Latest Development on MARDS – an Argon-37 Detection System

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Outline

- Application background
- History
- Primary objectives of improvement
- Current status of the MARDS system
- Field deployment in the IFE14
- Some thoughts of the future work
Application background

• $^{37}$Ar is a definitive and unambiguous indicator of an underground nuclear explosion (UNE).
  
  – $^{37}$Ar is produced underground by neutron activation of Calcium by the reaction $^{40}$Ca(n,$\alpha$)$^{37}$Ar.
  
  – long half-life of 35 days
  
  – low natural activities in subsoil gas of 1-100 mBq/m$^3$.(Robin A. Riedmann and Roland Purschert, 2011)
History

• To support technology for the On-site Inspection, the INPC proposed the $^{37}$Ar detection project, in the early 1990’s.

• $^{37}$Ar signature was verified during the last Chinese UNEs. Subsoil gas sample in two months after the explosion showed that the activity was in the order of $10^2$-$10^7$ Bq/m$^3$.
History

Prototype system, 1999

MARDS-I, 2003

MARDS-IA, 2007

MARDS-II, 2013
Primary objectives of improvement

• To decrease the Minimum Detection Concentration (MDC) for $^{37}$Ar

• To enhance suitability for the field deployment
Minimum Detection Concentration (MDC) for $^{37}$Ar

$$MDC = \frac{4.66 \times \sqrt{n_b} \times t}{V \times \eta \times \varepsilon \times I \times t}$$

- MDC – Minimum detection concentration for $^{37}$Ar in Bq/m³;
- $n_b$ – Background count rate in cps;
- $t$ – counting time in s;
- $V$ – Sampling Volume in m³;
- $\eta$ – Argon yield;
- $\varepsilon$ – counting efficiency ($\sim 0.9$);
- $I$ – Branch ratio ($\sim 0.9$).

- Decrease the background count rate
- Increase the sampling volume
- Prolong the counting time
Minimum Detection Concentration (MDC) for $^{37}$Ar

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- Sampling volume:
  - Ar: 0.934%
  - Constrained by the volume of proportional counter
  - No space to increase the sample volume dramatically
  - 200 L $\rightarrow$ 400 L
  - Yield: 50%
  - $\sim$ 2 L purified Argon

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Minimum Detection Concentration (MDC) for $^{37}$Ar

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- **Background count rate**
  - External gamma rays
  - Counter material
  - $^{39}$Ar

<table>
<thead>
<tr>
<th></th>
<th>Naked counter</th>
<th>Shield + anticoincidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total count rate / cps</td>
<td>8</td>
<td>0.4</td>
</tr>
<tr>
<td>Count rate in ROI /cps</td>
<td>0.6</td>
<td>0.03</td>
</tr>
</tbody>
</table>

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Minimum Detection Concentration (MDC) for $^{37}$Ar

\[ \text{MDC} = \frac{4.66 \times \sqrt{n_b \times t}}{V \times \eta \times \varepsilon \times l \times t} \]

- **MDC** – Minimum detection concentration for $^{37}$Ar in Bq/m$^3$;
- $n_b$ – Background count rate in cps;
- $t$ – counting time in s;
- $V$ – Sampling Volume in m$^3$;
- $\eta$ – Argon yield;
- $\varepsilon$ – counting efficiency ($\sim 0.9$);
- $l$ – Branch ratio ($\sim 0.9$).

**Counting time**
- Sampling volume: 400 L
- Argon yield: 50%
- Background count rate: 0.03 s$^{-1}$
Suitability for the field deployment

• Followed the operation concept of the OSI, optimize the system design
  – Vehicle mounted → operation in BoO
  – Integrated → modularized
Suitability for the field deployment

- Throughput
  - Temperature swing adsorption (TSA)
  - Pressure swing adsorption (PSA)
  - Decrease the regeneration time from 8 hours to 2 hours
  - Continuous operation by 2 traps alternate use
  - 1 sample per 2 hours
  - 4 samples per 8 hours
Suitability for the field deployment

• Logistic requirements
  – Pressure swing adsorption (PSA)
  – No coolant and heater needed during the sample process
  – Lower power consumption
Main specifications of MARDS system

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Prototype system</th>
<th>MARDS-I</th>
<th>MARDS-IA</th>
<th>MARDS-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development year</td>
<td>1999</td>
<td>2003</td>
<td>2007</td>
<td>2013</td>
</tr>
<tr>
<td>Sampling volume</td>
<td>200 L</td>
<td>200 L</td>
<td>200 L</td>
<td>400 L</td>
</tr>
<tr>
<td>Argon yield</td>
<td>40%</td>
<td>70%</td>
<td>70%</td>
<td>50%</td>
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<tr>
<td>Sample process time</td>
<td>3.5 h</td>
<td>2.5 h</td>
<td>3 h</td>
<td>2 h</td>
</tr>
<tr>
<td>Regeneration time</td>
<td>8 h</td>
<td>8 h</td>
<td>8 h</td>
<td>2 h</td>
</tr>
<tr>
<td>Background count rate</td>
<td>4 s⁻¹</td>
<td>0.2 s⁻¹</td>
<td>0.03 s⁻¹</td>
<td>0.03 s⁻¹</td>
</tr>
<tr>
<td>MDC for Ar-37 (10 hours counting time)</td>
<td>800 mBq/m³</td>
<td>100 mBq/m³</td>
<td>38 mBq/m³</td>
<td>26 Bq/m³</td>
</tr>
<tr>
<td>Coolant</td>
<td>Liquid nitrogen</td>
<td>Liquid nitrogen</td>
<td>Liquid nitrogen</td>
<td>None</td>
</tr>
<tr>
<td>Operation mode</td>
<td>Manual</td>
<td>Semi-automatic</td>
<td>Automatic</td>
<td>Automatic</td>
</tr>
</tbody>
</table>

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Basic principle of Argon separation

- H₂O, CO₂
- Separation of Ar from remain N₂

Diagram:
- Sampling Pump
- Flow Meter
- Air dryer unit
- Subsoil gas or atmosphere
- Nitrogen Separation Unit
- Deoxidation Unit
- Argon Separation Unit
- Argon Collection Unit
- Vacuum Pump
- Counter

Most of N₂
Most of O₂
Layout of the Argon process units
Field exercises

- IFE08, MARDS-IA
- NG09, MARDS-IA
- IFE14, MARDS-II
IFE08, MARDS-IA
NG09, MARDS-IA
IFE14, MARDS-II
• 10 samples
  – 2 BoO air samples
  – 3 SAUNA exhaust gas samples
  – 5 subsoil gas samples from the field
• $^{37}$Ar: $\sim$350 mBq/m$^3$
• Spike sample
Some thoughts of the future work

• System performance
  – From the laboratory instrument to the inspection equipment
  • Reliability
  • Maintainability
  – Fully operated by the trained surrogate inspector
Some thoughts of the future work

- Background concentration of $^{37}$Ar in subsoil gas
- Measurement and estimation, Roland Purschert, University of Bern
  - Measured natural $^{37}$Ar activities in soil air range over 2 orders of magnitude between $<3.1$ to $120$ mBq/m$^3$.
  - In high altitude soils, with large amounts of Calcium and with low gas permeability, $^{37}$Ar activities may reach values up to $1$ Bq/m$^3$.
  - 3 orders, $1$ mBq/m$^3$ to $1$ Bq/m$^3$.
- Investigation to understand the background concentration of $^{37}$Ar, compared with the understanding of the background of radioxenon.
• Thank J. S. Elisabeth WIESLANDER and Kirill KHRUSTALEV for fruitful discussions and comments.
Thanks for you attention!