- SAUNA III
- SAUNA II

# Source of most $^{131m}\text{Xe}$ detections most likely located in central Europe



Combined FOR for the 16 strongest SEX63 samples  
High  $^{131m}/^{133}$  ratio (between 1 and 10).



# PELLO – Lagrangean Particle Dispersion Model

- **PELLO** - Particle model in an **Etha Lat LOn** coordinate system
- Lagrangean Particle Dispersion 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

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JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE Model Intercomparison of Atmospheric <sup>137</sup>Cs From the

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Short communication

Atmospheric Environment 108 (2017) 287–296

Contents lists available at ScienceDirect

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The 2016 Al-Mishraq sulphur plant fire: Source and health risk area estimation

Oscar Björnham<sup>a</sup>, Håkan Grah, Pontus von Schoenberg, Birgitta Liljedahl, Annica Waleji, Niklas Bränmström

<sup>a</sup> Dept. of CBRN Defence and Security, The Swedish Defence Research Agency, P.O. Box 116002 Umeå, Sweden

**HIGHLIGHTS**

- Scattered earth tactics creates foul air quality
- The source term for the Al-Mishraq fire 2016 is estimated using satellite data.
- Dispersion simulation reproduced the atmospheric transport of the SO<sub>2</sub>.
- The health risk area where exposure may have caused injuries to people was determined.
- Casualty estimates in good agreement with reported injuries south of Mosul.

**GRAPHICAL ABSTRACT**

**THE 2016 AL-MISHRAQ FIRE**

Satellite Data → Dispersion Modeling → Health Risk Area Estimation

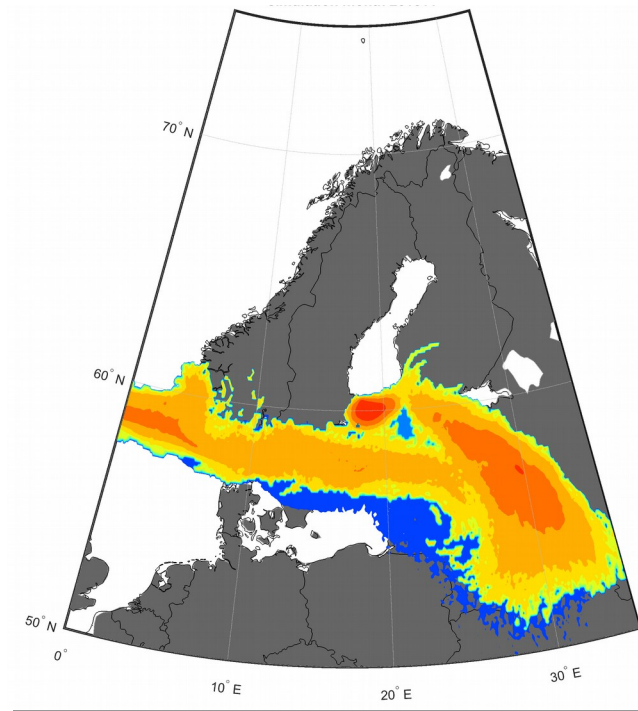
**ARTICLE INFO**

**ABSTRACT**

On October 26, 2016, 10000 tonnes of sulfur was fed into the sulfur production site Al-Mishraq in the north

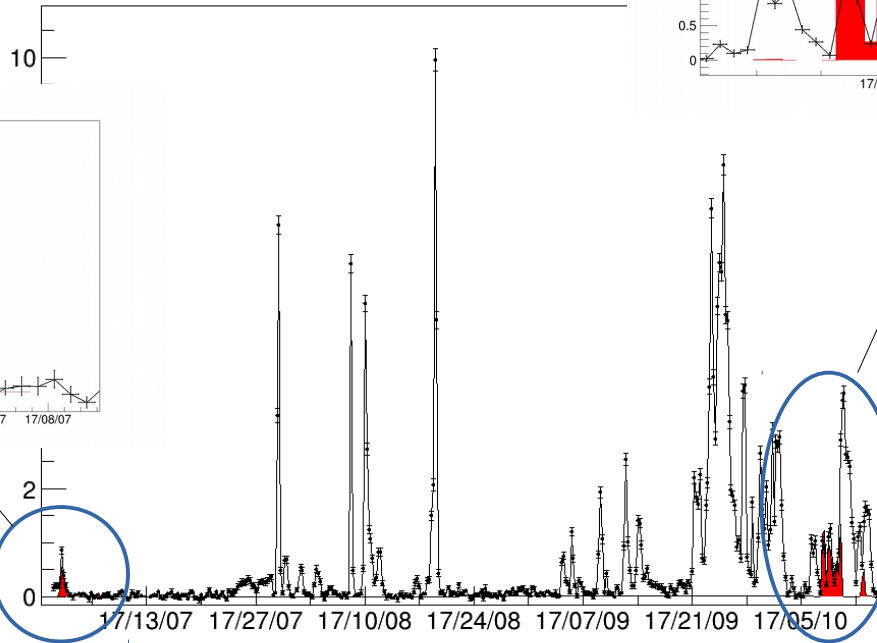
# PELLO – model data

- Weather forecast ECMWF
  - Resolution: 0.1x0.1 degrees
  - Boundaries: 45° - 65° latitudes 0 – 40° longitude
  - Forecast length 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 hours

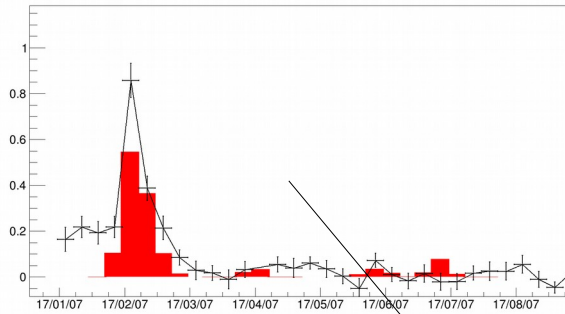


# Results June – Dec 2017

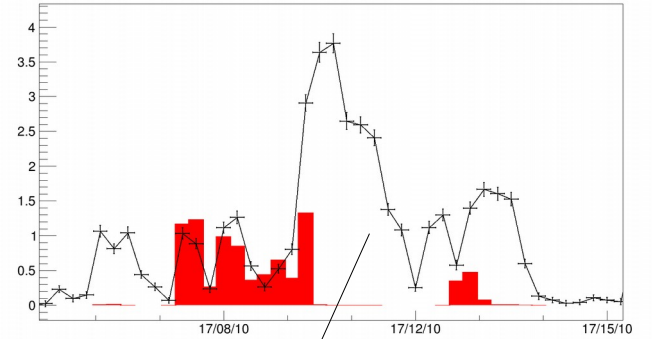
Graph



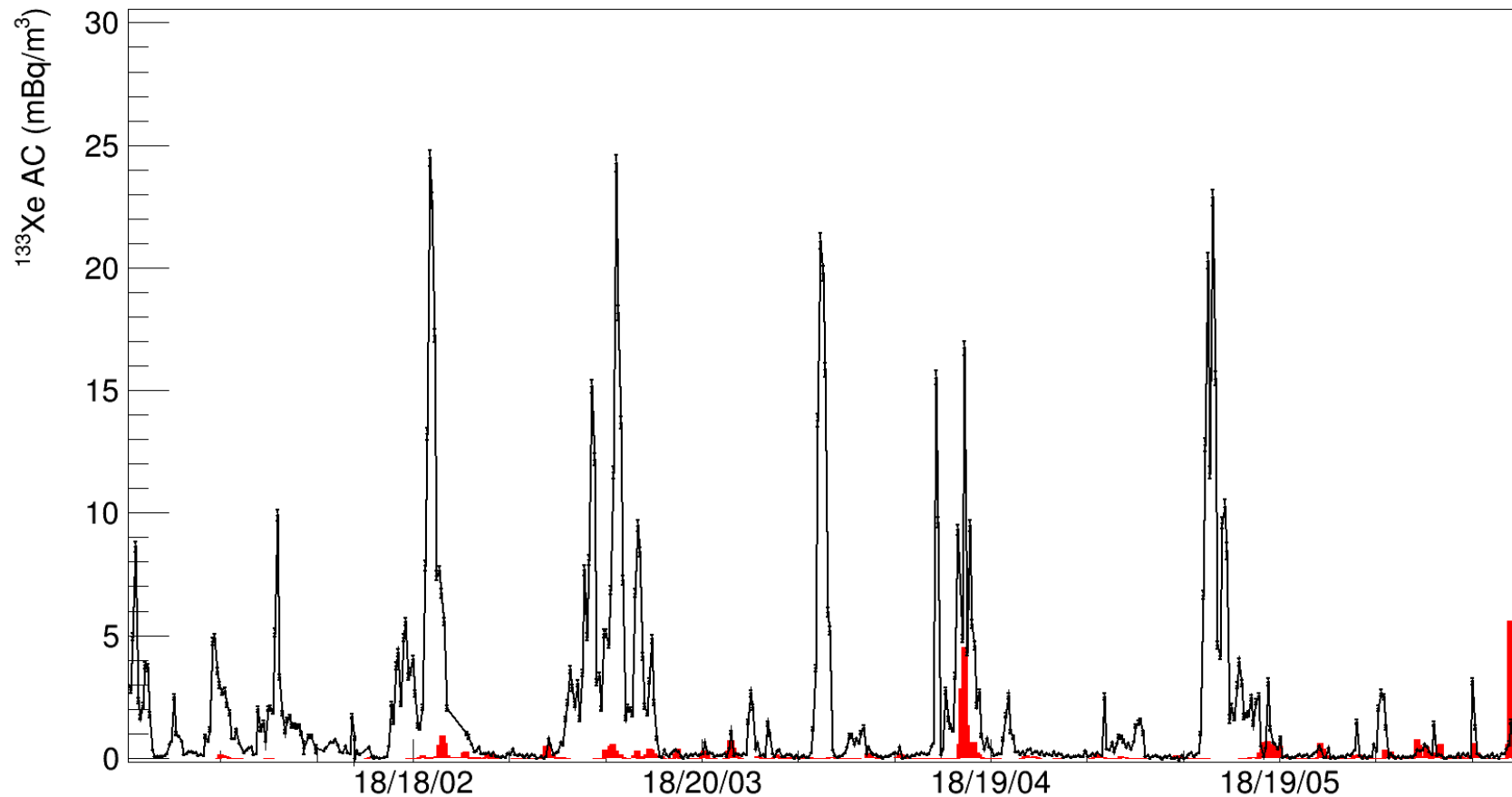
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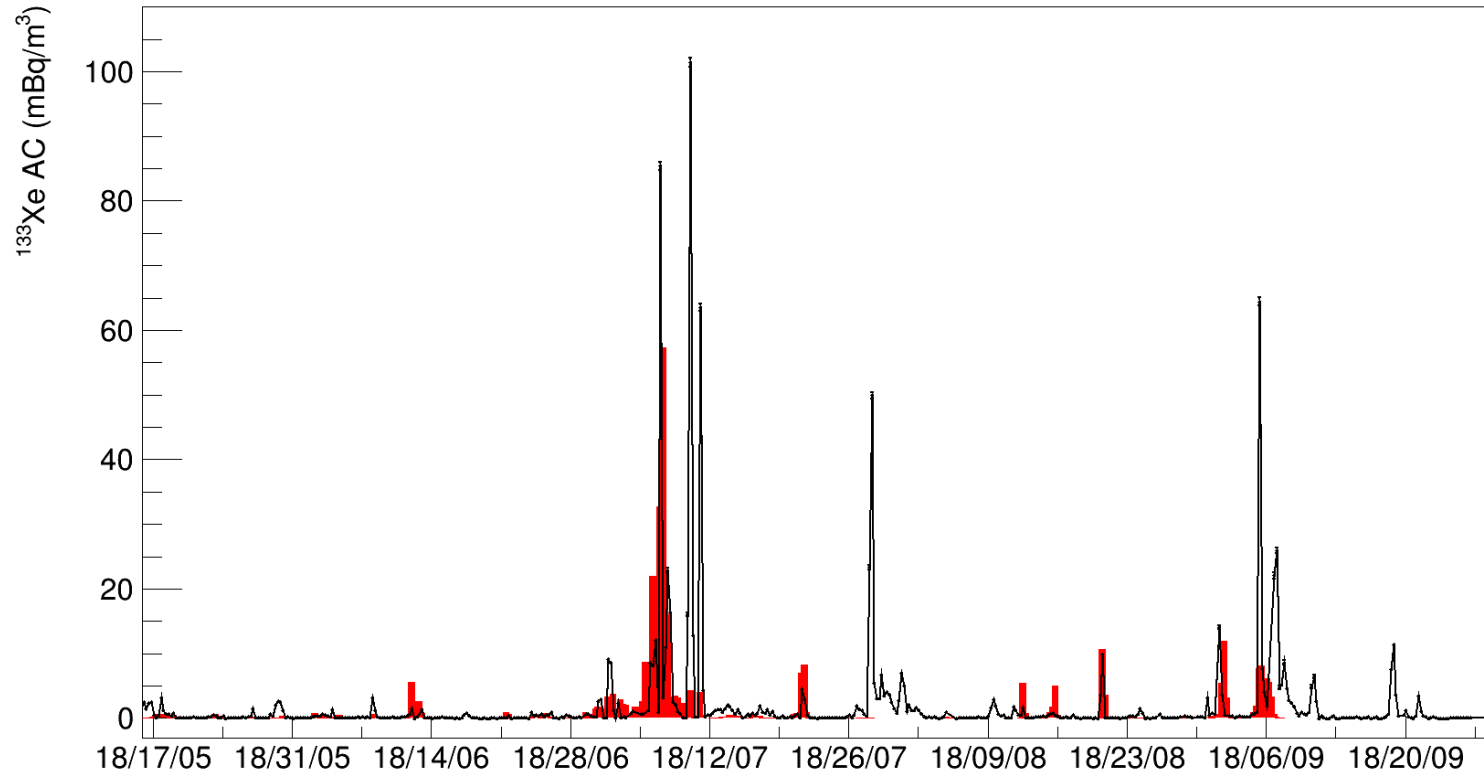
Graph



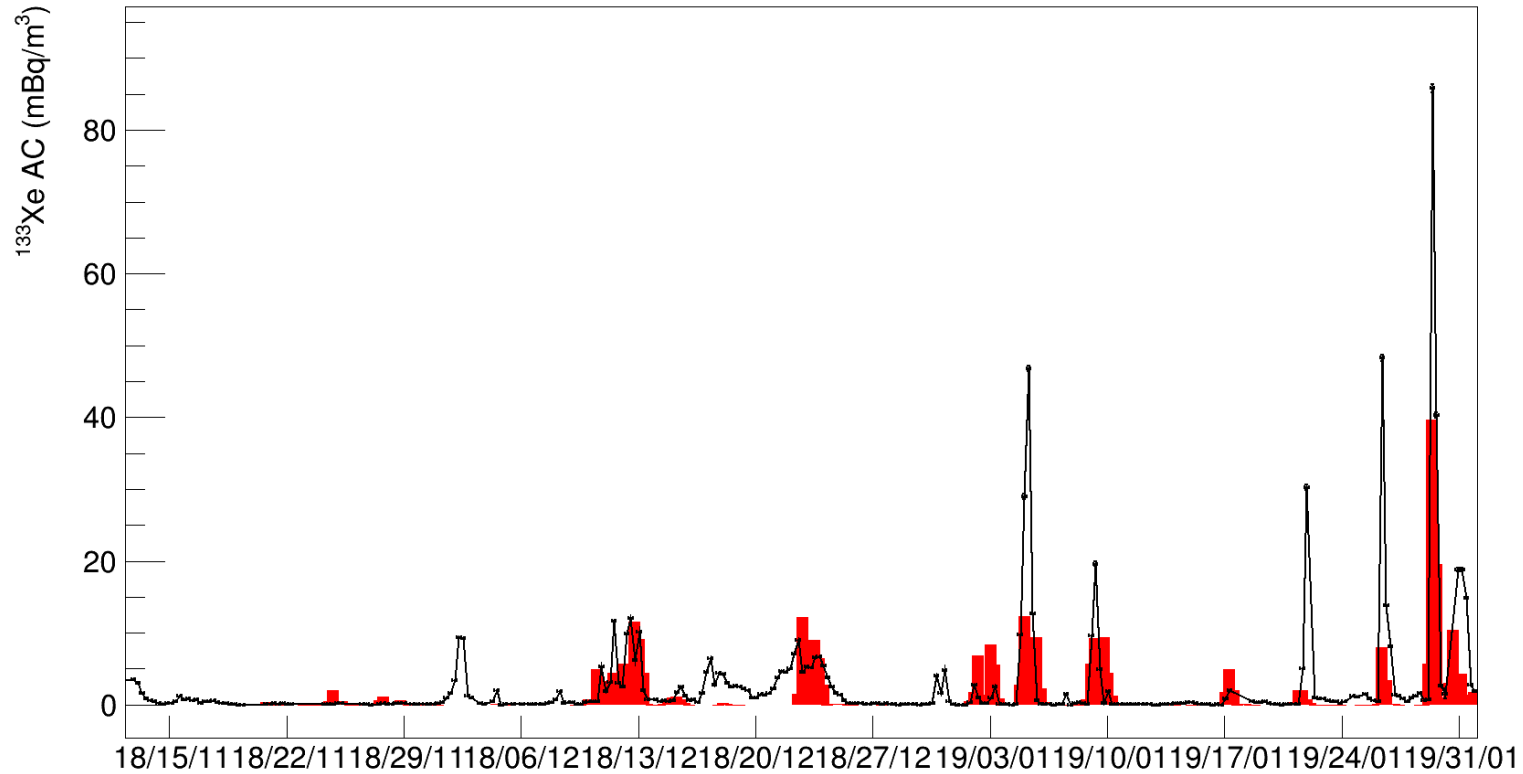
# Results Jan-June 2018



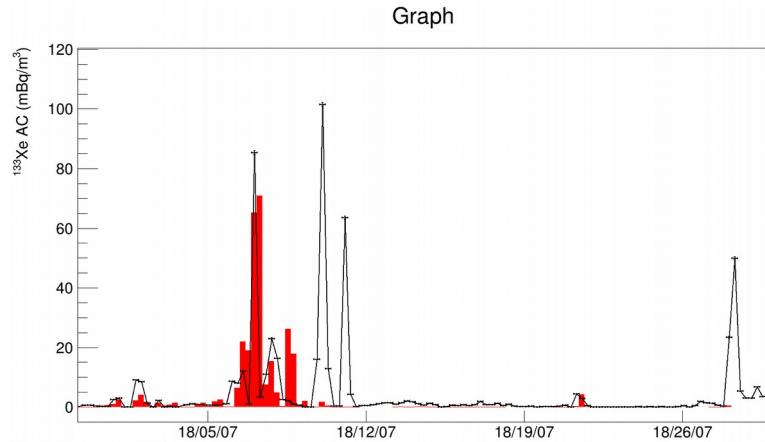
# Results Jun – Sep 2018



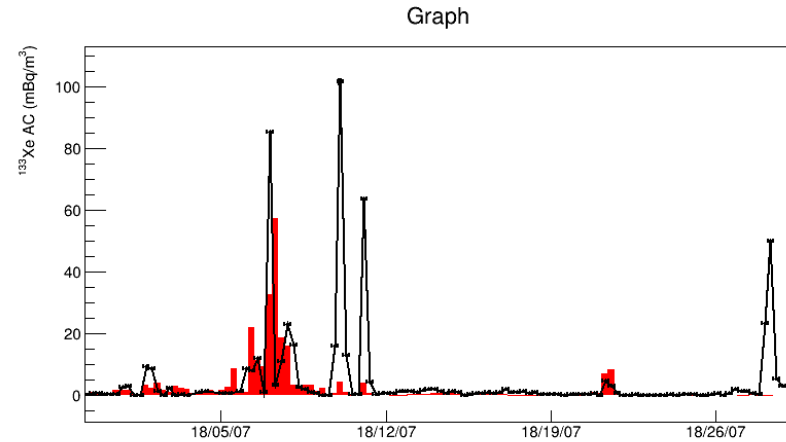
# Results Oct 2018 – Jan 2019



# Hysplit vs Pello, July 2018



Hysplit



Pello

Qualitative agreement

# 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  $^{133\text{m}},^{131\text{m}}\text{Xe}/^{133}\text{Xe}$  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.