

# Determination of fractional electron capture probabilities of Nickel-59 by means of Metallic Magnetic Calorimeters

Arshjot Kaur, Lucille Chambon, Martin Loidl, V. Lourenço, Matias Rodrigues

#### ▶ To cite this version:

Arshjot Kaur, Lucille Chambon, Martin Loidl, V. Lourenço, Matias Rodrigues. Determination of fractional electron capture probabilities of Nickel-59 by means of Metallic Magnetic Calorimeters. 20th International Conference on Low Temperature Detectors, Jul 2023, Daejeon, South Korea. 2023. cea-04137584

#### HAL Id: cea-04137584 https://cea.hal.science/cea-04137584v1

Submitted on 24 Jul 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



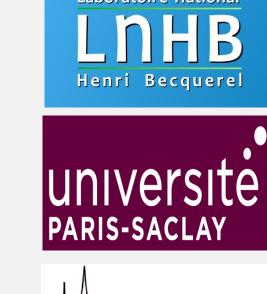
PrimA-LTD

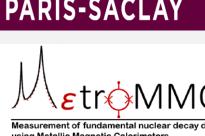
# Determination of Fractional Electron Capture Probabilities of <sup>59</sup>Ni by means of Metallic Magnetic Calorimeters



Université Paris-Saclay, CEA, LIST, Laboratoire National Henri Becquerel (LNE-LNHB), F-91120 Palaiseau, France







The measurement is part of the European metrology research project MetroMMC (2018-21). In the project, MMCs have been optimized and utilized for decay energy spectrometry of radionuclides decaying via electron capture (EC). Several EC-decaying radionuclides emitting radiation in the energy range between 20 eV and 100 keV were selected.

The project's main objectives are to measure fractional electron capture probabilities and absolute X-ray emission intensities. To improve theoretical models and calculations of electron capture and subsequent atomic relaxation and to validate the theoretical data with the high-precision experimental data from this project.

#### Motivation

Nickel-59, one of the radionuclides chosen for the MetroMMC project, decays mainly by EC to the ground state of Co-59 and has a long half-life of 76,000 years. The decay is a 2<sup>nd</sup> forbidden non-unique transition. The main applications where the electron capture probability ratios are required are:

Isotope geology: <sup>59</sup>Ni is used to date meteorites and determine the abundance of extraterrestrial dust in ice and sediment.

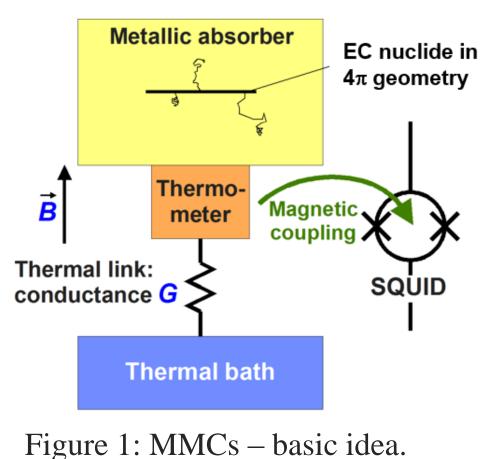
Signal :  $\Delta T = E/C$ 

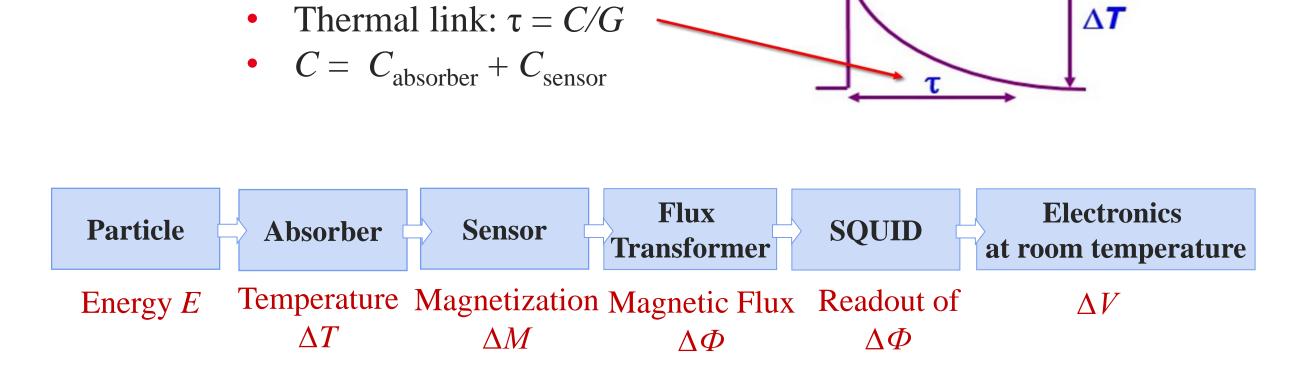
• Nuclear power plant radioactive waste qualification: <sup>59</sup>Ni is produced in nuclear reactors as an activation product of Ni-cladded control rods and other steel structural components. It is present in nuclear waste, and its detection is very difficult because of its long half-life and no  $\gamma$ -ray emission.

59	<sup>59</sup> Co shells E (keV)	
76 (5) 10 <sup>3</sup> a ε <sub>+</sub> (%)	K	7.7089
<b>∠</b> β΄ (%)	L1	0.9256
99.99996 0.000037	L2	0.7936
Co	L3	0.7786
keV	M	0.1007-
		0.0029

## Detection technique: Metallic Magnetic Calorimeters (MMCs)

• MMCs with the radionuclide embedded in the absorber  $\rightarrow$  Decay energy spectrometry (DES).





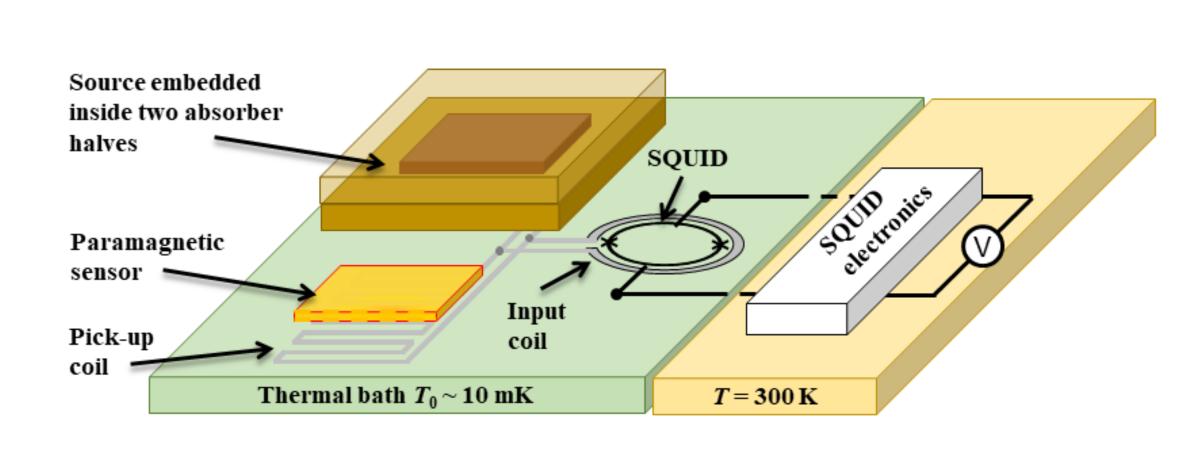
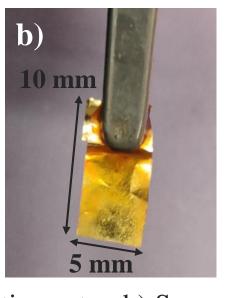


Figure 2: MMC readout by DC SQUID magnetometer via a superconducting flux transformer.

## **Absorber and source preparation**

#### **Electrodeposition Method**





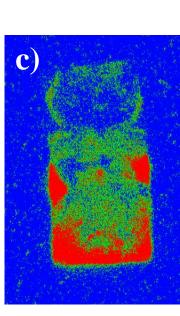
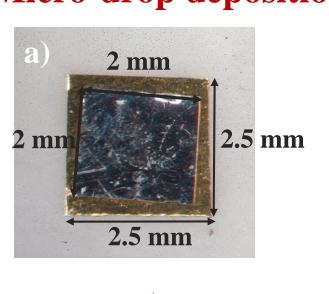
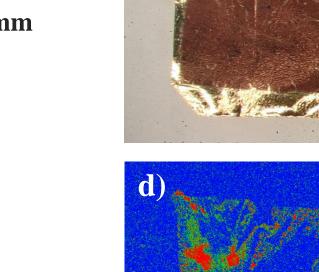


Figure 3: a) Electroplating setup b) Source foil after plating c) Autoradiography of the source foil.

- The electrodeposition using an in-house adapted two-electrode cell setup, as shown in Figure 3a.
- Anode: platinum wire and cathode: gold foil  $(10 \times 5 \times 0.005 \text{ mm}^3)$ .
- Electrolyte: 5 mL of DMSO & 100 μL of  $1 \text{ N HCl} + 0.1 \text{ N HNO}_3 + \text{NiCl}_2$ .
- A constant current source at I = 10 mA and V = 150 V was used for 20 min.
- The initial mass activity of the radioactive solution is 81 kBq/g.
- Activity obtained on the source foil (Figure 3b): 2.77 kBq.
- Figure 3c shows the autoradiography of the activity distribution of the source.

#### II. Micro-drop deposition on gold nanofoam







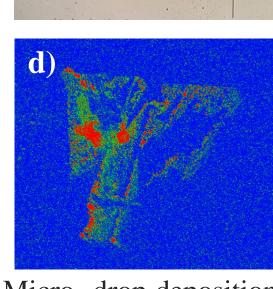


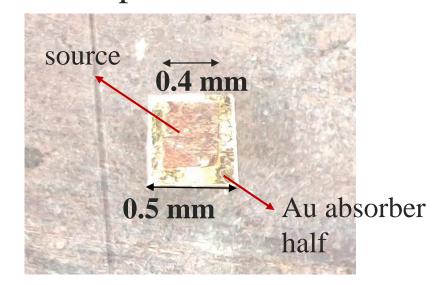
Figure 4: a) AuAg alloy on Au foil b) Micro- drop deposition on gold nanofoam c) Micro-drop dispenser d) Autoradiography of the source foil.

- Figure 4a:  $Au_{0.3}Ag_{0.7}$  (wt%) alloy (2×2×0.006 mm<sup>3</sup>) diffusion welded on gold foil  $(2.5 \times 2.5 \times 0.01 \text{ mm}^3)$ .
- Figure 4b: Gold nanofoam by dealloying through wet etching with 20% HNO<sub>3</sub> for 2 hours at 50 °C, dissolving silver, and forming nanoporous gold.
- Figure 4c: Micro-drop dispenser setup. For a 3 Bq activity, the drop volume was 41 nL (1216 drops); for 4 Bq, it was 55 nL (1671 drops).
- Figure 4d: Autoradiography of one of the sources.

## **Experiment setup:**

#### Decay energy spectrometry (DES)

- In DES measurement mode, the source is fully enclosed between the two absorber halves (Figure 5a) to have a  $4\pi$  detection geometry (*Figure 5b*).
- The decay energy from the source, except the neutrino, is thermalized inside the absorber. The obtained energy spectrum shows a single peak for each capture electron shell.



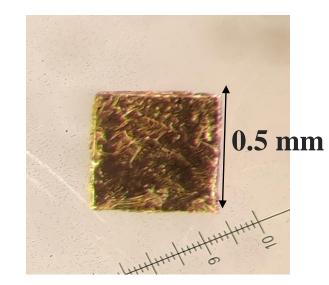
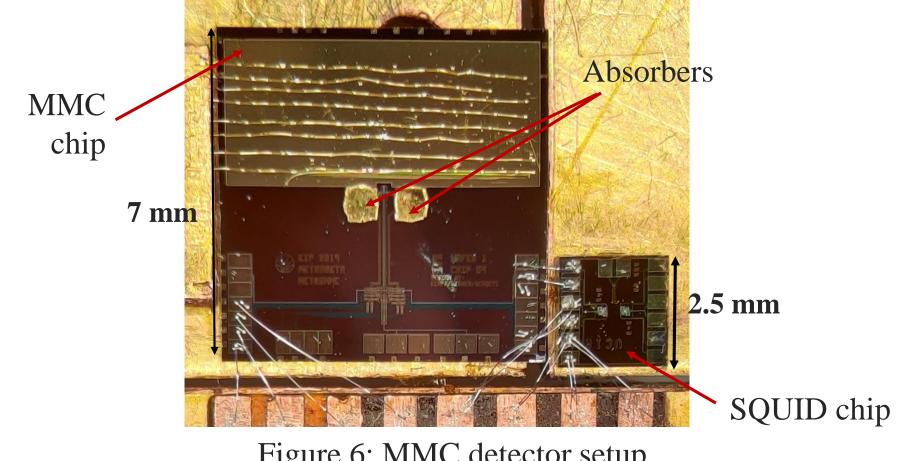


Figure 5: a) Source foil on one half of Au absorber b) Complete absorber-source ensemble.



#### Figure 6: MMC detector setup.

### Spectrum analysis and results

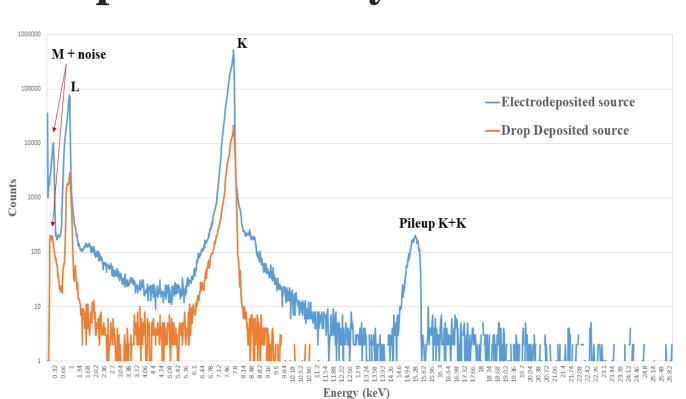


Figure 7: Comparison of both source's total energy spectra of <sup>59</sup>Ni.

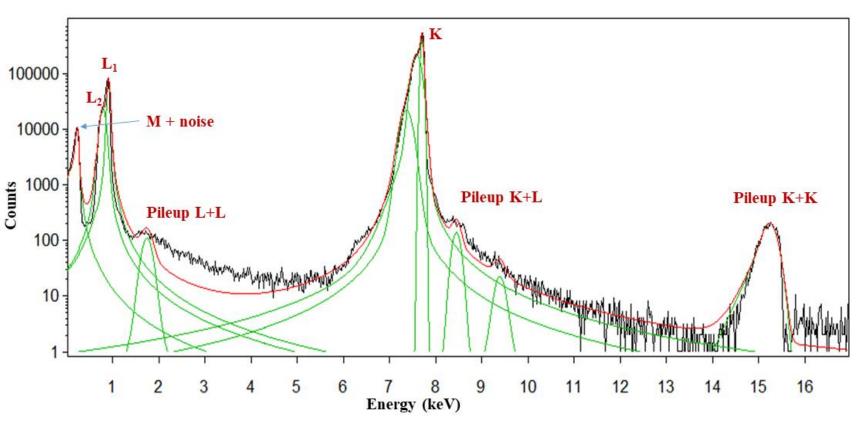
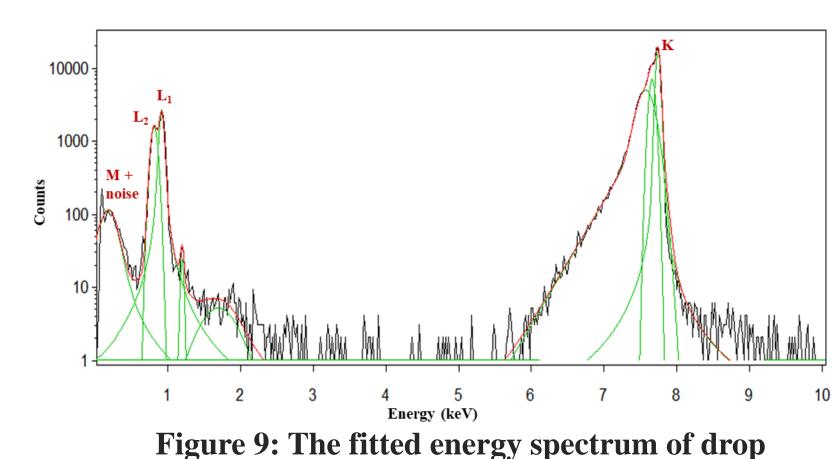


Figure 8: The fitted energy spectrum of electrodeposited



deposited <sup>59</sup>Ni.

 Fractional electron capture probability ratios

Measurement	$P_{\rm L}/P_{ m K}$	
Electrodeposition	0.1154 (11)	
Drop deposition	0.1122 (22)	
BetaShape *[3]	0.1159 (26)	
Literature	0.1210 (20) [4]	

\* Theoretical calculation code developed at LNHB.

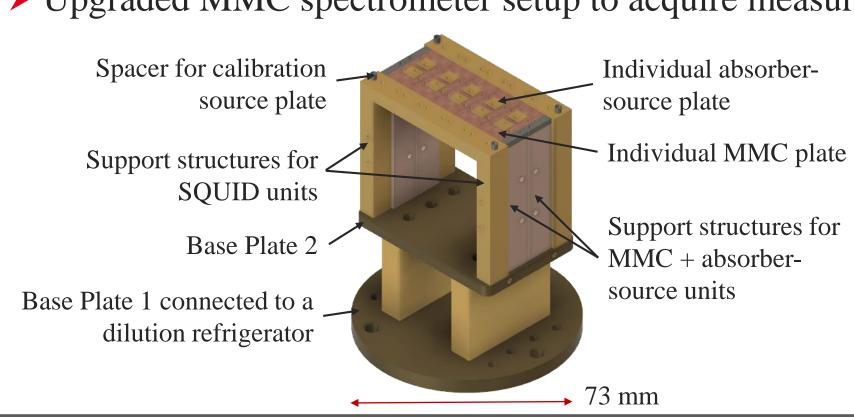
- The ratio of peak areas corresponds to the fractional capture probabilities. The quoted uncertainties comprise the statistical uncertainties and an estimation of the uncertainty due to the data analysis.
- The pulses had a 10-90% rise time of 170 μs in both sources, with exponential decay resulting in a 1/e decay time of 400 μs in the electroplated source and 440 μs in the drop-deposited source.
- In drop-deposited sources, due to the loss of a portion of the energy of Auger electrons in the source material causes a low energy tail (0.95% for K peak), less pronounced in electroplated sources (0.38% for K peak).

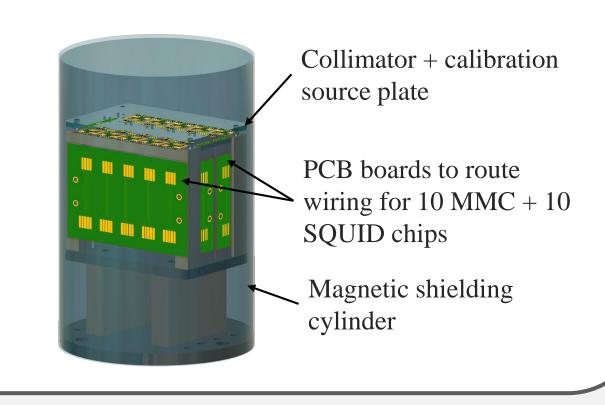
The fractional electron capture probability ratios from both sources are compatible with each other and the recent BetaShape calculation value.

#### The follow-up EMPIR project: PrimA-LTD (2021-2024)

- To develop a new primary method for decay scheme independent activity determination, high energy resolution, and statistics that exceed 10<sup>8</sup> events/spectrum.
- High statistics measurements of <sup>129</sup>I (beta spectrum shape; branching ratio) and <sup>55</sup>Fe (shake-up and shake-off effects) will be performed by the use of multiple detectors.

## $\triangleright$ Upgraded MMC spectrometer setup to acquire measurement statistics of >10<sup>8</sup> events per spectrum.





1. C. Enss, A. Fleischmann, K. Horst, J. Schönefeld, J. Sollner, J.S. Adams, Y.H. Huang, Y.H. Kim, G. Seidel. Metallic Magnetic Calorimeters for Particle Detection. J. Low Temp. Phys. 121 (2000) 137–176.

2. P. C.-O. Ranitzsch, D. Arnold, J. Beyer, L. Bockhorn, J. J. Bonaparte, C. Enss, K. Kossert, S. Kempf, M. Loidl, R. Mariam, O. J. Nähle, M. Paulsen, M. Rodrigues & M. Wegner. MetroMMC: Electron-Capture Spectrometry with Cryogenic Calorimeters for Science and Technology. Journal of Low Temperature Physics 199 (2020) 441–450. 3. X. Mougeot, Applied Radiation and Isotopes 154 (2019) 108884, doi: 10.1016/j.apradiso.2017.07.027

20<sup>th</sup> International Conference on Low Temperature Detectors | Daejeon, South Korea | July 23-28, 2023

4. W. M. Chew, A. C. Xenoulis, R. W. Fink, and J. J. Pinajian, "Nuclear matrix elements from L/K electron capture ratios in <sup>59</sup>Ni decay," Nucl. Phys. A, vol. 218, no. 2, pp. 372–380, Jan. 1974, doi: 10.1016/0375-9474(74)90010-4. Acknowledgment: This work was performed as part of the EMPIR Project 17FUN02 MetroMMC and 20FUN04 PrimA-LTD. This project has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme

