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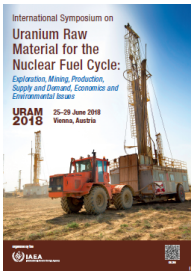

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ADVANCED QUANTITATIVE GAMMA SPECTROMETRY SOFTWARE FOR OPTIMIZED ENVIRONMENTAL ASSESSMENT DURING 'CRADLE-TO-GRAVE' URANIUM EXPLOITATION MANAGEMENT

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INTRODUCTION

Reliable, fast and cost effective assessment of various environmental parameters related to exploration, mining, production and decommissioning/remediation is an essential input parameter for the "cradle-to-grave" ("exploration-to-remediation") uranium management. In the present paper ANGLE software for advanced quantitative gamma-spectrometry is briefly outlined and its applicability to that aim discussed.

In any gamma-spectrometric measurement with semiconductor or scintillation detectors, the question of converting the number of counts (collected in a full energy peak) into the activity of the sample/source cannot be avoided. There are, in principle, three approaches to this problem [1]:

o Relative, where one tries to imitate as good as possible the source by a standard (or vice versa), while keeping the same counting conditions for the two. Paid enough care, the result is, in general, so accurate that cannot be surpassed by other methods. However, we all know what "enough care" means in practice. Combined with the inflexibility in respect with varying source/container parameters (shape, dimensions, material composition), this represents raison d'être of the other approaches, as follows.

o Absolute, like "Monte Carlo"calculations (MC), yielding full energy peak efficiency for a given counting arrangement. It is essentially statistical treatment of the events which photons undergo –from being emitted by a source atom until the interaction with the detector active body –including the treatment of the so produced electrons, positrons and other subsequent energy carriers. This approach is beautifully exact, on condition that we consider sufficiently large amount of incident photons, and that we know the details about a huge number of physical parameters characterizing the process. After many years of practice, still these are limiting factors for its applicability.

o Semi-empirical, trying to conciliate the previous two. Semi-empirical models commonly consist of two parts: (i) experimental (producing one kind or another of reference efficiency characteristic of the detector) and (ii) relative-to-this calculation of peak efficiency. Inflexibility of the relative method is avoided in this way, as well as the demand for some of the physical parameters needed in MC calculations. Numerous variations exist within this approach, with emphases either to experimental or to computational part. Most of them (over)simplify the physical model behind, i.e. the treatment of gamma-attenuation, geometry and detector response.

Stemming from the above, ANGLE purpose is to allow for simple, but accurate determination of the activities of gamma spectroscopic samples for which no "replicate"standard exists, in terms of geometry and matrix. It employs a semi empirical "efficiency transfer"(ET) approach, which combines advantages of both absolute and relative methods to determine sample activity by gamma spectrometry. In doing so, practical limitations of the latter methods are reduced, while the potential for systematic errors in the former is minimized [1, 2].

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 the source, the detector and

counting arrangement ("geometry"). These three parameters are accounted for through a simultaneous differential elaboration, which leads to complex mathematical expressions –however easily managed by means of numerical integration with ordinary computers (PCs). A sound theoretical foundation in the above sense is hence laid in the beginnings of ANGLE development [1-4].

ANGLE is conceived and developed at the University of Montenegro, while commercially distributed by AMETEK-ORTEC, U.S.A. [5]. International cooperation has been an essential part during its evolution. Numerous scientific and technical papers, as well as Ph. D. theses, have emerged from ANGLE progression and utilization.

OUTLINE OF ANGLE SOFTWARE

All relevant information about ANGLE –including theoretical background, features, downloads, references, papers, questions, etc. –is found in much detail at its web site [6]. During its development, care was taken to reflect and take into account numerous users (gamma-spectrometrists') needs, perspectives and feedback. User communication/support was thus an important part of the software development. Four main versions emerged since 1994 (current one being ANGLE 4), with nearly 300 updates.

ANGLE 4 main features can be summarized as:

o high accuracy –typical uncertainties at results obtained (quantitative gamma-spectrometry report) are of the order of a few percent –even introduced by input data, not the software itself;
o broad range of applicability (e.g. in environmental monitoring, fuel cycle and nuclear industry, waste management, regulatory control, nuclear security and safeguards, medicine, research and education, etc.);
o ease of use; there is a highly user oriented and intuitive interface, supported by graphical scaled visualization;
o all parameters characterizing efficiency calculations are shown at one screen, thus easy to control and comprehend;
o short computation times, which are an order of magnitude shorter than those of MC methods –even the most complex calculations are executed within minutes on ordinary PC machines;
o flexibility in respect with input parameters and output data;
o easy communication with another software –thus, can be regarded as a modular software;
o suitability for teaching/training purposes;
o calculates detection efficiencies for most common counting arrangements;
o software supports:
 semiconductor and scintillation detectors
 closed end, open end, planar, well-type detectors
 cylindrical, Marinelli, disc, point sources
 various source containers
 any source dimension
 any matrix composition
o detector calibration is done by the user;
o there is no need for detector factory characterization and.or re-characterization
o it is compatible with most common (ORTEC's and Canberra's) spectrum emulation software (GammaVision, Genie2000);
o one copy of the software can serve all detectors in the lab, regardless of detector type, age and manufacturer;
o transparent, hands-on software (no "black box"for the user) –all parameters of the detector, sample, counting geometry etc. are under control and subject to modification;
o practical educational and training tool for gamma-spectrometry courses at all levels;
o highly convenient for scientific research;
o software design is aimed at bringing user to a higher level of gamma-spectrometry practice;
o preview possibility for input data; visualizes counting arrangement (detector, source, geometry) and indicates potential systematic errors (blunders)
o enables easy programming of huge batch jobs for efficiency calculations; suitable for monitoring, research (e.g. error propagation studies), optimization, etc.
o has a modular nature –made to easily fit into more complex programs, which supply data to it and/or make use of its output results
o highly informative web site
o software architecture offers potential for accommodating other efficiency calculation methods of semi empirical or absolute (MC) type
o its current scope of applicability 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;
o multi language interface; currently exists in English, French, Spanish, Russian, Chinese and Japanese, but new languages can readily be added by translating (through a dedicated subroutine) an Excel file of cca 700 short strings

A key aspect and difference from other approaches, which greatly enhances practicality, is that no "factory

characterization"of the detector response is required. In fact any HPGe detector may be used so long as some basic knowledge concerning its construction is available. These technical data are normally supplied to the customers by detector manufactures, in form of accompanying data sheets, or can be obtained upon request. Care should be taken for the data to be as accurate as possible, since the accompanying uncertainties are propagated into final analytical results as systematic errors.

As to reliability, let us mention here an IAEA organized intercomparison exercise, which was conducted in 2010 by European Commission JRC IRMM (Geel, Belgium) [7]. Ten laboratories took part, applying nine prominent efficiency transfer calculation codes: semiempirical (source derived) and absolute (Monte Carlo). The exercise revealed that systematic errors (differences occurring between experimental and calculated efficiency results) are, for the most part, not due to the calculation methods/procedures themselves (including attenuation coefficients, cross sections and other physical parameters used), but more to uncertainties in input data (detector, source, materials, geometry). ANGLE was one of participating codes, scoring 0.65% average discrepancy from the exercise mean values, with no evidence of systematic bias.

APPLICABILITY TO URANIUM EXPLOITATION MANAGEMENT

ANGLE applicability in uranium exploitation management is evident and straightforward –its simplicity, flexibility and fast performance allows for quantitative analyses of large numbers of samples in short periods of time, regardless of type, origin, size, shape, matrix composition etc. In practice, this translates into ability of quantitatively analyzing thousands gamma-spectroscopic probes within the counting capacity limits of the equipment –including samples of geological, environmental, industrial, biological, medical···or whatsoever origin, as these may occur during uranium exploitation management –from exploration to remediation phase ("cradle-to-grave"). This constitutes a considerable source of reliable first-hand information, which is essential in the decision makings.

Applying ANGLE in uranium related matters is not a new story. Namely, in its various forms, ANGLE has been in use for 25 years now in hundreds of gamma spectrometry oriented laboratories worldwide, including many dealing with different aspects of uranium exploitation –either directly (in exploration, mining, processing, environmental and workplace monitoring, QC/QA, etc. facilities) or indirectly (e.g. within regulatory, health, research, educational or other institutions) [8]. However, a sort of topical (uranium) standardization –for instance in form of a dedicated "U"module –would be a welcome future development in this respect.

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