A novel approach to assess the verification capability of the IMS noble gas network

How good is the network – really?

Anders Ringbom, Anders Axelsson, Matthias Aldener, Tomas Fritioff, Anders Mörtsell
Swedish Defence Research Agency (FOI)
Outline

• Motivation
• Basic concepts – global network figure-of-merits
• Main results from earlier studies
• New results: Quantifying the impact from the radioxenon background
• Conclusions and outlook
Purpose and method

- Studies of global properties has so far focused on detection capabilities (coverage maps) using a simplified scenario ($^{133}$Xe only).
- This gives little information on the actual ability to say whether there was a NE or not.
- When designing new systems, or when studying the current one, the global network verification capability should be investigated.
- Method: Investigate the result from an automated verification process.
- In addition: Verification analysis techniques evaluated in the process.
Data sets \( \{C\}_i \) of "measured" data is obtained by a given network configuration \( C \) for a set of \( N \) explosions \( i=1, \ldots, N \).
Approach

\{C\}_1 \ldots \{C\}_n 

Detection
- Statistical analysis
- Background analysis
- Is it an anomaly?

Categorization
- Nuclear analysis
- Hypothesis testing
- Timing

Location
- PSR
- Cost function

Other information (seismic time, ...)

Decision 1
- Yes/
- No/
- Don’t know

Decision 2

Decision 3

n iterations
Detection power (D)

The fraction of explosions for which \( C_i \) results in at least one sample exposed to a mean activity concentration > MDC for any of the four relevant xenon isotopes.

Pu-239 explosion, 1kt, 100%

<table>
<thead>
<tr>
<th>Iso</th>
<th>A(Bq) 1h</th>
<th>A(Bq) 24h</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{133}\text{Xe} )</td>
<td>5.1x10^{14}</td>
<td>1.1x10^{16}</td>
</tr>
<tr>
<td>(^{133}\text{mXe} )</td>
<td>2.8x10^{14}</td>
<td>8.8x10^{14}</td>
</tr>
<tr>
<td>(^{131}\text{mXe} )</td>
<td>6.2x10^{10}</td>
<td>2.9x10^{12}</td>
</tr>
<tr>
<td>(^{135}\text{Xe} )</td>
<td>5.8x10^{16}</td>
<td>6.2x10^{16}</td>
</tr>
</tbody>
</table>

Current systems (12 h coll time)

- 40 stations: Xe-133 55%, Xe-135 25%
- 79 stations: Xe-133 75%, Xe-135 45%

“The Impact of System Characteristics on Noble Gas network verification Capability”

FOI-R-3856—SE, March 2014
Location power (L)

The fraction of explosions for which \( C_i \) results in a location error less than 25%.

Current systems
40 stations: 25%
79 stations: 40%
Rejection (R) and timing (T) power

**Rejection Power (R):** The fraction of explosions for which \( \{C\}_i \) allows a given false scenario to be rejected based on isotopic ratios.

**Timing Power (T):** The fraction of explosions for which \( \{C\}_i \) allows a fission time estimate, based on \(^{135}\text{Xe}/^{133}\text{Xe}\) ratios and correct scenario, better than 6 hours.

Current systems

- 40 stations: R = 40%, T = 20%
- 79 stations: R = 60%, T = 40%
Global Network Parameter Definitions

Network Verification Power (NVP):

\[ NVP = \frac{(D + L + R + T)}{4} \]

The verification capability of a network configuration described with a single figure of merit. Maximum possible NVP is 100%.

Current systems: 40 stations: 33% 79 stations: 53%
The radioxenon background

- By now, almost 100,000 radioxenon samples collected in IMS
- An analysis of 81,540 samples performed (see poster*).
- Main background source type: Isotope production facilities (IPF)

**Low background station: GBX68 (~5 year)**

Mean AC Xe-133: 0.03 mBq/m$^3$

**High background station: SEX63 (~5 year)**

Mean AC Xe-133: 1.2 mBq/m$^3$
Analysis of rejection power using measured background

For each simulated explosion IMS signal $\{C_i\}$:

- Assign a background data set to each IMS station
- Add measured background starting at time $T_b$
- $T_b$ is selected randomly inside the background time interval
- Perform hypothesis testing vs a selected scenario
- Perform the ”measurement” and hypothesis testing $n$ times
- Calculate the rejection power
Adding calculated signal and measured background

A background $C_1$ is measured with an uncertainty $\sigma^2_{C_1}$

$$\sigma^2_{C_1} = \frac{(n_1+n_0)}{S^2} \quad LC = \frac{k}{S} \sqrt{n_0} \quad MDC = \frac{1}{S} (k^2 + 2k \sqrt{n_0})$$

$S$ is the Analysis Power in \textit{counts/mBq/m}^3  \quad S = \frac{k^2}{MDC - 2LC}$

Add a second signal $C_2 = n_2/S$

$$\sigma^2_{C_1+C_2} = \frac{n_1+n_2+n_0}{S^2} = \sigma^2_{C_1} + \frac{C_2}{S}$$
Calculation of Rejection Power (R)

Degree of deviation from a scenario for N measurements is

\[
\Delta = \frac{1}{N} \sum_{i=0}^{N-1} \frac{d_i^2}{\sigma_i^2}
\]

Reject scenario if

\[\Delta > a; P\left(\chi^2_{\nu}/\nu > a\right) = 0.01; \nu = N\]

i.e. there is a 1% risk of rejecting a true scenario.

Perform n “measurements” for each explosion and calculate R as the fraction of rejected explosions.
Example: Explosion 55; 1 kt; 100%

“True” IMS Signal

MIRC3

Low background (GBX68)

400 iterations

High background (SEX63)

239Pu, 1h containment
Results Detection Power (D) (signal > MDC for at least one sample)

40 station network (SAUNA II), 144 explosions, Pu-239, 1h containment, 1 week forward ATM

D not directly connected to background other than through MDC
Results Rejection Power for the *true scenario*, relative to detectable explosions.

**Excl 55 (400 it):**

- **True scenario:** 0% GBX68
- **10%** SEX63
- **14%** USX75
Results Rejection Power for a *false scenario*, relative to detectable explosions

Not comparable to earlier number (40%). Different test performed.
Conclusions

- Definitions of global network figure-of merits (FoM) for the IMS NG network are suggested.

- A study using 144 virtual NE has been conducted in order to calculate the FoM and to estimate the network verification capability.

- The method has been further developed to include the observed background using measured data. First results presented.

- Example of results:
  - Definition of rejection power has to be modified if background included.
  - The existing background would cause a false rejection of a release corresponding to 0.1 kT in 11% of the detectable cases if all IMS NG sites were exposed to the same background as in Stockholm (high background station). Only isotopic ratios used in decision.
  - The corresponding number using a low-background station is below 1%.