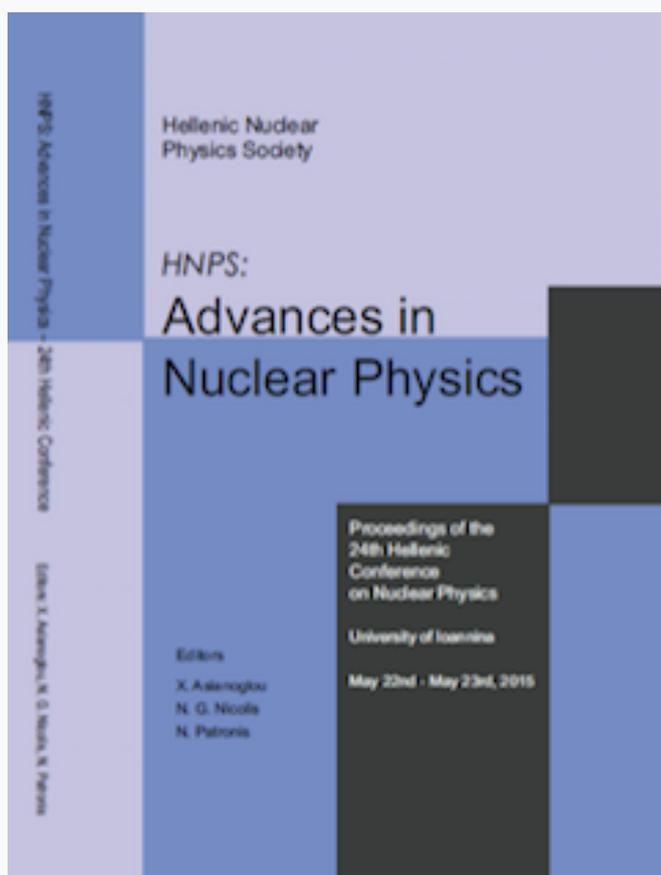


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## The Athens Mobile $\gamma$ -Spectrometry System (AMESOS)

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**Abstract** We report on a new mobile  $\gamma$ -spectrometry system (AMESOS) developed at the University of Athens. The system aims at carrying out *in situ* measurements to study distributions of NORM and TENORM at harsh environments or where sampling is difficult. AMESOS has been characterized by using standard calibration sources and minerals of known, independently determined, U and Th concentrations. Simulations of the system have been performed with MCNP and Geant4. As a proof of good field operation, AMESOS was deployed in a series of measurements at Mt. Kithaeron, near Athens, extending earlier data and estimating absorbed dose rates that concern the public.

**Keywords** AMESOS, environmental radioactivity, Kithaeron, simulation, absorbed dose rate

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### INTRODUCTION

Environmental radioactivity studies often require mobile spectrometers, mainly due to harsh environments or difficulties in sampling. NORM and TENORM levels can be measured efficiently by deploying mobile spectrometers in the field to perform *in situ* measurements. The relevant technology has made significant progress in the last decades, eliminating factors limiting power autonomy, detection efficiency and photopeak resolution.

The Athens Mobile  $\gamma$ -Spectrometry System (AMESOS) is a newly developed mobile  $\gamma$ -spectrometry system aiming at supporting the environmental studies program of NuSTRAP group. AMESOS will operate both as an independent spectrometer and as an assisting instrument for offline measurements. After detailed characterization, a proof-of-concept study was undertaken by expanding earlier measurements at Mt. Kithaeron near Athens urban area.

### DETECTOR CHARACTERIZATION AND METHODOLOGY

AMESOS is built around a 3"x3" NaI(Tl) scintillator equipped with a low-power EG&G Ortec DigiBase coupled to the PMT. The DigiBase is connected to a laptop PC that provides power to the detector and handles the collected  $\gamma$ -ray spectra. The detector is contained inside a hollow 2mm-thick cylinder made of aluminum that stands upright with the help of three 120mm-long legs welded on the outer side of the cylinder. The inner wall of the cylinder is covered by a 2mm-thick Pb shield. The cylinder is closed by a 3mm-thick plexiglass window on one end, upon which the detector stands, facing downwards. Despite the geometry is not standard for *in situ* measurements, it offers the advantage of focusing better on localized sources of radiation ignoring the influence of

the nearby radiation field. In our case, single-energy flux originates from a ground surface radius of 1.4 m and a depth of 17.6 cm

Prior to field deployment, AMESOS was first characterized using standard calibration point sources ( $^{22}\text{Na}$ ,  $^{137}\text{Cs}$  and  $^{60}\text{Co}$ ). Lacking large-surface reference soil slabs, typically used for calibrations of scintillator-based mobile spectrometers, AMESOS was calibrated with bulky samples minerals of known U and Th concentrations determined by independent techniques. Thorough examinations of full-energy peak efficiency, relative angular resolution (normalized at  $\theta=0^\circ$ ) and resolution (FWHM vs. energy) were carried out [2,3]. During analysis, the following assumptions were made: 2 $\pi$  geometry, equilibrium, and homogeneous distribution.

Full-scale simulations using the codes MCNP5 and Geant4 have also been carried out. The results from both simulations were compared to experimental data from a  $^{60}\text{Co}$  source to determine the relative energy efficiency of AMESOS.

Earlier offline  $\gamma$ -spectroscopy measurements [1] of geological samples collected in Mt. Kithaeron (Attica region) in 2007 showed elevated NORM levels. U-content was associated to dark calcitic and white dolomitic limestones. The geological findings, atypical for the surrounding area, triggered a second series of in situ measurements to both test AMESOS in field conditions and extend the range of previous measurements. The radiological hazard was assessed by estimating the absorbed dose rate,  $D$ , in the air (1 m above surface) using the equation [4]:

$$D \text{ (nGy/h)} = 0.462\mathbf{A}(\text{U}) + 0.604\mathbf{A}(\text{Th}) + 0.0416\mathbf{A}(\text{K})$$

where  $\mathbf{A}(\text{U})$ ,  $\mathbf{A}(\text{Th})$ ,  $\mathbf{A}(\text{K})$  are the activities for  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ , respectively. Since  $\mathbf{A}(\text{K})$  has not been measured in this work, the typical value 70 Bq/kg for limestones was adopted.

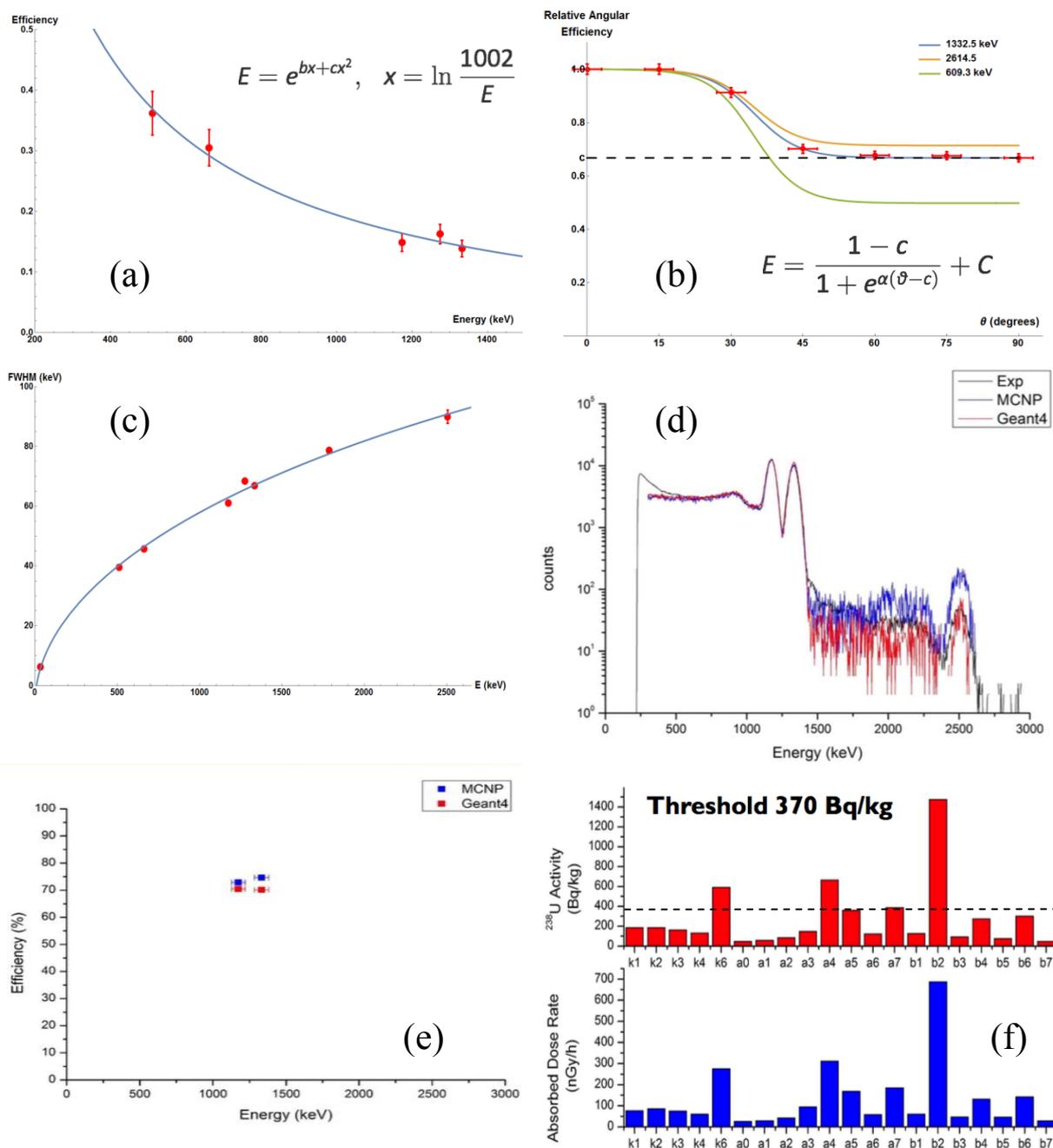
**Table 1** Results from in situ measurements of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  specific activities and corresponding absorbed dose rates,  $D$ . Data for locations k1-k4,k6 are from [1]. Errors shown in parentheses.

Location	$^{238}\text{U}$ [Bq/kg]	$^{232}\text{Th}$ [Bq/kg]	$D$ [nGy/h]	Location	$^{238}\text{U}$ [Bq/kg]	$^{232}\text{Th}$ [Bq/kg]	$D$ [nGy/h]
a0	45(8)	8.4(2.4)	28.9(4)	b1	126(11)	<4.2	63.4(10)
a1	58(7)	<5.2	32.6(5)	b2	1476(34)	<8.8	690.2(104)
a2	83(13)	5.8(2.5)	44.9(7)	b3	91(12)	9.3(2.2)	50.4(8)
a3	146(14)	45.3(3.3)	97.9(15)	b4	274(14)	8.3(2.1)	134.7(20)
a4	664(21)	<6.6	313.8(47)	b5	74(13)	20.6(2.8)	49.6(7)
a5	359(17)	<4.3	171.3(26)	b6	301(17)	5.8(2.7)	145.4(22)
a6	121(13)	<2.9	60.6(9)	b7	47(10)	10.5(2.5)	31.0(5)
a7	387(18)	11.1(2.2)	188.2(28)				
k1	184	--	76.5	k4	130	--	60.1
k2	185	--	85.6	k6	539	--	275.2
k3	162	--	74.9				

**RESULTS AND DISCUSSION**

The characterization of AMESOS with calibration sources is summarized in the following figures depicting the experimentally deduced intrinsic full-energy peak efficiency (Fig. 1a), the relative angular efficiency (Fig. 1b), and the resolution calibration (Fig. 1c). Spectra and relative efficiencies simulated by MCNP5 and Geant4 are compared to experimental data (Figs. 1d & 1e).

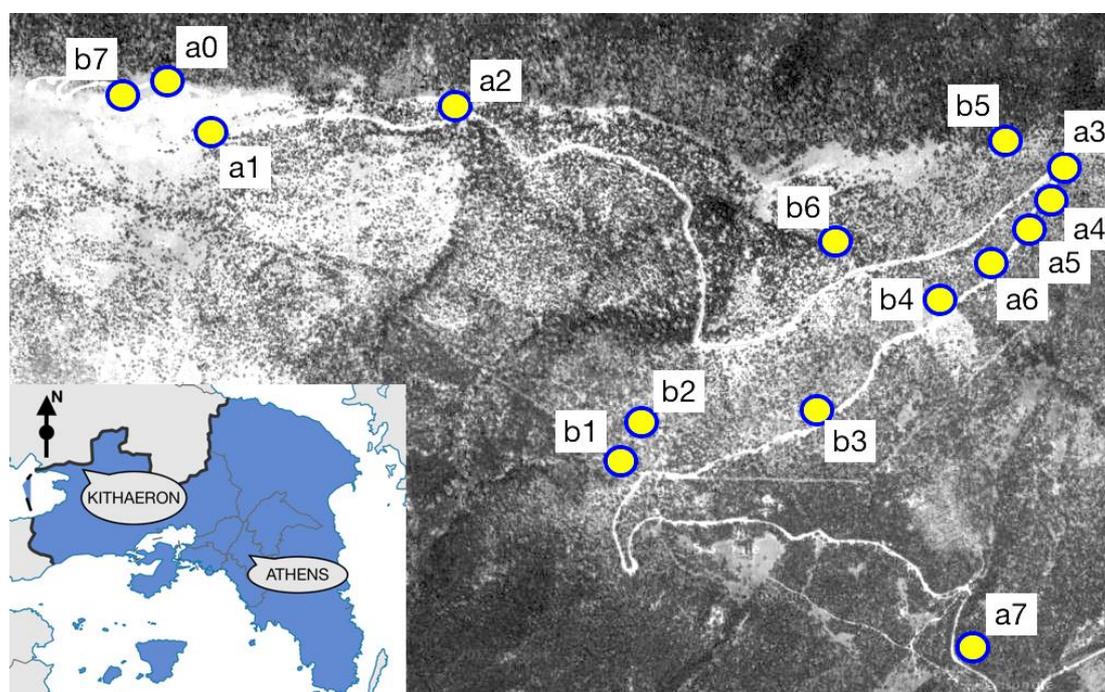
**Figure 1** (a) Energy efficiency (b) normalized angular efficiency (c) resolution (FWHM) (d) experimental and simulated spectra (e) simulated efficiencies for 1173 and 1332 keV lines of <sup>60</sup>Co (f) aggregate plot of dose rates per location (threshold is according to IAEA)



Comparison of the simulated to the experimental data resulted in excellent agreement for both codes. The value of relative efficiency has been estimated to 72% on average. From the shape of the spectra, Geant4 seems to reproduce the summing peak of  $^{60}\text{Co}$  at 2.5 MeV slightly better than MCNP5.

The measurements at Mt. Kithaeron correspond to 15 different locations (a0-a7 and b1-b7 in Table 1, see also Fig. 2). Specific activities of  $^{238}\text{U}$  and  $^{232}\text{Th}$  were deduced after comparison with reference samples of known activities. Existing  $^{238}\text{U}$  data [1] are also given in the table (k1-k4,k6). The corresponding absorbed dose rates are listed and correlated to U-content (Fig. 1f).

**Figure 2** A terrain map showing the locations of *in situ* measurements with AMESOS. a0 corresponds to Mt. Kithaeron's peak. The inset shows an outline map of Attica region.



## CONCLUSIONS

The new UoA mobile spectrometer, AMESOS, was calibrated, characterized and simulated. The efficiency was estimated to approximately 72% by comparing experimental and simulated data. The *in situ* measurements carried out at Mt. Kithaeron extended prior NORM measurements from 2007 in the same area. In addition, 4 out of the 20 locations show dose rates above the limits set for the general public by EU and IAEA.

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