Contribution of ionizing-radiation metrology to the measurement of radionuclides in the environment

Kellett M.A., Corbel M., Dulieu C., Loidl M., Lourenço V., Mougeot X., Rodrigues M., Branger T.

CEA, LIST, Laboratoire National Henri Becquerel

Introduction

Nuclear decay data are essential to good radioactivity measurements, especially throughout the cycle of nuclear energy production. For a number of radionuclides, their knowledge needs to be significantly improved. On the other hand, the reliability of measurements is ensured by their traceability to national radioactivity standards.
This work is part of the mission of the French national metrology laboratory for ionizing radiation, the Laboratoire National Henri Becquerel (LNHB) of CEA LIST.

Realization of inter laboratory tests

The metrological traceability of measurements in the nuclear industry and environmental monitoring laboratories can be ensured by their participation in inter-laboratory tests periodically organized by the LNHB. Environmental reference materials, produced by the LNHB, are measured by participants whose results are compared with the reference values of the LNHB. These reference materials must have characteristics similar to those of real measured samples, in liquid or solid form: aqueous solutions, vegetal matrices (grass, lentils) spiked with mixed gamma emitters, liquid effluents, etc.

Evaluation and dissemination of radionuclide decay data

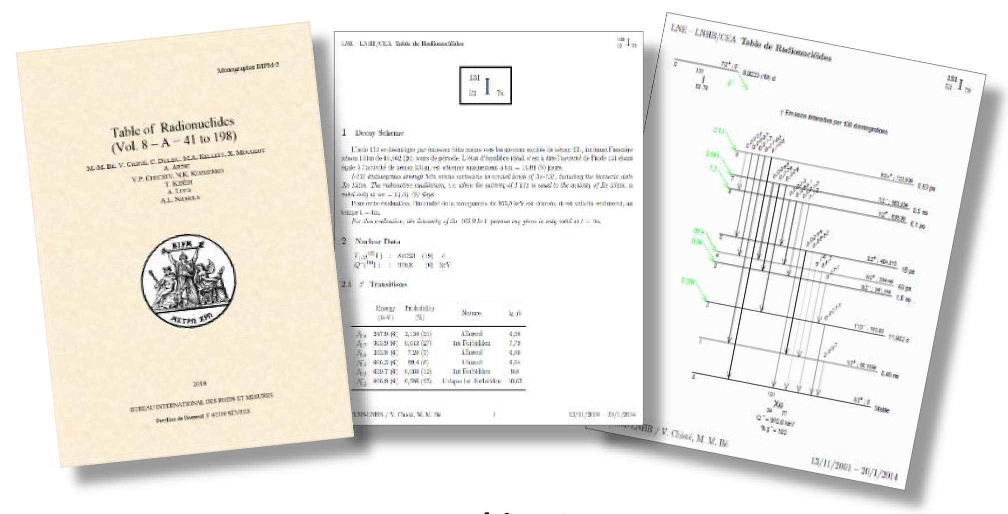
The LNHB, coordinator and co-founder of the Decay Data Evaluation Project (DDEP), is deeply involved in decay data evaluation and their publication. A common evaluation methodology, written by the LNHB, has been adopted by all members, ensuring traceability. The LNHB organizes the dissemination of the recommended decay data and oversees the evaluation review process. Various media are used for this purpose: tabulated data files on our website, regular or special paper publications, and online access through a specially developed web application, LARAWEB.

DDEP Members

Member	Affiliation
Mark A. Kellett (Coordinator)	LNHB, France
Xavier Mougeot	
Christophe Dulieu (IT support)	
Arzu Arinc	NPL, UK
Andy Pearce	
Valery P. Chechev	KRI, Russia
Nikolai Kuzmenko	
Mónica Galán	CTBTO
Xiaolong Huang	CIAE, China
Aurelian Luca	IFIN-HH, Romania
Alan L. Nichols	Surrey Uni., UK
Members joining in 2016:	
Herbert Janssen	PTB, Germany
Haoran Liu	NIM, China
Brian Zimmerman	NIST, USA

http://www.nucleide.org/NucData.htm

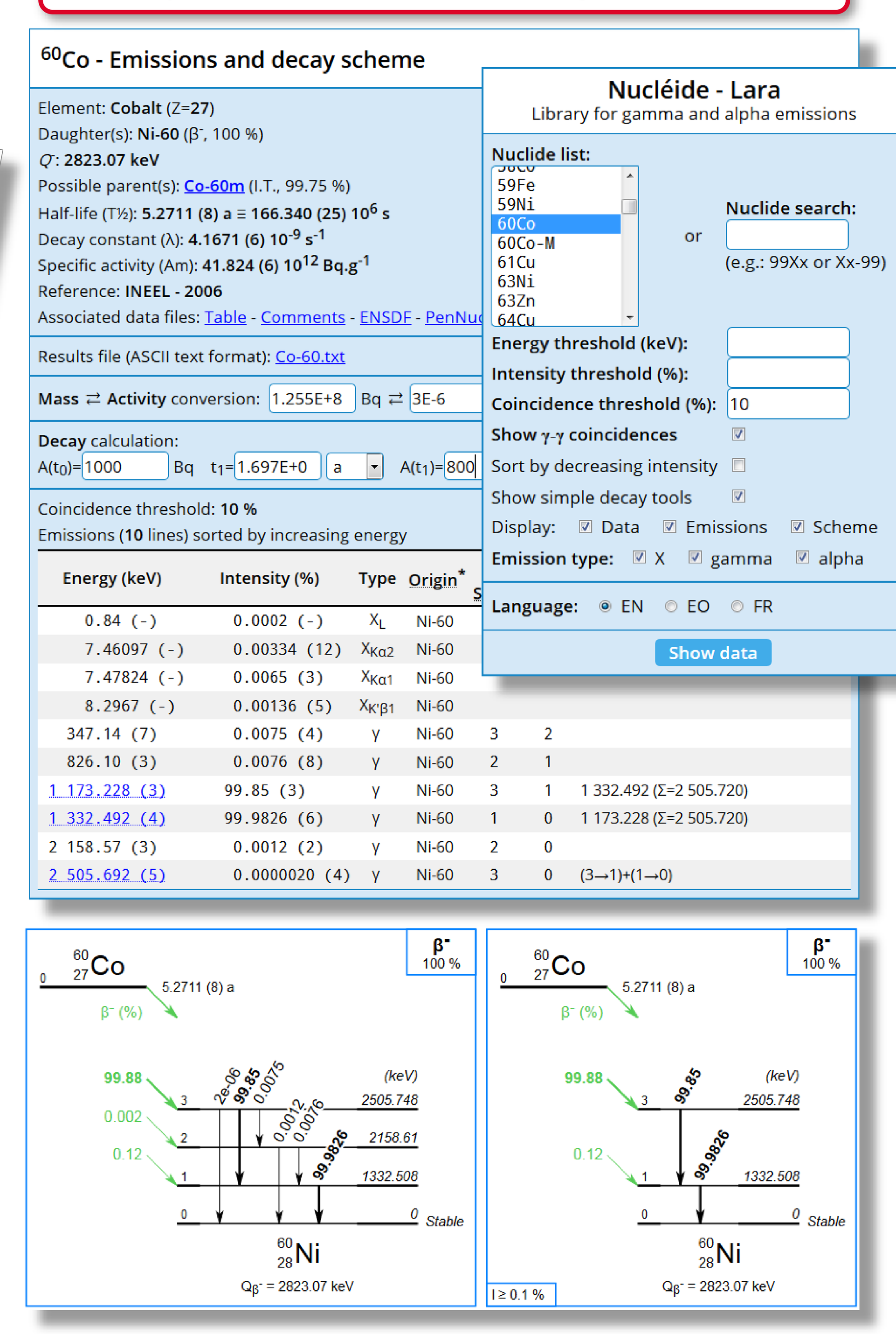
Publications



Monographie BIPM-5
Volumes 1 – 8 published

Mini Table of Radionuclides
New edition published in 2015

http://www.nucleide.org/Laraweb



Theoretical and experimental study of beta spectra

Theoretical study

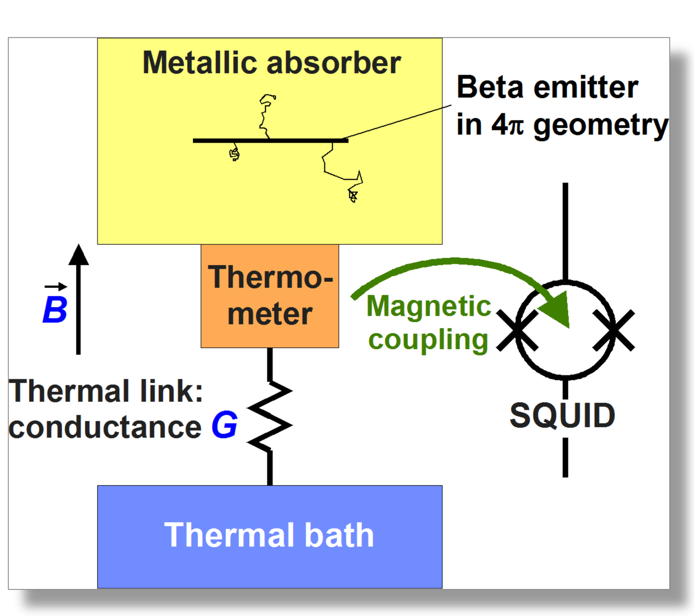
In-house developed code *BetaShape* for theoretical calculation of beta spectra:
- Improved calculation of allowed and forbidden unique transitions; advanced correction of atomic effects (screening, exchange) for allowed transitions.
- Adopted by DDEP for beta emission properties in decay data evaluations.
- Inclusion of nuclear structure in progress in collaboration with University of Strasbourg: towards specific calculation of forbidden non-unique transitions.

Experimental study

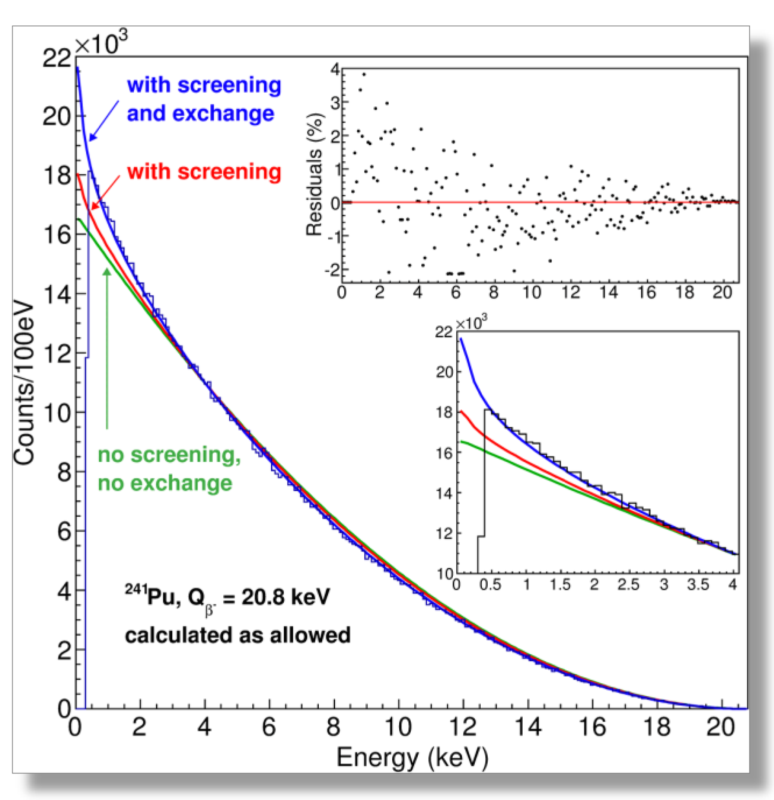
Metallic magnetic calorimeters (MMCs) developed specifically for beta spectrometry:
- Beta emitter enclosed in the detector absorber
  - 100% detection efficiency above threshold (few 100 eV)
  - no dead layer, no problem with self-absorption in the source
- Excellent linearity in energy.

Complementary measurements with a setup using semiconductor detectors under vacuum, in particular for high energy beta emitters.

Excellent agreement between calculated and measured spectra for ^{241}Pu and ^{63}Ni.



Schematic of an MMC enclosing the beta emitter in the metallic absorber offering a 4π sr solid angle



Theoretical beta spectrum of ^{241}Pu including advanced correction of screening and exchange effects and experimental spectrum measured with an MMC

Dilution refrigerator at LNHB
(Base temperature < 10 mK)

On-going project *MetroBeta* (2016-2019) in the framework of the European metrology programme EMPIR, coordinated by LNHB, and partners from PTB, Germany; CMI, Czech Republic; IRA, Switzerland; Heidelberg University, Germany; University Marii Curie-Sklodowskiej, Poland; and Gonitec, the Netherlands.

Metallic Magnetic Calorimeters: Principles

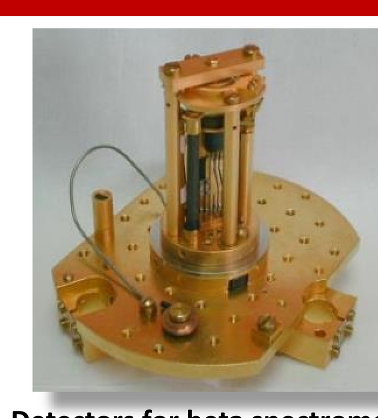
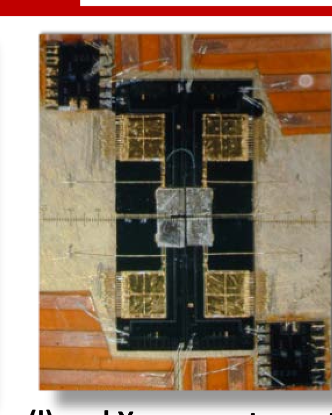
Metallic magnetic calorimeters (MMCs) are thermal detectors:

$$\Delta T = E/C$$

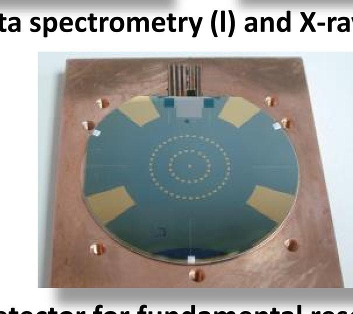
E particle energy
C detector heat capacity

ΔT measured by a paramagnetic thermo-meter coupled to a SQUID magnetometer
Very low temperature (10 – 20 mK):
- small heat capacity, low noise
  - excellent energy resolution
  - very low energy threshold

Flexibility in absorber material and size
- can be optimized for particle type (α, β, or X / γ) and energy range (sub-keV to 100s of keV)

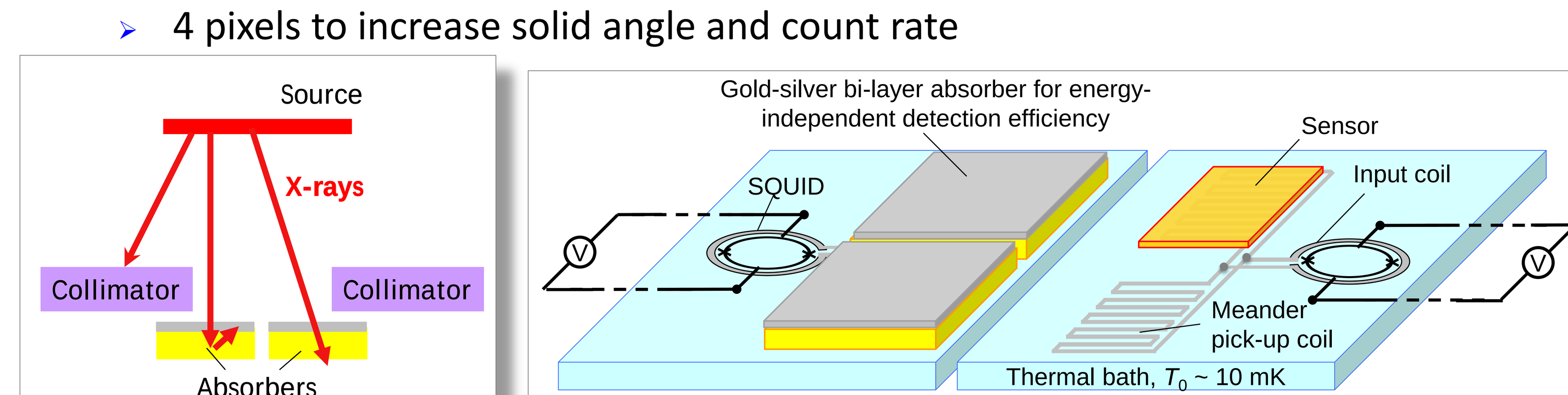
Detectors for beta spectrometry (l) and X-ray spectrometry (r)

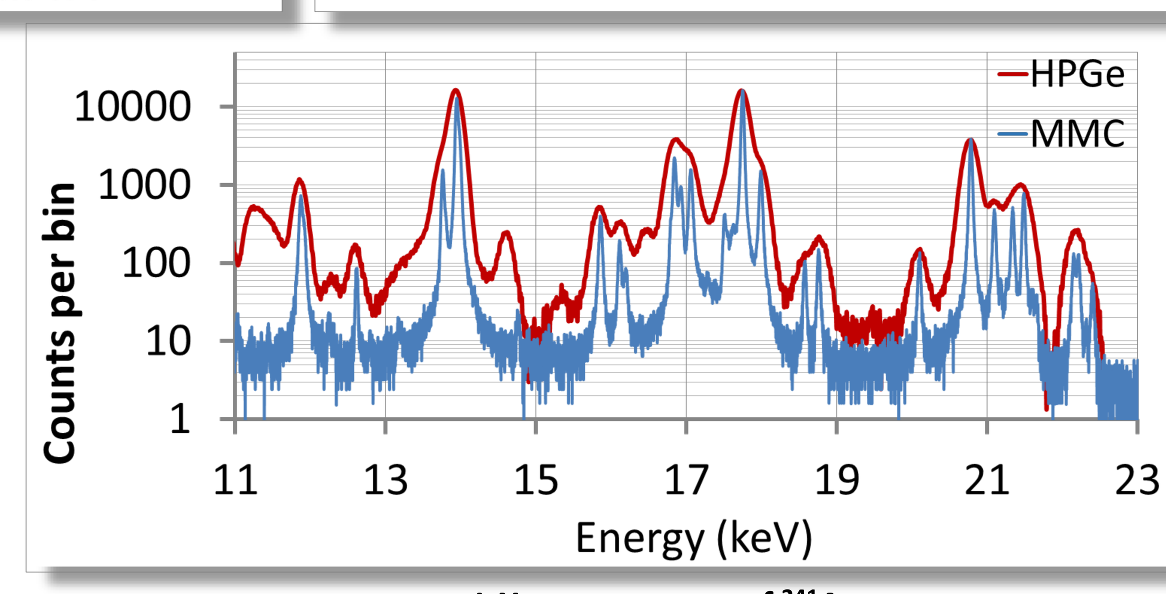


Detector for fundamental research

Study of actinide L X-rays

Actinides are key radionuclides in many applications (nuclear fuel cycle, safeguards for non-proliferation, environmental surveys, …)
Actinides have intense, but not well known, L X-rays between 10 and 25 keV
A dedicated MMC has been developed to improve knowledge of actinide L X-ray spectra
- High energy resolution: FWHM 26 eV up to 60 keV
- Intrinsic detection efficiency constant and close to unity below 25 keV
- 4 pixels to increase solid angle and count rate





L X-ray spectrum of ^{241}Am