The CORSAIR Project. Characterization of a portable instrument for NORM characterization of stone blocks

The CORSAIR project

Cloud Oriented Radiation Sensor for Advanced Investigation of Rocks

TARGET:
Realization of an automated and real-time system for the detection, identification, quantification of the radioactive concentration in building materials

• 4 Partners
• 3 SME industries
• 1 University

Call for EU Funded Research and Developments Projects of Tuscany region (Italy)
Building materials regulation

  - Set the reference level to indoor external exposure to gamma radiation emitted by building materials (1 mSv/y)
  - For the identified building materials (ANNEX XIII), before they are placed on the market
    - Gamma detection measurement: $^{226}$Ra, $^{232}$Th, $^{40}$K
    - Activity Concentration Index (ACI)
    - Radiological index ($I$)
  - Information to the Competent Authorities of the results, if requested
  - Appropriate measures in case of doses exceeding the reference levels ($I > 1$)
Radioactive sources:

- **Natural**: soil, water, air and food contribute to our exposure to ionizing radiation
- **Cosmic rays**
- **Industrial**: mining, inspection or sterilization sources
- **Medicine**: nuclear medicine
- **Military**

Naturally Occurring Radioactive Materials (NORMs)

The natural gamma emitters are the so called KUT:

- $^{40}$K
- $^{238}$U
- $^{232}$Th

For building materials:

- alum-shale,
- granitoids,
- porphyries,
- tuff,
- pozzolana

https://www.who.int/ionizing_radiation/env/en/
CORSAIR

For building materials which are considered worrisome from a radiation protection point of view, several countries ask the control of the radiological activity and concentrations of the natural radionuclides to enhance the safety of the population, before placing such materials on the market.

Realization of an automatized system for a non destructive and with a real time measurement and analysis for the identification and the extraction of the radiological index of rocks and building materials

The CORSAIR goal is the traceability of the material along the production chain, increasing the competitiveness of supply chain in the reference market and opening new market segments.
The CORSAIR idea

CORSAIR introduces a fast, repeatable, real-time and non-destructive method to measure radiological emissions and store other parameters of each single building material item, uniquely identified by an applied RFID tag.

CORSAIR is designed to be managed by non-radiological experts without requiring specific skills and represents a screening tool, but it also introducing the Industry 4.0 technologies and IoT applications in the stone market thanks to its automatized measurement procedure and the integration of a cloud database.

The information acquired from CORSAIR sensors is available among all stakeholders for commercial, traceability and regulatory purposes, depending on needs.

It also reduces human errors and provides reliable and valuable information to both sellers and buyers and maintain the knowledge of the market chain from the digging/extraction till the final client.
The architecture

CORSAIR is based on a start-of-stars network topology.

- Cloud Platform with storage and processing capabilities with online web-services for machine-to-machine (M2M) communications
- GUI based on a dedicated web-application allowing multi-users & profiles accesses
- Monitoring systems organized as a sensors network
  - sensor nodes
  - data gateway
  - handheld device
The Cloud Platform

- Scalable platform with processing and storage capabilities
- Online web service for data upload and retrieval of the operations performed by each sub systems
- Web application for multi-users/profile data access

All incoming measured data are processed to calculate its radiological indexes and to compare such results with per-country ACI thresholds.

A dedicated web application provides these information upon user authentication.
Local monitoring system

A minimal structure:

- **Sensor node** a fully autonomous and real time gamma spectroscopic analysis based on CAEN GammaStream with LoRa connection sending periodic status update to the gateway;
- **Gateway** that aggregates data coming from sensor nodes with additional information;
- **Handheld device** to interact with nodes through WiFi direct connections.

**Gateway**

- LoRA WAN protocol to/from sensor
- LAN interface to/from CLOUD
- Web-based GUI:
  - Sensor nodes status monitoring
  - Retrieve and browse data
  - Integrate measurements with additional optional data

**Handheld device**

- Rugged industrial RFID reader
- WiFi and 3G/4G connectivity
- Android OS
- App used for the sensor node management and measurements
The Sensor Node

The element performing the radiological measurement and the extraction of the activity concentration levels

- Gamma spectrometer: 2”x2” CeBr$_3$
- Lead shielding of 1.25 cm 60% background reduction
- LoRA communication to gateway
- WiFi communication to handheld
- GPS antenna
- Rechargeable battery
- RFID tag identifier
- Heat dissipation
- Acquisition and analysis software
- IP67 shockproof case
Measurement procedure

**STEP I** – User login and block characteristics set up

**STEP II**
Block RFID tag scanning (Digital block identification)

**STEP III**
Sensor RFID tag scanning (Digital sensor identification)
&
Start acquisition (predefined measurement time)

**STEP IV**
Measurement monitoring

**STEP V**
Data storing & measurement report creation
A. Preliminary on-field tests on *granitoid* (M₁) stone block and sand (M₂)
   - Infinite geometry approximation
   - Window Analysis Method, IAEA 2003

B. A sample of each stone then analyzed by a HPGe spectroscopy system (MCA_RAD system)
   - Cylinder volume = 180 cc
   - 4-weeks wait for the ²²⁶Ra-²²₂Rn secular equilibrium
Results

The performance of the CORSAIR detector has been compared with the high-resolution apparatus used for laboratory radiometric analysis.

**M2(SAND)** setup was used to compare the experimental measurement to the Monte Carlo simulated semi-infinite planar environment used for the calibration. **M1(GRANITE)** to verify the calibration process. The CORSAIR equipment estimated effective dose D and ACI showing an excellent agreement with the laboratory analysis for both M1 and M2.

All the quantities measured in-situ by the prototype are compatible within 1σ with the HPGe apparatus results with the exception of M1’s measured CK.

<table>
<thead>
<tr>
<th>ID</th>
<th>Detector</th>
<th>$C_K$ [Bq kg$^{-1}$]</th>
<th>$C_{eU}$ [Bq kg$^{-1}$]</th>
<th>$C_{eTh}$ [Bq kg$^{-1}$]</th>
<th>$D$ [nSv h$^{-1}$]</th>
<th>ACI</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>CORSAIR</td>
<td>556 ± 83</td>
<td>32 ± 5</td>
<td>51 ± 8</td>
<td>47.4 ± 4.2</td>
<td>0.55 ± 0.05</td>
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<td></td>
<td>MCA_Rad</td>
<td>889 ± 53</td>
<td>27 ± 2</td>
<td>41 ± 3</td>
<td>51.6 ± 2.2</td>
<td>0.59 ± 0.03</td>
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<tr>
<td>M2</td>
<td>CORSAIR</td>
<td>454 ± 68</td>
<td>20 ± 3</td>
<td>22 ± 3</td>
<td>28.8 ± 2.6</td>
<td>0.33 ± 0.03</td>
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<tr>
<td></td>
<td>MCA_Rad</td>
<td>498 ± 31</td>
<td>17 ± 11</td>
<td>20 ± 2</td>
<td>28.3 ± 3.8</td>
<td>0.32 ± 0.04</td>
</tr>
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Summary

• Development of an innovative platform to measure the NORM content in the building materials
• The platform is based on a star-of-stars network topology, where each subsystem send and retrieve data from a central CLOUD platform
• Each subsystem is composed by a set of sensors controlled by a rugged handheld, which transmit measurement data via LoRA to a data gateway sending them to the central CLOUD platform
• The CORSAIR equipment exploits several cutting edge technologies (LoRa, WiFi and 4G as communication protocol, GPS coordinates, RFID tags, SaaS cloud platform)
• Preliminary on-field tests performed, and results obtained, are within 2σ compared with laboratory tests
• Potential benefits provided by CORSAIR platform include compliance with international regulations, cost and time saving, quality management improvement
• CORSAIR equipment designed to help companies that work in building materials and stone markets, to be compliant with the EU directive and the Italian DGLS 101/2020 in term of radiological characterization of the stone blocks.
• These promising results require to be validated with higher statistics and compared with independent laboratory, with different commercial rocks, in various operative situations.
• destructive tests
• Long preparation measurement tests
• Long waiting time of about 1 month required for establishing the radioactive equilibrium between $^{226}$Ra and $^{222}$Rn
• thick shielding structure used to reduce the external background
• High Purity Germanium (HPGe) or with a higher efficiency NaI spectrometer.
• Offline & Manual analysis
• It requires radiological experts
• complexes procedures for calibrating the equipment.