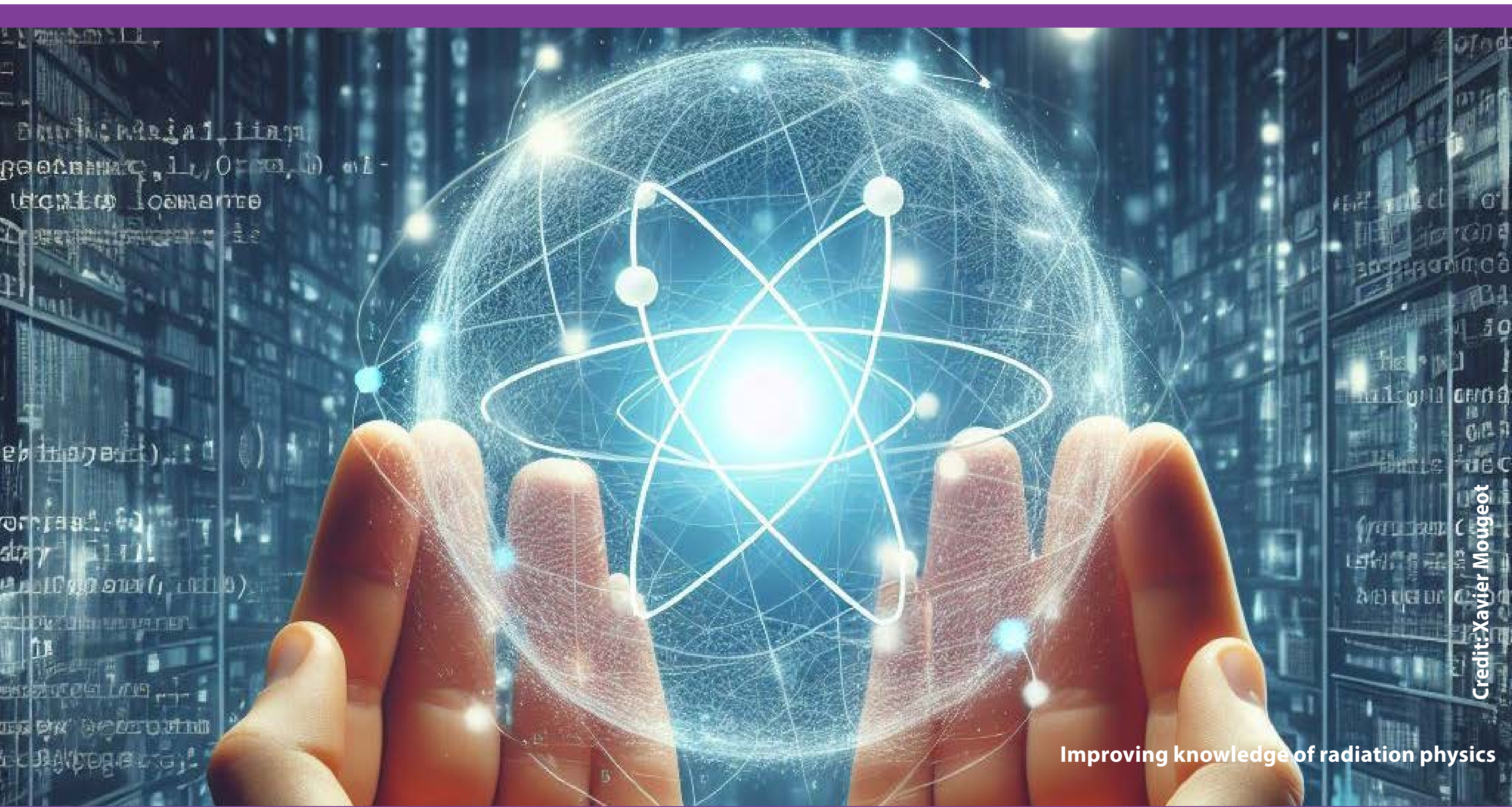
European Metrology Programme for Innovation and Research

Delivering Impact



Improving knowledge of radiation physics

BetaShape: An improved code for calculating beta radiation decay spectra

Accurate knowledge of radioactive decay is vital in areas such as the nuclear industry, doses to patients in medical physics and in understanding the formation of our universe. Direct decay measurements are often difficult to perform and are thus supported by simulations. However, these were subject to serious measurement issues as models used in the first decades of the 21st century still relied on codes developed in the 1970s.

Europe's National Measurement Institutes working together

The European Metrology Programme for Innovation and Research (EMPIR) has been developed as part of Horizon 2020, the EU Framework Programme for Research and Innovation. EMPIR funding is drawn from 28 participating EURAMET member states to support collaborative research between Measurement Institutes, academia and industry both within and outside Europe to address key metrology challenges and ensure that measurement science meets the future.

Challenge

Radioactive decay occurs in unstable nuclides with an excess of protons or neutrons in the nucleus. Accurate knowledge of the decay process is vital in the nuclear industry where it is used in waste processing, storage, powerplant decommissioning or adherence to Directives such as 2013/59/Euratom on basic safety standards for protection against ionising radiation.

A common form is beta minus (β-) decay where neutron-rich atoms convert a neutron into a proton, ejecting an electron and an antineutrino. In neutron-deficient nuclei, two competing decay processes can occur, beta plus (β +) where a proton converts into a neutron, releasing a positron and a neutrino, or Electron Capture (EC). In EC, an atomic electron is absorbed from an orbital shell, converting a proton into a neutron, releasing a neutrino and leaving a 'hole' in the electron cloud.

Atomic and nuclear rearrangements are accompanied by energy release, such as X-rays from the electron cloud, until the nuclide becomes stable.

Each radionuclide is unique and decays randomly, from almost instantaneous to far longer than the age of the universe, making direct measurements difficult.

Recommended decay data, publicly available in the 'Evaluated Nuclear Structure Data File' (ENSDF) database, have been evaluated from measurements and complemented by calculations using the LogFT code since the 1970s. However, the limited computer processing power at the time of its development meant it contained simple approximations, often leading to inaccurate decay data.

Solution

Prior to the start of the EMPIR project MetroBeta in 2016, a new code, BetaShape, was being developed by France's Alternative Energies and Atomic Energy Commission (CEA) to more accurately model the spectra of nuclides undergoing beta decay. MetroBeta refined the code against experimental data and, even at an early stage, it demonstrated the ability to account for discrepancies in experimental cobalt-60 (Co-60) measurements. As well as improvements in nuclide mean decay energies and half-lives, the probability of EC occurring was added.

In the subsequent MetroMMC project, improved sample preparation and measurements of fundamental nuclear decay data were developed. The EC model of the BetaShape code was adapted to a more accurate atomic model, which provides realistic binding energies, wave functions and electronic configurations, including the 'hole' effect on orbitals due to the vacancy created by the capture process.

Impact

After the first release of the BetaShape code in 2018, it was adopted by the Decay Data Evaluation Project (DDEP). This was an important step as the DDEP's high-quality decay data is recommended by the *Bureau International des Poids et Mesures* (BIPM) for use in metrology.

In 2022 the International Network of Nuclear Structure and Decay Data Evaluators (NSDD), who maintain the ENSDF database, formally adopted BetaShape – replacing the legacy LogFT code.

During this time the code was further refined in the EMPIR project PrimA-LTD to include accurate atomic corrections (screening and exchange) and the code validated against LogFT values covering the existing ENSDF database.

A new version of the code was released in 2023. Influence of improved nuclear structure and electron correlations has been explored in the PrimA-LTD project. They will be part of the improvements in future BetaShape released versions.

BetaShape is now the ***de facto*** code for modelling beta spectra and its data is included in the JEFF database used by the European nuclear industry, which will improve knowledge of the types of radiation present in waste and help adherence to relevant directives.

The improved knowledge is also impacting a wide range of other areas, such as microdosimetry in radiotherapy, helping advances in fundamental research about neutrino physics, and in the detection of dark matter.

Improving knowledge of radiation physics

The MetroBeta project (2016-2019) improved theoretical and experimental approaches for beta spectra data with unprecedented accuracy. During this, a new model for beta decay spectra, BetaShape, was improved and published in 2017.

The subsequent MetroMMC project (2018-2021) improved nuclide sample preparation methods and, along with enhanced measurements using Metallic Magnetic Calorimeters and Microwave Coupled Resonators, developed novel detection techniques to better understand Electron Capture (EC). This data was used to improve EC modelling in the BetaShape code. Measurement uncertainties were also reduced for several nuclides required for industrial applications, including the half-life of calcium-41 which is relevant for research into the history of the solar system as well as radioactive waste management.

The PrimA-LTD project (2021-2024) further extended measurements for low-energy beta and electron capture decay, helping improvements in the atomic model of the BetaShape code.

The work of these projects will have a significant impact on a wide range of areas, for many years to come.

EMPIR EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

http://www.euramet.org/project-17FUN02

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11326/0324 - 17FUN02