dr hab. Chiara Mazzocchi, prof. ucz.
Institute of Experimental Physics
Faculty of Physics
University of Warsaw
ul. Pasteura 5, 02-093 Warsaw

Warsaw, January 24^{th}, 2024

Review of the habilitation dissertation, *Metrology and instruments in environmental radioactivity measurement and dosimetric dating* by dr. Konrad Tudyka

1 Scientific activity

The habilitation dissertation *Metrology and instruments in environmental radioactivity measurement and dosimetric dating* consists in a cycle of nine publications in peer-reviewed journals. The cycle has a mono-thematic character, covering a broad range of technical aspects in the measurements of low radioactivity from natural sources, like uranium and thorium decay chains, ^{40}K and ^{14}C, with the latter relevant in particular in the application to the fuel industry for determining the bio-content in products obtained from fossil materials.

The body of work collected in the cycle of publications can be subdivided into three main aspects, i.e. background suppression, the measurement of low-activity natural samples and the characterisation of uncertainties stemming from the different properties of certified standards typically used in such context for calibration purposes.

The first aspect addressed is the phenomenon of after-pulses correlated with the the primary pulse that are observed in photomultiplier (PMT) signals. Such phenomenon leads to a larger standard deviation in the counts statistics than expected if a Poisson distribution is assumed and induces an apparent increase in the sensitivity of the PMT, in particular when single-photon counting is involved. This becomes important in typical low-radioactivity dosimetry applications, like thermoluminescence (TLD) and optically-stimulated luminescence (OSL), since secondary effects like after-pulses become non-negligible. The origin of such after-pulses, and the consequent deviation from Poisson distribution with a larger-than-expected variance, are identified in the work led by dr Tudyka as due to various secondary effects

in the PMT, the most important of which are generated by the presence of residual gas in the PMT, in particular He ions and electrons. A solution is proposed to reduce such background and is supported by measurements and modelling of these mechanisms together with MonteCarlo simulations. It is not clear though how large this improvement in background subtraction is and whether the method is later applied.

The bulk of the scientific activity consists in the development of methodologies and systems for measuring very-weak activity of naturally occurring radioactive isotope like ^{14}C, ^{226}Ra, ^{222}Rn, ^{238}U, ^{235}U, ^{232}Th and ^{40}K. Despite the advent of accelerator mass spectrometry over 40 years ago, decay counting in radiocarbon dating is still a popular method in many applications, in particular those linked to the determination of bio-content in materials of fossil origin (fuels, plastic, lubricants). When determining the activity of ^{14}C by β-counting, the decay chains of the contaminant ^{226}Ra and its daughter ^{222}Rn can generate background that would result in overestimating the ^{14}C activity and therefore underestimating the age of the sample by even several hundreds of years. The method proposed allows to simultaneously determine the β activity of the sample and the component due to ^{226}Ra and ^{222}Rn. The latter is achieved by measuring in delayed coincidence the β and α particles emitted by their decay products, namely $^{214}\mathrm{Bi} \rightarrow \beta + {}^{214}\mathrm{Po} \xrightarrow{(T_{1/2}=164\mu s)} \alpha + {}^{210}\mathrm{Pb}$. Such methodology is implemented in a prototype spectrometer with custom electronics based on liquid scintillators that is developed within this work.

The same concept of exploiting delayed coincidences for background subtraction in low-radioactivity measurements is then implemented in order to improve the accuracy in determining the equivalent total radiation dose absorbed and the radiation dose rates for trapped charge dating applications, like TLD and OSL. The main source of natural radioactivity in the environment, which are relevant for such applications, are the non-extinct natural decay chains originating at ^{238}U, ^{235}U and ^{232}Th, and ^{40}K. A set of four pairs of β/α decays is used in this case to assess the specific activity of ^{40}K and of thorium and uranium decay chains (^{238}U: ^{214}Bi/^{214}Po; ^{232}Th: ^{220}Rn/^{216}Po and ^{212}Bi/^{212}Po; ^{235}U: ^{219}Rn/^{215}Po; while ^{40}K is determined from the difference of total β activity and the specific activities of ^{238}U, ^{235}U and ^{232}Th), when secular equilibrium is not broken.

On the basis of this, a new device based on a dual α/β scintillation module, called μDOSE is proposed, designed and developed in this work, with custom

electronics and software, including analysis algorithms. The algorithms allow to calculate an effective dose rate and minimise the uncertainties with a Monte Carlo approach and Bayesian statistical methods. Such algorithms are made available to the broader scientific community via a web-based application (μRate).

A common issue in every measurement is the reliability of calibration measurement and in particular of those with certified calibration standard. This issue is addressed in the work of dr Tudyka with a thorough study and characterisation of ^{222}Rn leakage of different IAEA certified standards of common use as a function of the way the samples are prepared, driving the attention to the issue. A systematic measurement of ^{222}Rn escaping the samples has shown detectable amounts from all the samples considered. A broad range of leakage rates was observed, starting at only a few percent all the way to a very large 35%. The difference in leakage rates seems to be due to the difference in the properties of the materials tests, like material preparation (e.g. mixing the material to measure with wax) and the quality of the sealing of the sample in the beaker.

It is important to highlight that Dr Tudyka had a leading role in the work collected in his dissertation, he is the first author in all nine publications, in which the author list is non-alphabetical, and which is confirmed by the coauthors statements. He shows also a good record in supporting his research, given the role pf principal investigator in two grants and of collaborator in a few others. Although the scientiometric record is limited (30 publications, index factor 8), it has to be noted that not many high impact-factor peer-review journals are available for disseminating results in the field of dosimetry.

Although he has no experience in international scientific environments from extended stays abroad, the international reach of dr Tudyka's research is confirmed by his active participation at international conferences in the field with several oral presentations, although none upon invitation, and by his very good activity as referee for several peer-review journals in the field.

2 Didactic, organisational and outreach activity

Dr Konrad Tudyka's record in teaching at various levels is very good. It spans over lectures, laboratory exercises and exercises at the blackboard in various subjects from numerical methods, to modern physics and English for computer science, over

a broad range of studies, like Technical Physics and others in scientific and technical sciences. He shows also a very good activity in research teaching and outreach, with the supervision of one master student and the assistance in the supervision of one doctoral student, as well as the supervision of students clubs.

He has also a good record in organisational activities, with the membership in the organising committee of the international conference *Radiocarbon in the environment III* and the role of CEO in the spin-off company miDose Solutions Sp. z o.o., as well as the management of projects and grants.

3 Cooperation with the social and economic sectors

Dr Tudyka's scientific activity has several socio-economic outcomes, like the prototype liquid scintillator spectrometer based on time coincidences dedicated to measure ^{14}C, ^{226}Ra and ^{222}Rn activities, the μDOSE system for measuring low alpha and beta activity from ^{238}U, ^{235}U, ^{232}Th and ^{40}K in samples, the management of a spin-off company to commercialise low-radioactivity measurement solutions and the development of a web-based application for the dosimetric dating community.

Dr Tudyka's scientific activity included also a series of technological developments that led to industrial property rights with an uncommonly large number of patents registered, some of which are already implemented in industrial applications.

4 Summary

The scientific activity of dr Konrad Tudyka and his involvement in didactic, organisational and outreach activities, as well as his cooperation with the economic sector demonstrate that he is an independent scientist, capable of initiating and leading scientific projects. The outcome of such activity constitutes a significant contribution to the development of the discipline and fulfils the requirements necessary to obtain the habilitation degree. I therefore ask for the admission of dr Konrad Tudyka to the next steps of the habilitation process.

Chiara Mazzocchi