

Report from the Technical Meeting on Current Trends and Developments in Nuclear Instrumentation

IAEA Headquarters

Vienna, Austria

C0440/C0437

3–7 December 2018

Ref. No.: F1-TM-1703707

Executive summary

The meeting was organized by the IAEA Nuclear Science and Instrumentation Laboratory (NSIL), Physics Section (PS).. NSIL has developed strong capacities for in situ measurement campaigns and has a variety of portable instruments. The objectives of this meeting were to highlight, review and discuss the state of the art portable nuclear instrumentation for in situ environmental monitoring including analytical methodologies. The geostatistics based interpretation of large data sets allows the simulation of a model that can be used to describe the statistical and geostatistical variability of the measurement results, and to provide useful tools to represent an estimate of the distribution of the contaminants, to evaluate the volume of contaminated material and to support decision-making in environmental remediation processes

The meeting was attended by eleven participants from ten Member States (MS) (list of participants in Annex 1) who shared their work experiences and knowledge relevant to the scope of the Meeting (agenda in Annex 2). The presentations resulted in technical discussions on:

- examination of capabilities and shortcomings for effective operation and maintenance of state of the art instrumentation and interpretation tools used for environmental studies
- effective utilization of portable nuclear instrumentation for environmental applications, including development of conventional and, e-learning tools
- review of the role of national and international networks, including ENVIRONET and its INSITU Working Group
- activities that should be included in further training activities and the role of the IAEA.

The participants concluded that the objectives of the meeting were accomplished by the wealth of information exchanged in presentations and discussions. Summarizing, the participants came to the following conclusions:

- The training activities, expert missions, technical and consultancy meetings coordinated by the IAEA in the field of in situ approaches are very important services to MSs.
- The planned training workshop for 2019 will be useful to build the laboratory capacity of participating MSs.
- The current trends of in situ instruments were evaluated, regarding detector capacities and software for data processing and visualization.
- The constraints related to in situ methodologies were discussed.
- Maintenance services of the instrumentation as well as calibration of the instruments were discussed.
- Inter-comparison exercises are beneficial to MSs within the in situ working group.
- There are very few in-situ detectors in many MSs laboratories. Therefore, the donation of redundant/unused instruments might be useful.

- IN-SITU working group could be expanded for a wider group of end-users among MSs with annual meetings exchanging experiences and planning future activities.

These conclusions resulted in the following recommendations to the IAEA:

- To continue fostering information exchange through training workshops and fellowships, consultancy meetings and scientific visits, technical meetings, expert missions in the field of in situ/portable measurements and data visualization using geospatial mapping tools.
- To continue integration and extend the scope of collaborations of NSIL with other relevant IAEA departments and to promote the interaction with other IAEA initiatives (i.e. CGULS, ALMERA).
- To provide support for knowledge transfer on instrument maintenance, calibration and repair. Additionally, to facilitate MSs access to existing calibration pads for geological purposes worldwide or build new calibration pads in Seibersdorf laboratory.
- To support development of in situ instrumentations and measurement methodologies for aquatic environmental applications as well as for soil erosion assessment.
- To provide advisory services of upgrading old detectors (i.e. NaI crystals) with novel electronics and software adapting them for in-situ measurements for MSs.
- To initiate an inter-comparison exercise facilitated by the *IN-SITU* working group.
- To facilitate the possibility of sharing, donating and/or lending (for a pre-arranged period) available equipment to MSs.
- To consider the development of technical documentation of in situ approaches with case studies examples including outreach materials
- With the aim of promoting in situ techniques to the national authorities of the MSs it would be beneficial to organise Side event during the IAEA General Conference.
- IAEA should continue providing support to MSs upon their request, for field applications using *in situ* approaches for site characterization.

At large, the IAEA is recommended to continue the organization of activities (trainings and meetings) on subjects related to the use of portable instruments and advanced data interpretation techniques for radiological characterization of different types of sites, as well as to support requests from Member States within relevant TC projects for human capacity building.

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1. Overview

Radioactively contaminated sites exist all over the world and occurred due to past activities that were excluded from regulatory control or regulated, but not in proper way and accordance to prevailing international standards and recommendation. Contaminated sites that occurred due to nuclear and/or radiological accidents, can lead to the elevated exposure due to ionizing radiation to human and nonhuman biota.

Many factors must be taken into account with the aim to achieve a comprehensive characterization of environmental problems. Designing of an assessment program based on interdisciplinary approaches leads to solving a problem. At different stages of environmental radiological assessment large amount of data, including the nature, concentration and distribution pathways of the investigated contaminants of concern is required. To investigate, control and regulate a radiological contaminated site it is recommended to perform screening surveys of the area of interests using in-situ techniques. Using portable detectors instrumentation for an in-situ approach is an important alternative which leads to improvement the sampling strategies and to reduction of the costs of an analytical survey.

Environmental remediation projects involve activities as: (i) initial site characterization and selection of remediation criteria; (ii) identification of remediation options and their optimization, followed by subsequent development and approval of the remediation plan; (iii) implementation of the remediation plan; and (iv) post-remediation management. Following the completion of each of these main activities, a decision should be made about whether to release the area or part of the area for either restricted or unrestricted use, or to proceed to the next activity. Methodology of *in situ* approach have reached a high level of performance and offer certain advantages over other more traditional characterization procedures, such as:

- Fast determination of contaminant concentrations/activities in many spots/areas across the contaminated site, without time-consuming sampling and samples preparation procedures.
- Fine adjustment of the contaminant spatial distribution, followed with immediate real time identification of areas of interest ('hot-spot' areas), which allows further investigation of these areas with a better spatial resolution sampling.
- Cost reduction for the investigation of all the assessment stages, and remediation process. Larger size of the effectively inspected sample contributes to a drastic reduction of the time required for measurements and results and renders more representative results.
- Optimization of sampling strategies for more accurate laboratory analysis.

The use of *in situ* techniques in environmental monitoring and remediation strategies has increased lately. However, there is an uneven level of experience and access to such techniques in the IAEA Members States. It is highly beneficial that *in situ* methodology promotes and present to the MSs. It would be of great importance to develop comprehensive guidelines that can be useful for implementing site characterization approaches in the IAEA MSs.

The INSITU Working Group was created within ENVIRONET ⁽¹⁾, with the aim to produce a variety of products and services aimed at facilitating and increasing the exchange of information and experiences in the specific field of *in situ* methods for characterization of sites. The INSITU Working Group tends to build capacity in the different IAEA Member States and to facilitate the full implementation of remediation projects.

The Waste Technology Section (IAEA Division of Nuclear Fuel Cycle & Waste Technology within the Department of Nuclear Energy) fosters technology transfer, promotes information exchange and cooperative research, as well as builds capacity in Member States to manage radioactive wastes resulting both from the nuclear fuel cycle, nuclear applications and NORM related industries. Among other activities, the Section provides technical guidance aimed at supporting the management of legacy waste and environmental remediation actions at radioactively impacted sites.

The Nuclear Science and Instrumentation Laboratory (NSIL, IAEA Division of Physical and Chemical Sciences within the Department of Nuclear Sciences and Applications) support the IAEA Member States in the effective operation and maintenance of radiological instrumentation appropriate for their activities, including the application of nuclear spectrometry techniques in different fields. Great efforts have been made in recent years to the need of creating capabilities to support Member States in introducing the use of *in situ* measurement techniques to support environmental studies.

NEFW and NSIL have organized several activities aimed at developing a Mobile Unit that could be offered to the IAEA Developing Member States to support the radiological assessment of sites in environmental remediation-related projects. Several consultancy and technical meetings have been organized to outline recommendations and to demonstrate the capabilities of such a mobile unit. These efforts have been supported by the assistance of consultants from a variety of government agencies and institutions that perform similar work, including Instituto de Radioproteção e Dosimetria (Brazil), Commissariat à l'énergie atomique (France), Nuclear Energy Corporation (South Africa), Environmental Protection Agency (USA), SARAD GmbH (Germany), and Hellenic Centre for Marine Research (Greece). Several demonstration exercises have proven the usefulness of deploying the IAEA Mobile Unit for site characterization and training exercises upon petitions from IAEA Member States (Gabon, Azerbaijan - 2012; Kyrgyzstan - 2013; Kenya, Mexico, Azerbaijan - 2014; Argentina, Zambia, Japan, Nepal - 2016; Indonesia - 2017; Uzbekistan - 2018).

A comprehensive characterization of sites requires an interdisciplinary approach where many factors are considered to produce a proper assessment. An online course was developed to provide an introduction to *in situ* techniques and is available from ENVIRONET share point website in the IAEA CONNECT platform ⁽²⁾.

¹<http://www.iaea.org/OurWork/ST/NE/NEFW/WTS-Networks/ENVIRONET/overview.html>

²<http://connect.iaea.org/sites/connect-members/environet/insitutechniques/topics/t1.html>

2. Objectives

The purpose of the meeting was to highlight, review and discuss the state of the art portable nuclear instrumentation for in situ environmental monitoring including analytical methodologies. The following topics were included in the programme:

- Examination of capabilities and shortcomings for effective operation and maintenance of state of the art instrumentation and interpretation tools used for environmental studies;
- Discussion of practical training in the operation and effective utilization of portable nuclear instrumentation for environmental applications, including development of conventional and e-learning tools;
- Discussion and review of the role of national and international networks, including ENVIRONET and its INSITU Working Group;
- Consider and advise on the role of the IAEA in support of developing Member State's activities to effectively apply nuclear instrumentation for environmental and other applications.

3. Meeting activities and participants

The opening words of the Technical Meeting were given by Ms Meera Venkatesh, Director Division of Physical and Chemical Sciences (NAPC) and Mr Ridikas Danas, Head Physics Section IAEA-NA. The Technical Meeting was attended by participants from 10 MSs (Brazil, Bulgaria, Egypt, Kenya, Mongolia, Montenegro, Senegal, Serbia, Tunisia, Zambia), as well as by staff members from TEL, IAEA-EL and NSIL, IAEA-NA (see List of Participants in Annex 1). Two participants, from Ghana and Nigeria, due to problems travel arrangements, did not attend the meeting. The Agenda of the TM (see Annex 2) included individual presentations, discussion sessions, work in subgroups and a visit to the IAEA Laboratories at Seibersdorf.

The participants of the meeting agreed to elect Ms Hanne Diab (Egypt) as the Chairperson, and Mr Nivaldo Carlos Da Silva (Brazil) and Mr Ian Kaniu, as the rapporteurs of the meeting.

The meeting included the presentations from the participants. Each participant summarized results of their work in fields related to the topics covered by the meeting. Abstracts of each presentation are provided in Annex 3.

4. Highlights of the Technical Meeting

This section includes the relevant information gathered from the presentations of the participants and discussions.

Environmental characterization requires a wide range of competencies, from knowledge of available instrumentation, its operation, environmental sciences to Information Technology skills, such as data loading, cleaning, validation, analysis, visualization, mapping and dissemination.

The participants acknowledged the efforts of the NSIL for offering a variety of services aimed at facilitating and increasing the use of *in situ* techniques for characterization of contaminant of interest in the MSs. Representatives of the NSIL presented results and experience from previous site characterizations expert missions in MSs and explained that this kind of cooperation could be possible via TC projects or direct petition to Physics Section. The broad spectrum of available state-of-the-art instrumentation offers multiple choices to implement *in situ* surveys for different environmental case studies and surveys. *In situ* techniques have reached a high level of analytical performance and offer a number of advantages over other laboratory techniques, including fast determination of contaminant concentrations/activities, cost reduction for the investigations, and fast determination of the contaminant's spatial distribution.

Participants of the TM agreed that there is an uneven level of experience and access to *in situ* techniques across the IAEA Members States. It is of interest to identify targeted audience/participants for the training workshop in MSs. Taking that in mind, hands-on training on the use of portable detectors, measurements strategies, data handling and interpretation to support investigations related to different environmental problems will be set. Planned training activities for the 2019 in the field of *in situ* nuclear applications will be held in Hungary in cooperation with IAEA-TEL.

Radionuclide activity concentrations measurements are important part of environmental monitoring program worldwide. It is highly important for radioactivity measurements reported by different laboratories worldwide to yield traceable, accurate and comparable results which are accordance to ISO standards. Inter-comparison exercises are beneficial to MSs within the *in situ* working group and one such exercise could be carried out during the training workshop. In this case, it is assumed that each of the participants in the inter-comparison exercise, participates using his own instrumentation, while organisers e.g. NSIL will set up the inter-comparison exercise rules which should be followed.

The current trends of *in situ* instruments, detector capabilities and software for data processing and visualization were discussed. MSs noted that an ideal *in situ* system is one that has capability for both dose-rate and spectra measurements as well as GPS recording. It was however observed that manufacturers are not producing versatile instruments especially adaptable for research. MSs were informed about the role of IAEA technical officers in equipment specifications for TC projects to ensure that they meet the minimum requirements. Furthermore, it was observed that commercial software was not only costly, but also lacks various functionalities necessary for data processing and visualization. MSs were introduced to an open-source R markdown tool recently developed by IAEA NSIL. It was observed to be quite versatile with advanced capabilities (and possibility for future improvements) which are usually not available in a single commercial software. The tool was made available to MSs.

Geo-statistics-based interpretation of large data sets allows simulating a model that can be used to describe the statistical and geo-statistical variability of the measurements results, and to provide useful tools to represent an estimate of the distribution of the contaminants, to evaluate the volume of contaminated material and to support decision making in environmental remediation processes. The availability of open source resources for mapping and geo-statistics interpretation of results is a cost-effective alternative to reduce the costs of the projects and to foster further developments by the attracted community of users.

Most MSs reported that they lack detectors for in-situ measurements. It was thus concluded that the donation of redundant/unused instruments from IAEA or other MSs could be useful. MSs were informed that IAEA has in the past facilitated equipment transfer from MSs; an example was given of Ghana where IAEA facilitated the delivery and technical preparations for an accelerator from The Netherlands. Additionally, MSs were informed that IAEA is considering donation of unused equipment to MSs and is currently reviewing the donation procedure to make it less complicated and more transparent.

For IAEA MSs interested in *in situ* methodology it would be of great importance to develop comprehensive guidelines in the form of a technical document, which would consist/combined current knowledge and experience within the *in situ* approaches.

5. Recent developments on instrumentation and interpretation tools

5.1 Portable Radiation detectors for field measurements

Ionizing radiation can be measured through the physical and chemical effects of its interaction with matter. Field and laboratory methods are based mainly on the ionizing properties of radiation and the use of instruments that convert the radiation to electrical signals. Ionization chambers, proportional counters, Geiger-Muller tubes, scintillation counters, semiconductor detectors, thermo-luminescence detectors and various mechanical and chemical track detectors are used to monitor and quantify the α , β , γ and neutron radiation of the environment. The nature and character of the radiation governs the selection of a suitable detector.

Detectors are chosen depending on their sensitivity (efficiency) and the level of activity to be measured. If the identification of radionuclides is required, only detectors capable of producing a signal proportional to the energy of the detected photons or alpha particles can be used. Ionising radiation detectors are characterized by several features of performance. The main important features are the type of radiation that can be detected, efficiency, count rate capability and energy resolution. Before selecting an instrument, it is important to understand both the activity concentration values that are to be verified, the capabilities of the monitoring instruments and the characteristics of the potentially contaminated material. Some types of instruments are quite expensive, a factor that may limit their availability for a given study.

Radiation detectors can be classified following several principles. Some detectors are exposed to radiation during a long period of time (usually several days) in order to produce a significant effect, and the interpretation of this effect requires of additional processing. Since the recorded effect of radiation is cumulative, the measurement results are usually considered as 'passive' measurement technique. When the measurements are carried during shorter periods of time (from a few seconds to hours) and the interpretation is instantaneous, the

detectors are considered as producing 'active' measurements. Detectors can also be classified based on the effect produced in the detector material or in the type of response signal (counting or spectrometry). The table below summarizes the main characteristics of different types of detectors.

Table 1. Classification of radiation detectors

Detector denomination	Sensor material	Energy resolution	Active / Passive	Effect used for detection
Track edge	Film	None	Passive	Alpha particles produce damage (tracks)
Film dosimeter	Film	None	Passive	Chemical interaction (darkening)
Luminescence dosimeters	Special crystals / mineral	None	Passive	Electrons in the crystal's atoms are driven to higher energy states. Later luminescence is excited by either thermal (TLD) or optical stimulation (OSLD)
Ionization chambers	Gas	None	Active	Ionization of the gas and collection of charge from produced discharges
Geiger Müller counters	Gas	None	Active	Ionization of the gas and collection of charge from produced discharges
Proportional counters	Gas	Poor	Active	High voltage is limited as to have an intensity of the sparks proportional to the incident energy
Scintillators	Special crystals	Moderate	Active	Photons produce the emission of light in the crystal, which is then sensed by an additional device
Semiconductor	Semiconductor with different conductivity arrangements	High	Active	Pulses of charge are collected after the ionization of the semiconductor material

Advantages of in situ methodology for site characterization

In situ measurements are becoming popular due to the advantage of producing comprehensive, rapid and cost-effective measurement results. Laboratory methods have consolidated in general analytical practice due to the possibility of validating the accuracy of the measurement results following widely accepted protocols and standards. Cognizant of the

benefits of each of the approaches, both methods can be useful for specific needs of remedial action programs.

There are several considerations when designing a proper site characterization strategy for a remediation activity combined with the measurement and associated interpretation of the results. Some of them are given below:

- Rational characterization needs depending on the tentative goals of the remediation project.
- Inhomogeneity composition of samples and the level of concentration of contaminants are usually unknown.
- Heterogeneous spatial distribution of the common radioactive contaminants of concern.
- Need to investigate different environmental compartments (soil, water, biota) and to establish potential migration pathways and receptors.
- As a rule, a large amount of results are usually required to evaluate the status and extent of the contamination.

Sampling design

It is worth to note that collecting large amounts of samples for laboratory analysis might not necessarily produce useful information, since sampling in the site requires of previous knowledge (historical background). Therefore, and depending on the information available for a given site, different sampling strategies must be designed for laboratory analysis.

Similarly, the pathways to be followed and the spots to be selected must be defined for *in situ* measurements. The advantage is that the measurement strategy for *in situ* measurements can be always redesigned and additional measurements to be carried out, whereas laboratory-based studies in general can afford only limited re-sampling due to time and financial constraints.

Measurement sensitivity

Intrinsic efficiency of radiation detectors is proportional to the detector response signal and sensitive volume. Therefore, radiation detectors designed for laboratory analysis can have a larger intrinsic efficiency than that of the portable instruments, for which the needs for low weight and power consumption are a compulsory requirement.

However, the geometry efficiency in laboratory analysis is limited to the physical size of the sample, whereas in field measurements the effective sample size depends on the energy of the radiation and its attenuation in the media. This can be illustrated by the estimation of such volumes for gamma spectrometry analysis: in laboratory analysis the sample volume is limited to about one cubic decimetre, whereas for in-situ measurements it can reach several cubic meters. The latter leads to a significant gain in overall sensitivity, a considerable reduction in the time required for attaining similar counting statistics and the resulting gain in productivity.

Quality of results

In situ techniques are extremely useful to establish the spatial / depth distribution of the radioactive contaminants (including the identification of hot spots). In most of the situations, the more important information for a site assessment might be the distribution trends or the gradient in the measured values. 2D and 3D representation of the results can be of help to address remediation / clean-up actions and to optimize the costs of associated projects. When the activity or dose rate levels are needed for a verification of compliance to a given criterion (admissible exposure dose levels, compliance to a remediation criterion, among others), a very accurate determination is of less relevance, and *in situ* techniques might be the best choice in terms of rapid delivery of results and reduced costs.

Therefore, the evaluation of usefulness of *in situ* measurement results has to be made on the basis of how accurately the results represent the contaminant concentration levels and the pattern of distribution of the contamination in a given site.

Accuracy of results

Laboratory analysis has the advantages of reproducing the same conditions for the measurement of the unknown samples as assumed for the calibration, a better uncertainty for any individual result can be obtained. However, as it was commented above, there is always the risk of not having analysed a sample that fully represents the problem under study.

In situ techniques, although measuring a signal produced by a larger sample, are prone to differences in measurement geometry and other effects arising from uncontrolled environmental conditions. Variations in temperature and humidity may induce instabilities in the operation of portable instruments, thus producing alterations on the measurement. For example, shift in position of the photo peaks in gamma spectra might be caused by drifts in the operational parameters of the excitation source, and by changes in conversion gain in the pulse processing unit and the multi-channel analyser (MCA).

The calibration of portable detectors for surface measurements is made upon assumptions of flat surface and constant depth distribution of the activity, and consequently remains only as a relative measure and not as an absolute, traceable one. Rugged terrains can lead to significant departures from assumed measurement geometry, and vegetation and other absorbers such as snow cap or leaf litter on forest floors can significantly attenuate radiation. Surface measurements are influenced by the activity distribution through depth, which may vary from site to site. Therefore, borehole measurements are required to elucidate the depth distribution of the pollutants if required.

Complementarity of the laboratory and in-situ approaches

Laboratory analysis might serve to verify the accuracy of *in situ* results, or to make an unequivocal identification of radionuclides in the cases of complex contamination. The investigation of effects of contamination on the flora, fauna or the population usually requires of measuring relatively low activity levels, and the use of laboratory analysis is then the only alternative. A balanced combination of in-situ and laboratory based techniques is the ideal approach for performing a comprehensive assessment in complex environmental scenarios.

Main applications of detectors for in-situ measurements

Before selecting an instrument, it is important to understand both the activity concentration values that are to be verified, the capabilities of the monitoring instruments and the characteristics of the potentially contaminated material. Some types of instruments are quite expensive, a factor that may limit their availability for a given study.

Different models of Ionization Chambers, Proportional Counters, Geiger-Muller tubes, scintillation counters and semiconductor detectors are used to monitor and quantify activity and dose rate levels in the environmental measurements.

A screening of the probable extent of the contamination can be made by performing measurements of the *dose rate*, *exposure rate*, and *contamination levels* from the impacted land areas and structural surfaces.

In the case of surveying small areas where accidental spills of radioactive material are suspected or known, surface contamination monitors can be used, which are usually calibrated as to provide the measurement results in either count rate, exposure or dose rate values. The monitors are commonly based on Geiger Müller detectors and are easy to operate. There is always the possibility of defining a threshold level for audible or visual signalization in case of exceeding such levels.

In many cases the nature of the radioactive contaminants is known from the available background history on the nature of the facility, practice or accidental releases. However, it is always good to corroborate the type of radionuclides present at the site. Gamma emitting radionuclides can be identified by the discrete and well defined emission energies. Using in-situ *gamma spectroscopy*, scintillator- and semiconductor-based detectors can be used. New scintillators based on LaBr₃ and CeBr₃ crystals have a relative efficiency of about 11% but offer a comparatively better energy resolution than conventional NaI detectors, thus allowing determining the activity of different radionuclides in most of the cases (e.g. ¹³⁴Cs and ¹³⁷Cs photopeaks).

High purity germanium detectors are indispensable in the event of having a very complex composition of radionuclides (such as products from neutron or gamma activation). HPGe detectors have been recently used to determine the depth profile distribution of the contamination with NORMs based on the difference in activity of the radionuclides from uranium and thorium progeny due to changes in attenuation at different energies.

Radionuclides released to the atmosphere are usually attached to air particulate matter (APM) and aerosols. Since the *activity concentration in air* is usually low, the in-situ measurements are only effective in the cases of significant release of radionuclides, such as the cases of nuclear power plant accidents, situations which are not in the scope of this report. Gamma monitors are commonly set in networks of monitoring stations as to detect anomalous concentrations of radionuclides in such cases. Additionally, sampling stations are installed to collect *APM on filters* at different locations, which can be analysed near a facility using portable alpha/beta counting systems, and/or sent to laboratory for analysis.

Several instruments have been designed for *aquatic and sediment measurements*. Gamma spectrometers for aquatic measurements are based on tightly sealed constructions incorporating both the detector and the signal processing unit working in autonomous mode, and ensuring the longest possible autonomy in operation. Different efficiency calibrations are required for each of the cases. For the measurement of radioactivity in the water, solutions containing different radionuclides can be placed in artificial tanks and the measurement

results be compared with efficiency calculated by Monte Carlo simulation (Bagatelas et al., 2009; Tsabaris et al., 2008). For the measurement of underwater sediments (Androulakaki et al., 2015), the activity of the latter can be validated by laboratory measurements.

^{222}Rn and ^{220}Rn (Thoron) are odourless, colourless, inert radioactive gases with relatively short half-lives and associated decay series products. Consequently, its presence must be determined using techniques that depend on the radioactive properties either of radon itself or of its decay products. Although there are several techniques for the *measurement of radon* and its short lived progeny, the majority of them are based on the detection of the alpha particles from ^{222}Rn , ^{218}Po and ^{214}Po or a combination of any of these, or on the detection of gamma rays arising from the decay of ^{214}Pb and ^{214}Bi .

Scintillation cells and ionization chambers are available that allow the *detection of alpha particles in collected air*. These units can be operated in closed or flow through mode and, depending on the background and the chamber volume, they can achieve detection limits as low as 4 Bq/m³. More recently, surface barrier detectors arrangements have been designed to measure ^{222}Rn and ^{220}Rn in flow mode.

Borehole measurements allow determining the distribution of radionuclide activity through the depth. Such measurements are quite relevant to estimate the volume of tailings in buried repositories, as well as to determine the activity concentration. Borehole measurements can also be used to determine the depth distribution of ^{137}Cs in soil erosion studies. Bore-hole probes have been extensively used in oil and mineral prospection. With the advent of high density scintillation crystals, the size of the measurement head has been significantly reduced with no loss of efficiency.

5.2 Software tools for data representation

Integration of GIS information into the measurements

Plotting of data as maps or cross-sections is the traditional means of representing geological and geographical data. It is critical to distinguish between the factual or raw data (postings) and derived or interpreted representations of the spatial character of geochemical data. Contouring, colouring and shading can both illuminate and mask relationships in the data.

Geographic Information Systems (GIS) have proven the potential to provide considerable aid in spatial data analysis. When in-situ measurements are made with geo-referenced data, the results can be used to produce maps depicting the spatial distribution of the pollutants.

Portable systems for geo-referenced *in situ* measurements may be assembled from separate components:

- Global Navigation Satellite Systems (GNSS), such as GPS and/or GLONASS, receiver/antenna.
- Radiation meter with digital output.
- Mobile computer.
- Data collection software / firmware.

- Geographic information system (GIS) software.

The GPS (Global Positioning System) system allows anyone with an inexpensive GPS receiver to find their location to within 2 –15 m. This extraordinary technology is indispensable to any GIS project in that anyone can 'create' their own geospatial layers. There are two common groups of GPS instruments: navigation units and data loggers.

For every measuring system, a quality assurance plan has to be established, describing the program and actions to ensure a constant quality of measurements with an in situ gamma spectrometer.

The quality assurance plan includes, among other activities:

- Periodical quality checks (internal quality control).
- If possible, external calibration of the instruments by accredited services.
- Special qualification and training of the personnel, and
- Documented records of quality control activities.

Measurement instruments, whenever feasible, must be periodically sent for calibration to credited laboratories. It is recommended to use in every measurement campaign at least one instrument having calibration made by an accredited laboratory. The measurements obtained with other instruments can be re-scaled to the values of the calibrated instrument.

In the case of using different devices in a site characterization, it is always advisable to compare the readings among the different instruments at several locations. These locations can be selected during the measurements whenever different dose rate levels are found. Having measurement results for more than three of such locations allows verifying the linearity in the response of all the instruments within the interval of dose rate or activity levels found in the site. Differences not exceeding 25 % of relative bias for a given instrument measurement results can be re-scaled to those of the instrument selected for reference.

As each of instruments incorporates different models of GPS sensors, it is advisable to compare the coordinate readings across the instruments at selected spots. In case of observing noticeable differences for a given GPS unit, the coordinates can be re-scaled as to re-locate the measurement pathways into the maps.

In the absence of good quality geo-referenced maps, aerial photographs can be used. Measurements of the GPS readings must be performed at locations than can be later easily identified in the photographs or in the unreferenced maps. Such spots must be selected as close as possible to the opposite vertices of the surveyed area (north-east, south-west or north-west, south-east). The images can then be re-scaled from pixels to GPS coordinates.

Data interpretation and 2D/3D representation of results

Fully-processed gamma ray survey data can be presented in a variety of ways to enable interpretation of radionuclides profiles and grids. The traditional presentation methods, such as profiles and contour maps, have their advantages, and are still in common use today.

Although some visualization methods can be considered as routine in the presentation of surface characterization data, none of the individual methods are universally applicable to all gamma ray mapping applications. In general, one should experiment with different methods to find those that are optimally suited for a given interpretation.

The most common way to present data is in a surface map form, using Geographic Information Systems (GIS). A map format can include topography, representation of surface water flows, buildings, highways, known mines and so forth as background picture to give the environment context of measures and results. Maps from the surveyed areas must be available and properly geo-referenced. They can be obtained from various providers or from libraries included in several dedicated software (ARCGis, Vertical Mapper, among other). When possible, studying the evolution in time of a site through satellite views is a great source of information.

Then according to the objective of the survey, a sampling strategy can be planned as to estimate how long the surface characterization may take. All of the following patterns may be combined and used iteratively in order to better fulfil the evaluation objectives.

Common sampling plans are: real time acquisition (short-time acquisition of data (every 1 to 10 seconds) which allows to perform rapid identification of areas of interest where counting rate/ dose rate); regular grid (usually long-time acquisition survey which provides finer results, essential for radionuclides identification); circular grid (usually designed to characterize a site after an atmospheric incident, the extent of the contamination may be more important in this particular); random (used for statistical tests essentially).

Data validation

The data sets need to be carefully inspected to validate the usability of the measurement results. Data validation shall incorporate different actions, including:

- **Coordinate validation:** The data sets have to be thoroughly examined to correct positioning uncertainties, using PDOP (quality of GPS) or any accuracy information in combination with background map or visual localization. In open areas, the GPS signal is mostly stable and needs no attention. Approaching high facilities, buildings with glass fronts or dense forests may affect the correct reception of the GPS signal and then it is important to ensure that the data points are not misallocated. This validation can be easily done by observing the position of couple of data which were collected one after the other.
- **Incorrect values:** The data sets have to be thoroughly examined to exclude the cases presenting missing or wrong values (probe saturation or probe failure for instance). This validation can be performed by analyzing graphs such as the histogram of scatterplot where outliers are usually isolated.
- **Detection limits:** Values reported as below the detection limits shall be considered as valuable information. Depending on the intended processing algorithm the values can be replaced by either the detection limits, or by different fractions of the detection limits.
- **Duplicates:** Results that can be considered as duplicates (e.g. measurements performed within a distance less than the targeted spatial resolution in a grid plan)

must be removed or replaced by a single value (the minimum, the maximum or the average of the defined cluster), depending on the targeted interest. If the interpretation intends to be conservative, the average of such two neighboring measurements can be adopted. In case of radiation safety concern, it is preferred to use the maximum of the two values.

2D Data analysis and interpretation

Statistical interpretation of the results from *in situ* measurements includes several actions, such as:

- Simple statistical treatment, to reveal minimum and maximum values, as well as the variability of the data.
- Correlation among different variables (if more than one has been measured).
- Understanding the spatial variability of data.
- Interpretation and representation of the results.

Simple Statistics

The minimum, maximum and standard deviation of the values characterize the site comparing with background levels or with expected verification criteria. The histogram displays adjacent rectangles that are erected over an interval, with an area equal to the frequency of the measure corresponding to the interval. The representation of the data population in histograms allows identifying the background level of the studied data on the investigated site, as well as to explore the overall data distribution. The latter is of value as to have an initial estimate of the data fraction (area surveyed) that could be exhibit elevated readings (if any hot spots appear). When facing a radiological contamination, the statistical distribution is expected to be strongly skewed. Log scale or magnifying at small range of values may facilitate the histogram analysis.

When there is no contamination on the investigated area, the histogram tends to look like a Gaussian bell curve, where values vary around the mean of the data set. Scatter plots are useful for analysing the inter-relationships between radionuclides and for identifying trends and clusters. Anomalous radionuclide signatures, for example, can often be recognized as distinct clusters. Interpreters should be aware, however, that there is always greater scatter at higher concentrations of the radionuclides.

Exploration of spatial variability

Experimental variogram is the key element of geostatistical data processing. It represents the variability of the measurement values according to the distance between each pair of data points. Such dependence can be used to infer some information from the spatial structure of the data set which describes the phenomenon, if there is one present. Several scale structures may be identified, depending on the extent of the contamination of the investigated site.

The variogram can be also used to assess if an adequate sampling plan has been performed. The knowledge of the data variability can be improved if additional measurements are performed, in order to smooth as much as possible the trend of the spatial

structure. Attention has to be paid specifically for variability at small scale as it will impact interpolation results.

Each dataset leads to a different experimental variogram but they tend to follow a usual pattern. In the case of well-identified and bounded surface contamination, the variogram should have a low Y-intercept and reach and stabilize at a certain sill. This reproduces the physical fact that close data points tend to have a similar value, then considering data points farther one from another, the difference of the values will be likely to be greater until getting no correlation at all.

This approach highlights the fact that a reasonable minimum distance between data points is required in case of regular grid, in order to be able to capture the spatial structure of the dataset. Nugget effect (non-negligible variability at small scale) occurs in the experimental variogram when close data points have very different values, usually due to an isolated hot spot. It may also come from not accurate location, detector statistical counting fluctuation (too short counting time), variation of measuring conditions (distance between detector and measured surface), variation of measured soils (with different background levels). While on field, an efficient solution is to collect more data around the hot spot in order to know the boundaries and the precise short-scale behaviour around it. For more thorough analysis, the variogram cloud sometimes needs to be inspected to identify precisely which data points are outliers, affecting the spatial structure. The experimental variogram needs to be fitted to a mathematical curve. Exponential, spherical and cubic models are usually used to reproduce the spatial structure of radiological contaminations.

Interpretation and representation of results

A number of simple interpolation methods, such as inverse distance weighting, bilinear interpolation and nearest-neighbour interpolation, are well known. Geostatistical data processing goes beyond the pure deterministic interpolation by considering the studied phenomenon at unknown locations as a set of correlated random variables and taking the spatial structure of the phenomenon (variogram) into account.

An open source-based tool applicable to a diversity of relevant user cases, implemented through a series of template R scripts and R notebooks [file:///C:/Users/win10/Desktop/TM%20on%20Instrumentation/Presentations/TRAINING%20WORKSHOP-%20Seibersdorf,%2026-30%20Nov%202018_no_API.html]. R software is a state-of-the-art free and open-source software analytical platform widely used by a very large community of users and contributors today in domains like data science, statistical analysis, environmental mapping and machine learning, among other fields. This approach increase awareness regards to widely used and state-of-the-art analytical platforms actively used in Statistics and Data Science in general. The R platform is particularly relevant as it provides widely used packages relevant for in-situ results interpretation and visualization.

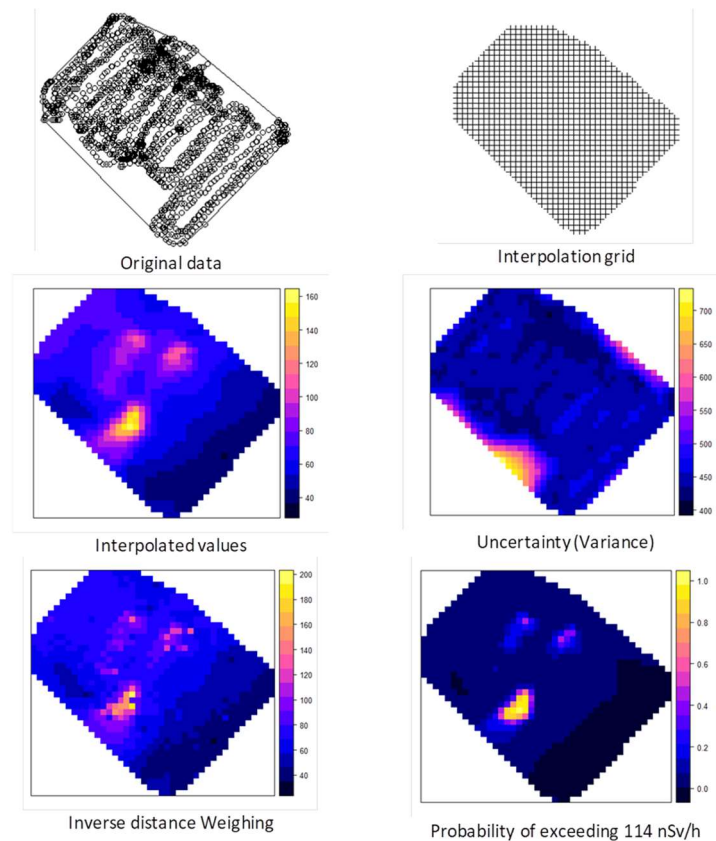


Figure 1: Representation on maps using R software

Estimation maps

Geostatistics based interpretation of results delivers 2D/3D accurate and reliable results. The estimation map is obtained by using ordinary Kriging method (developed to be the best linear and unbiased interpolator). This represents the general trend of the studied variable. Adapting the color scale and the intervals of values is essential in order to highlight a result. The map produced using the kriging method will highlight areas of interest which can originate from actual radiological contamination.

Uncertainty maps

An associated map representing the kriging variance identifies under-sampled areas that shall require additional sampling to reduce the uncertainty arising from the interpolation with insufficient population statistics. If the uncertainties are too numerous and wide, this means that the sampling strategy did not comply with the extent of the investigated site. More data are needed, the pathway of a real time acquisition strategy should have been tightened, or the size of a systematic grid should have been reduced. The first mapping should however orientate the priority areas.

Confidence intervals maps

A confidence interval map is provided as well as to represent the width of the interval which includes a given value with some defined level of confidence. Such map allows setting the areas presenting a remarked change in the values: in the vicinity of hot spots, or in

transition areas between low and high contamination levels. This map is also helpful to decide how to prioritize areas for further investigation due to the variation of the measurements. The color scale shows from blue to red the width of the confidence interval where the bluer is the better.

Different probability-based maps

A probability map presents the local risk of exceeding a defined level of contamination threshold. Several values of the latter are usually chosen to compare the extent of highlighted areas, considering various levels of decontamination scenarios or levels of criteria of acceptance, in the case of remediated areas. Such maps can be a good communication result to prove a site is radiologically clean or has been properly remediated, according to the objective of the characterization.

6. Recent and future activities of the INSITU working group

A number of recommendations have been provided by participants of previous meetings organized within the INSITU working group, including a Workshop to outline training programs on In Situ Radiological Characterization of Sites ((F1- TM-49821, May 2015) and a Technical Meeting on the Development of Nuclear Instrumentation for In Situ Environmental Monitoring Programmes (F1-TM-49618, December 2015). In April 2017 a Joint ICTP-IAEA Workshop on Environmental Mapping: Mobilizing Trust in Measurements and Engaging Scientific Citizenry was organized in ICTP Trieste with the participation of more than 30 young specialists from more than 20 IAEA Member States.

The Training Workshops dedicated to *in situ* methodology was implemented by NSIL as part of its projects and was organized in November 2018. In the future Regional or National Technical Cooperation projects could benefit from training activities such this, which promote and spread knowledge in the *in situ* field.

The activities of the INSITU working group could be extended beyond the scope of the ENVIRONET. Other IAEA units, such as the IAEA Environmental Laboratories (NAEL), Nuclear Applications Department and the Waste and Environmental Safety Section of the Department of Nuclear Safety and Security could benefit from the support of the INSITU Working group. The introduction of *in situ* techniques could be introduced in the activities of a large number of IAEA Technical cooperation projects.

7. Conclusions

The following conclusions are provided from the participants:

- The training activities, expert missions, technical and consultancy meetings coordinated by the IAEA in the field of in situ approaches are very important services to MSs.
- The planned training workshop for 2019 will be useful to build the laboratory capacity of participating MSs of this meeting.
- The current trends of in situ instruments were evaluated, regarding detector capacities and software for data processing and visualization.

- The constraints related to in situ methodologies were evaluated.
- Maintenance services of the instrumentation as well as calibration of the instruments were evaluated.
- Inter-comparison exercises are beneficial to MSs with in the in situ working group.
- There are very few in-situ detectors in many laboratories of MSs. Therefore, the donation of redundant/unused instruments might be useful.
- IN-SITU working group could be expanded for the wider group of end-users among MSs with annual meetings exchanging experiences and planning future activities.

8. Recommendations to IAEA

The Role of IAEA in Supporting Member States are the following:

- Supporting missions in MSs related to in situ/portable field measurements and mapping
- Testing of equipment and recommendations to MSs for equipment requisitions
- Development/adaptation of commercial equipment for in situ measurements
- Training and building capacity of in situ and mapping techniques for MSs

Recommendations to IAEA are the following:

- To continue fostering information exchange through training workshops and fellowships, consultancy meetings and scientific visits, technical meetings, expert missions in the field of in situ/portable measurements and data visualization using geospatial mapping tools.
- To continue integration and extend the scope of collaborations of NSIL with other relevant IAEA departments and to promote the interaction with other IAEA initiatives (i.e. ENVIRONET, ALMERA).
- To provide support for knowledge transfer on instrument maintenance, calibration and repair. Additionally, to facilitate MSs access to existing calibration pads for geological purposes worldwide or build new calibration pads in Seibersdorf laboratory.
- To support development of in situ instrumentations and measurement methodologies for aquatic environmental applications as well as for soil erosion assessment.
- To provide advisory services of upgrading old detectors (i.e. NaI crystals) with novel electronics and software adapting them for in-situ measurements for MSs.
- To initiate an inter-comparison exercise facilitated by the *IN-SITU* working group.
- To facilitate the possibility of sharing, donating and/or lending (for a pre-arranged period of time) available equipment to MSs.
- To consider the development of a technical documentation with the support of a consultancy meeting to present in situ approaches with case studies examples including outreach materials and eventually side event during the GC.
- IAEA should continue on request providing support to MSs for field applications using *in situ* approaches for site characterization.

REFERENCES

Annex 1. List of participants

Annex 2. Agenda of the meeting

Annex 3. Abstracts of participant presentations

- Brazil
- Egypt
- Greece
- Kenya
- Mongolia
- Montenegro
- Senegal
- Serbia
- Zambia

Annex 1

Participants of Technical Meeting on Current Trends and Developments in Nuclear Instrumentation

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4	Ms CUJIC, Mirjana	Vinca Institute of Nuclear Sciences P.O. Box 522 11001, BELGRADE, Serbia cujicm@vinca.rs
5	Ms DIAB, Hanan	Radiation Protection Department Egyptian Nuclear and Radiological Regulatory Authority, Egypt
6	Mr DA SILVA, Nivaldo Carlos	Brazilian Commission for Nuclear Energy CNEN, Brazil
7	Ms SUKHBAATAR, Erdenetsetseg	National Agency for Meteorology and Environment Monitoring NAMEM, Mongolia
8	Mr MANSOUR, Oueslati	Technopole Sidi Thabet, TUNISIA
9	Mr JOVANOVIC, Slobodan	Centre for Nuclear Competence and Knowledge Management (UCNC), Montenegro
10	Mr LUBABA, Douglas	National Institute for Scientific and Industrial Research, Zambia

11	Mr KANIU, Ian	Department of Physics Univeristy of Nairobi, Kenya
12	Mr TRAORE, Alassane	Insitute of Nuclear Techniques for Applications (ITNA), Senegal
13	Ms DIMITROVA, Petya	Kozloduy Nuclear Power Plant Safety Division, Bulgaria

Annex 2

Agenda of Technical Meeting on Current Trends and Developments in Nuclear Instrumentation

IAEA Headquarters,
Vienna, Austria, C C0440/C0437
3 – 7 December 2018
AGENDA

Monday 3		
08:30 – 9:30	Registration	
9:30 – 10:00	Official Opening:	<i>Ms Meera VENKATESH, Director Division of Physical and Chemical Sciences (NAPC), IAEA- NA Mr Francois FOULON, Head Nuclear Sciences and Instrumentation Laboratory (NSIL), IAEA-NA</i>
10:00 – 10:15	Brief self-introduction of the participants	
10:15 – 10:30	Organizational arrangements Presentation of the Workshop Agenda, Election of Chairperson and Rapporteurs	<i>Mr Natko SKUKAN NSIL, IAEA- NA</i>
10:30 – 11:00	Coffee Break	
	Session 1: IAEA support to nuclear instrumentation and field measurements	
11:00 – 11:15	The NSIL support to IN-SITU working group and field characterization demonstrations	<i>Mr Natko SKUKAN, NSIL, IAEA-NA</i>
11:15 – 11:45	TEL activities in support of environmental studies	<i>Mr Manfred GROENING, TEL, IAEA-EL</i>
	Session 2: Overview of in-situ vs laboratory techniques	
11:45-12:15	New Trends on the Assessment of the Environmental Radioactivity	<i>Ms Hanan DIAB Radiation Protection Department Egyptian Nuclear and Radiological Regulatory Authority, Egypt</i>
12:15 – 13:45	Lunch Break	
13:45 – 14:45	Challenges for NORM residue characterization: in situ vs lab measurements	<i>Mr Nivaldo Carlos DA SILVA Brazilian Commission for Nuclear Energy CNEN, Brazil</i>
14:45-15:15	Environmental radiation monitoring in Mongolia	<i>Ms Erdenetsetseg SUKHBAATAR National Agency for Meteorology and Environment Monitoring NAMEM, Mongolia</i>

Monday 3		
15:15-15:45	<i>Coffee break</i>	
	Session 2: Overview of in-situ vs laboratory techniques (cont.)	
15:45-16:15	Estimation of natural radioactivity in local and imported granite used as building materials in Tunisia	<i>Mr Oueslati MANSOUR, Technopole Sidi Thabet, TUNISIA</i>

Tuesday 4	Session 2: Instrumentation and software for in-situ techniques	
09:00 – 09:30	An Outline of the Broadly Applicable ANGLE 4 Software for Advanced Gamma Spectrometry	<i>Mr Slobodan JOVANOVIC Centre for Nuclear Competence and Knowledge Management (UCNC), Montenegro</i>
09:30 – 10:00	Analysis and Implications of Less than Unity Calibration Factor for Radiation Survey Meters - Case Study with Calibration Factor for an ATOMTEX AT1117M Radiation Survey Meter	<i>Mr Godfred Kodzo QUASHIGAH National Nuclear Research Institute (NNRI) Ghana Atomic Energy Commission (GAEC), Ghana</i>
10:00 – 10:30	Status of implementation state of the art In-situ nuclear techniques for environmental studies around a nuclear facility centre in Nigeria	<i>Mr Muhammad Auwal MUSA Centre for Energy Research and Training, Ahmadu Bello University, Nigeria</i>
10:30 – 11:00	<i>Coffee Break</i>	
11:00 – 11:30	In-situ radon gas measurement in water using a portable Radon Monitoring Instrument; The challenges experienced	<i>Mr Douglas LUBABA, National Institute for Scientific and Industrial Research, Zambia</i>
11:30 – 12:00	The IAEA R-markdown for creation of dose-rate and activity concentration maps	<i>Mr Roman PADILLA ALVAREZ, NSIL, IAEA-NA</i>
12:00 – 13:45	<i>Lunch Break</i>	
	Session 3: Application studies	
13:45 – 14:15	Applications of an in-situ medium resolution gamma-ray spectrometer for continuous monitoring of radioactivity in aquatic ecosystems	<i>Mr Christos Tsabaris Hellenic Centre for Marine Research, Institute of Oceanography, Attica, Greece</i>
14:15 – 15:15	Utility of GPS-Enabled Portable Detectors in the Assessment and Mapping of Kenya's High Background Radiation Areas	<i>Mr Ian KANIU, Department of Physics University of Nairobi, Kenya</i>
15:15 – 15:30	<i>Coffee Break</i>	
15:30 – 16:00	Mapping of dose rate and heavy metal distribution in in Zircon mining areas using a portable XRF analyser and GIS	<i>Mr Alassane TRAORE, Institute of Nuclear Techniques for Applications (ITNA), Senegal</i>
	Interest on Current Trends and Developments in Instrumentation	<i>Ms Mirjana CUJIC Institute of Nuclear Sciences VINCA, Serbia Ms Petya DIMITROVA, Kozloduy Nuclear Power Plant Safety Division, Bulgaria</i>
16:00 – 17:00	Technical Discussion on presentations	

19:00 -	Social event
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Wednesday 5	Session 4: Current trends in instrumentation and techniques	
09:00 – 10:30	Round Table: Instrumentation and techniques	Moderator: Mr Nivaldo Carlos DA SILVA
10:30 – 10:45	Coffee Break	
10:45 – 12:10	Round Table: Software tools for mapping	Moderator: Mr Roman PADILLA-ALVAREZ
12:00 – 13:30	Lunch Break	
13:30 – 14:15	Transportation to Seibersdorf Departure point: Airport bus stop	
14:15 – 16:00	Visit to NSIL and TEL laboratories	
16:00 – 16:45	Transportation to Vienna Departure point: Seibersdorf Main Gate	

Thursday 6	Session 5: The role of IAEA in supporting MSs	
09:00 – 10:15	Round Table: The role of IAEA in support of MSs Moderator: Mr Natko SKUKAN	
10:15 – 10:30	Coffee Break	
10:30 – 12:15	Round Table: Future activities of the INSITU Working Group Moderator: Mr Roman PADILLA-ALVAREZ	
12:15 – 13:45	Lunch Break	
	Session 6: Drafting of Meeting report	
13:45 – 14:00	Discussion on report structure and creation of working groups	Mr Natko Skukan, NSIL, IAEA-NA
14:00 – 17:00	Work in groups	

Friday 7	Session 6: Drafting of Meeting report	
9:00 – 10:15	Presentation of contents drafted by the working groups	
10:15 – 10:30	Coffee Break	
10:30 – 11:30	Discussion of conclusions and recommendations	
11:30 – 12:00	Closing remarks	

Annex 3

Abstracts of participant presentations

Egypt:

NEW TRENDS ON THE ASSESSMENT OF THE ENVIRONMENTAL RADIOACTIVITY

D. Abdul-Aziz, H. M. Diab

Egyptian Nuclear and Radiological Regulatory Authority (ENRRA), Cairo, Egypt

The Egyptian monitoring programme was established on 1987 focus on determination of natural and anthropogenic radioactivity all over the country. A radiological baseline map had been evaluated through the routine monitoring by sampling the main environmental compartments (soil samples, bottom samples, airborne particulates, surface water, drinking water and plant samples).

The use of in-situ techniques in environmental monitoring has increased during the last years. In emergency situations time to assess the contamination is important, so, in-situ direct measurements are used. The in-situ measurements, although quick and relatively inexpensive, are affected by such things as environmental conditions and soil inhomogeneity, which make interpretation of the data difficult. These effects can be minimized by laboratory analysis of soil samples, but the process is slow and more expensive. The use of in-situ techniques in environmental monitoring will eventually have in place a proper infrastructure and technologies for radiological characterization of the sites in a timely, safe and cost-effective manner at facilitating and increasing the exchange of information and experiences in the specific field of in-situ methods for characterization of sites.

At present, analytics and environmental monitoring are among the most dynamically developing new trends in environmental radioactivity analysis. The pursuit of getting the complex information on environmental quality leads to developing new methods and analytical techniques. These trends can be classified into two basic groups; development of new methodological procedures and new achievements in construction of measuring instruments (instrumentation).

One of the missions of the Central Laboratory for Environmental Radioactivity Measurements Inter-comparison and Training (CLERMIT) on monitoring the radiological hazard associated with radioactive effluents from nuclear medicine discharges, NORM's releases into the environment and with contaminated scrap metal, among others. Before applying the procedure to field measurements, a laboratory calibration procedure was performed to HPGe using MCNPX model.

A model of Canberra N-type detector with 68.5 mm length, radius and core cavity with 4.55 mm radius and 59.8 mm height as shown in figure 1, was designed to determine the Full Energy Peak Efficiency (FEPE) curve. The detector has a Be end-cap window with 0.5 mm thickness. For a precise degree of accuracy, several factors in the response of detection system such as interferences in spectra and characteristics of background parameters were taking into consideration. A polypropylene cylindrical container with 6.40 cm diameter, 2 ml thickness and 7.8 cm height is the standard geometry container used in the lab. The efficiency curve measured experimentally using four calibration point sources (Ba-133, Co-60, Na-22 and Cs-137) were compared with the corresponding computational ones, obtained by the

Monte Carlo simulation (MCNPX) model. The method is then used to analyze unknown samples with different matrix materials. The coincidence summing effects due to non-single gamma-emitters is negligible considering their experimental uncertainties (3-5%).

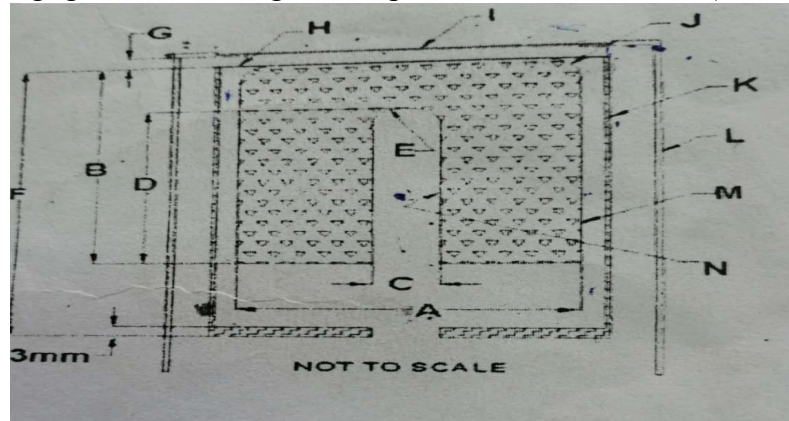


Figure 1: Schematic view of the hpGe detector

The gamma emitted from standard gamma point sources with known original activity and manufacture, data of the calibration, the activity is given by the following expression:

$$A = A_0 e^{-\lambda t} \quad (1)$$

where A is the activity present after time (t) has passed, A₀ is the initial activity of the source, λ is decay constant; has a reciprocal unit of time and t is time. The gamma spectra were analyzed, and net areas under the gamma peaks (total counting) for each one of the gamma energies considered were determined. The efficiency was calculated according to the following equation:

$$\varepsilon(E) = \frac{N}{A \rho t} \quad (2)$$

where N is a net peak area, ε(E) is the full energy peak efficiency, E is the gamma energy of source, A is the activity (Bq), ρ is the absolute γ-ray emission probability, t is the elapsed time. The efficiency calibration curve was fitted to a polynomial function in order to obtain the most accurate values.

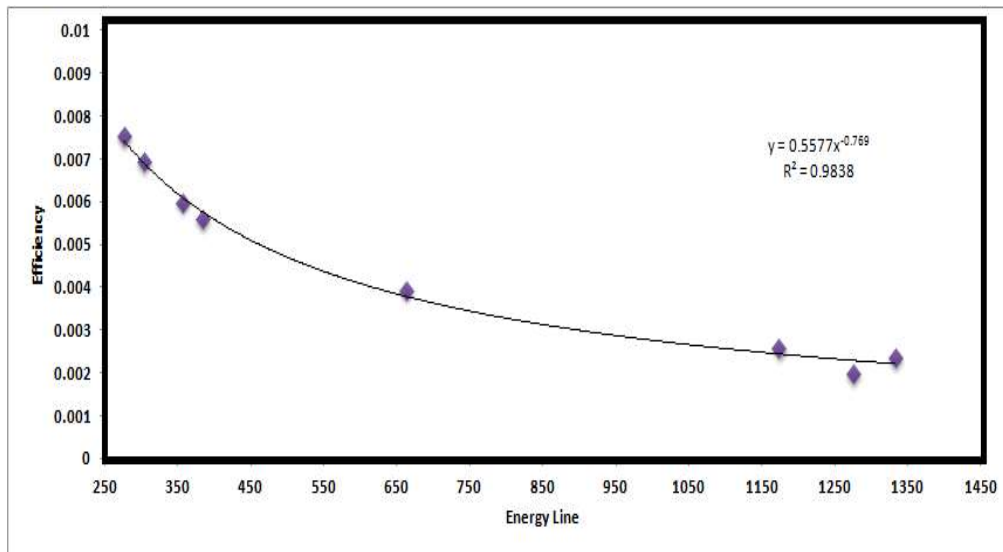


Figure2: Experimental efficiency curve for point reference sources (Ba-133, Co-60, Na- 22 and Cs-137)

The measurements performed and their comparison with the computational results are obtained are presented. The agreement between calculated and experimental efficiencies is calculated and the average ratio is 1.001. From the data obtained, using theoretical modeling (MCNPX code) for in-situ measurements will improve the efficiency calibration of high purity germanium detectors.

Greece:

APPLICATIONS OF AN IN-SITU MEDIUM RESOLUTION GAMMA-RAY SPECTROMETER FOR CONTINUOUS MONITORING OF RADIOACTIVITY IN AQUATIC ECOSYSTEMS

C. Tsabaris, E. Androulakaki, F.K. Pappa, S. Alexakis, D.L. Patiris

Hellenic Centre for Marine Research, Institute of Oceanography, Attica, Greece

Abstract

A new medium resolution gamma-ray spectrometer is developed and applied for measuring radioactivity in aquatic environments. This apparatus named GeoMAREA is designed for qualitative and quantitative radionuclide measurement in aquatic environments with maximum depth of deployment 600m. A special software development to support (near) real-time applications as well as to provide sequential data for continuous monitoring in a stand-alone mode. The spectrometer was calibrated first using point sources for energy, energy resolution and efficiency. The system offers activity concentrations of all detected gamma-ray emitters in Bq/m³ using the marine efficiency calibration (which is reproduced via the MCNP5 code). Two experimental points were used for validating the theoretical estimation along with gamma-ray energy by diluting two reference sources (¹³⁷Cs, and ⁴⁰K) in a special tank and acquiring for specific period of time for background and foreground spectra. The subsea detector is tested in a region where submarine groundwater discharge takes place in a closed aquatic system (Anavalos, Kyberia, Greece). A first estimation is given for the intrinsic background of the crystal itself at the emission energy area of ⁴⁰K.

1. Introduction

The in-situ method has been applied in many countries of the world during the last decades for monitoring, mapping and emergency applications. The biggest advantage of the in-situ methods is the rapid output of data analysis and characterization of the area in a cost effective manner. In most cases low resolution crystals (especially NaI) are widely used to continuously monitor the marine radioactivity [1-3]. The last years a lot of effort has been made to use LaBr₃ crystals but the high intrinsic radiation does provide qualitative results for ⁴⁰K which is the major radionuclide at the sea and key parameter for calibration purposes. The implementation of CeBr₃ based systems is increasing [4, 5] but they have not yet been applied in the marine environment.

2. History of the area of deployment

Nafplion and Argos are still facing difficulties with their water resources and there were no any implementation plans after the Water Crisis at 2007, although important sectors such as tourism and agriculture affect dramatically the availability of water resources in the specific area. One of the key issues of the EU Water Framework Directive 2000 is the Integrated Water Resources Management (IWRM) approach which has as main goal to manage and

control the water resources effectively and to prevent the water scarcity in a long-term basis. The actual name of the springs in the area is that of “Micros Anavalos” and “Saint George Springs”. Next to the Dini springs, which are located very close and away from the coastline are called Genesion, and Apovathmi. The water is discharged in the coastal zone of the specific area with an origin from Nestani sinkhole. The underground hydraulic connection, which was known to ancient Greeks, was verified with tracing experiments during the eighties. The connection between the sinkhole of Arcadia Plateau and the three major karstic springs of Argolis is depicted schematically elsewhere http://geonet.geo.auth.gr/ege2004/articles/GA1_160.pdf.

3. Detection system description

The marine sensor was developed for measuring in-situ the activity concentration of gamma-ray emitters in the marine environment using medium resolution crystal and digital electronic units. It is characterized by: capability to offer free-of-error continuous functionality; pluggable watertight cabling system for real time data transmission in case of operation at a buoy; high efficiency due to the detection crystal and to the minimum gamma-ray absorption in the enclosure material. Along with the sensor, a methodology has been developed (by using simulation codes and laboratory experiments) to convert the acquired gamma-ray counts to quantitative activity concentrations (in absolute units Bq/L or Bq/m³), even for low level radioisotope concentrations. The combination of the state-of-the-art in situ gamma-ray underwater medium resolution sensor with the reliable quantification methodology renders GeoMAREA a gamma-ray spectrometer which is capable of performing measurements for different applications in the marine environment.

The system has been designed for aquatic applications at depths up to 600 m. During its development phase it has been tested and deployed in the laboratory and in Mediterranean Sea for geophysical and radioecology studies. Intercalibration exercises have also been performed ensuring the reliability and the quality of the results using in-situ and lab results from the same environment.

GeoMAREA detection system has small dimensions (40 x 10 cm), allowing easily transportation worldwide. It is packed in typical suitcase along with all necessary auxiliary instrumentation (cables, specific application platform and housing of the battery pack) and it can be easily manipulated in the field.

4. Deployment options

GeoMAREA can be installed on floating measuring systems (buoys) for continuous operation in the marine environment and the data can be either transmitted in real-time mode to any operational centre or can be saved in an internal memory. The detection system provided data every specific time lag (user adjusted) Alternatively, GeoMAREA operates autonomously supplied by underwater battery packs. Furthermore, GeoMAREA may provide count rates in sequential mode for specific energy window. The applications areas are mainly focused to support decision making policies via the use of an in-situ detection system optimized for radio-ecology purposes though routine monitoring and emergency tasks. In coastal zone where nuclear power and waste processing plants operate (continuous monitoring and early warning) such detection system may provide significant information for the levels of radioactivity and pollution assessment for site characterization (especially close to nuclear and non-nuclear industry. Another application for such system deployment is the detection of energy resources via the monitoring of natural radioactivity for hydrocarbons exploration activities. Radioactivity of rainwater measurements are also encouraged for meteorology purposes for estimating the height of the cloud using NORM progenies and cosmogenic radionuclides. A lot of studies are also planned to monitor radon progenies in areas where gas

emanation activity takes place in many areas of interest such as submarine faults, volcanoes and cold seeps while submarine groundwater discharge is qualified and quantified using as tracers radon gas and natural radionuclides.

5. Preliminary results

The radioactivity detection system GeoMAREA is deployed in combination with temperature and salinity meters. The measurements of radon progenies were performed using the GeoMAREA subsea detection system, while the conductivity/temperature (CT) data loggers were used to monitor the temperature and salinity in the groundwater spring. The temperature and conductivity/salinity sensors (CT) were internally battery powered, whereas the GeoMAREA system was powered by a custom-made underwater battery which keeps the detector operable for about 35 days. The installations and the deployment of the whole platform was performed by the Radiomariners' group of HCMR. The data exhibited high concentration of radon progenies (from 20 till 50 kBq/L) and there well correlated with ^{40}K measurements. The ^{40}K is the tracer for seawater while radon progenies (^{214}Pb , ^{214}Bi) are adequate tracers for groundwater sources. The combination of the above tracers provided significant information for the mixing zones of the whole submarine groundwater discharge system.

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Kenya:

UTILITY OF GPS-ENABLED PORTABLE DETECTORS IN THE ASSESSMENT AND MAPPING OF KENYA'S HIGH BACKGROUND RADIATION AREAS

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The use of products containing naturally occurring radioactive materials (NORM) such as minerals, rocks, laterite, sand, clays, etc. especially from high background radiation areas (HBRA) is widespread, but they are not subject to radiological quality control in Kenya. As a result, exposure to ionizing radiation may be increased and thus radiological risks need to be assessed in order to inform radio-protection policy and regulatory framework. Compared to laboratory based techniques, mobile gamma-ray spectrometry offers low-cost, rapid and spatially representative radiometric measurements for rapid assessment of such exposure in the rugged terrestrial environment. This is because in mobile gamma ray spectrometry, the detector is placed over the ground surface thus measuring radioactivity directly with minimum photon attenuation over an area of several meters with reduced sampling times, making it possible to perform extended field measurements. Furthermore, the high spatial resolution realized in the measurements enables the assessment of environmental radioactivity in greater detail and precision. In this work we present the Kenyan experience on the use of low cost nuclear instrumentation and open source software for data analysis and visualization, and results from a wide-ranging radiometric survey in various parts of Kenya. Finally, a summary is made of radiometric measurement results obtained from one of Kenya's well-known HBRA in the south coastal region, as well those of dose-rate measurements from the central and western parts of Kenya.

The measurements were obtained using the 2.0 l NaI(Tl) PGIS-2 portable detector from Pico Envirotec Inc integrated with GPS (PEI, 2013) and an open-source bGeigie Nano GPS-equipped mobile radiation detector from Safecast (Azby, et al., 2016). Data visualization and mapping were performed utilizing python and QGIS open-source software. The gamma dose-rate measurements obtained using the Safecast detector are shown in Fig. 1. Several hotspots (areas with dose-rates $> 600 \text{ nGy h}^{-1}$) were observed in the Kwale (south coast), Athi River (south east of the capital city Nairobi) and along the Nairobi – Namanga road (south of Nairobi). Absorbed gamma dose-rates in air measured in the well-known Mrima Hill HBRA located in Kwale (see Fig. 2) found $40 - 2368 \text{ nGy h}^{-1}$ (Kaniu, 2018), which is approximately up to 39 times higher compared to the world population weighted average value of 60 nGy h^{-1} (UNSCEAR, 2000). The elevated background radiation in the area is attributed to presence of deeply weathered carbonatite rock with high concentrations of thorium-rich monazite and pyrochlore minerals (Baker, 1953; Kaniu et al., 2018). A comparison of the measurements obtained by both the PGIS and Safecast detectors in Mrima Hill is presented in Fig. 3. An almost similar pattern of absorbed gamma dose-rates can be observed in all the gates apart from gate 5. The results indicate that the low-cost Safecast detector and open-source software can be used for preliminary ground based dose-rate measurements and mapping.

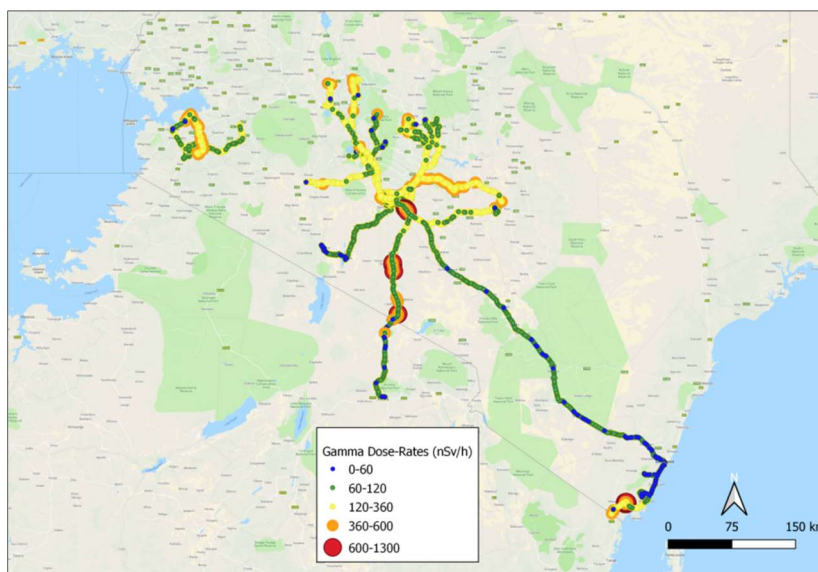


Fig. 1: Gamma dose-rate mapping for the central, western and southern parts of Kenya overlaid on Google Map utilizing the Safecast detector.

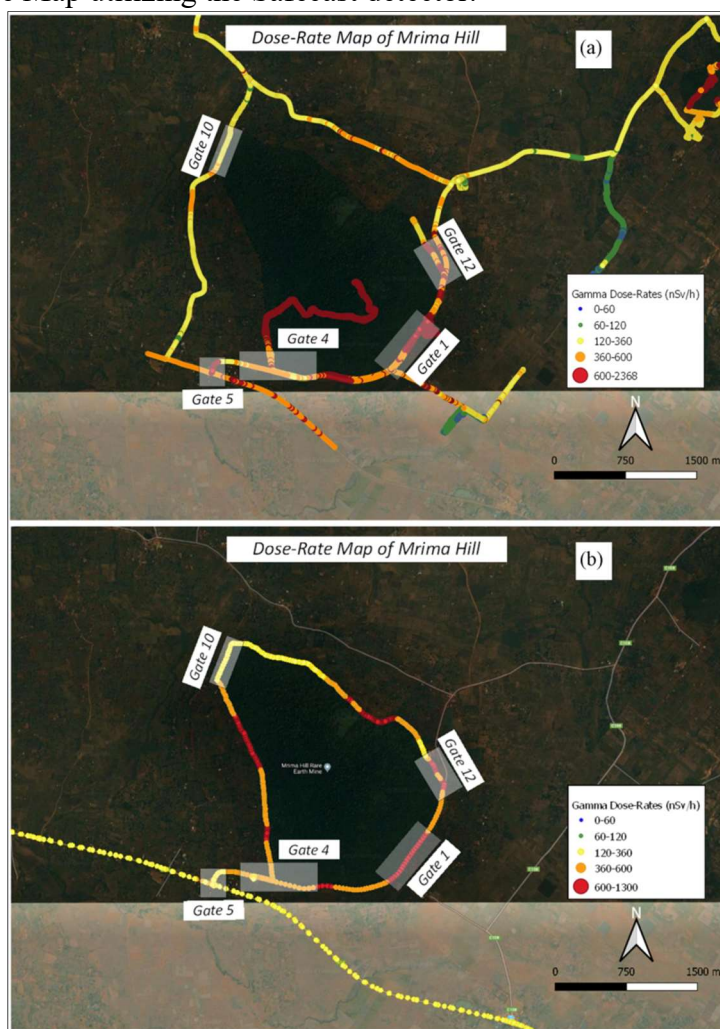


Fig. 2: Gamma dose-rate mapping for the Mrima Hill HBRA by (a) PGIS detector and (b) Safecast detector.

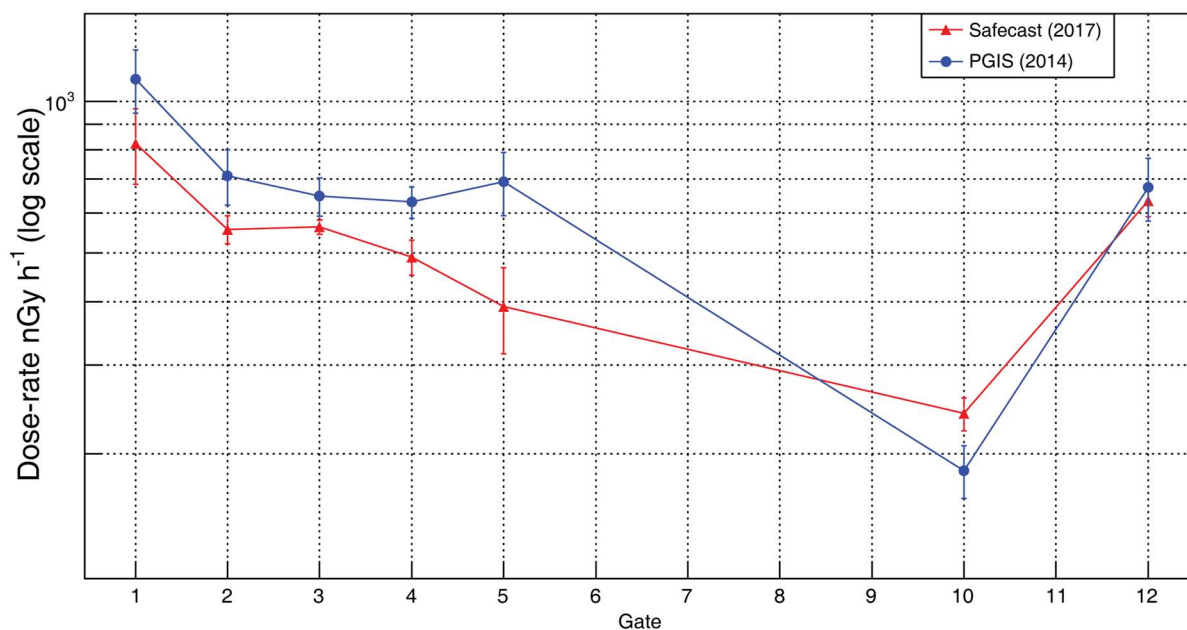


Fig. 3: Comparison of measured gamma dose-rates in Mrima Hill by Safecast and PGIS detectors. Gates are indicated in Fig. 2.

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Montenegro:

AN OUTLINE OF THE BROADLY APPLICABLE ANGLE 4 SOFTWARE FOR ADVANCED GAMMA SPECTROMETRY

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In its various forms ANGLE software for advanced quantitative gamma-spectrometry [1] has been in use for 25 years now in hundreds of gamma-spectrometry based analytical laboratories worldwide (Fig. 1), including many dealing with various aspects of environmental monitoring.

ANGLE purpose is to allow for the accurate determination (laboratory or *in situ*) of the activities of gamma spectroscopic samples for which no “replicate” standard exists, in terms of geometry and matrix [2,3]. It employs a semi-empirical “efficiency transfer” approach, which combines advantages of both absolute (Monte Carlo) and relative (traceable-source-based) methods to determine sample activity – while reducing the practical limitations of the latter methods and minimizing potential for systematic errors in the former.

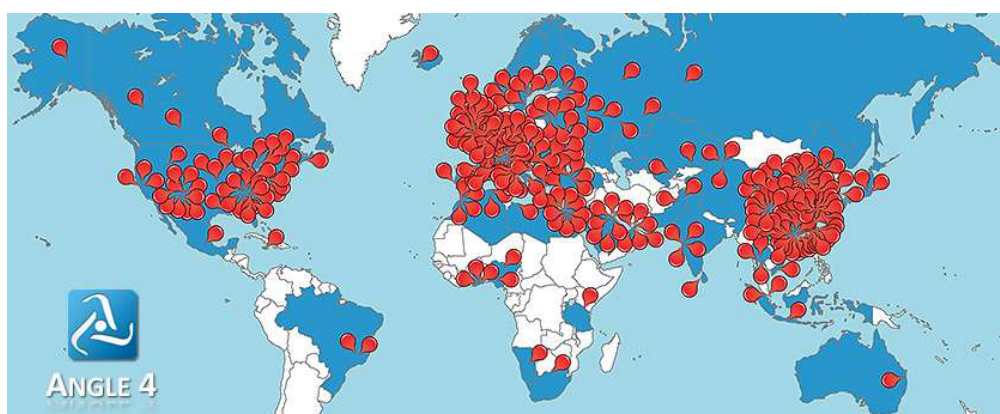


Figure 1. Some of ANGLE users worldwide

The physical model behind is the concept of the effective solid angle – a parameter calculated upon the input data on geometrical, physical and chemical (composition) characteristics of (1) *the source* (incl. its container vessel), (2) *the detector* (incl. crystal housing and end-cap) and (3) *counting arrangement* (incl. intercepting layers between the latter two). ANGLE main screen – intuitive, user friendly and self-teaching – is shown in Fig. 2. Theoretical background and numerous examples of successful application can be found at ANGLE web site.

ANGLE is characterized by (1) a wide range of applicability, (2) high accuracy, (3) ease-of-use, (4) short computation times, (5) flexibility in respect with input parameters and output data, including easy communication with another software and (6) suitability for teaching/training purposes. The ANGLE architecture also offers (7) potential for accommodating other efficiency calculation methods of different types. In addition, its current scope of applicability (8) can readily be extended to further/particular user's needs

and/or fields of interest – it can be thus regarded as an “open-ended” computer code. A key aspect and difference from other approaches, which greatly enhances practicality is that (9) no “factory characterization” of the detector response is required. In fact (10) any detector may be used as some basic knowledge of its construction is available.

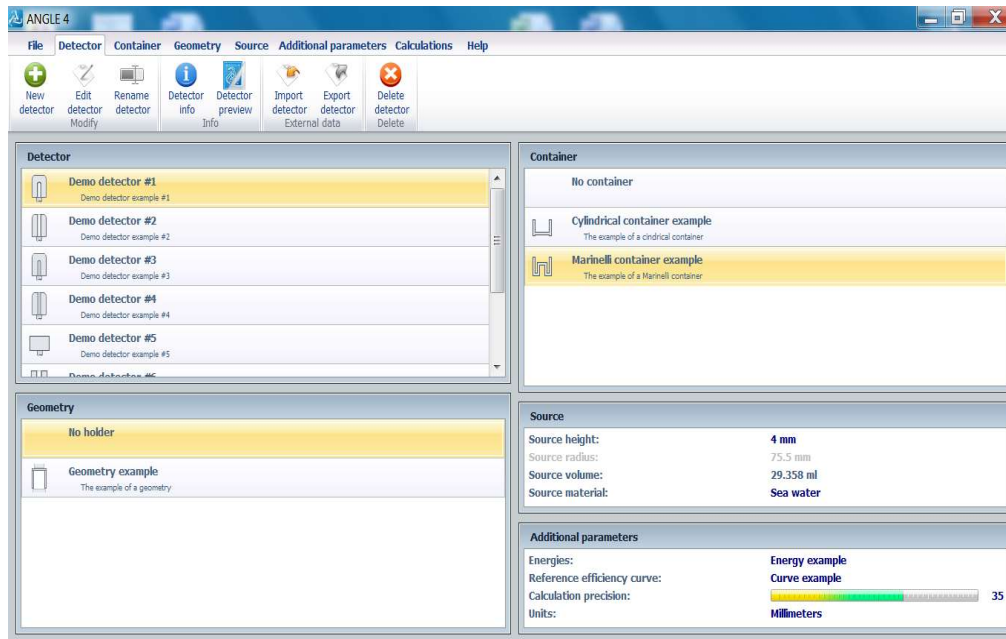


Figure 2. ANGLE main screen

The program can be applied to practically all situations encountered in gamma spectrometry practice, thus not only for environmental monitoring, but also for radioactivity control, waste management, fuel analysis, scientific research and applied sciences, etc. Point, disc, cylindrical or Marinelli samples, small or large, of any matrix composition, measured on coaxial, planar or well-type detectors. Practically any type of semiconductor or scintillation detector can be handled.

The latest version ANGLE 4 was released in 2016, fully refurbished and introducing many new functionalities, including (i) support to scintillation detectors (in addition to the existing semiconductor ones), (ii) “discrete” reference characterization of the detector, (iii) XML file format, (iv) command line parameters, (v) scaled preview (with zooming option) of the counting arrangement, including all relevant details: detector, source, container, intercepting layers, and their positioning, (vi) multilanguage support (currently operating in English, Chinese, Russian, French, Japanese and Spanish), etc.

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Serbia:

**INTEREST ON CURRENT TRENDS AND DEVELOPMENTS IN NUCLEAR
INSTRUMENTATION**

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Institute of Nuclear Sciences Vinča, University of Belgrade Serbia, seventy years from its founding to the present day, has been engaged in research activities in the nuclear field for peaceful purposes. During the years, measurements of radioactivity concentrations in different environmental matrix, originating from different areas of the country, were carried out. Those data could be found in scientific papers and most of these measurements were performed in laboratory conditions, and the use of in situ techniques and portable instrumentation is not so much represented. Republic of Serbia in cooperation with International Atomic Energy Agency, several years before began national campaign of indoor radon measurements. On the other side it is not dedicated enough significance to radon monitoring in the environment. It is well known that radon could be used in various field of the geosciences (e.g. potential earthquake precursor; proxy for tectonic stress in volcanic environments or tectonic zones), also radon can be used as environmental tracer. Overview of capabilities and shortcomings for effective operation and maintenance of state of the art instrumentation and also novel one (e.g. optical fiber doped with scintillating material) for radon, as well other radionuclides, detection will be beneficial. Participating in in situ working group activities is great opportunity for adopting new knowledge, experience exchange, networking, and expanding possibilities for the future researches.

Zambia:

IN-SITU RADON GAS MEASUREMENT IN WATER USING A PORTABLE RADON MONITORING INSTRUMENT; THE CHALLENGES EXPERIENCED.

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1.0 Introduction

Radon gas monitoring in water is very important because of the human health effect that may be experienced by consuming radon gas containing water. Further, high lung cancer risk could be expected from exposure to radon gas that is released to air from such water. The national institute of scientific and industrial research sponsored a PhD student to conducted in-situ radon gas measurement in water using the Sarad RTM 2000 Radon monitor instrument in Zambia's North Western Province. The main aim of the study was to evaluate the contribution of (^{222}Rn) to public exposure due to natural radioactivity in drinking water in a potentially uranium rich area. During the execution of this study, a number of challenges were encountered which could have resulted from the choice of method especially instrumentation that was used. This extended abstract was meant to highlight or share the challenges that were experienced during the study.

2.0 Instrumentation

The Sarad Radon Thoron Monitor (RTM) 2000 instrument, was used to carry out Radon gas measurements in water [1]. The instrument was equipped with an Alpha Spectrometer for detection and quantification radon progenies alpha emitting radionuclides. The instrument had also a Membrane Pump for pumping of air. The instrument was configured to have the sensitivity of 3 kBq/M^3 and the detection limit of 0.33 Bq/L (2- Sigma).

2.1 Basic Measurement Principle

In order to measure the Radon activity concentration of a water sample, there has to an equilibrium state between Radon in air & water activity concentrations which has to take place within a sealed system after a certain time [2].

The ratio between the activity concentrations in a water sample is entirely temperature dependent. Oswald coefficient (equation 1 below) expresses the relationship between the solubility of Radon in water and temperature. This implies that the solubility of Radon decreases with increase in temperature. Hence higher water temperature results into higher Radon concentration within the surrounding air.

$$K_{\text{Oswald}} = C_{\text{Rn}}(\text{Water})/C_{\text{Rn}}(\text{Air}) \dots\dots\dots 1$$

For temperature range from 0°C to 40°C , the Oswald coefficient can be estimated as expressed in equation 2.

$$K_{\text{Oswald}} = 0.425 * \text{EXP} (0.05 * -\text{Temperature in } ^\circ\text{C}) + 0.1 \dots\dots\dots 2$$

Within the sealed system, absolute concentrations are dependent on initial water sample concentration and on the ratio between the water and air volumes. Higher activity concentration within the air volume is expected when there is a higher water volume compared to the air volume within the sealed system. Over the measurement period, the total activity within the sealed system can be regarded to be constant, as shown in equation 3.

$$A(\text{Water}) = A_1(\text{Water}) + A(\text{Air}) \dots\dots\dots 3$$

Where;

$A(\text{Water})$ = Total activity water before de-gassing

$A_1(\text{Water})$ = Remaining activity water sample after de-gassing

$A(\text{Air})$ = activity in the air volume

Since $C_A = A/V$

Equation 3 can be rearranged into equation 4.

$$C_A(\text{Water}) * V(\text{Water}) = C_{A1}(\text{Water}) * V(\text{Water}) + C_A(\text{Air}) * V(\text{Air}) \dots\dots\dots 4$$

Where;

$C_A(\text{Water})$ = Activity concentration of the water sample before degassing.

$V(\text{Water})$ = Volume of the water Probe

$C_{A1}(\text{Water})$ = Activity concentration of the air within the system after the degassing

$V(\text{Air})$ = Air volume within the sealed system

$C_A(\text{Air})$ = Activity concentration of the air within the system after degassing.

Inserting equation 1 into equation 4 results in equation 5.

$$C_A(\text{Water}) * V(\text{Water}) = K_{\text{Oswald}} * C_A(\text{Air}) * V(\text{Water}) + C_A(\text{Air}) * V(\text{Air}) \dots\dots 5$$

Therefore Radon concentration in a water sample can be estimated as in equation 6.

$$C_A(\text{Water}) = \{C_A(\text{Air}) * [K_{\text{Oswald}} * V(\text{Water}) + V(\text{Air})]\} / V(\text{Water}) \dots\dots\dots 6$$

2.2 Measuring Method

The measuring procedure that was chosen required that there was no radon gas in the instrument that could have remained from previous measurement [2]. To achieve that, the instrument and the air loop was flushed with fresh air for at least 15 minutes as recommended in the instrument user manual. The instrument was connected to the bubbling flask as shown in fig 1. For actual Radon gas measurement, the water volume of 500 ml and air volume of 380 ml were used. Measurement was made after 30 minutes of continuous air pumping in a sealed system. After 30 minutes, it was assumed that there was equilibrium concentration of Radon gas between water and air in the sealed system.

Radon gas concentration was read using a Radon In Water Calculator Software. The water temperature was also recorded.

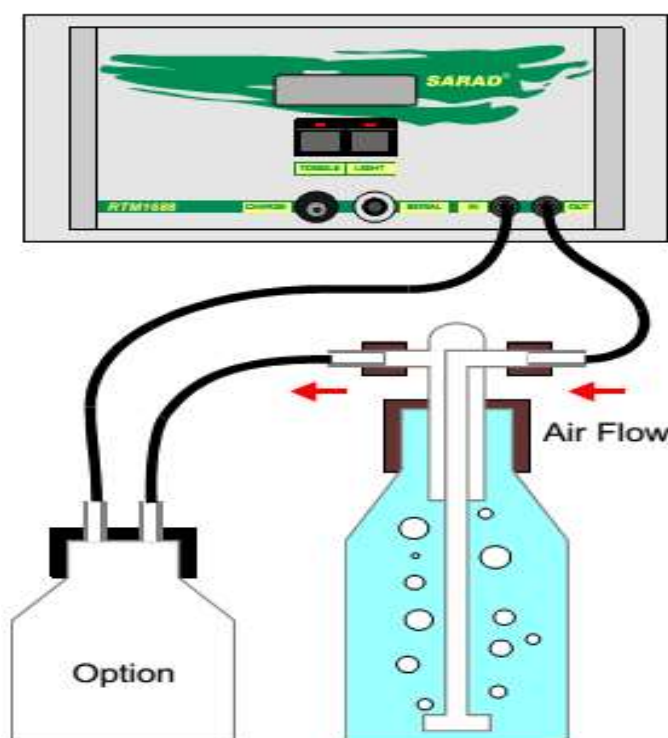


Figure 1; Sarad RTM 2000 Instrumentation & bubbling flask set up, adopted from the Sarad RTM 2000 instrument Manual

3.0 Results

The results from the measurement were in range from 3 ± 0.05 Bq/l to 30 ± 0.13 Bq/l.

3.1 Experienced Challenges

The following are the challenges that were experienced during Radon gas measurement;

Table 1; Challenges experienced during In-Situ Radon gas measurement

No	Challenge	Cause
1	Blackout of the screen during measurements which resulted in disruptions of such measurements. Once screen blacked-out, measurement had to be restarted	Instrument
2	Condensation of water vapour in the monitor during measurement disturb the measurement & lead to unreliable readings. To obtain reliable reading, water sample was discarded, equipment was dried and the procedure was restarted	Method, Environmental
3	Insufficient instructions in the instrument manual. For instance the recommended 30 min to attain equilibrium was not enough.	Instrument user manual
4	Long time it took to process one sample meant that very long time had to be devoted to complete lots of samples in the field.	Instrument, Method
5	The instrument lack of a calibration source. In addition, the user had difficulties in obtaining a water sample with a well-defined Radon concentration.	Instrument development, User
6	Changing environmental conditions resulting in higher	Environmental

	uncertainty.	
7	Degassing (losses) of radon gas during sampling & filling of the apparatus.	Instrument, Method
8	The Instrument lack the capability to convert radon concentration (Bq/l) into exposure units ($\mu\text{Sv/h}$)	Instrument software

4.0 Discussion

Most of the challenges that were experienced during in-situ Radon gas measurement in water were as a result of the type of equipment that was chosen to conduct the work. The blacking out of the screen during measurement for instance was inherent to the equipment. The incapability of the instrument to have a program that perform tasks such as conversion of Radon concentration Bq/l to exposure units ($\mu\text{Sv/h}$) would have reduced the time required to complete the work. The instrument had some limitations which the user had to contain with during measurements. These limitation extended on the length of time that was required to conduct field work.

Environmental factors also impacted on the measurements. The analyst carrying out the measurements had to conduct such measurements several times in order to reduce the impact from the environment.

5.0 Conclusion

Sarad RTM 2000 Radon monitor that was used for Radon gas measurement impacted on the length of time it took to accomplish the work and in the process pushed the cost of carrying out the in-situ work (field) upwards.

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