Analysis of two years of data from the Swedish Radioxenon Array

Anders Ringbom, Mattias Aldener, Klas Elmgren, Tomas Fritioff, Peter Jansson, Sofie Liljegren, Henrik Olsson

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INTRODUCTION AND MAIN RESULTS

The Swedish Xenon Array is a first-of-its-kind measurement system, consisting of five SAUNA QB units placed around Sweden with an inter-distance around one order of magnitude smaller than the IMS. Here, we present an analysis of the first two years of data (2021-2022). Among the results, we find that the array detects twice as many $^{131m}Xe/^{133}Xe$ samples and 35% more $^{133m}Xe/^{133}Xe$ samples, compared to the IMS SAUNA III station SEX63 in Stockholm. One significant benefit of the array is that it can, in contrast to a single station, exclude potential local sources. Further, we find a clear difference in the location of potential sources depending on the isotopic composition of the plumes.

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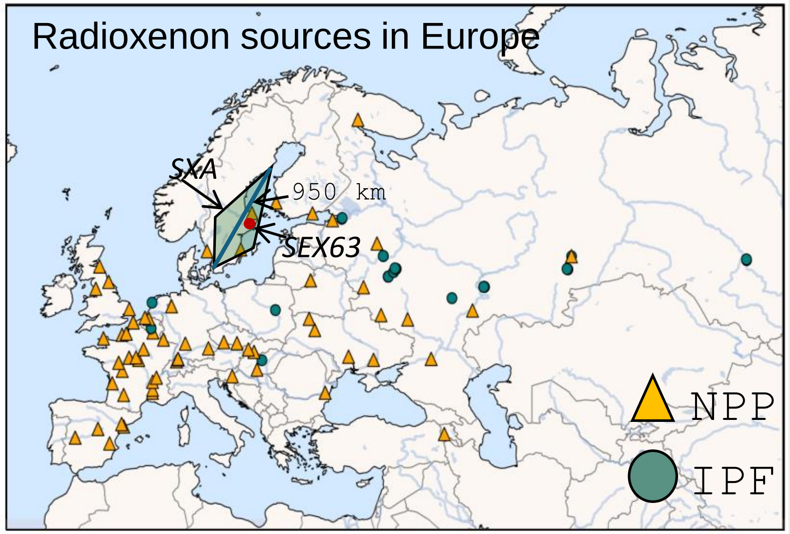
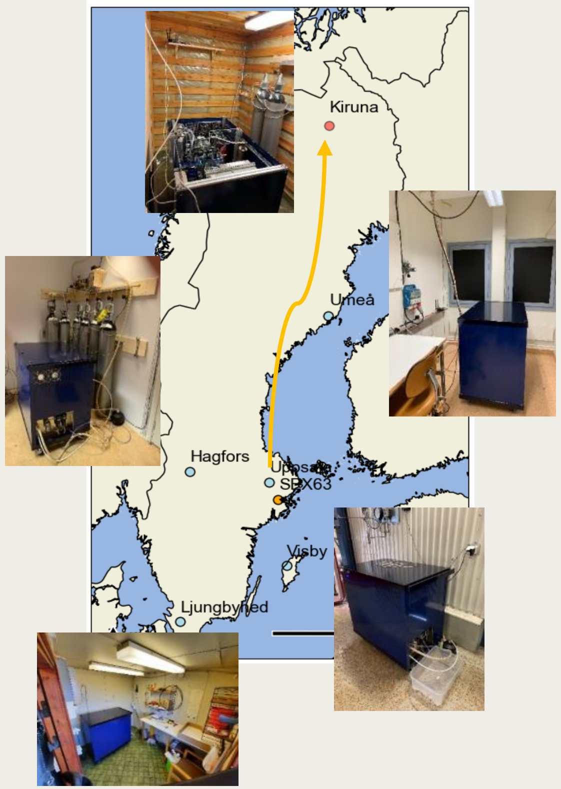
P3.6-394

Introduction – the background source problem

In radioxenon CTBT verification it is of great importance to identify and locate possible background sources associated with measured plumes. In Europe, this problem is particularly challenging due to the large number of nuclear facilities (se map below). In this work, we use an array of five radioxenon measurement units (SAUNA CUBE) to characterize the radioxenon background observed in Sweden. Some results are compared to results from the IMS station SEX63 in Stockholm, which is equipped with an ultra-sensitive SAUNA III – system, with higher time resolution (6 h vs. 12 h) and lower minimum detectable concentration compared to the SAUNA CUBE.

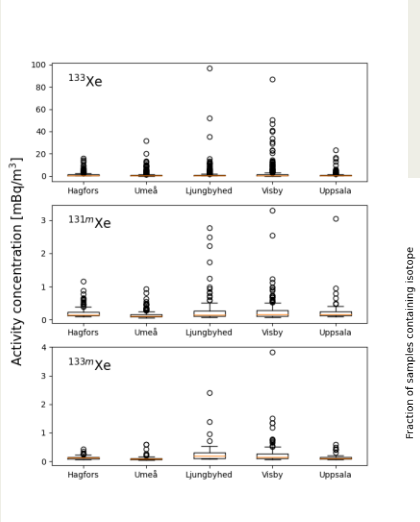


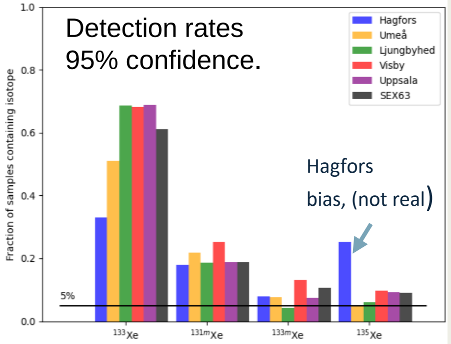
The Swedish radioxenon array



The Swedish radioxenon array (SXA) [1] is the first of its kind, consisting of five SAUNA CUBE units, each with a measurement sensitivity comparable to the SAUNA II systems used in IMS, but considerable lower cost. The size of the array is abut 950 x 450 km (see map to the left). Later, one unit was moved to the north of Sweden. The IMS station SEX63 is located in Stockholm (red dot).

The data set





The data set, collected between May 2021 and February 2023, contains 4299 array samples and 2461 SAUNA II samples. The upper left figure shows box-whisker plots of three of the CTBT-relevant isotopes ^{133}Xe, ^{133m}Xe, and ^{131m}Xe for all array units. The short-lived ^{135}Xe (9 h) was not clearly detected in this data set. Data show a general trend towards higher values in south and south-east of Sweden. This is further illustrated in the right figure, where detection rates are shown. Here, also the IMS SAUNA III in Stockholm is included. Data contained many ^{131m}Xe- and ^{133m}Xe plumes.

[1] https://doi.org/10.1016/j.jenvrad.2023.107136

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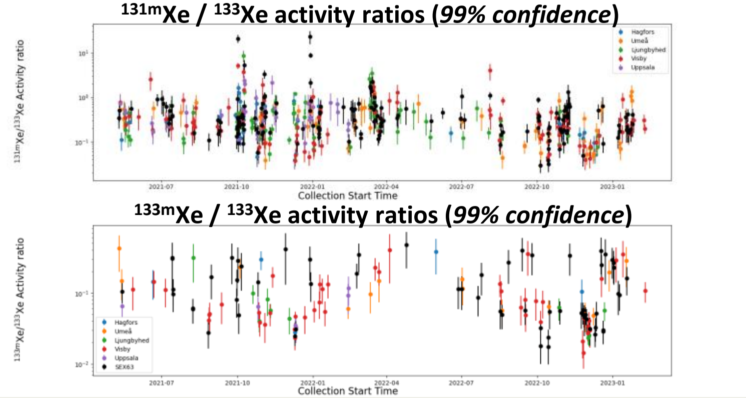
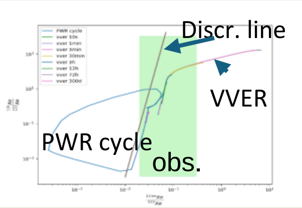
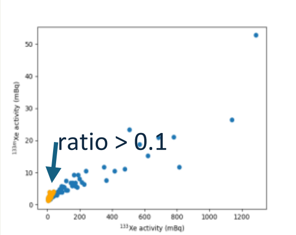
Observed isotopic ratios

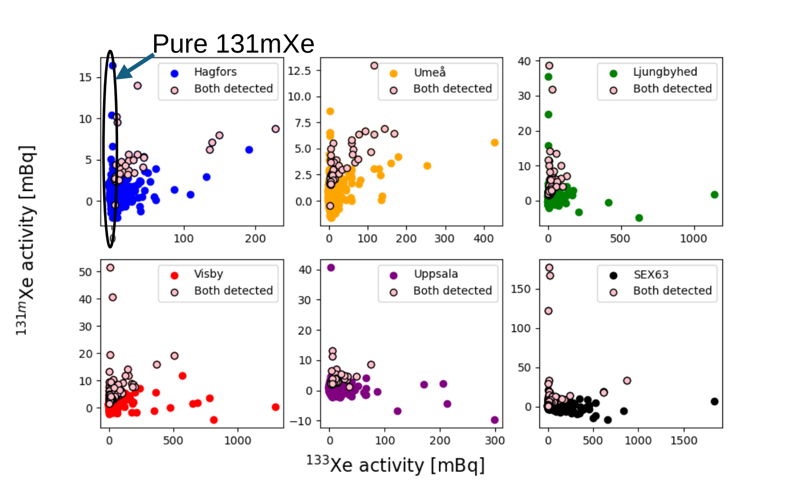


The two figures above show observed isotopic ratios. About 7% of all samples contained detectable quantities of $^{131m}Xe/^{133}Xe$, with values between 0.02 and 25. The array detects twice as many $^{131m}Xe/^{133}Xe$ samples compared to SEX63. About 2% of the samples contained $^{133m}Xe/^{133}Xe$, between 0.02 and 0.3. A larger fraction of the latter ratios was observed in the south and south-east of Sweden. The fractions varied between 0.7 and 5% in the array. The largest $^{133m}Xe/^{133}Xe$ ratios were all associated with large errors and low activities (see lower right figure). The range of observed $^{133m}Xe/^{133}Xe$ is illustrated in green in the multi-isotope plot.

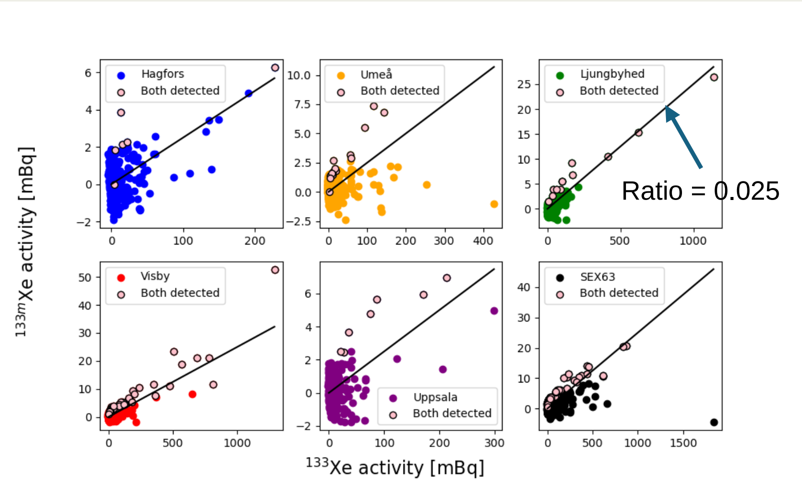




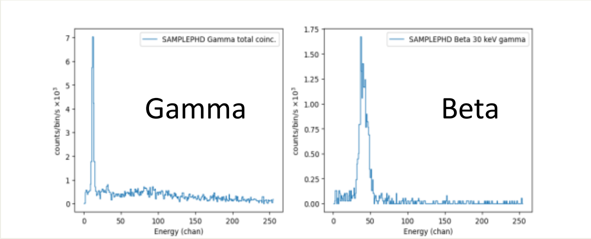
Correlation analysis



To gain further confidence in the observed isotopic ratios, *i.e.*, to investigate any systematic effects in the analysis, correlations between different isotopes were studied. Since both metastable isotopes have ^{133}Xe as background in the measured spectrum, a systematic error in the background subtraction factor could result in a bias in the metastable activities. The figure above shows ^{133}Xe vs. ^{131m}Xe activities for both the array and the IMS station SEX63. No significant bias was observed, except for maybe in the Uppsala unit, showing a tendency towards negative ^{131m}Xe activities with increasing ^{133}Xe levels (a 1% effect). Several pure ^{131m}Xe samples were measured (see example spectra to the right).



A corresponding plot for ^{133}Xe vs. ^{133m}Xe is shown above. Also here, no significant bias could be observed with increasing ^{133}Xe activities. The strongest samples all have a ratio of about 0.02, for both the array and the IMS SAUNA III. This serves as an independent check that the SAUNA CUBE units measure the same ratios as the certified IMS station.



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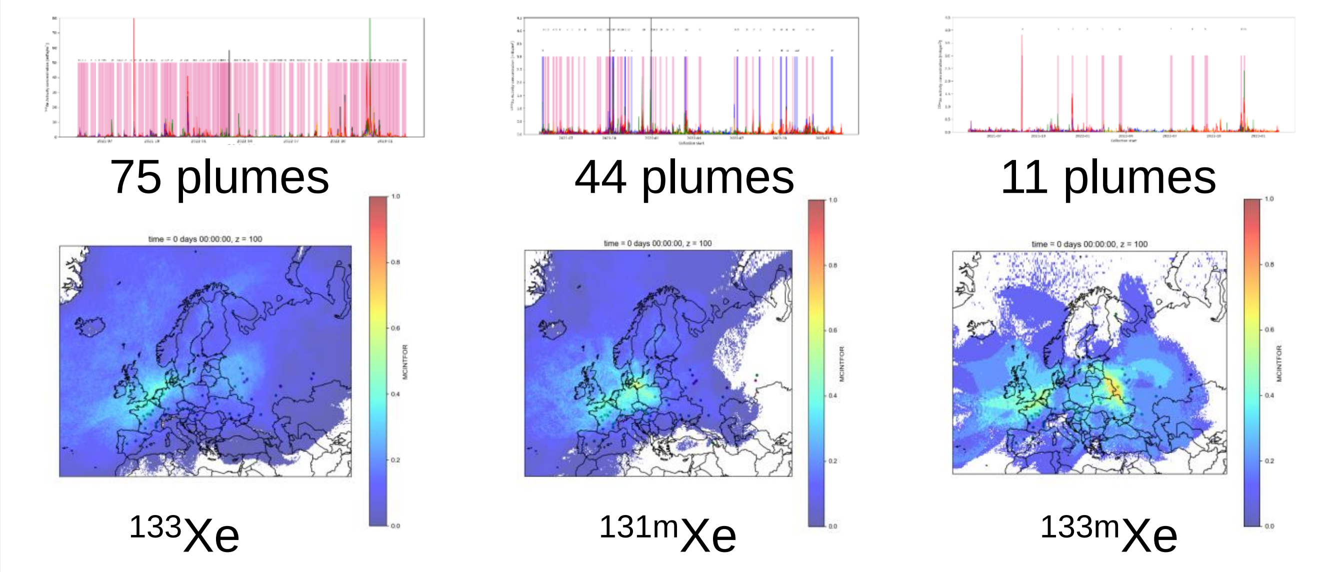
Location analysis



The array data set contained a large number of plumes with one or several isotopes. An automatic plume association method was used (see P3.6-559 at this conference) in order to achieve a consistent and coherent analysis. The method identified for example 75 ^{133}Xe plumes in the array, on the average consisting of 19 samples. The IMS SAUNA III observed 64 ^{133}Xe plumes with 14 samples/plume on the average. To study the most common source locations, atmospheric transport modelling was used in an aggregated analysis. Possible source regions (PSRs) were calculated for all plumes three days back in time.

Logical fields=1 in grid points where the time integrated PSRs had a correlation > 0.5 were made for all plumes, added together, and the result normalized to one. The array results for each observed isotope are shown above. The main source locations are clearly different for the three isotopes. The isotope production facility in Fleurus, Belgium, are indicated as a source for all three isotopes. Another ^{133}Xe source are likely isotope production in Russia, while ^{131m}Xe mainly originates from isotope production in Poland. The main source(s) of ^{133m}Xe seems to be located south of the ^{133}Xe sources, likely being nuclear reactors in the region.

Conclusions

The Swedish radioxenon array is the first of its kind, and has been operating since May 2021. The array produces a wealth of radioxenon data for inter-system distances an order of magnitude smaller than in IMS. Here we present analysis of a two-year data set containing 4299 array samples, and 2461 samples measured by the IMS station SEX63, collected during the same time period. The detection rates varies depending on the location in Sweden, with the highest values measured in south and south-east. This is consistent with the shorter distance to the main release sources. At the 99% confidence level, the array measured twice as many ^{131m}Xe/^{133}Xe samples compared to SEX63, and 35% more ^{133m}Xe/^{133}Xe samples. The ratio uncertainties are comparable between the two systems. Several pure ^{131m}Xe samples were also measured. Data was investigated with respect to any bias due to systematic uncertainties in the ^{133}Xe background subtraction done in the spectrum analysis. No significant bias was found, gaining further confidence in observed metastable activity concentrations.

Using a new automatic sample association method, a large number of plumes were identified. An aggregated location analysis were performed, using isotope-specific plumes. This analysis show different main source locations depending on radioxenon isotope.

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