Coordinator's 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.

Dedicated website: http://www.lnhb.fr/icrm_bs_wg/

Recent and on-going activities

- Theory

  i) A new version (2.2) of the BetaShape code has been released in June 2021. Various options have been added, e.g. including or not the different corrections, automatically updating the transition energies from the latest recommended Q-values (AME2020 database) or creating CSV files for automatic coupling with other codes. Executables have been made available for various platforms on LNHB website: Windows 10, macOS Big Sur (Intel and M1 processors), Scientific Linux 6.7, Ubuntu 20.04 and Centos 8.
  http://www.lnhb.fr/rd-activities/spectrum-processing-software/

  ii) Developments are ongoing for the next version, which release is expected in 2023. Beta transition modeling will be improved by taking precisely into account various atomic corrections (overlap, screening and exchange).

  iii) Inclusion of a realistic nuclear structure in beta decay calculations has been conducted. Nuclear structure is determined with the NuShellX code, which provides a list of single particle nucleon-nucleon transitions to describe a given transition between two nuclear states. Studies of some forbidden non-unique transitions have highlighted the importance of the conserved vector current hypothesis and of the Coulomb displacement energy for accurate estimate of relativistic vector matrix elements.

  iv) Atomic exchange formalism in beta decay has been extended to forbidden unique transitions.

v) Calculation of electron energy spectrum from internal auto-ionization (shake-off) process associated to electron capture decay has been studied. Preliminary results look promising.

- Measurements

  i) The beta spectrum of ^{151}Sm decay measured with metallic magnetic calorimeters at LNHB has been carefully analyzed in a collaboration with PTB. A new Q-value has been extracted from the spectrum with an uncertainty decreased by a factor of seven compared to the latest recommended value. The ξ approximation has been found to be insufficient if a 3% precision or less is aimed for to describe the spectrum shape. New branching ratios have also been established and could be used for updating the ^{151}Sm DDEP evaluation.

  ii) The beta spectrum of ^{176}Lu decay measured with solid scintillator crystals at TU Delft (Gonitec) has been carefully analyzed in a collaboration with LNHB and NSCL (Michigan, USA). Thanks to a Penning trap measurement, new transition energies have been established with uncertainties decreased by a factor of 1.5. The spectrum shape of the dominant transition has been found to be very sensitive either to the Coulomb displacement energy or to the effective value of the axial-vector weak interaction coupling constant.

  iii) The beta spectrum of ^{99}Tc decay measured independently with metallic magnetic calorimeters at both LNHB and PTB has been carefully analyzed. A new Q-value has been extracted from the spectrum, not compatible with the latest recommended value with an uncertainty decreased by more than a factor of five. The best theoretical description of this second forbidden non-unique transition necessitates an adjustment of the value of the axial-vector weak interaction coupling constant.

  iv) The beta spectra of ^{14}C and ^{204}Tl decays measured at LNHB with a detection system based on silicon detectors in a quasi-4π configuration have been reanalyzed. Extracted transition energies have been found perfectly consistent with the latest recommended Q-values. The ^{14}C shape factor has been found linear in energy, with a coefficient fully consistent with the best theoretical predictions available of the weak magnetism term. The ^{204}Tl shape factor has been found consistent with the reference value in the literature, extending the experimental knowledge of the spectrum down to 60 keV.

- Evaluations

  i) The adoption of the BetaShape code has been proposed for ENSDF evaluations at the 24th Technical Meeting of the NSDD network (October 2022, Australia). The NSDD network has given its agreement in principle, upon some modifications of the BetaShape code to treat non-numerical uncertainties.

  ii) A collaborative work has been carried out between B. Singh from McMaster University (Canada), S. Turkat and K. Zuber from TU Dresden (Germany) and X. Mougeot (LNHB) aiming for an update of the 1998 review of log-*ft* values. Decay schemes and data with beta transitions and electron captures have been updated manually. BetaShape, with the new developments since version 2.2, has been run over the entire database to update the mean energies and the log-*ft* values. Selection of well-defined transitions which data can be trusted has been performed, and potential Pandemonium nuclei have been flagged.

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.

- European metrology project (EURAMET, EMPIR programme) PrimA-LTD 20FUN04, 2021-2024. Website: https://prima-ltd.net/. Partners are from France, Germany, Portugal, Spain and Switzerland.

  Summary. Radionuclide metrology and specifically activity standardization 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 standardization 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

- 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:

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

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

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

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

  B. 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 2nd MetroMMC stakeholders meeting took place at NPL (December 17, 2021).

- The PrimA-LTD Workshop took place at CIEMAT (November 24, 2022).

- The more recent Working Group meeting took place in Bucharest during the ICRM 2023 conference (March 27-31, 2023). The meeting was in hybrid format, with attendees of the ICRM conference and 24 additional attendees online. Four presentations were given, with one online:

  i) K. Kossert (PTB) – Overview of the European project PrimA-LTD.

  The aim of the project has been presented, i.e. to achieve new primary activity standardization methods based on metallic magnetic calorimeter. The electron spectra from ^{55}Fe and ^{129}I decays are planned to be measured with high statistics (>10^8 counts). Direct ion implantation into gold absorber will be used. A high-precision theoretical description of these two decays, including both nuclear and atomic structure, is also being conducted.

  ii) D. Bergeron (NIST) – Progresses and plans on Decay Energy Spectrometry with Transition Edge Sensors.

  A new Decay Energy Spectrometer is being developed at NIST based on Transition Edge Sensors, with the help of experts in cryogenic detectors from NIST Boulder. Radioactive sample is incorporated in a metal absorber and the decay heat is measured with high precision. The transition edge sensor is set in a superconducting state and the decay heat basically breaks Cooper pairs, moving the sensor to a normal state. Applied to alpha spectrometry, an energy resolution of 1 keV at 5 MeV can be reached. In view of using the Decay Energy Spectrometer for activity standards, a preliminary comparison with TDCR counting has been made for ^{241}Am decay.

  iii) G. Cavoto (Sapienza Uni. Roma & INFN Roma) – Development of detectors for ultra-low energy neutrinos. (*online*)

  Within the Ptolemy project, a new electro-magnetic filter is being constructed for the detection of neutrino cosmological background. Ultimately, interaction of cosmic neutrinos with a tritium target will be measured with a transition edge detector, aiming at an energy resolution of less than 50 meV. A prototype has been developed using a silicon detector. Tritium, as the target, is stored on a graphene layer, developed and characterized in collaboration with M. Capogni from ENEA. Proof-of-concept has been demonstrated with the first results.

iv) X. Mougeot (LNHB) – Recent collaborative studies on beta decays.

New high-precision measurements with cryogenic detectors have been made available over the past few years of forbidden non-unique beta transitions. In parallel, realistic nuclear structure has been implemented in calculation of beta decays. Comparison between experimental and theoretical results has been shown for ^{151}Sm, ^{176}Lu and ^{99}Tc decays, demonstrating that accurate decay data can be extracted from beta spectrum measurements with competitive uncertainties. New analysis of ^{14}C and a complete re-evaluation of the log-ft values of all existing beta transitions and electron captures (>26,000 in the ENSDF database) have also been reported.

On behalf of the Beta-Particle Spectrometry Working Group,

Xavier Mougeot (coordinator)

CEA Saclay
Laboratoire National Henri Becquerel
Bât. 602 – PC111
91191 Gif-sur-Yvette
France

Phone: +33 1 69 08 23 32
E-mail: xavier.mougeot@cea.fr