Coordinator's Extended Report

Beta-Particle Spectrometry Working Group

Background

The Beta Particle Spectrometry Working Group is devoted to the development of the metrological aspects of beta spectrometry and its applications. This includes:

- Theory. Beta ($\beta^{\pm}$) and electron capture (ε) transitions; Theoretical shape factors and influence of the nuclear current; Atomic effects.
- Experiments. Instrumentations used for beta spectrometry; Techniques that need beta information; Confidence on experimental shape factors; Data analysis and unfolding methods.
- Simulations. Confidence on the physical processes: low energies, radioactive decays, atomic rearrangements; Comparison of the results of different codes.
- Evaluations. Confidence and uncertainties on experimental shape factors; Procedure for establishing recommended shape factors; Mean energies, log *ft* values, database.

Interested communities in radionuclide metrology are: nuclear decay data, liquid scintillation counting, ionising chambers, 4π β-γ counting.

Recent and on-going activities

- A dedicated website was created in 2016 and can be found at the following address: http://www.lnhb.fr/icrm_bs_wg/.

- Theory

  i) Further developments of calculations of electron capture decays. Precise atomic energies and radiative corrections have been demonstrated to be of high importance for accurate theoretical predictions.

  ii) Inclusion of the nuclear structure in beta decay calculation has been conducted through the determination of single particle nuclear matrix elements. Formalism has been explicitly extended to electron captures. A preliminary study has been conducted in order to include realistic nuclear structure in the calculation of some forbidden non-unique transition, with promising results.

  iii) A new version of the BetaShape code has been released in June 2019. This version includes improvements in the calculation of radiative corrections for beta decays and an update of the database of experimental shape factors. In addition, calculation of electron capture decays is included, with provision of capture probabilities and capture-to-positron probabilities for all subshells, log(ft) values and splitting of the branch between capture and beta plus transitions. This new version is made available for the community at the same address:
  http://www.lnhb.fr/rd-activities/spectrum-processing-software/

- Simulation

  i) A decay module for Geant4 has been developed at LNHB, in the same spirit as the PenNuc module developed by CIEMAT with support from LNHB, but with improvements such as a coupling with the BetaShape code. This module was presented at the ICRM 2019 conference (May 27-31, 2019) and will be made available for the community.

  ii) An unfolding algorithm has been developed at PTB based on Monte Carlo simulations (EGSnrc). The purpose is to correct a ^{36}Cl spectrum measured with a metallic magnetic calorimeter for the distortion due to the escape of bremsstrahlung photons. A similar algorithm has been developed at LNHB using Geant4 and Penelope simulations and successfully applied to beta spectra measured with silicon detectors.

- Measurements

  i) Beta spectra of ^{14}C, ^{36}Cl, ^{99}Tc and ^{151}Sm decays have been measured with metallic magnetic calorimeters at LNHB and PTB.

  ii) Beta spectra of ^{87}Rb and ^{176}Lu decays have been measured with solid scintillator crystals at TU Delft (Gonitec).

  iii) A magnetic spectrometer has been developed at IRA (CHUV) dedicated to beta spectrometry and beta spectra of ^{36}Cl, ^{60}Co, ^{99}Tc and ^{134}Cs decays have been measured.

  iv) A detection system based on silicon detectors in a quasi-4π configuration has been developed at LNHB and beta spectra of ^{14}C, ^{36}Cl, ^{99}Tc and ^{204}Tl decays have been measured. Excellent agreement has been obtained with the beta spectra measured with metallic magnetic calorimeters for ^{14}C and ^{99}Tc. Source preparation difficulties have been encountered for ^{36}Cl; work is in progress to minimize the size of the crystals. This work has been done in the context of the PhD thesis of Abhilasha Singh.

- Evaluations

  The BetaShape program is the reference code for DDEP evaluations. The first version of the code is used in the IAEA LiveChart to display beta spectra related to the decay of radionuclides: https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html
  Discussions are ongoing for an adoption by the NSDD network for ENSDF evaluations.

Related projects

- European metrology project (EURAMET, EMPIR programme) MetroBeta 15SIB10, 2016-2019. Website: http://metrobeta-empir.eu/. Partners are from Czech Republic, France, Germany, Netherlands, Poland and Switzerland.

Summary. The MetroBeta project is taking both theoretical and experimental approaches to improving the knowledge of beta spectra. On the theoretical side, existing knowledge of the calculation of nuclear wave functions is being used to take into account the nuclear structure effect on these spectra. On the experimental side, beta spectrometry with MMCs is being developed, as well as solid scintillators containing the beta emitters in the structure of the scintillator crystal. Comparison of the newly calculated and measured spectra will validate the quality of the spectra.

- European metrology project (EURAMET, EMPIR programme) MetroMMC 17FUN02, 2018-2021. Website: http://empir.npl.co.uk/metrommc/. Partners are from France, Germany, Portugal, South Korea and United Kingdom.

  Summary. The main objective of the MetroMMC project is to improve the knowledge of electron capture decay and subsequent atomic relaxation processes. New theoretical calculation techniques and extensive experiments using MMCs will be developed to determine important decay data which are relevant for primary activity standardisations in radionuclide metrology, in cancer therapy on the DNA level, and when studying the early history of the solar system. The experimental parts will be complemented with a new approach based on microwave-coupled resonators.

- The European metrology project (EURAMET, EMPIR programme) PrimA-LTD 20FUN09 will start in June 2021, with three years duration. Partners are from France, Germany, Portugal, Spain and Switzerland.

  Summary. Radionuclide metrology and specifically activity standardisation are based on well-established measurement techniques, which have been used and improved for decades. However depending on the decay mode, for some nuclides, the achievable uncertainty on the activity is up to an order of magnitude larger than usual. The aim of this project is to achieve new primary activity standardisation methods based on low-temperature detectors, in particular by measuring with high statistics the ^{55}Fe and ^{129}I decays. A high-precision theoretical description of these two decays, including both nuclear and atomic structure, will also be conducted.

Recent and future meetings

- A Working Group meeting took place in Salamanca during the ICRM 2019 conference (May 27-31, 2019). Three presentations were given:

  i) M. A. Kellett (LNHB), Overview of the MetroBeta Project.

  ii) K. Kossert (PTB), Comparison and validation of beta spectra measurements.

  iii) D. Arnold (PTB), Overview of the MetroMMC project.

- The MetroMMC Workshop took place at LNHB (October 24, 2019).

- Abhilasha Singh successfully defended her PhD thesis at LNHB (September 25, 2020) with the following topic: Metrological study of the shape of beta spectra and experimental validation of theoretical models.
- Joint radionuclide metrology meetings took virtually place at LNHB (October 26-30, 2020):

  i) Decay Data Evaluation Project (October 26, 2020).

  ii) Nuclear Decay Data Working Group (October 27, 2020).

  iii) Beta-Particle Spectrometry Working Group (October 27, 2020).

  iv) Radionuclide Metrology Technique Working Group (October 28, 2020).

  v) Gamma Spectrometry Working Group (October 29-30, 2020).
- The virtual character of the Working Group meeting (October 27, 2020) noticeably increased the audience, with 26 attendees. This possibility should be kept for future meetings, even without any travel restriction. Four presentations were given and are described below. In addition, B. E. Zimmerman (NIST) announced that the Radioactivity Group successfully defended a project dedicated to the development of a cryogenic facility for radiation measurements. This project will last 5 years and will start in 2021.
- The next Working Group meeting has still to be planned. It was expected to take place in Bucharest during the ICRM 2021 conference (May 31 - June 4, 2021) but the conference has been postponed to 2023 due to the Covid-19 pandemic.

On behalf of the Beta-Particle Spectrometry Working Group,

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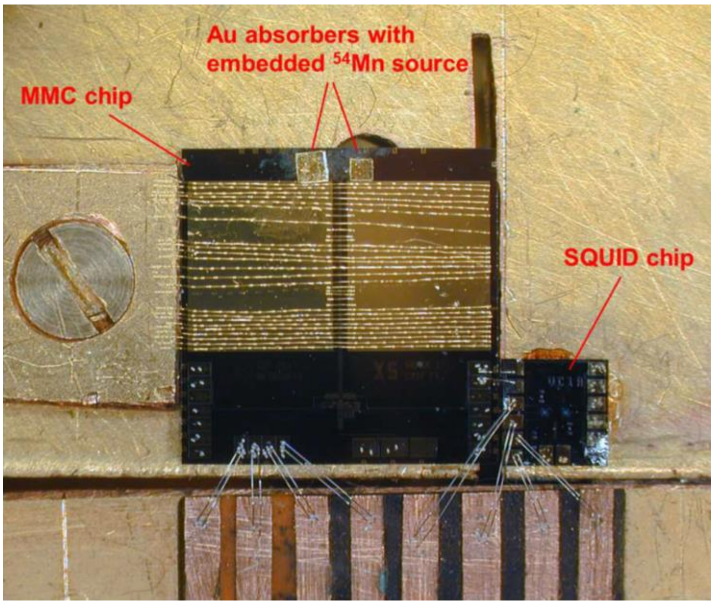
Presentations given during the latest Working Group meeting (October 27, 2020)

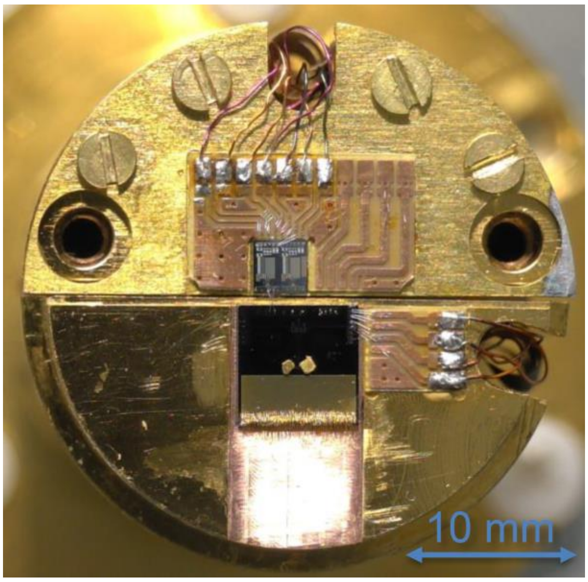
i) M. Loidl (LNHB), Measurement of nuclear decay data by means of metallic magnetic calorimeters within European metrology research (EMPIR) projects.



MMC device at LNHB for the determination of ^{54}Mn capture probabilities

Summary. Recent developments on metallic magnetic calorimetry (MMC) at LNHB, conducted within the MetroBeta and MetroMMC European projects, have been presented. Several new chip designs optimised for different energy ranges have been fabricated by KIP (Heidelberg University). They have been tested and employed at LNHB for the measurements of ^{99}Tc and ^{151}Sm beta decays, ^{54}Mn fractional capture probabilities and photon emission probabilities of ^{240}Pu nucleus from ^{244}Cm decay. Different source preparation technique have been tested: kneading, electrodeposition on Au absorbers, dispensing micro-drops of the radioactive solution directly on Au absorbers. Several measurements are planned for the following decays: ^{59}Ni, ^{65}Zn, ^{109}Cd and ^{125}I.

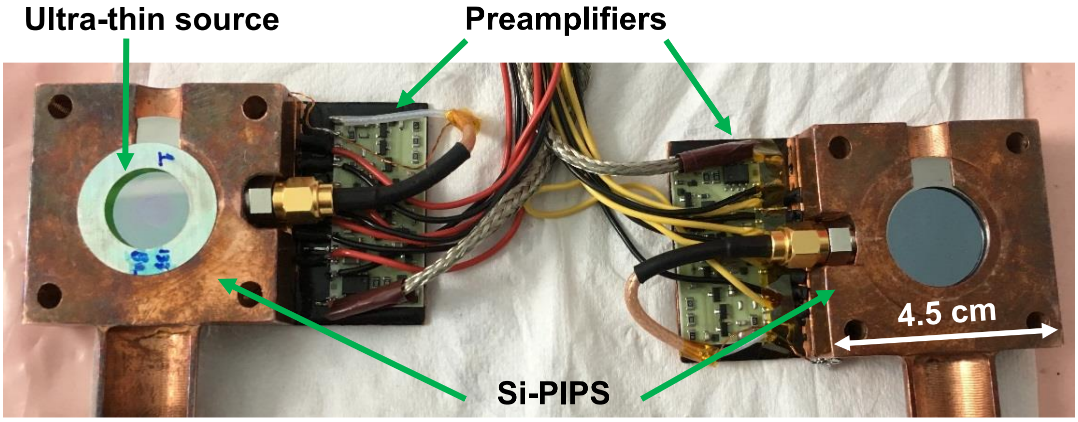
ii) P. Ranitzsch (PTB), MMC measurements at PTB-BS.



MMC spectrometer at PTB

Summary. Since 2016, PTB has been developing a metallic magnetic calorimetry device (MMC) dedicated to the measurement of beta and electron capture spectra. This apparatus has been characterised measuring the ^{65}Zn capture decay with an external ^{241}Am source, and the ^{99}Tc beta decay with an external ^{57}Co source. Experiment placement, vibrations, noise and temperature behaviour have been optimized, leading to much better proficiency and understanding of the experimental setup. The radionuclide source preparation has been demonstrated to have too much influence on the measured spectra for high-precision results. A procedure for nanoporous Au fabrication has been established and tested on bulk material. The next step is to apply it for absorber-source preparation.

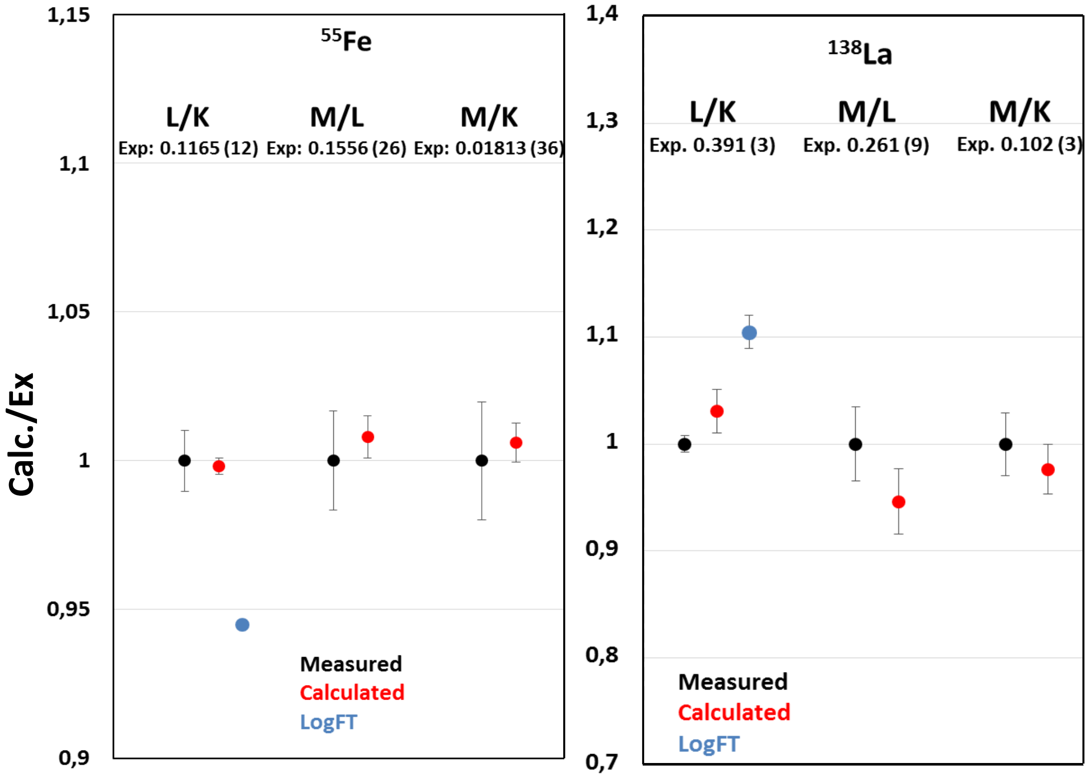
iii) A. Singh (LNHB), Measurements of beta spectra with silicon detectors.



Beta spectrometer opened to position the source

Summary. A β spectrometer has been developed based on two silicon detectors and a radioactive source in the middle, and has been optimised in order to reach a quasi-4π geometry. Different source preparation techniques have been studied and their influence on the shape of the β spectrum has been quantified. The device has been characterised using the conversion electron peaks of ^{109}Cd and ^{207}Bi decays, and the β spectra from ^{14}C, ^{36}Cl, ^{99}Tc and ^{204}Tl decays have been studied. An unfolding method has been developed to correct for the remaining distortions based on Penelope Monte Carlo simulations. The response function of the detection system has been built from mono-energetic simulations and the measured spectra have been unfolded by applying the matrix inversion method. The resulting spectra have been compared with some high-precision measurements performed with Metallic Magnetic Calorimeters at LNHB, showing excellent agreement in the common energy range. The experimental shape factors have been extracted for ^{14}C, ^{99}Tc and ^{204}Tl spectra and compared with results available in the literature.

iv) X. Mougeot (LNHB), New version of the BetaShape code.



Ratios of calculated-to-measured capture probability ratios for the allowed decay of ^{55}Fe and the second forbidden unique decay of ^{138}La. Red points have been obtained with BetaShape, blue points with LogFT.

Summary. The second version of the BetaShape program has been presented. This code provides improved information needed for nuclear decay data evaluations and is now able to treat both beta and electron capture decays. From a comparison with precise measurements available in the literature, precise atomic energies and radiative corrections have been demonstrated to be of high importance for accurate theoretical predictions. Compared to the LogFT code that has been used for a long time in nuclear decay data evaluations, BetaShape provides additional detailed information needed for radionuclide metrology and various applications. In particular, capture probabilities and capture-to-positron probabilities for all subshells are given. Executables for Windows and Linux are available on LNHB website, while MacOS executable are still pending. Feedbacks on the results, comments, suggestions and bug reports are highly expected.