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

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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

- **Council Directive 2013/59 EURATOM of 5th December 2013,** *finally transposed into Italian National Law (D.Lgs. 101/2020)*
  - 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)


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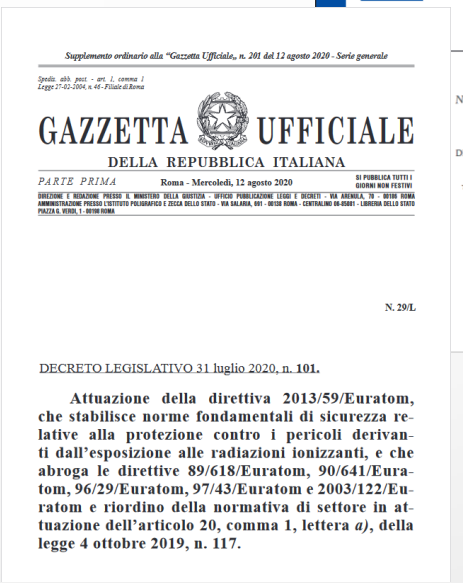
Legislation

Non-legislative acts

DIRECTIVES

★ Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom 1


GAZZETTA UFFICIALE

DELLA REPUBBLICA ITALIANA

PARTE PRIMA Roma - Mercoledì, 12 agosto 2020

N. 29/L

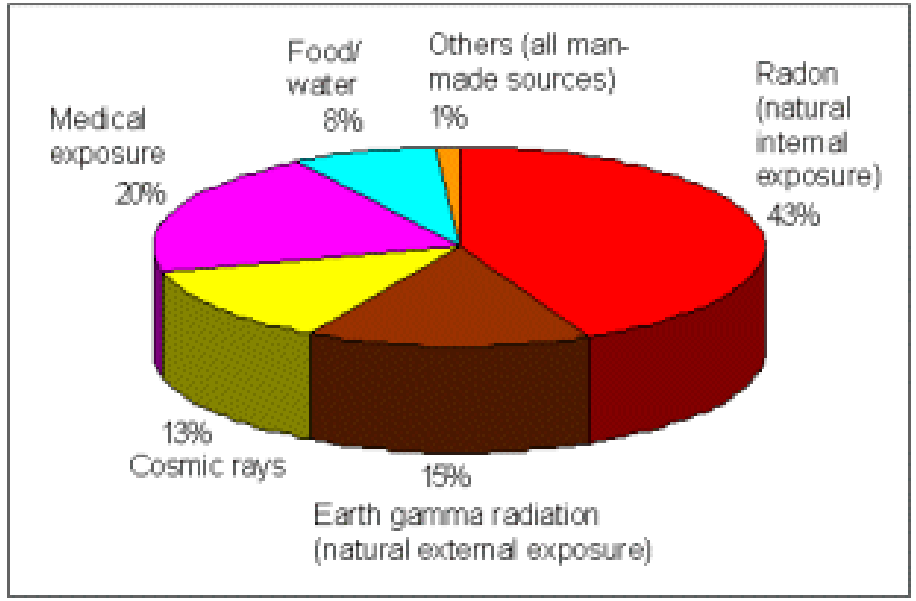
DECRETO LEGISLATIVO 31 luglio 2020, n. 101.

Attuazione della direttiva 2013/59/Euratom, che stabilisce norme fondamentali di sicurezza relative alla protezione contro i pericoli derivanti dall'esposizione alle radiazioni ionizzanti, e che abroga le direttive 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom e 2003/122/Euratom e riordino della normativa di settore in attuazione dell'articolo 20, comma 1, lettera *a)*, della legge 4 ottobre 2019, n. 117.

NORM - Environmental radioactivity

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***



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

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

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.

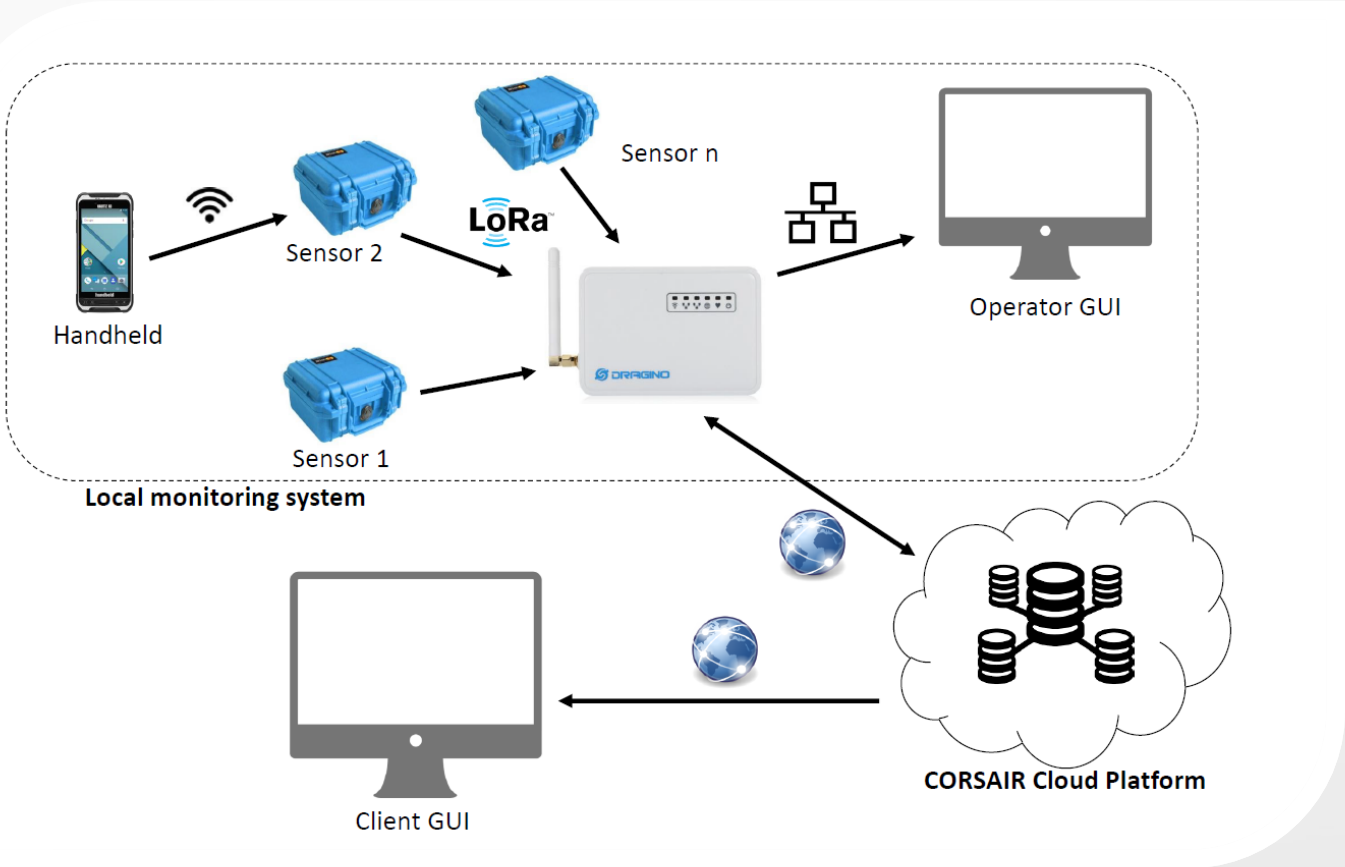
The information acquired from CORSAIR sensors is available among all stakeholders for commercial, traceability and regulatory purposes, depending on needs.

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

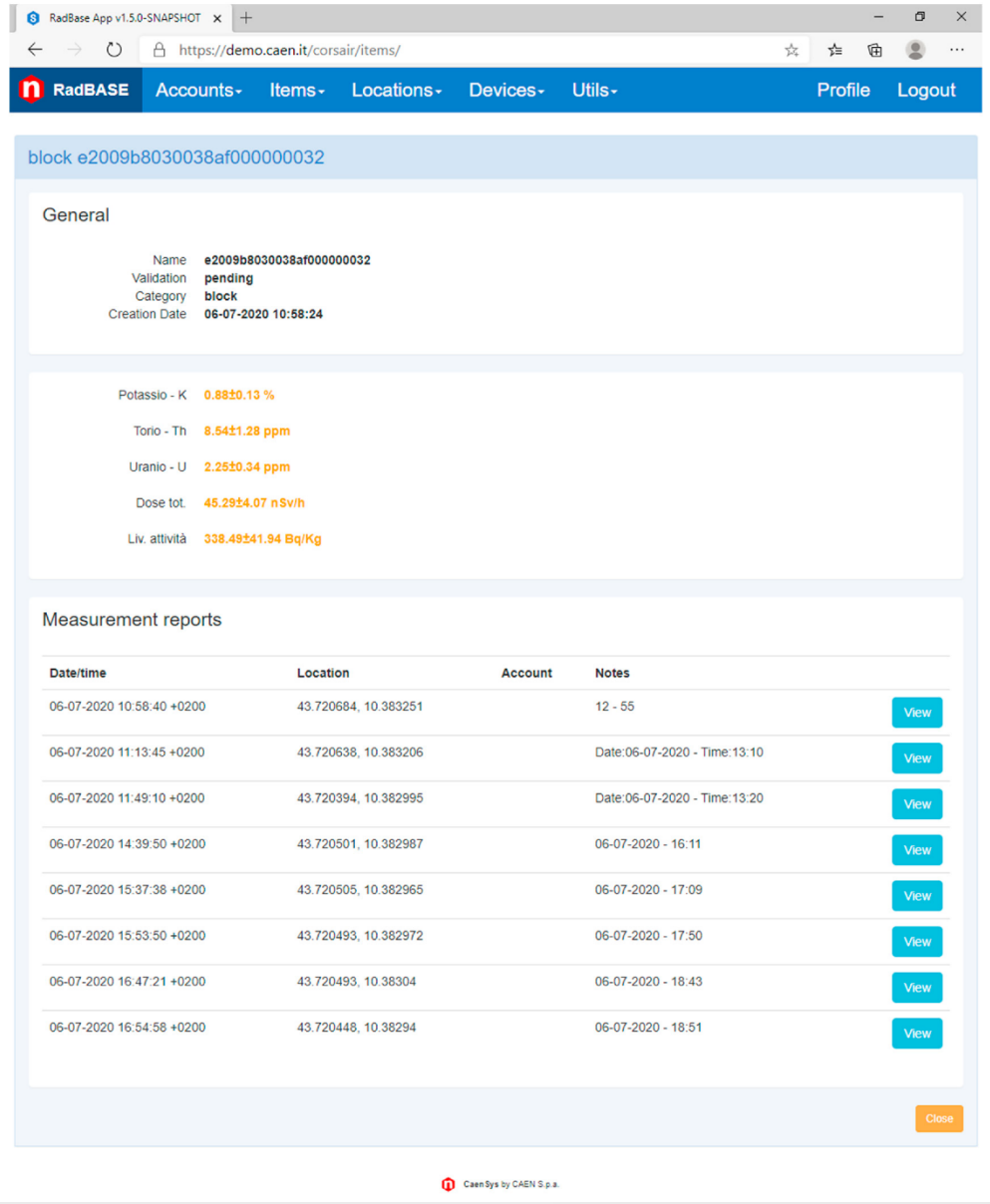


The Cloud Platform

- 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.

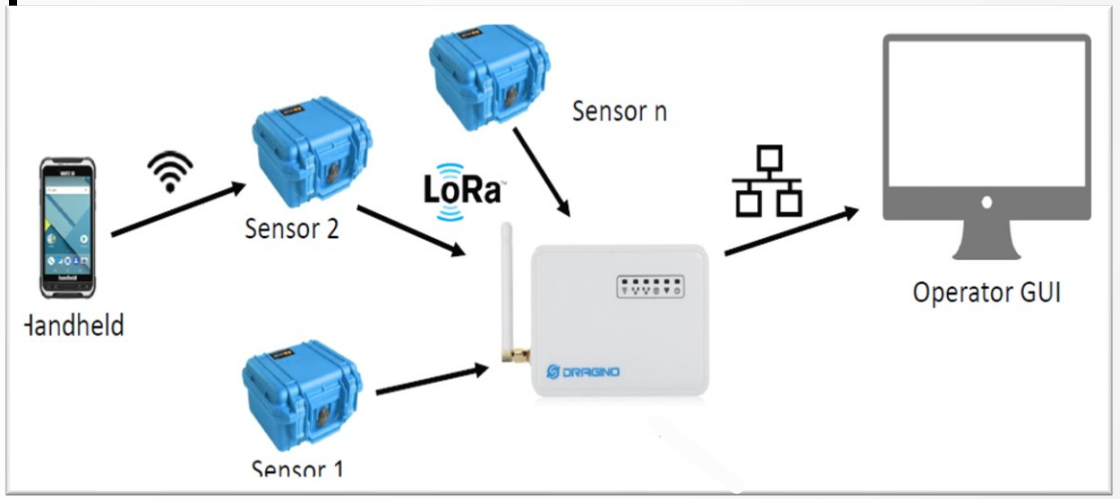
A dedicated web application provides these information upon user authentication.



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

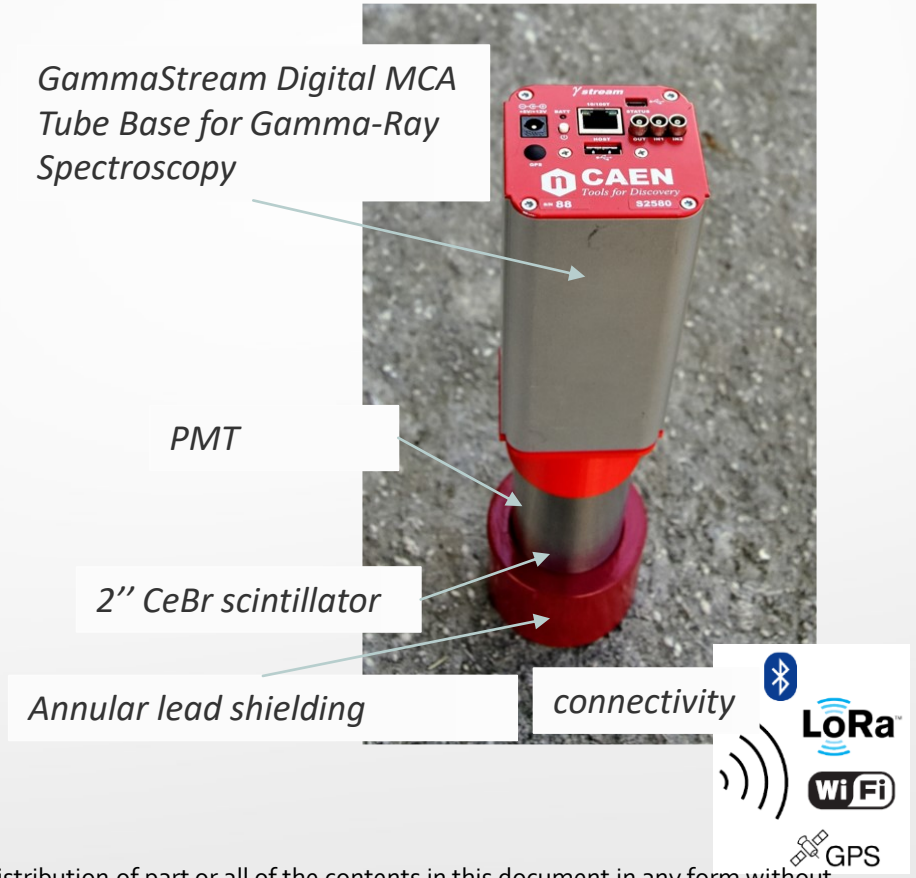
Handheld device

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

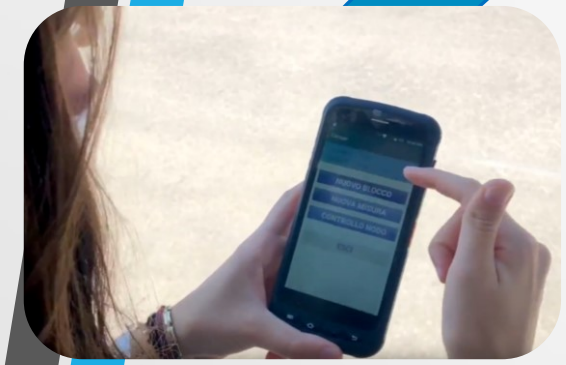
The Sensor Node

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



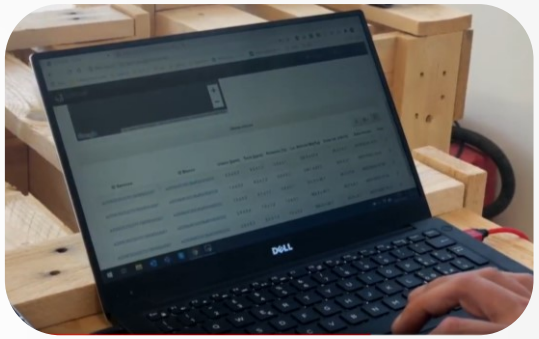
Measurement procedure



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

CORSAIR

Cloud Oriented Radiation Sensor for Advanced Investigation of Rocks

CERTIFICATO DEL BLOCCO

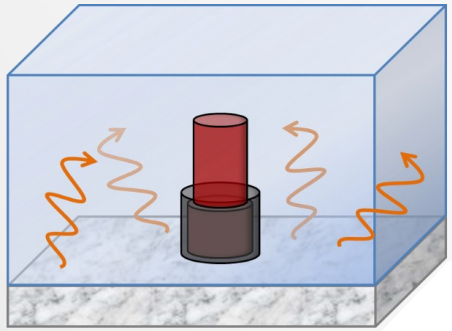
Identificativo del blocco: e2009a8010054af000000144
Data e ora di misura: 2020-07-09T07:19:19.39Z
Luogo di misura: lat: 44.054348, lon: 10.071895
Data e ora di emissione: 09/07/2020 - 11:21

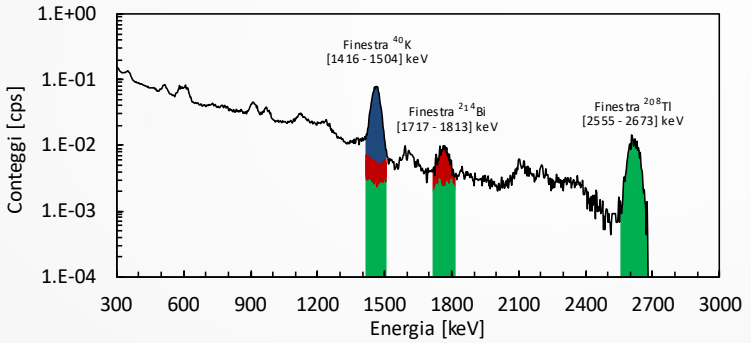
RISULTATI MISURA

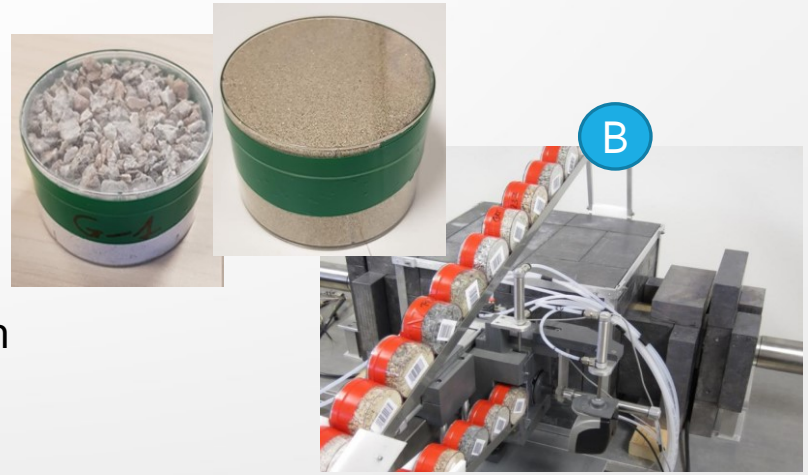
Potassio: 0.16 ± 0.02 %
Torio:1.51 ± 0.23 ppm
Uranio: 1 ± 0.15 ppm
Dose totale: 11.49 ± 1.07 nSv/h
Livello attività: 68.28 ± 7.75 Bq/Kg

In field tests and laboratory comparison

A. Preliminary on-field tests on *granitoid* (M_1) stone block and sand (M_2)
   - Infinite geometry approximation
   - Window Analysis Method, IAEA 2003[2]







B. A sample of each stone then analyzed by a HPGe spectroscopy system (MCA_RAD system[1])
   - Cylinder volume = 180 cc
   - 4-weeks wait for the ^{226}Ra-^{222}Rn secular equilibrium

[1] *Gerti Xhixha, GP Bezzon, C Broggini, GP Buso, A Caciolli, I Callegari, S De Bianchi, G Fiorentini, E Guastaldi, M Kaçeli Xhixha, F Mantovani, G Massa, R Menegazzo, L Mou, A Pasquini, C Rossi Alvarez, M Shyti, The worldwide NORM production and a fully automated gamma-ray spectrometer for their characterization, Journal of Radioanalytical and Nuclear Chemistry 295 (1) (2013): 445-457.*

[2] *Guidelines for radioelement mapping using gamma ray spectrometry data (IAEA-TECDOC-1363), 2003, International Atomic Energy agency (IAEA).*

Results

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

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.

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.

EXTRA

- 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.

	HPGe [8–13]	NaI [13–15]	B-NORM ($LaBr_3$) [16]	CORSAIR ($CeBr_3$)
Not destructive meas.	No	Yes	Yes	Yes
Back-end time	≥21	≥21	0	0
Energy Res. (@ 662 keV)	~ 0.3%	~ 7%	~ 3%	~ 3.8%
Measurement time	day(s)	hours	n.a.(~hours)	30 min
Sample preparation	Yes	Yes	No	No
Background meas.	Yes	Yes	Yes	No
Automatic data analysis	No	No	No	Yes
Automatic ACI calculation	No	No	No	Yes
Simulation of the experimental set-up	by construction	by construction	required	defined by procedure
Expert personnel for using the equipment	Yes	Yes	Yes	No
Shielding	Yes	Yes	No	Yes
On-site measurement	No	No	Yes	Yes
Stable experimental setup	No	No	Yes	No
Wireless data transfer	No	No	No	Yes
Sensors network cloud/IoT based	No	No	No	Yes