The optimization and application of an underwater γ - ray spectrometer for identifying threats in immersed objects

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Motivation & Goals

❖ Growing need for rapid and reliable monitoring of ships and immersed objects in terms of radioactivity (due to nuclear accidents, contamination events, and illicit nuclear activities).

❖ Real-time underwater radiation monitoring remains a challenge, as most existing detection systems operate in a standalone configuration.

❖ Development and optimization of compact detection system for deployment on robotic platforms and autonomous monitoring applications.

1. To verify of buoyancy of the compact system

2. To validate the simplified threat identification algorithm with lab-based methods.

3. To apply the system in real-time mode using an acoustic modem and the corresponding transducers.

4. To optimize and apply the compact system for identifying potential threats during continuous underwater operation with a power autonomy of at least 3 hours.

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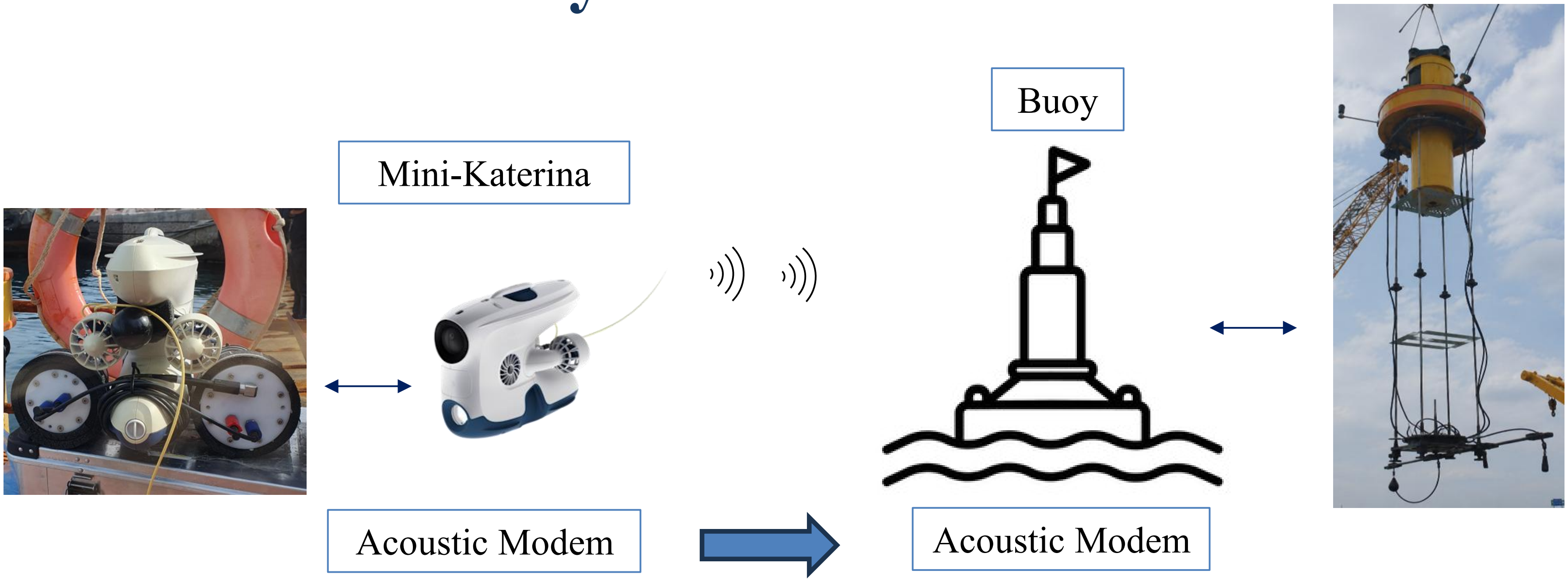
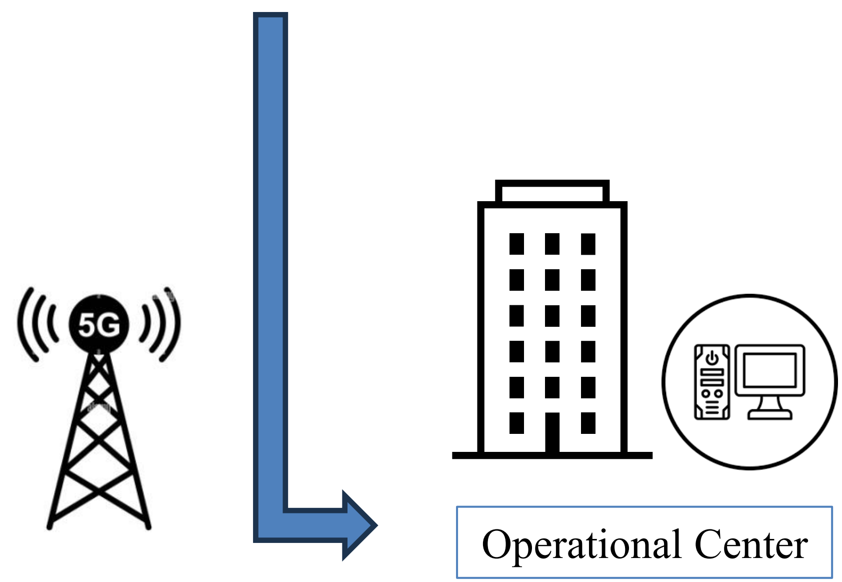
Underwater system setup

- **Underwater system** with camera and lights
- **Mini –Katerina enclosure**
  - Detector NaI(Tl) crystal 2″ x 2″
  - Silicon photomultiplier (SiPM)
  - Multi channel analyser (MCA)
  - Single-board computer Raspberry Pi (RPi):
    - → Communication and control of the whole detection system
    - → Data analysis
    - → Built-in Wi-Fi for connection to a mobile hotspot.
- **Acoustic modem enclosure**
  - Acoustic modem
  - Battery of the whole system
- A new measured spectrum is received every two minutes

Communication System



- ❖ An acoustic modem is a device that sends digital data through sound waves in water.
- ❖ A transducer (transmitter) is installed in the marine drone. The other transducer (receiver) was deployed in the sea.



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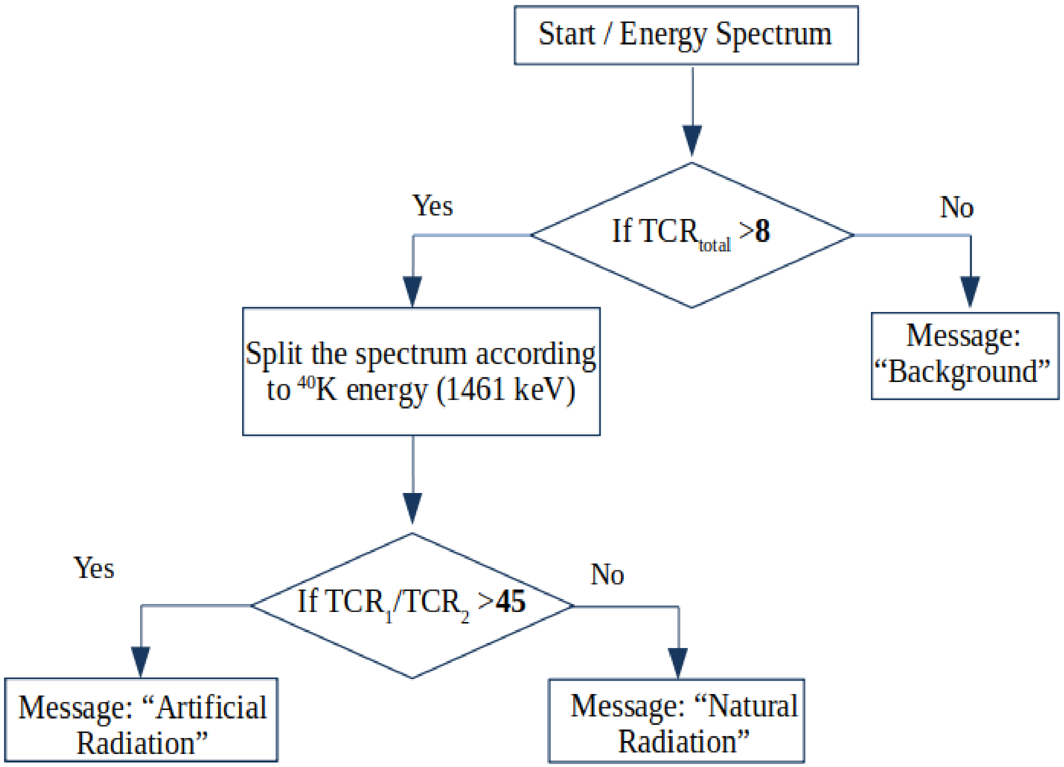
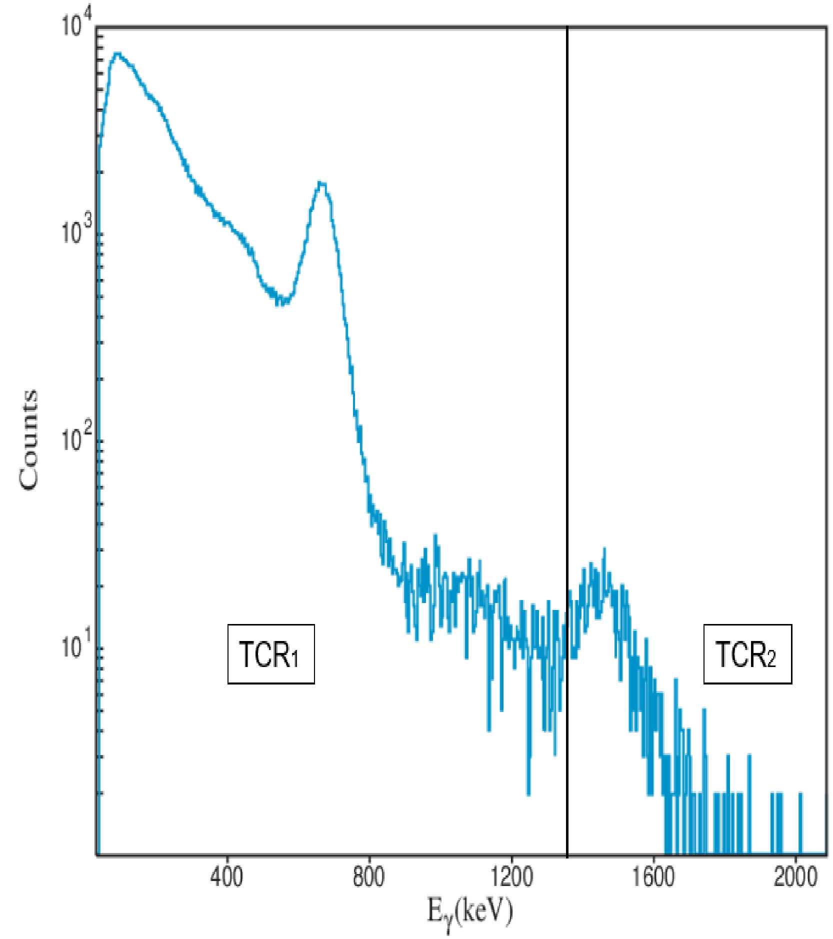
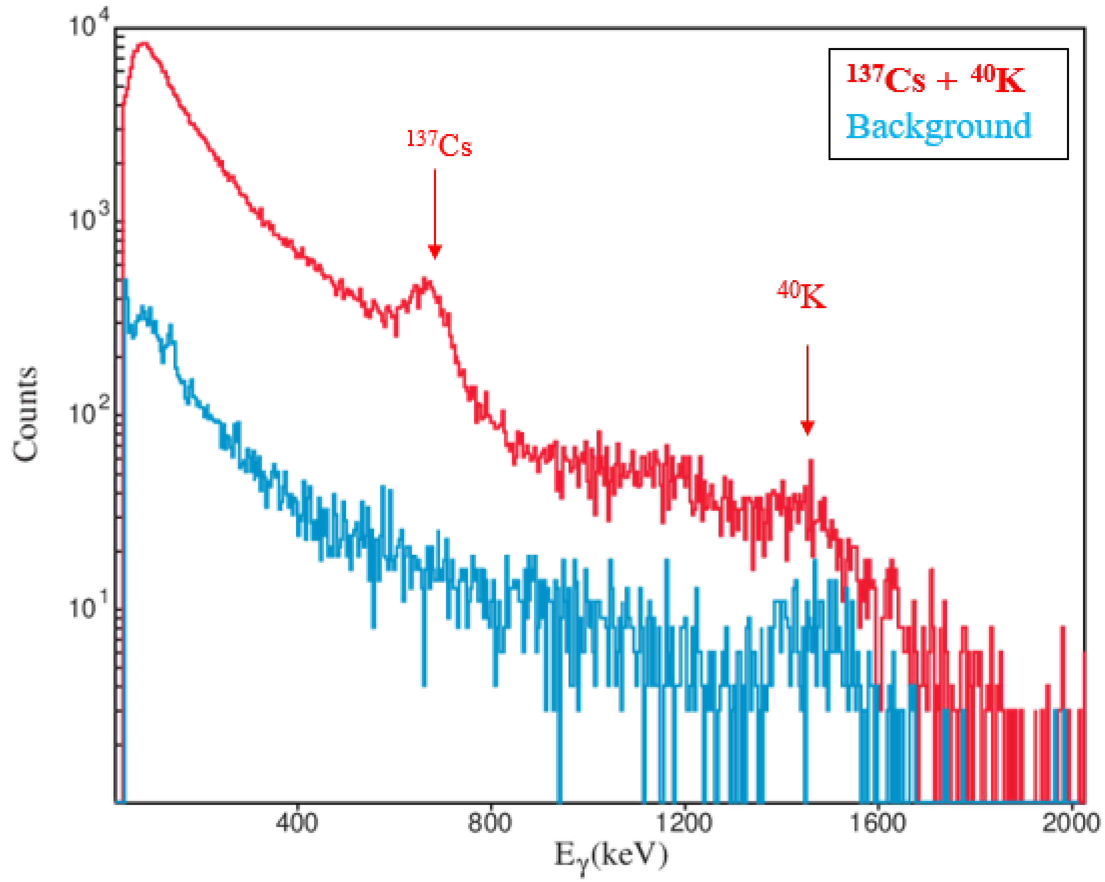
A simplified threat identification Algorithm





- ❖ Determination of the total counting rate.
- ❖ Splitting the energy spectrum into two regions, using the energy of ^{40}K (1460.8 keV) as the reference point.
- ❖ TCR1: **artificial radiation** (energy <= 1400 keV)
- ❖ TCR2: **natural radiation** (energy > 1400 keV)
- ❖ The channel at the beginning of ^{40}K photopeak is used for the splitting is stable at 381.
- ❖ The algorithm thresholds were determined empirically based on experimental data.

Background and spectra from the ^{137}Cs - ^{40}K simulant



HCMR simulant

Background

- Verification of buoyancy
- **Background** spectrum with an acquisition time of 1200 s → Background message
- **^{137}Cs + ^{40}K Simulant** spectrum with an acquisition time of 1200 s → Artificial radiation message
- In HCMR simulant spectrum there is an intense peak of ^{137}Cs energy (662 keV) and a small increase of counts in a ^{40}K region (1460.8 keV), compared to background spectrum.

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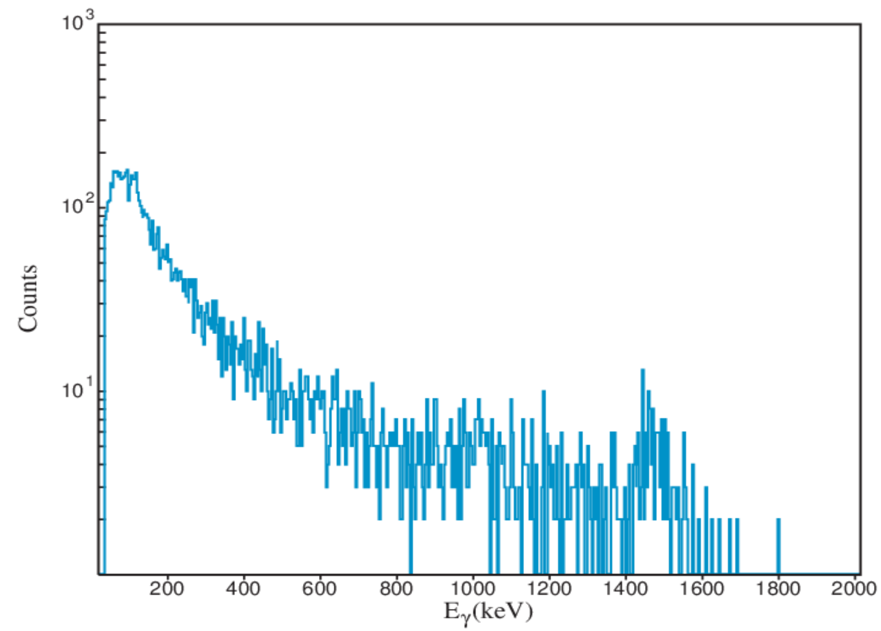
Fertilizer source

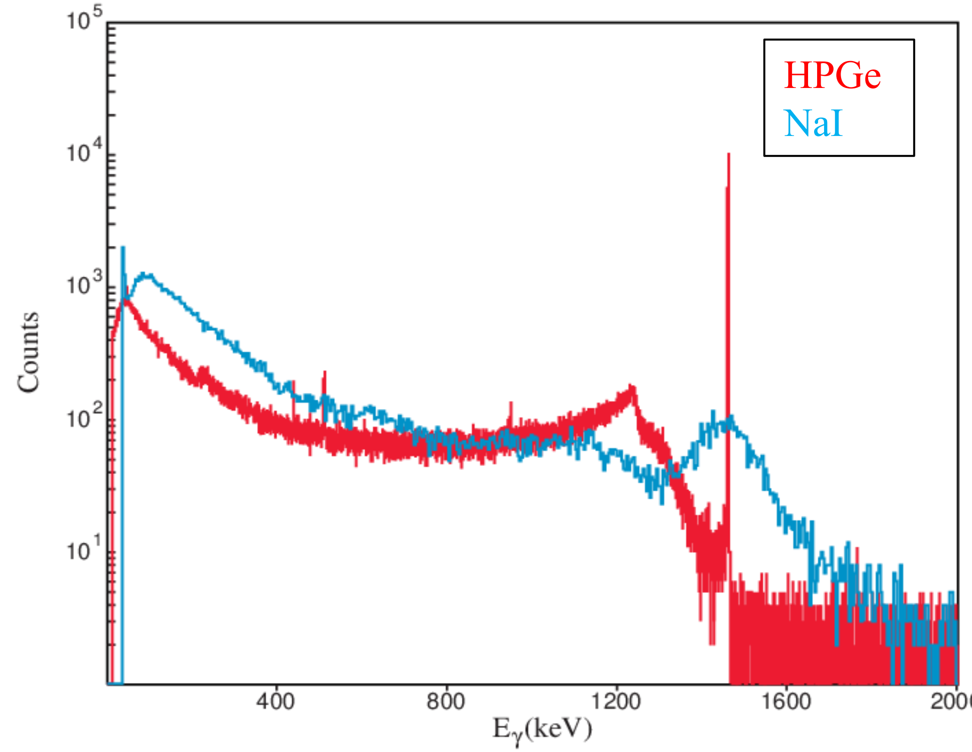
- ❖ The compact system (Mini Katerina and marine drone) was tested on the detection of a barrel containing fertilizer (Technologically Enhanced Naturally Occurring Radioactive Materials TENORM) considered as a non artificial threat.
- ❖ The barrel contained 40 kg potassium phosphate (KH_2PO_4) fertilizer.
- ❖ The simulant with fertilizer was measured in order to acquire spectra at various distances.
- ❖ When the system approached the fertilizer closely, the message of artificial radiation appeared, which was considered incorrect (false alarm).
- ❖ Spectrum acquisition time: 480 s.

Detection of Fertilizer barrel using the camera of drone



Classification and Identification of a potential threat

Comparison of low and high resolution analyzing the fertilizer sample



- A small sample of the fertilizer was placed near the detector window for 40 minutes (2400 s) to analyze its composition. The measurement was performed qualitatively outside the water.

- To achieve higher energy resolution and accurate analysis of the fertilizer composition, an HPGe detector was used.

- The sample was placed in a cylindrical container with a diameter of 6.8 cm and a height of 1.9 cm and was measured using an HPGe detector with a acquisition time of 86400 s.

- The HPGe spectrum (red) exhibits resolved peaks enabling more accurate radionuclide identification and quantification of the activity concentration.

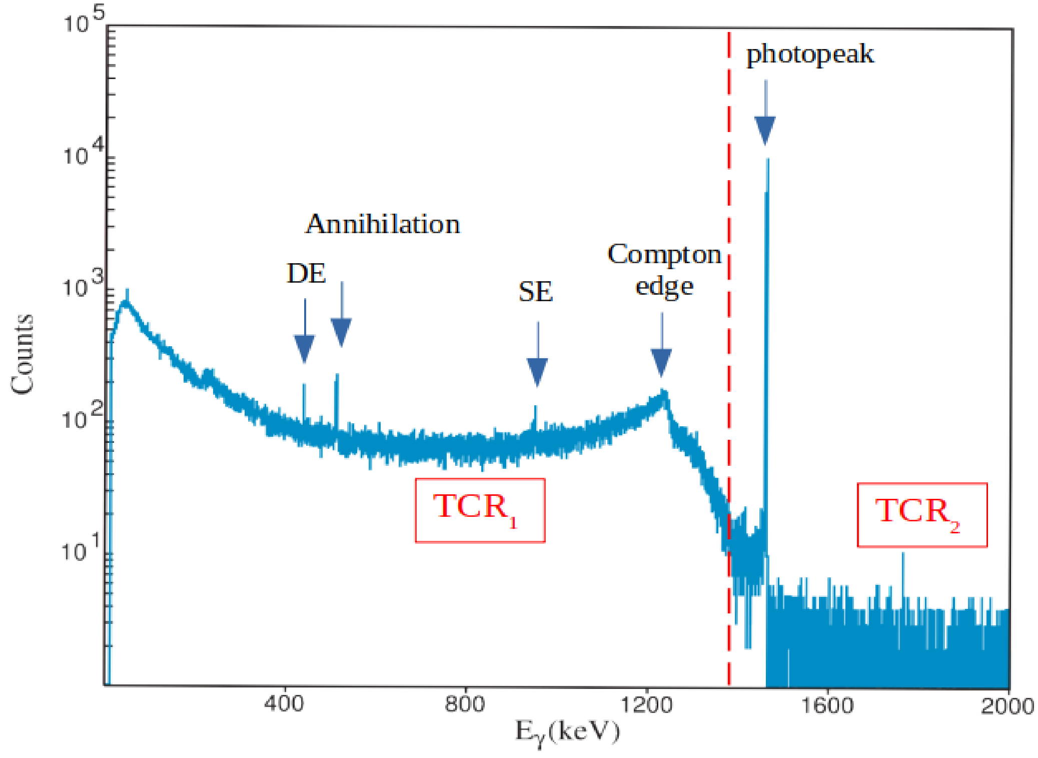
Spectrum Interpretation

❖ There is a substantial contribution from ^{40}K due to its high concentration in the fertilizer (KH_2PO_4), 32 kBq/kg. For 40 kg ~ 350kBq.

❖ ^{40}K contribution in soil ~ 0.5kBq/kg

❖ The high concentration leads to an inaccurate threat identification by the algorithm due to enhanced Compton scattering contribution that increases the counts within the TCR_1 region.

❖ Since the photopeak energy of ^{40}K (1460.8 keV) exceeds the pair-production threshold (1022 keV), the single-escape (949.8 keV), double-escape peaks (438.5 keV) and the annihilation peak (511 keV) which appear in the energy region of TCR_1 (threshold-1400 keV), causing the algorithm to falsely identify a threat.



Conclusions

❖First implementation of a compact detection system in underwater mobile platforms in real-time mode.

❖We test the simplified identification algorithm in TENORM materials, artificial point sources and background.

❖Both analyses of the recorded datasets and the corresponding spectra indicates that the Mini-Katerina system successfully identified the scanned objects, while the simplified threat identification algorithm was validated for artificial sources.

❖Even at extended source – detector distances (up to 1.5 m), the detector remains capable of identifying the objects and to generate the corresponding warning message.

❖When the system approached the fertilizer source closely, a false warning of "artificial radiation" appeared. Improvement of the algorithm is required for these cases.

❖Full power autonomy of the HCMR system was achieved for the standard operational period of time (three hours).

Perspectives

- The optimization of the simplified threat identification algorithm in cases of TENORM materials where the immersed object is enriched with high concentration of natural radionuclides.

- Further miniaturization of the acoustic modem to improve maneuverability and the full power autonomy.

- Imaging the objects in terms of radioactivity.

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Thank you!

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