

Monte Carlo simulation of γ -ray spectra from natural radionuclides recorded by a NaI detector in the marine environment

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Aim of the project

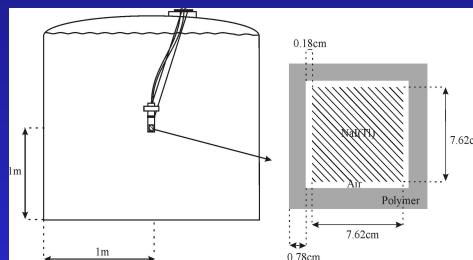
In the studies of radiological assessment, ^{137}Cs is the most important radioactive contaminant, produced from the atmospheric bomb tests, discharges from nuclear reprocessing plants and the Chernobyl reactor accident. The systems most commonly used for the in situ monitoring of γ -radiation in seawater, are based on NaI(Tl) detectors, which are characterized by high detection efficiency and low cost. They have, however, the disadvantage of relatively poor energy resolution and high background mainly originating from the Compton effect during the detection process of the high energy γ -rays from the deexcitation of natural radionuclides, such as ^{40}K and ^{214}Bi [Tsabaris et al., 2004]. This makes the systems incapable for precise peak identification of the various gamma ray contributions, especially for low level radioactivity studies and in the low energy region, where the 661keV γ -ray of ^{137}Cs , is situated in the spectra.

In an attempt to increase the confidence of the spectra analysis and produce more reliable results in the concentration of low level environmental radioactivity, Monte Carlo simulations with the GEANT4 code [CERN, 1993] were performed to produce the background spectra induced by the natural radionuclides in the marine environment. The simulated γ -ray spectra were compared with real data recorded in seawater by a NaI detector operational on oceanographic buoys, developed by the Hellenic Centre for Marine Research [Tsabaris et al., 2004], for the in situ monitoring of radioactivity in the Aegean sea. The comparison between the measured spectrum and the simulated one, could control the operation of the submersible detection system, to increase the confidence of the spectra analysis and produce more reliable results in the concentration of low level environmental radioactivity.

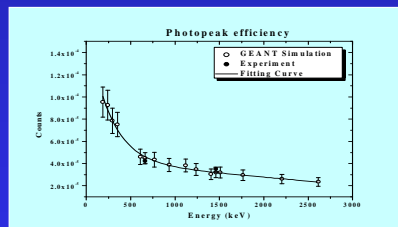
Experimental calibration of the NaI spectrometer

The NaI detector system, developed by the Hellenic Centre for Marine Research [Tsabaris et al., 2004], has been tested and calibrated in the NTUA Nuclear Physics laboratory, in a 5.5m^3 water tank, before its deployment in seawater. It was thus surrounded by one meter of water, which is adequate to imitate the real marine environment, due to the high attenuation of the γ -rays in the water.

The γ -rays used to perform the energy calibration of the system were the 661keV of ^{137}Cs and the 1461keV of ^{40}K . 1995gr natural KCl and liquid ^{137}Cs were diluted in the tank water (together with 65% HNO_3 , 0.005N), resulting in (3980 ± 25) Bq/ m^3 and (6037 ± 120) Bq/ m^3 volumetric activity, respectively for ^{137}Cs and ^{40}K .



Experimental spectra taken by the NaI spectrometer in the tank, with the above mentioned activities of ^{137}Cs and ^{40}K diluted in the water, were analyzed in order to extract the experimental values of the photopeak efficiency. The derived values are shown in the figure, in comparison with the efficiency curve simulated by the GEANT code. The good agreement indicates that the simulated efficiency of the NaI spectrometer could be used over the full energy range for the concentration of any radionuclide emitting γ -rays.



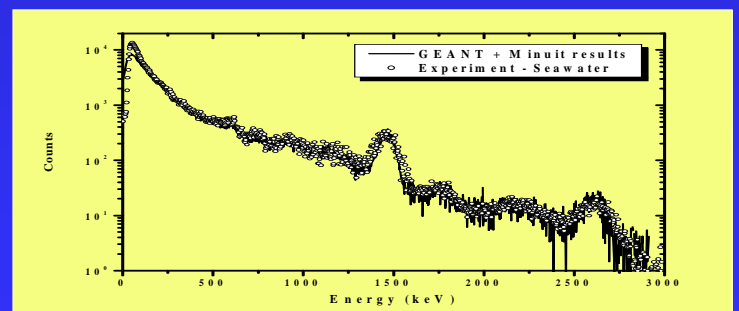
The GEANT code simulations

The GEANT code has been developed at CERN for high-energy physics experiments and simulates all relevant physical processes taking place in matter, along the passage of elementary particles from the source to the detector of any configuration. A detailed description of the geometry of the experimental set up (water tank and detector) and environment (water with radionuclides) with respect to their dimensions, materials and shapes, as well as the particle generator (radionuclides emitting photons), are required by the program to simulate and store the history of each photon from its generation in the water to full deposition of its energy in the detector system.

In order to simulate the efficiency of the NaI detector in seawater, 16 strong γ -rays from the series of ^{238}U and ^{232}Th natural radioactivity were used to produce 16 spectra, one for each gamma ray, as well as for ^{137}Cs and ^{40}K . By integrating the photopeak counts and dividing by the total number of counts in each spectrum, the photopeak efficiency of the NaI spectrometer was deduced as a function of energy, as shown in the figure.

Experimental and Simulated seawater Spectra

In order to simulate the spectra of natural radioactivity in seawater, 67 gamma rays from the series of ^{238}U , ^{232}Th and ^{40}K were used. The contribution from the natural series of ^{235}U was considered to be negligible. Spectra were generated by the GEANT4 code for all the strong γ -rays (weighted by their relative intensity) of ^{234}Pa , ^{226}Ra , ^{222}Rn , ^{214}Pb , ^{214}Bi , ^{228}Ac , ^{220}Rn , ^{212}Pb , ^{212}Bi , ^{208}Tl and ^{40}K . By varying the relative contribution of these spectra and getting the best fit to the real spectrum (taken with the NaI detector in seawater) with the MINUIT code by the χ^2 minimization technique, the relative abundance of ^{238}U and ^{232}Th series and ^{40}K in sea water was deduced. [Vlastou et al., 2005]. The expected deficiency of radium and lead has been confirmed by the fitting procedure, verifying the disequilibrium of the natural radioactivity in seawater. Good fit between real and simulated spectra could be achieved without any contribution from ^{137}Cs . This implies low concentration of ^{137}Cs in the seawater, below the lower limit of detectability of the NaI system. This result is corroborated by laboratory measurements of the ^{137}Cs concentration in seawater from the same region, which was found to be very low, between 2-3Bq/ m^3 [Delfanti et al., 2004].



Conclusions : The simulated spectrum representing the natural radioactivity, could be used to test the performance of the detection system, to monitor the fallout and to improve the detectability and concentration of low-level radioactive pollutants, such as ^{137}Cs .

Publications

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2. Tsabaris, C., Thamos, I. and Dakylas, Th., 2004. The development and application of an underwater γ -spectrometer in the marine environment. Radioprotection Suppl.1, in press.
3. Vlastou, R., I.Th. Ntziou^a, M. Kokkoris, C.T. Papadopoulos and C. Tsabaris. Monte Carlo simulation of γ -ray spectra from natural radionuclides recorded by a NaI detector in the marine environment. Accepted in Applied Radiatopn and Isotopes.
4. Delfanti, R., Tsabaris, C., Papucci, C., Kaberi, H., Lorenzelli, R., Zervakis, V., Tangherlini, M. and Georgopoulos, D., 2004. Re-distribution of ^{137}Cs Chernobyl signal in the Aegean Sea. Proceedings of the International Conference on Isotopes in Environmental Studies-Aquatic Forum, Monaco.