Title: Towards new primary activity standardisation methods based on low-temperature detectors

Abstract
Nuclear decay data is essential for determining the radioactivity present in all radionuclide measurements, but results are theoretical decay model dependent limiting the accuracy achievable. To remove reliance on these models research is needed into new theoretical decay scheme models based on fundamental atomic principles. It is also needed to support the introduction of innovation in radionuclide primary standardisation techniques such as Low temperature detector (LTD)-based spectrometers that can achieve near 100 % quantum efficiency or the quantification of metallic magnetic calorimeter (MMCs) results to remove uncertainties generated by radionuclide measurement sample preparation. These have the potential to create a step change in the accuracy with which the Becquerel can be realised by introducing new standardisation techniques for use by the NMI community.

Keywords
Nuclear decay data, Low temperature detectors (LTDs), metallic magnetic calorimeters (MMCs), theoretical decay model, beta spectrum shapes, electron-capture decay, radionuclide primary standardisation, Becquerel.

Background to the Metrological Challenges

Precise nuclear decay data based on fundamental atomic characteristics underpins all radioactivity measurements. Nuclear medicine, the nuclear power industry and research in neutrino physics all depend on knowing the nuclear decay mechanisms present. These also have a major influence on individual radionuclide measurement uncertainties. For beta-gamma emitting nuclides such as ^{60}Co, uncertainties of 0.1 % can be achieved, but for nuclides with pure electron-capture these are significantly higher. Detailed knowledge of beta particle or Auger electron decay spectra shapes are essential for developing improved theoretical calculation models, whilst new experimental data on branching ratios is needed to generate increased accuracy in nuclear decay schemes.

The ability to calculate any beta or electron-capture transition regardless of its nature and apply this to any radionuclide is critical in many scientific fields. The most elaborate modelling codes currently available have too many restrictive approximations to provide the precision needed. Atomic wave functions have potential for extending existing simple nuclide theoretical modelling to the more complex and precise decay chain predictions required in radionuclide metrology. To reduce an over dependence on theoretical modelling, experimental validation is required. The use of metallic magnetic calorimeters (MMCs) has significantly improved beta spectrum shapes and EC probabilities across the energy range 100 eV to several MeV but to date only a few radionuclides have been evaluated. This number needs extending to provide the essential nuclear data that underpins radionuclide standardisations. A promising emerging activity standardisation technique, Low temperature detector (LTD)-based spectrometers, can achieve quantum efficiencies near 100 % without reliance on nuclear decay data. However further development is needed to enable its use for radionuclide standardisations.

Conventional radionuclide standardisations for beta-emitting nuclides are routinely performed using liquid scintillation counting (LSC) which due to the use of potentially out of date decay data and models better suited to higher-energy beta emitting nuclides have uncertainties of 1 %. For alpha emitting nuclides, alpha spectrometry is a frequently used technique. Both rely on extensive sample preparations that introduce additional components into the measurement uncertainty budget. Preparation requirements for MMC is significantly reduced but a lack of quantitative results must be overcome so that this innovative technique can gain greater acceptance in radionuclide metrology.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on developing methods for determining radionuclide activity, which are not reliant on the use of nuclear decay data.

The specific objectives are

1. To develop a new primary method for decay scheme independent activity determination using low temperature detector-based spectrometers with a quantum efficiency of 100 %, high energy resolution and with the capability of processing measurement statistics which exceed 10^8 events / spectrum.
2. To combine new source preparation techniques (e.g. ion implantation), and modern detectors (e.g. metallic magnetic calorimeters, etc.), in order to standardise one α emitter (^{241}Am), one β emitter (^{129}I) and one electron-capture nuclide (^{55}Fe). This should aim to considerably reduce the uncertainty compared to existing methods.
3. To develop a method for the measurement of ^{55}Fe energy spectra with a better energy resolution and a lower energy threshold (< 50 eV) than existing techniques, to be used to determine fractional electron-capture probabilities. This should include determining L-subshell probabilities and a precise study of shake-up and shake-off effects. In addition, this approach should be used to determine the beta spectrum shape of ^{129}I down to 0 keV.
4. To compute beta spectrum shapes and electron-capture decay using new calculation techniques, which consider all relevant effects from atomic and nuclear structure.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs, DIs, research laboratories) and users (authorities with responsibilities in radiation protection and environmental monitoring, researchers in allied fields).

Proposers shall give priority to work that aims at excellent science exploring new techniques or methods for metrology and novel primary measurement standards, and brings together the best scientists in Europe and beyond, whilst exploiting the unique capabilities of the National Metrology Institutes and Designated Institutes.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMPIR projects 15SIB10 MetroBeta and 17FUN02 MetroMMC and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 40 % of the total EU Contribution across all selected projects in this TP.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the healthcare, nuclear power generation and fundamental research sectors.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards

- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Time-scale

The project should be of up to 3 years duration.