Tuning alarm levels for Xenon isotope detection

Peter Kimstrand, Peter Jansson, Mattias Aldener, Henrik Olsson, Sofie Liljegren and Anders Ringbom

FOI, Swedish Defence Research Agency

INTRODUCTION AND MAIN RESULTS

In this work we utilize MIRC activity ratios and activity concentration thresholds to set automatic alarms on radioxenon detections in the IMS network. Three alarm priorities are used: Low, Medium and High. The alarm criteria are evaluated on historical data from four stations in combination with simulated nuclear explosion events using the in-house NEMOS framework.

Alarms are raised for 72.4 +/- 7.3% of the simulated events.

The main cause for not raising an alarm is that both the activity concentration is below threshold as well as the combination of detected isotopes not being MIRC compatible.

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Introduction

Radioxenon detection is one of the key methods used in the IMS for detecting a nuclear explosion event. However, since there are numerous civilian sources of radioxenon, such as isotope production facilities and nuclear power plants, any detection of radioxenon must be carefully analyzed in order to determine if the source could potentially be a nuclear explosion.
We present alarm critera to apply to radioxenon detections in order to raise an alarm if an event warrants a closer inspection.

Methods

In this work we utilize published discrimination methods based on the isotopic activity ratios of the four relevant isotopes (^{131m}Xe, ^{133}Xe, ^{133m}Xe and ^{135}Xe) in combination with historical IMS data and simulated nuclear explosion events to evaluate alarm levels for radioxenon detections. The in-house software framework NEMOS (Nuclear Event Monitoring Simulator) [1] is used to simulate the full chain of nuclear explosion events, from explosion, via atmospheric transport, to detection.

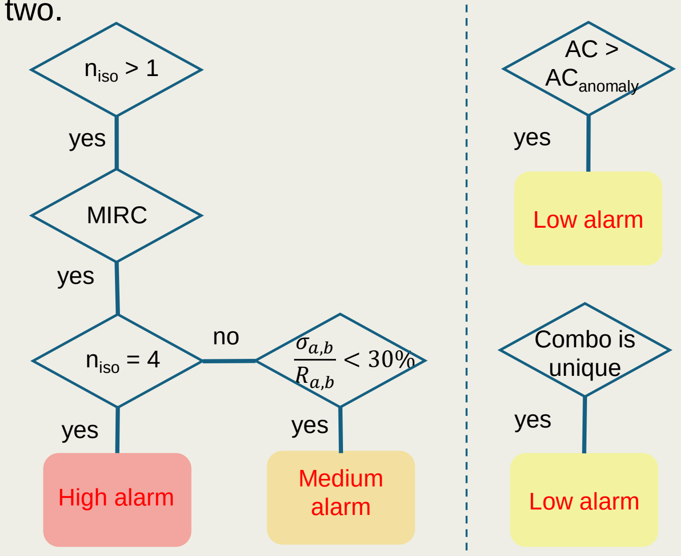
Alarm criteria

The alarm criteria are setup on two separate paths, the first path evaluates the MIRC activity ratios according to Kalinowski et al [2].

The second path compares the current detection versus the detection history for the current station over the past year and raises an alarm if the current detection is above the IMS anomaly threshold, or if the current combination of isotopes has not been detected in the past year. The anomaly threshold is defined as

$$AC_{anomaly}(t_0) = \text{median}\big(AC(t)\big) + 3 * \text{IQR}\big(AC(t)\big),$$
$$t \in [t_0 - 365\ \text{d}, t_0]$$

Three alarm priorities are used, plus the possibility of no alarm being raised, see fig 1. The combined alarm for the two paths reports the highest alarm priority out of the two.



n_{iso} = *number of detected isotopes*
a,b = ^{133m}Xe, ^{133}Xe OR ^{135}Xe,^{133}Xe

Fig 1. Alarm evaluation scheme.

Station	# low alarms	# medium alarms	# high alarms
SWEIX	30	0	0
SWESX	26	0	0
SEX63	89	1	0
NOX49	51	0	0

Table 1. Number of alarms raised when pure measurements were evaluated for the chosen period.

Simulation setup

The nuclear events are simulated as follows, a 1 kT atmospheric nuclear explosion was placed on Swedish territory, two per day at random start times and location, over a period of one year. For details see source scenario A of [1]. In this work we reuse simulated responses for one SAUNA III and one SAUNA Qb.

Alarm evaluation

Simulated detections for each event are added at a randomly chosen point in time to existing historical data (2024-01-01 – 2024-12-31) from two SAUNA III systems (SEX63 and NOX49), and two SAUNA Qb systems (placed in Hagfors (SWESX) and Visby (SWEIX), Sweden).

The summed activity and activity concentration, for each detection of the plume resulting from each event are evaluated according to the described alarm criteria.

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Results

In total, the mean and standard deviation of the detection rate (alarm priority = Low, Medium or High) over the four stations was 72.4 +/- 7.3%. An example with two events, were one is undetected by the alarm criteria and one raises a high priority alarm is shown in figure 3.

The distribution of alarms raised for each priority per station is shown in figure 2.

All detections for events that raised no alarms were below the anomaly threshold as well as not unique in the isotope combination. A breakdown of causes for no alarm from the MIRC criteria is shown in table 2.

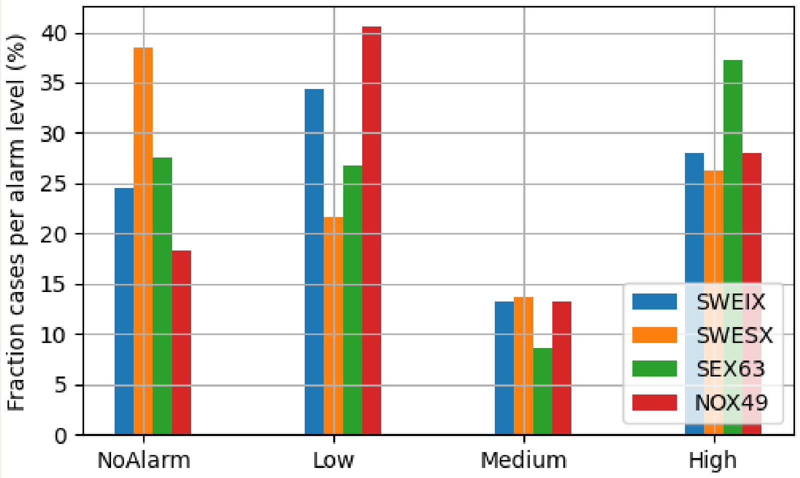

Fig 2. Number of raised alarms per priority and station.

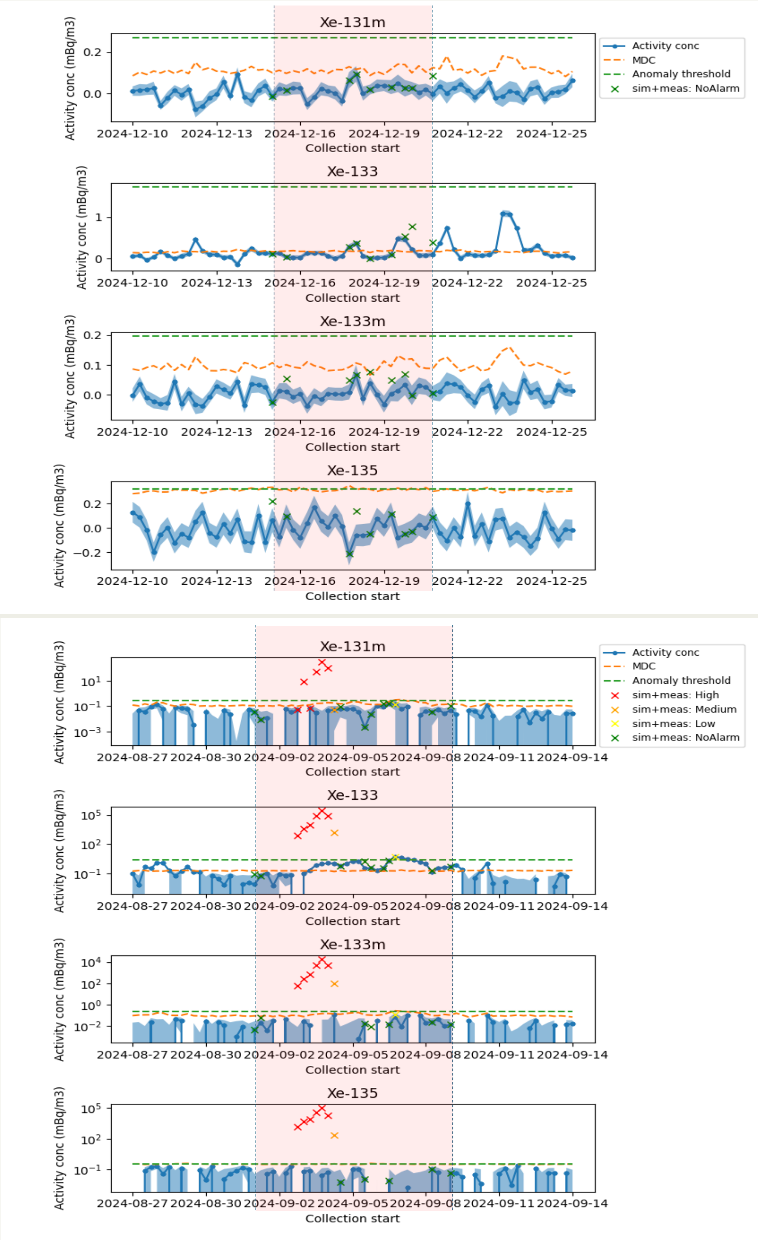

Fig 3. Example of the detections of two simulated events, on the top no alarms were raised, while on the bottom a high priority alarm was raised. The extent of the plume is marked shaded red area.

Station	MIRC N/A (%)	Not MIRC consistent (%)	Rel. uncertainty > 30% (%)	Station failure (%)
SWEIX	73.0	15.2	7.6	4.3
SWESX	70.9	11.6	8.6	9.0
SEX63	75.9	14.4	6.7	3.1
NOX49	84.2	11.4	3.1	1.3

Table 2. Breakdown of causes for no alarm being raised.

Discussion

The results show a fairly good detection rate, however approximately every fourth event is undetected. It is unlikely that alarm criteria such as the ones presented here can be tuned to also detect these without an excess of false alarms. Detection capability has to be improved by either a denser grid of stations or a different type of anomaly detection algorithm.

Related contributions @ SnT

P3.4-517 NEMOS – a software framework to simulate the response from nuclear explosion detection networks

References

P. Jansson et al 2024 Modelling the response of systems for detection of nuclear explosions and other nuclear events, FOI-R--5626—SE

M. Kalinowski et al 2010 Discrimination of Nuclear Explosions against Civilian Sources Based on Atmospheric Xenon Isotopic Activity Ratios Pure and Applied Geophysics 167(4):517-539

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