In-situ radionuclide quantitative characterization in aquatic ecosystems using the KATERINA detector

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Developed and constructed at
Hellenic Centre for Marine Research (HCMR)

Calibrations performed at
National Technical University of Athens (NTUA)

Simulations performed in collaboration with NTUA
Outline

- Status of measuring techniques for marine radioactivity
- The KATERINA system
- Laboratory facilities – calibrations
- Monte Carlo Simulations (GEANT4 code)
- Real Time operation (POSEIDON network)
- Field measurements
- Comparison
- Future Plans
Status of Measuring Techniques

- **Lab based Technique**
  Traditional Sampling and Laboratory Analysis by using HpGe detectors.
  The method is applied at HCMR for NORM and $^{137}$Cs analysis.

- **In-Situ Monitoring Technique (option to Real-Time)**
  **Detectors**: HPGe in-situ (high consumption) and NaI($\sim$1-2W)
Radioprotection and Oceanographic applications (Geophysical and Meteorological)

Advantages in radioprotection:
1) Screening of Contaminated areas concerning facilities which pollute the marine environment
2) Mapping of large areas to estimate levels and distribution of N/A radionuclides
3) Information on the nature of radioactive substances contained in underwater objects
4) Continuous monitoring and Real-Time data transmission provides early warning

In situ Applications:
Radon daughters measurements on Submarine Groundwater Discharge
Radon daughters measurements near fault region
Radon daughters variations on rainfall
Seabed mapping
$^{40}\text{K}$ and $^{137}\text{Cs}$ decay schemes

They belong to the first group at the periodic table

They are monoenergetic gamma emitters
The underwater spectrometer KATERINA patented INT.CL: G01T 7/00

Specifications
• Crystal: 3x3” NaI
• Consumption ~ 1.2 W (100mA)
• Resolution at 662keV: <6%
• Variable Energy Range
• Adjustable spectroscopy: max of 2048 channels
• Operating Temperature: 0-50°C.
• Correction for voltage drifts.
• Adjustable HV voltage
• Adjustable amplifier gain, PZC and shaping time.
• Autonomy (without PC connect)
• Option for Real Time (software independent)
Hardware

- **Analog Nuclear Electronics** (Pre-amplifier, Shaping Amplifier + Gain + Base Line Restoration + Pole Zero Cancellation + shaping time).

- **Digital Electronics** (Multichannel Analyzer + successive approximation ADC + RS232 and USB Interface).
Experimental set up (lab)

- Point sources calibration (15cm and 25 cm)
- Without housing (first figure)
- With housing (second figure)
Comparison for $^{137}$Cs (with and without the housing)

- Similar energy resolution
- Similar Compton tail
- Variation of the total efficiency
- Peak to total ratio variation
# Marine Calibration Sources

**Gamma ray sources**

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{40}$K</td>
<td>1461</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>661</td>
</tr>
<tr>
<td>$^{99m}$Tc</td>
<td>141</td>
</tr>
<tr>
<td>$^{111}$In</td>
<td>162, 246</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Half Life</th>
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<tbody>
<tr>
<td>1.3x10⁹ years</td>
</tr>
<tr>
<td>30.17 years</td>
</tr>
<tr>
<td>6 hours</td>
</tr>
<tr>
<td>67.9 hours</td>
</tr>
</tbody>
</table>
Laboratory facility at NTUA

- Tank with volume of 5.5m³
- Pump for circulation of the water
- Hardware and software for the acquisition
- The SPECTRG software package for the analysis of the measured data (NCSR “Demokritos”)
Calibration spectra

Energy (keV)

Counts

- Cs-137 K-40 with background
- Cs-137 K-40 without background
Continued (\(^{99}\text{mTc}\))
Resolution calibration

Measurements

\[ f^2 = -669.48 + 4.55E \]
Comparison with DUS system

![Graph showing comparison of counts vs. energy for $^{137}\text{Cs}$ and $^{40}\text{K}$ from D.U.S and K-A-TE-RINA.](image-url)
Comparison with RADAM system (\(^{99m}\text{Tc}\))
**Intercalibration exercises (in-situ and lab)**

### Broad Energy Germanium Detector

<table>
<thead>
<tr>
<th></th>
<th>$^{214}\text{Pb}$ (Bq/l)</th>
<th>$^{214}\text{Bi}$ (Bq/l)</th>
<th>$^{208}\text{Tl}$ (Bq/l)</th>
<th>$^{137}\text{Cs}$ (Bq/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>in-situ</strong></td>
<td>1.7±0.2</td>
<td>1.9±0.1</td>
<td>0.12±0.01</td>
<td>0.012±0.003</td>
</tr>
<tr>
<td><strong>lab</strong></td>
<td>1.9±0.2</td>
<td>2.0±0.2</td>
<td>0.10±0.02</td>
<td>0.010±0.001</td>
</tr>
</tbody>
</table>
Monte Carlo Simulation using GEANT4

Taking into account the typical interactions in the water, in the material of the housing and in the NaI crystal.

**Interactions**
- Compton scattering
- Photoelectric
- Pair production
Effective volume of gamma rays in water
Simulated values of $V_{\text{eff}}$

*Photopeak counts versus volume, input: 2,000,000 gammas/m$^3$*
Simulated $^{40}$K spectrum

$^{40}$K
Measuring Time: 3 days

- **measured data**
- simulation A (no scattering in the POM housing)
- simulation B (taking into account the scattering in the POM housing)
Simulated spectrum of $^{111}$In
Efficiency simulation with GEANT4

1) Running the code with constant number of gammas/m$^3$ (~2,000,000 gammas/m$^3$)

2) Volume values are above the $V_{eff}$

$$
\varepsilon_m = \varepsilon_{ph} V_{eff} = \frac{N_{photopeak}}{N_{total} / V}
$$
Simulated Marine efficiency
published in Env. Mon. & Assessment
Natural and anthropogenic R/N in Butrint lagoon, Albania
Seabed sediment characterization

\[ F = -0.048A_{Ra} + 0.24A_{Tb} + 0.65A_{Co} - 0.0020A_K - 3.6 \]
Thermaikos Gulf (North Greece)
Thermaikos Gulf (surficial $^{137}$Cs variation)
**Height:** 7.9 m  
**Width:** 1.75 m  
**Weight:** 900 kgr  
**Energy:** Solar panels + batteries  
**Communication:** Imarsat C, GSM every 3 hours
Field measurements (Aquatic measurements) published in Applied Radiation and Isotopes

Dust load over Mediterranean, forecast image from the POSEIDON system.
Application in Monaco: Groundwater fluxes on Submarine discharges

**Results:**
- Measured activity: 1450 Bq/m³
- Activity at open sea: 3-5 Bq/m³

Application in Monaco: Groundwater fluxes on Submarine discharges

Flow rate: 6 m³/min

\[
y = -0.5102x + 21.236
\]

\[
R^2 = 0.3675
\]
Third Deployment using an ROV in Stoupa

published in Sea Technology

Minimum flow rate: 16m³/min
Results (Stoupa experiment)

$^{222}\text{Rn}$ results:
- averaged activity: $1700$ Bq/m$^3$
- activity at open sea: $3.5$ Bq/m$^3$
System Improvements

Software for automated analysis of the acquired gamma ray spectra

Installing the system in a network of floating measuring systems and platforms

Upgrade for depths up to 6000m

Marine system for geophysical and radioprotection purposes

(Warning/Alarm)
Future Plans

- GEANT4 and MCNP5 simulations on sediment spectra for efficiency estimation.
- Include special hardware for user-independent automatic gamma ray spectra analysis in order to inform directly the responsible operational centre.
- Applying the system as a dosimeter in the water as well as in the sediment for NORM and $^{137}$Cs.
- Applying the system in a network for monitoring radon on submarine faults (ESONET project in Marmara Sea).
- Seabed characterization at specific NORM sites with increased activity concentration (like fertilizer industry) (test in Cyprus).
- Real-Time Monitoring radioactivity in terrestrial environment as well as in air-sea interaction environment.
Test deployment in Stoupa (South Peloponnesus)