PAUL SCHERRER INSTITUT

PSI

Repetition of the Re-Measurement of the ^{60}Fe Half- Life

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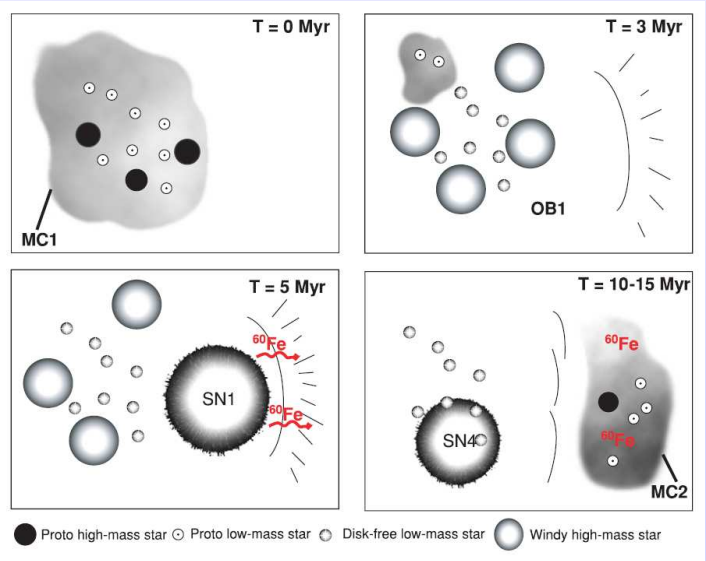
Outline

- Introduction
- γ-Measurement
- ICP-MS Measurement
- Next Steps

Supernova Propagation and Cloud Enrichment: A new Model for the Origin of ^{60}Fe in the early Solar System

M. Gounelle, A. Meibom, P. Hennebelle, Shu-ichiro Inutsuka:

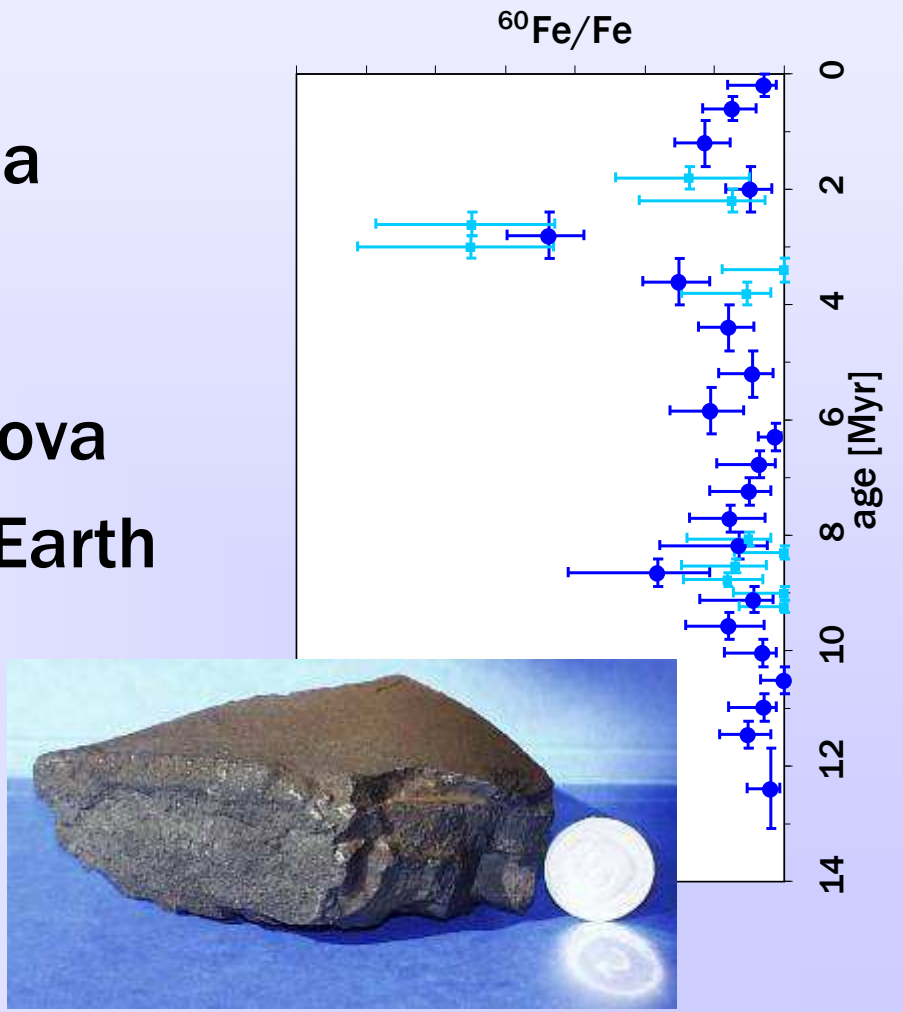
Astrophysical J. **694** (2009) L1



Abstract:
The radioactive isotope **^{60}Fe ($t_{1/2}$ = 1.5 Myr)** was present in the early solar system. It is unlikely that it was injected directly into the nascent solar system by a single, nearby supernova (SN). It is proposed instead that it was inherited during the molecular cloud (MC) stage from several SNe belonging to previous episodes of star formation.

^{60}Fe in Deep Sea Crust

- ^{60}Fe horizon at 2.8 Ma
  - *Based on*
    ^{10}Be $t_{1/2}$ = 1.51 Ma
- Produced by Super Nova
- 40 pc distance from Earth
  - *Based on*
    ^{60}Fe $t_{1/2}$ = 1.49 Ma

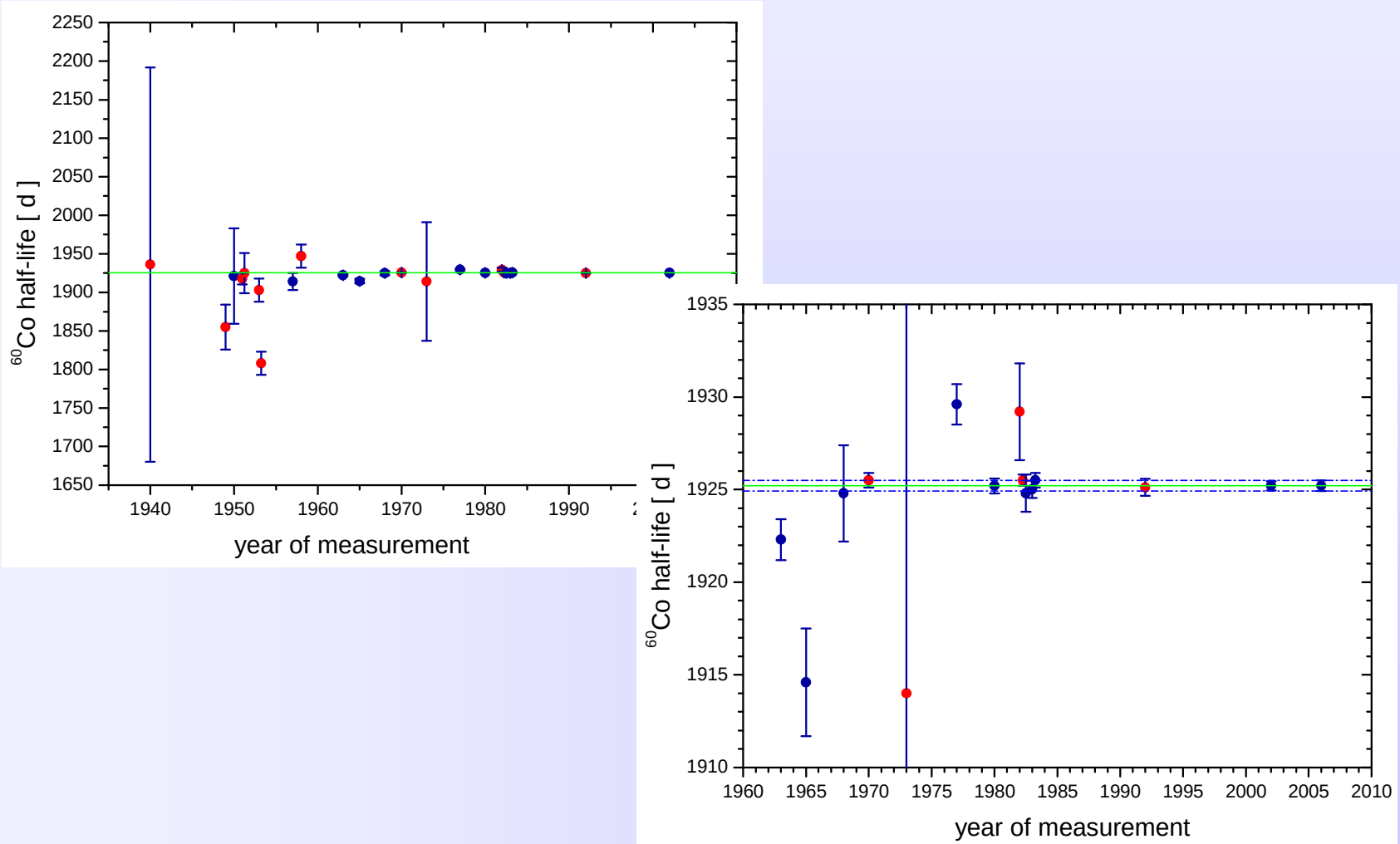


K. Knie, et al.: Phys. Rev. Lett. **93** (2004) 171103

Why Re-Measurement of ^{60}Fe Half-Life

- dating of cosmic or terrestrial samples using ^{60}Fe
  - *^{60}Fe $t_{1/2}$ = 1.49 Ma ± 0.27 Ma*
    W. Kutschera et al., Nucl. Instrum. Methods B 5 (1984) 430
  - *^{60}Fe $t_{1/2}$ = 2.62 Ma ± 0.04 Ma*
    G. Rugel, et al.: Phys. Rev. Lett. 103 (2009) 072502

History of ^{60}Co Half-Life Measurements



^{60}Fe Sample Preparation

- Purification Steps
  - *^{60}Fe target dissolved in 7 M HCl*
  - *Liquid- liquid-extraction of Fe with methyl isobutyl ketone*
  - *Aqueous phase: Ni, Co, Cu organic phase: Fe*
  - *Back extraction with 0.1 M HCl repetition of procedure*
  - *Chemical yield about 80%*

Last separation: 28.08.2009 11:00

- Prepared Samples
  - *2 samples each 3.5·10^{15} atoms for γ-measurements (PSI & Uni Vienna)*
  - *1 sample 1.7·10^{15} atoms for ICP-MS measurements (PSI)*
  - *1 sample 1.7·10^{15} atoms for thermal neutron capture (Uni Vienna)*

γ-Spectroscopic Set-Up

Data Acquisition System

- Canberra hardware
  - High Voltage Supply
  - Amplifier
  - ADC
  - Digital Stabilizer
  - Acquisition interface
- Canberra software
  - *Genie 2000*

γ-Spectroscopic Set-Up

Well HPGe-Detector

Princeton Gamma-Tech

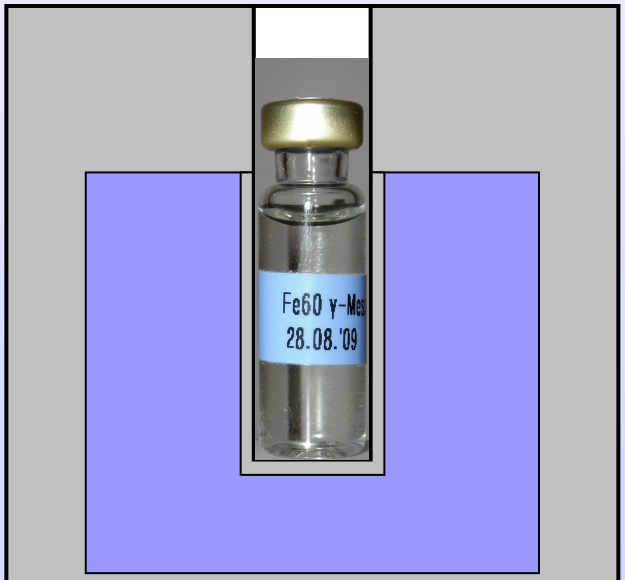
- Crystal
  - *Diameter ∅60 mm*
  - *Length 53 mm*
  - *Blind well hole ∅19 mm x 40 mm*
  - *Sample Hole ∅15 mm x 60 mm*
- Resolution
  - *1.54 keV @ ^{57}Co 122 keV*
  - *2.38 keV @ ^{60}Co 1332 keV*
- Efficiency
  - *abs. 4.3% @ ^{60}Co 1332 keV*

Sample Container

- 4-CV 4mL crimp top vial
- ∅15 mm x 46 mm

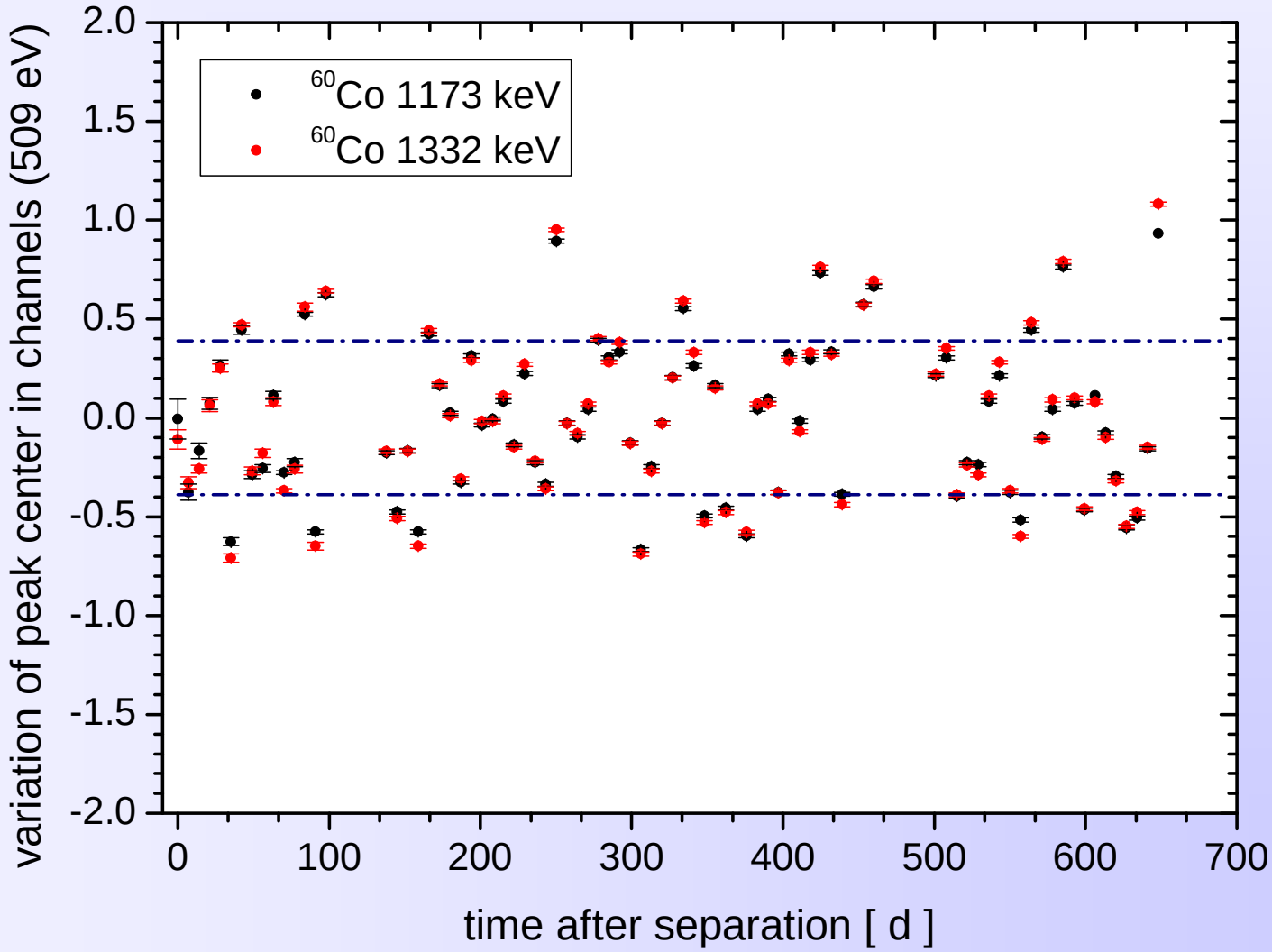
γ-Measurement Schedule

- Weekly Schedule
  - *refill liquid nitrogen*
  - *activate digital stabilizer*
  - *^{60}Co ^{241}Am source*
    4h measurement
  - *hold digital stabilizer parameter*
  - *^{60}Fe source*
    160 h measurement
- Start measurement:
  28.08.2009 15:01:02
- Collected spectra: 86
  total 13760 h

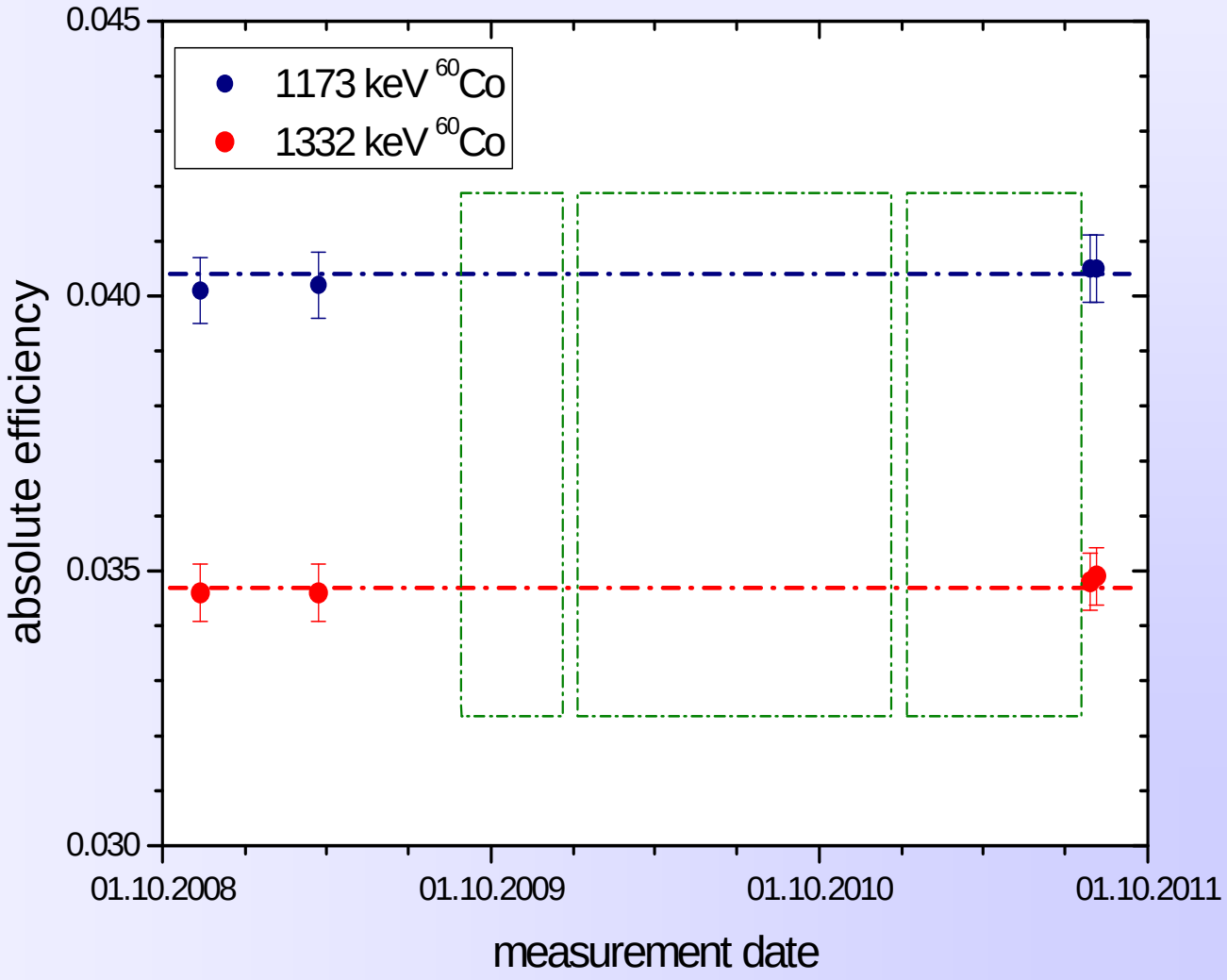


energy	abs. eff.
59.54 keV	63.4%
1173.22 keV	4.04%
1332.49 keV	3.47%

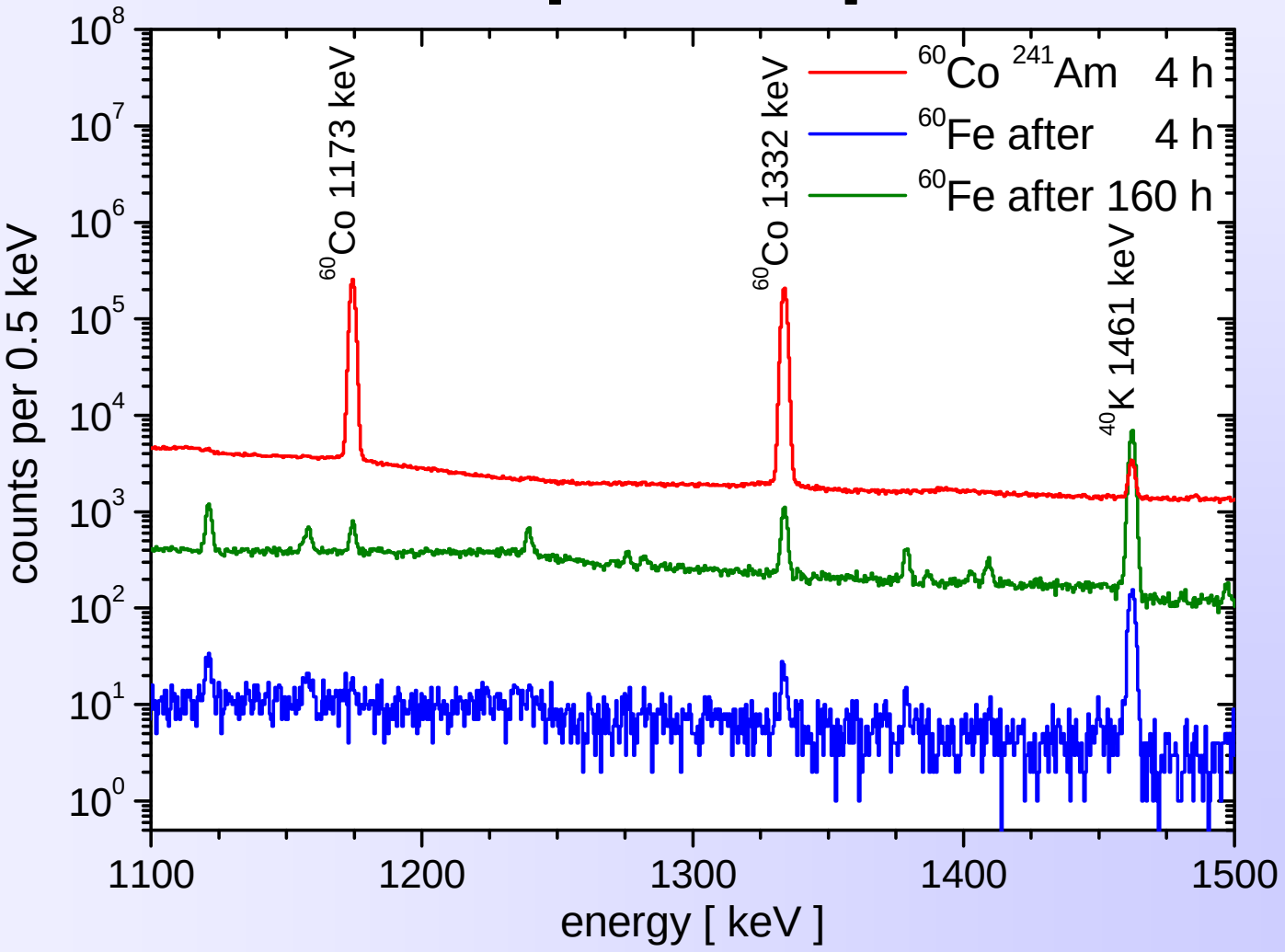
Stability of Spectrometer



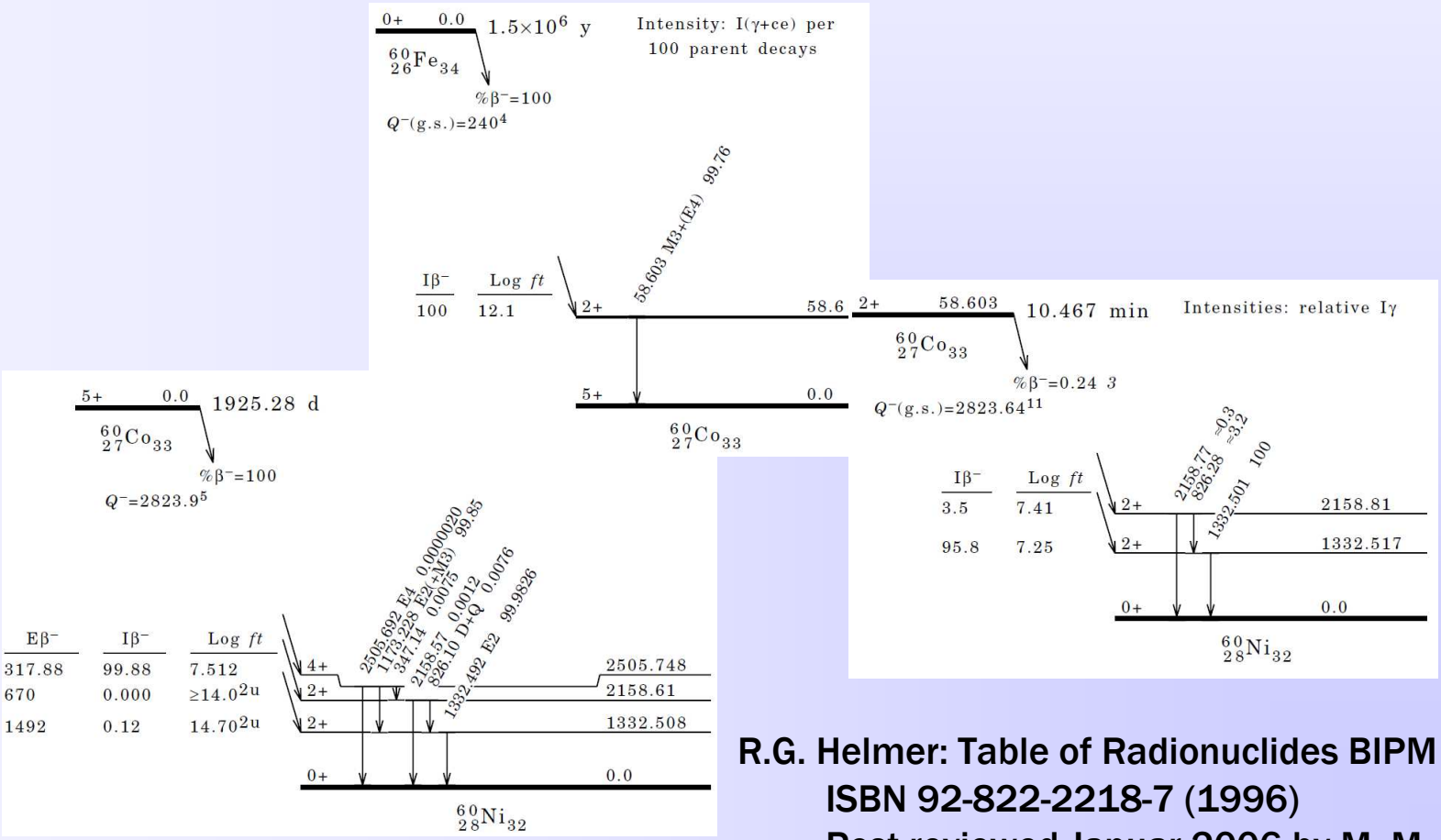
Full Energy Peak Efficiency of ^{60}Co



First γ-Spectra after Sample Preparation

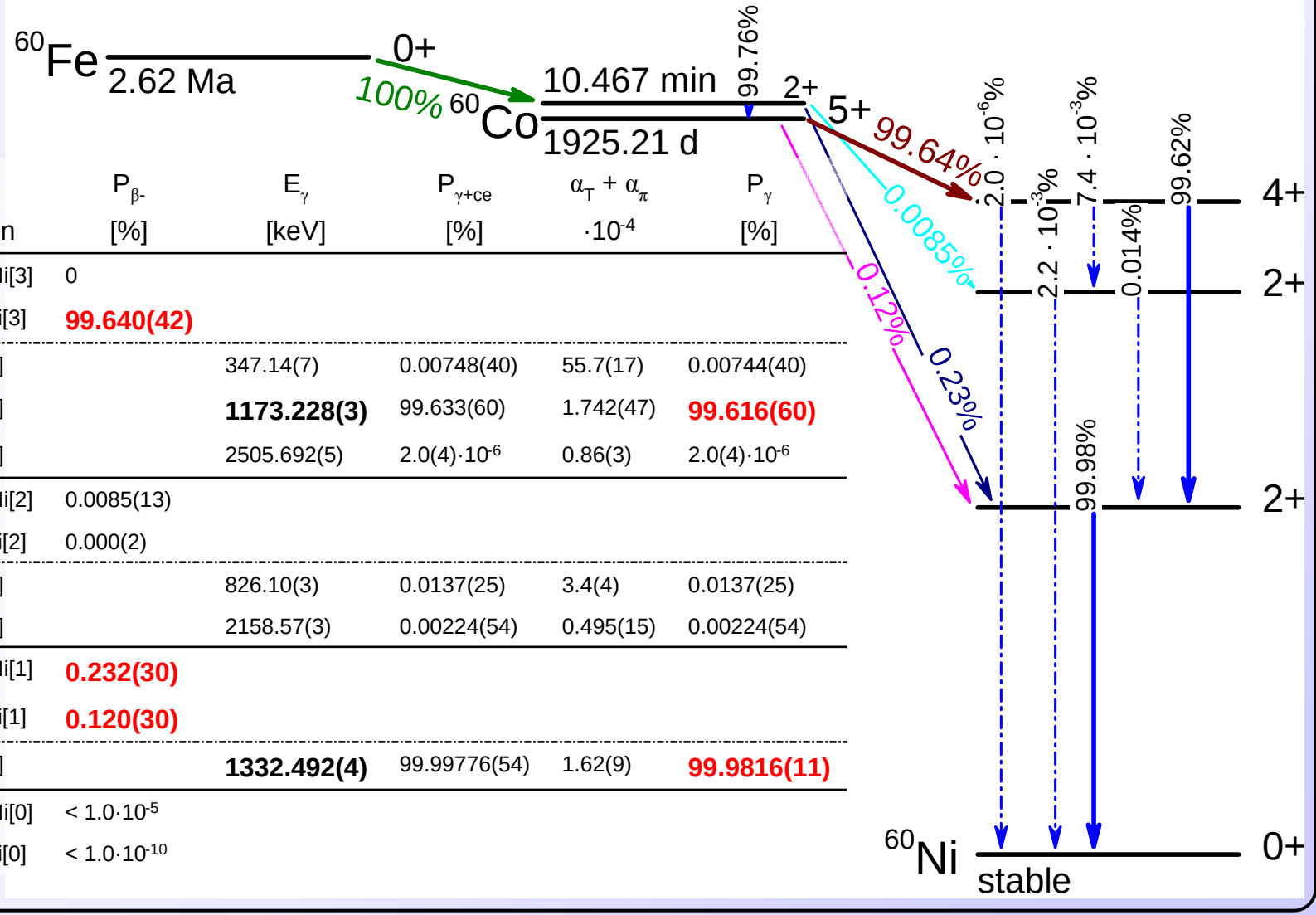


Decay Schema
^{60}Fe to ^{60}Ni



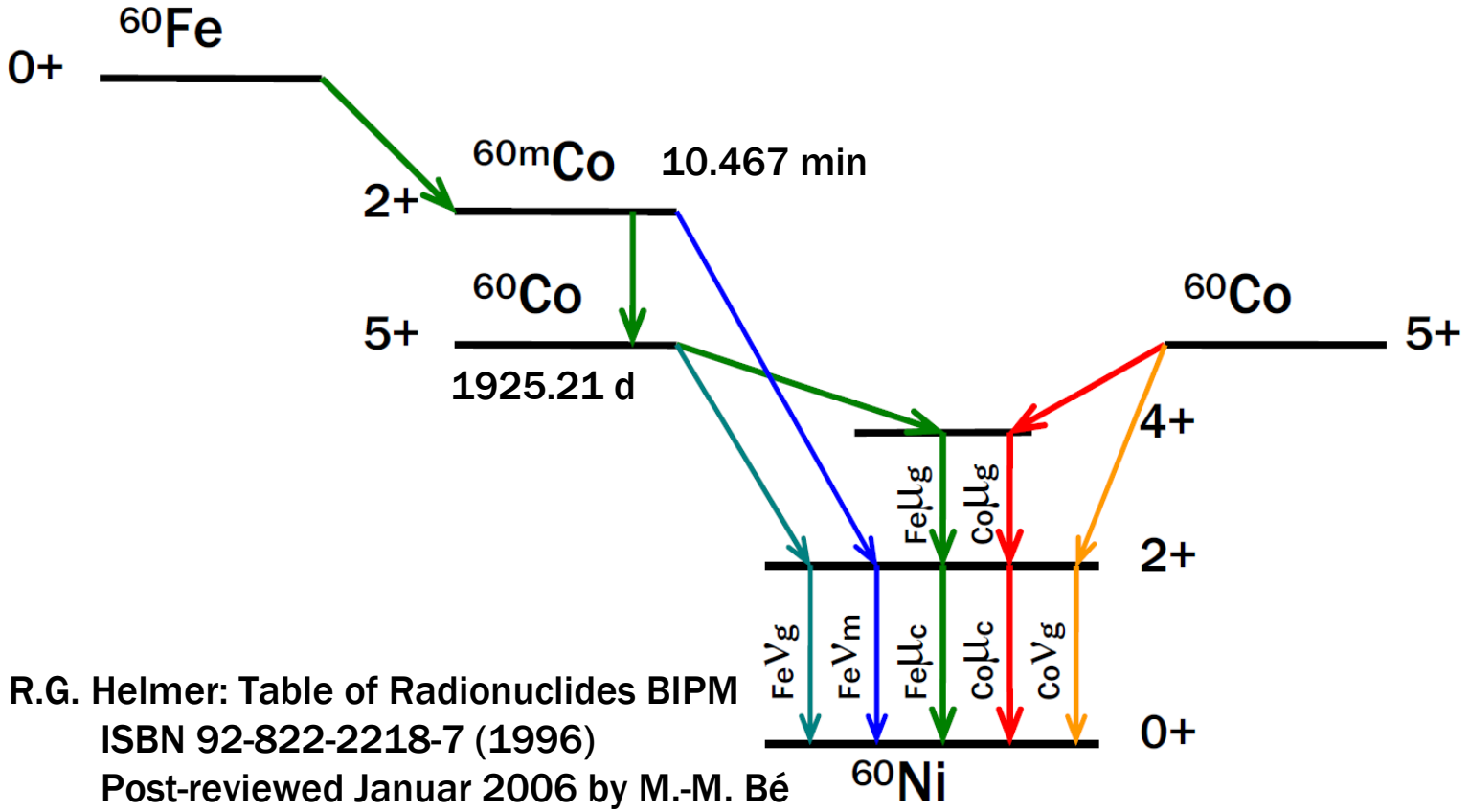
R.G. Helmer: Table of Radionuclides BIPM
ISBN 92-822-2218-7 (1996)
Post-reviewed Januar 2006 by M.-M. Bé
J. K. Tuli: Nuclear Data Sheets **100** (2003) 347

Adopted Decay Schema ^{60}Fe to ^{60}Ni



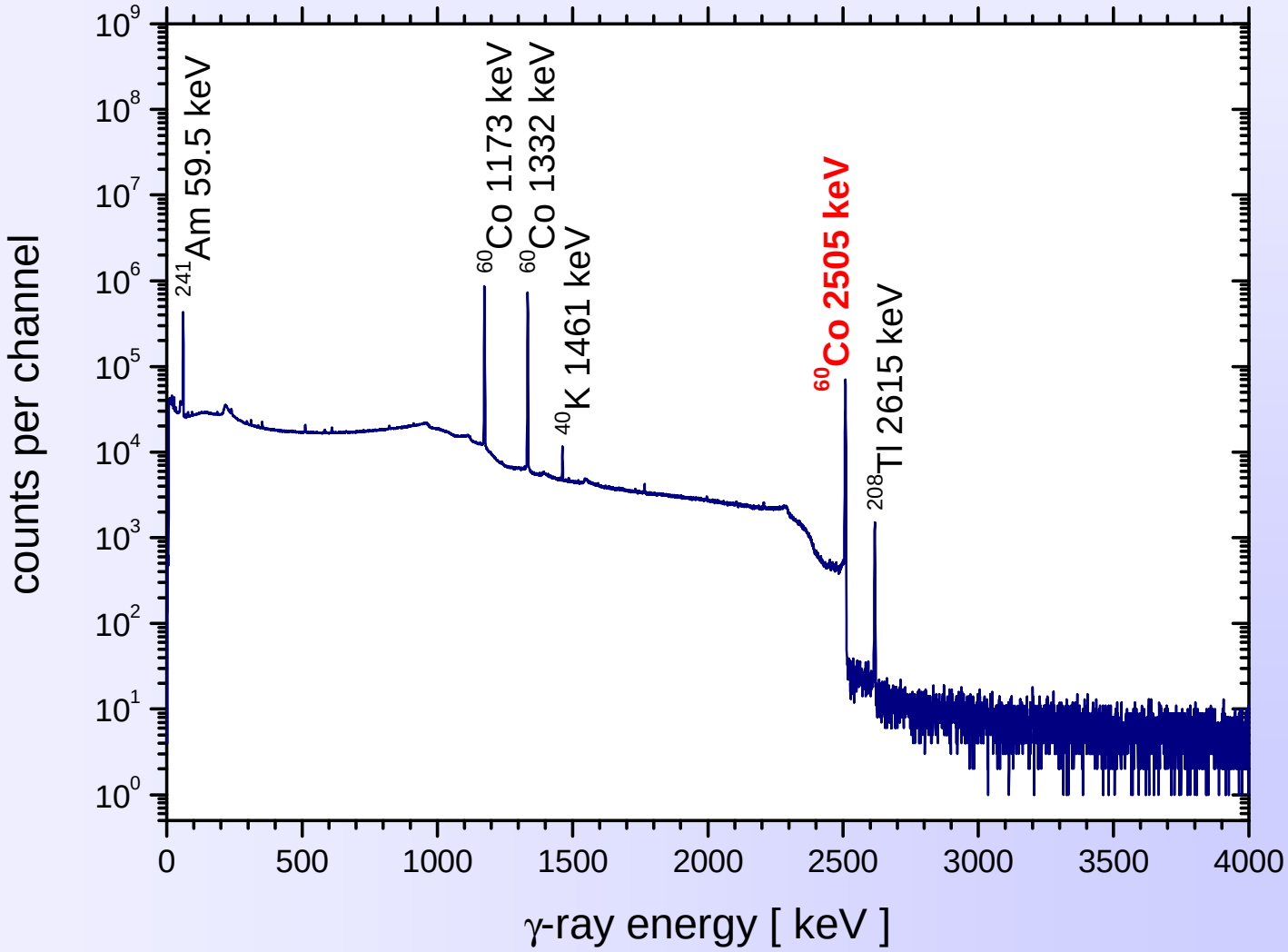
transition	$P_{\beta-}$ [%]	E_γ [keV]	$P_{\gamma+ce}$ [%]	$\alpha_T + \alpha_\pi$ $\cdot 10^{-4}$	P_γ [%]
^{60m}Co→^{60}Ni[3]	0				
^{60}Co→^{60}Ni[3]	**99.640(42)**				
→^{60}Ni[2]		347.14(7)	0.00748(40)	55.7(17)	0.00744(40)
→^{60}Ni[1]		**1173.228(3)**	99.633(60)	1.742(47)	**99.616(60)**
→^{60}Ni[0]		2505.692(5)	$2.0(4)\cdot10^{-6}$	0.86(3)	$2.0(4)\cdot10^{-6}$
^{60m}Co→^{60}Ni[2]	0.0085(13)				
^{60}Co→^{60}Ni[2]	0.000(2)				
→^{60}Ni[1]		826.10(3)	0.0137(25)	3.4(4)	0.0137(25)
→^{60}Ni[0]		2158.57(3)	0.00224(54)	0.495(15)	0.00224(54)
^{60m}Co→^{60}Ni[1]	**0.232(30)**				
^{60}Co→^{60}Ni[1]	**0.120(30)**				
→^{60}Ni[0]		**1332.492(4)**	99.99776(54)	1.62(9)	**99.9816(11)**
^{60m}Co→^{60}Ni[0]	$< 1.0\cdot10^{-5}$				
^{60}Co→^{60}Ni[0]	$< 1.0\cdot10^{-10}$				

Reduced Decay Schema for Non-Linear Fit

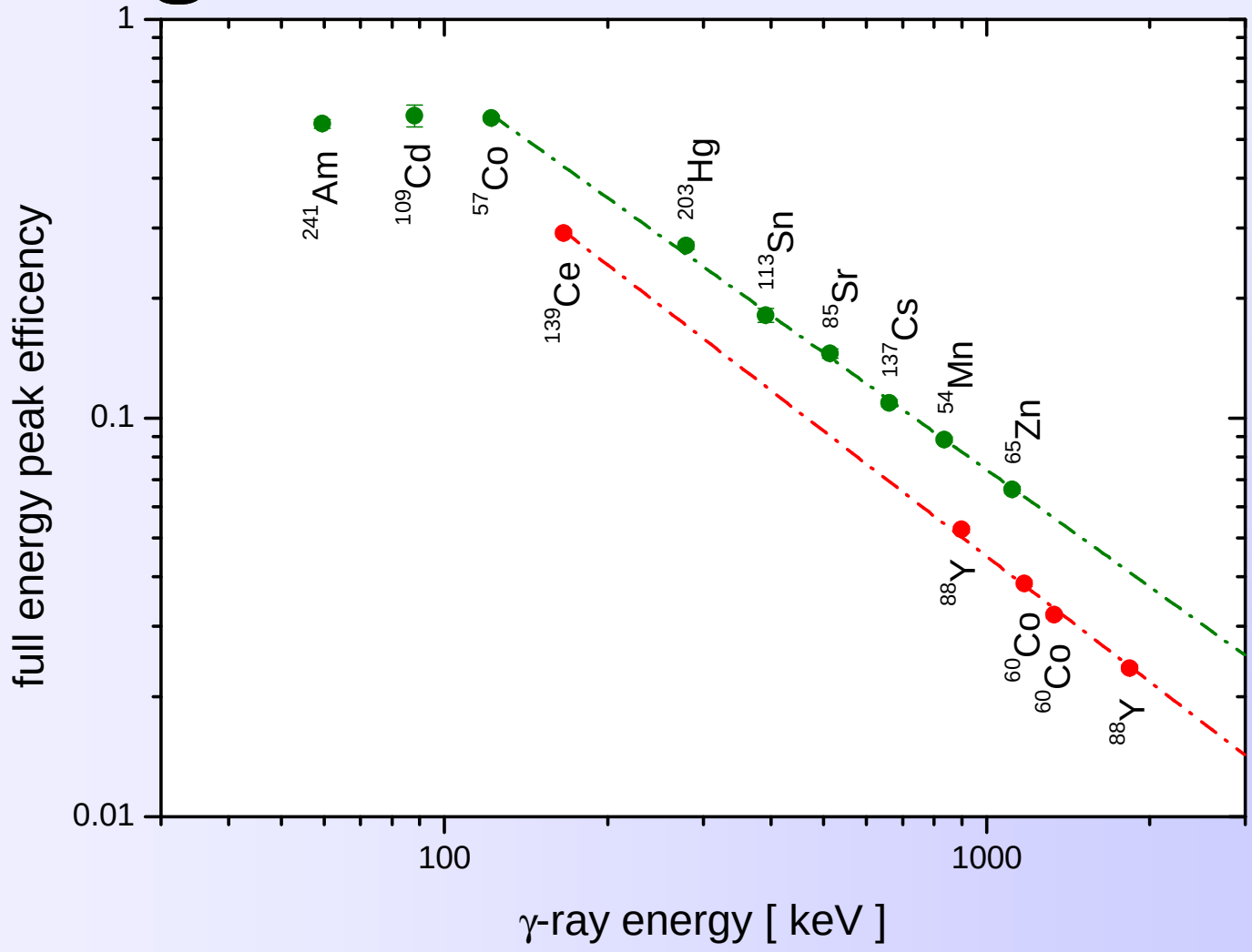


R.G. Helmer: Table of Radionuclides BIPM
ISBN 92-822-2218-7 (1996)
Post-reviewed Januar 2006 by M.-M. Bé

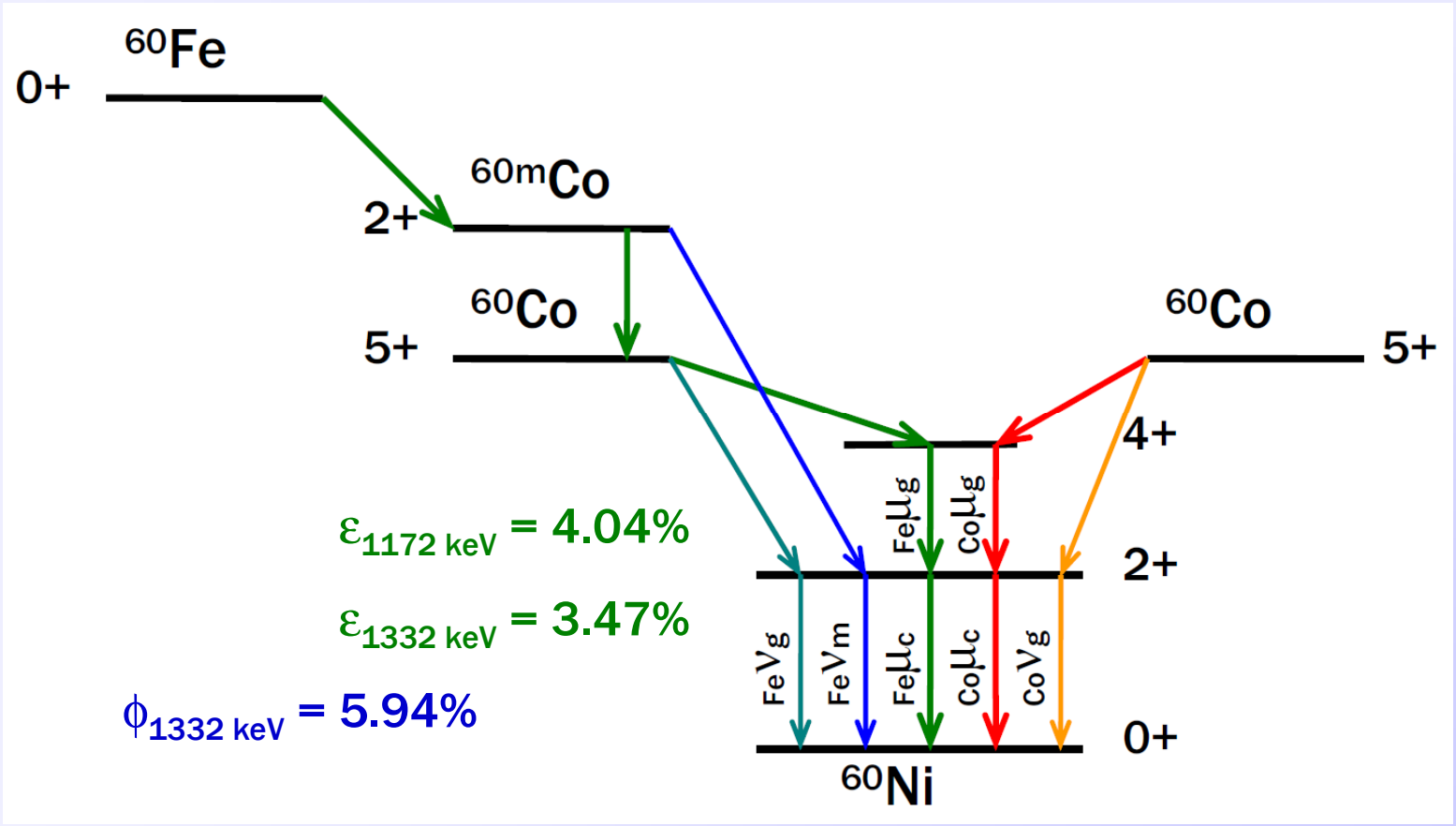
^{60}Co ^{241}Am Spectrum



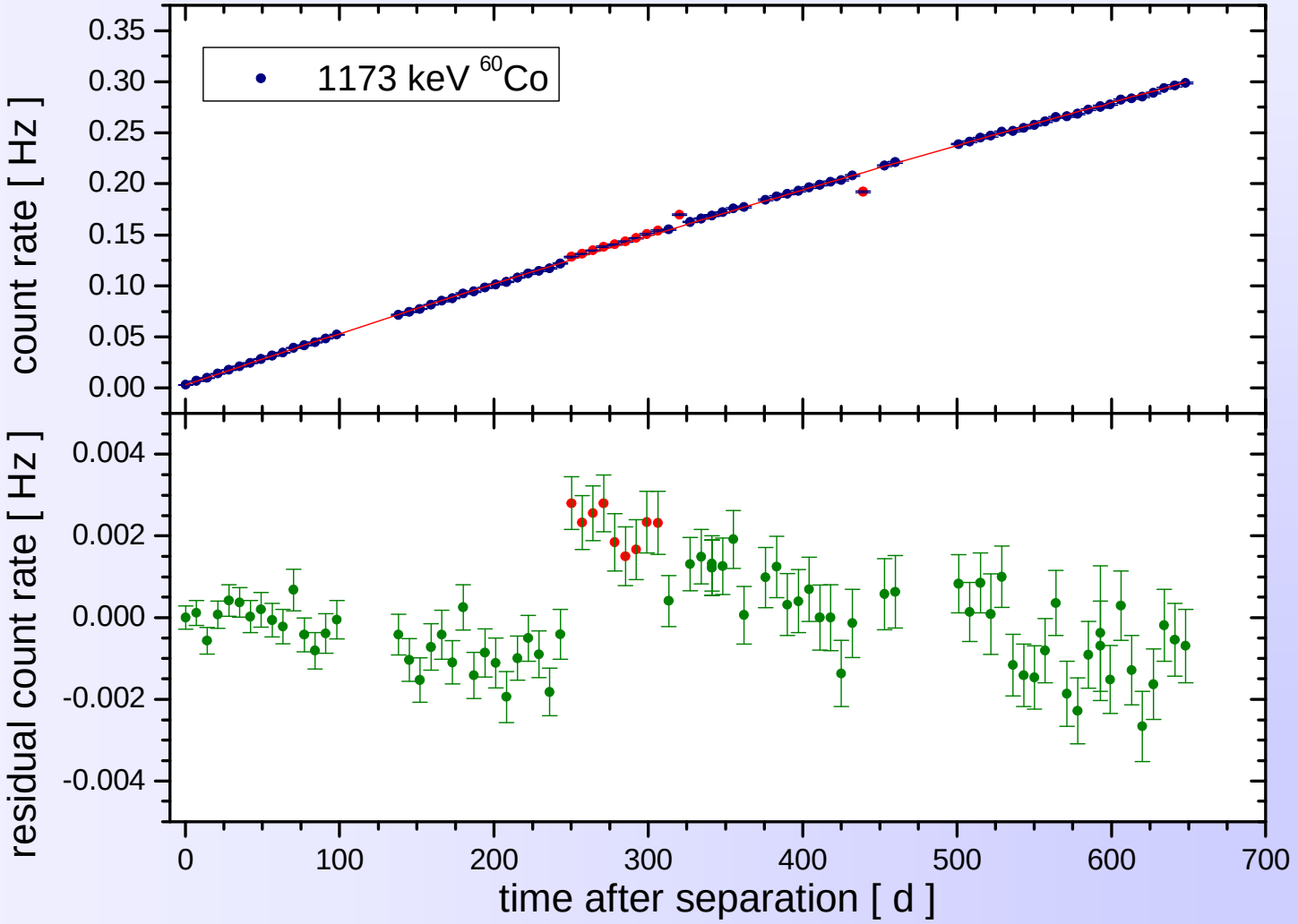
Full Energy Peak Efficiency using NG7 Multi Nuclide Solution



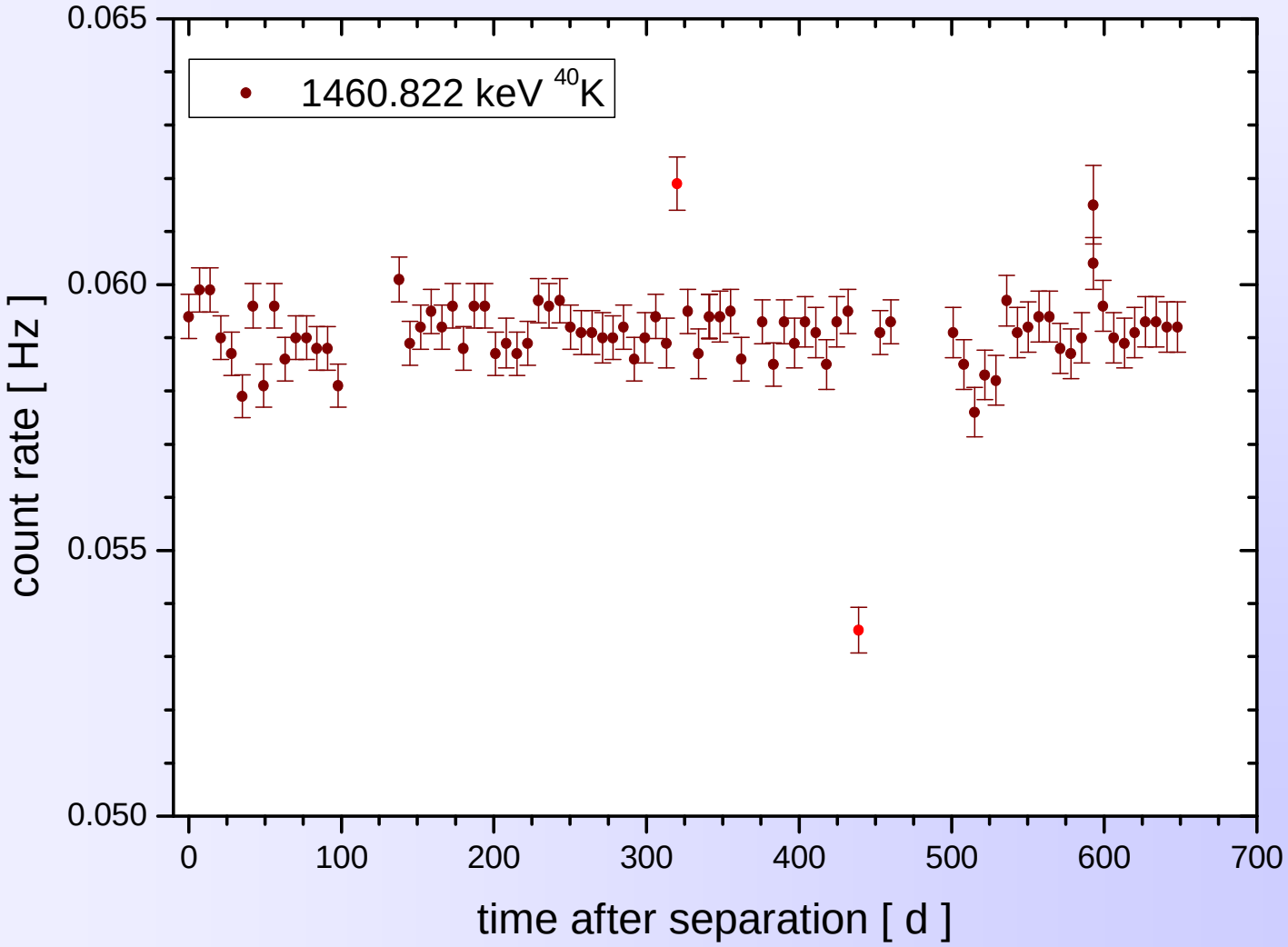
Reduced Decay Schema for Non-Linear Fit



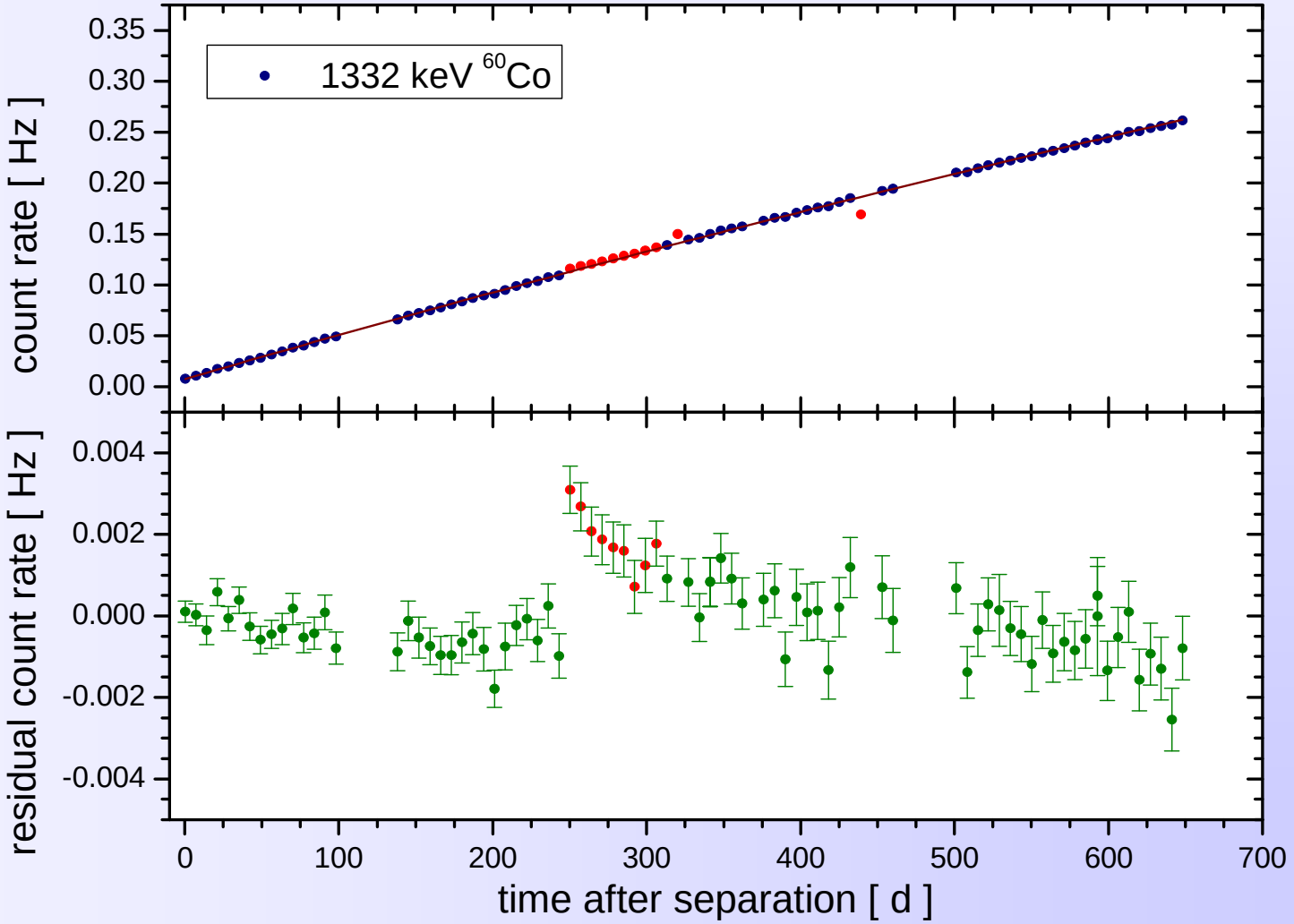
Non-Linear Fit ^{60}Co 1173 keV



^{40}K Peak


1460.822 keV ^{40}K
count rate [Hz]
time after separation [d]
0.065
0.060
0.055
0.050
0
100
200
300
400
500
600
700

Non-Linear Fit ^{60}Co 1332 keV



Fit Result
^{60}Fe Activity

1173 keV

$\varepsilon_{1173keV}$ = 4.04% ± 0.20%

A_{Fe} = 35.422 Bq ± 0.024 Bq

A_{Co} = 0.0270 Bq ± 0.0025 Bq

1332 keV

$\varepsilon_{1332keV}$ = 3.47% ± 0.17%

A_{Fe} = 35.339 Bq ± 0.028 Bq

A_{Co} = 0.0307 Bq ± 0.0030 Bq

Mean:

A_{Fe} = 35.381 Bq ± 0.018 Bq ± 1.77 Bq

A_{Co} = 0.0289 Bq ± 0.0020 Bq ± 0.0015 Bq

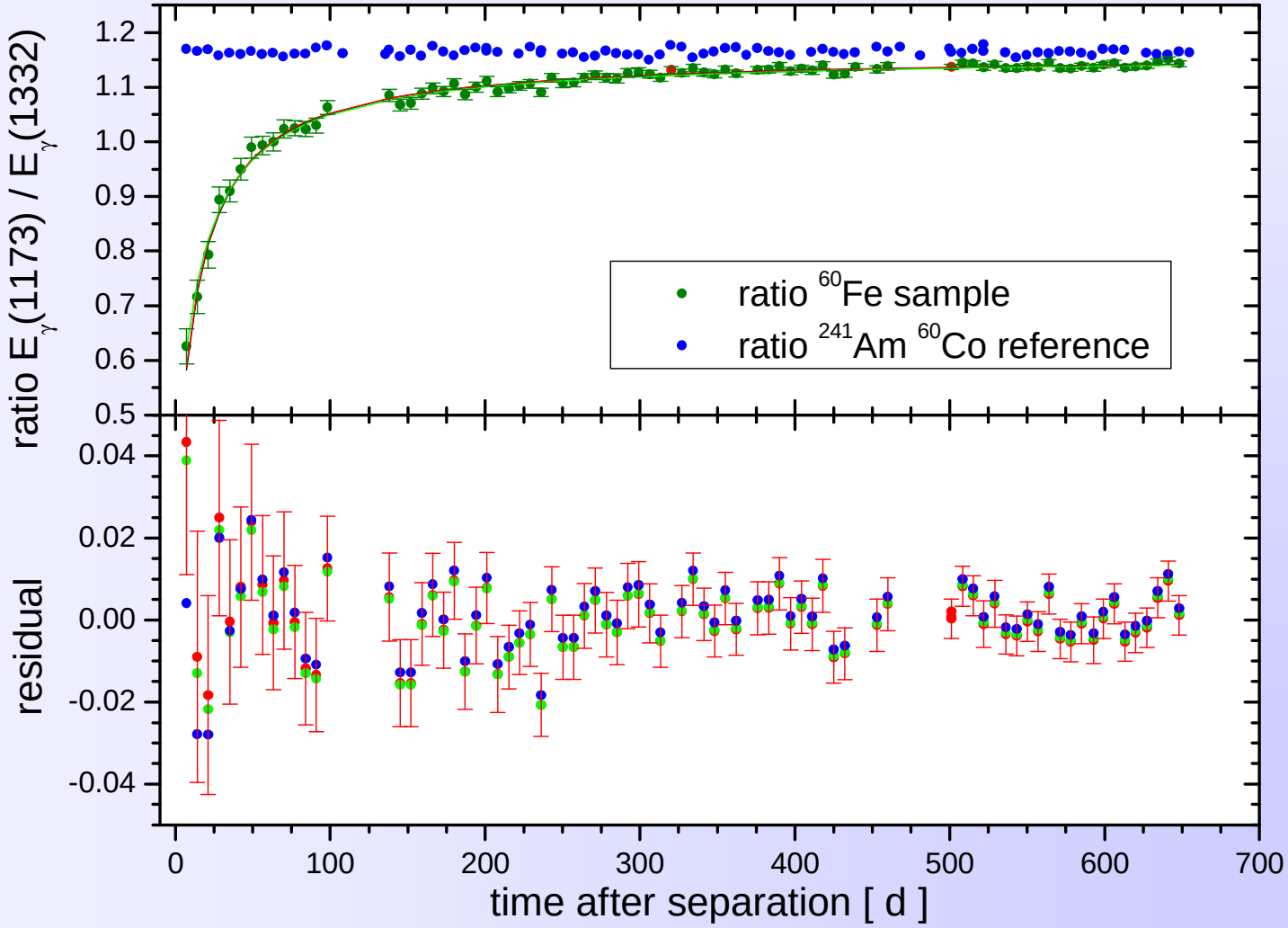
G. Rugel, et al.: Phys. Rev. Lett. 103 (2009) 072502

$\varepsilon_{1173keV}$ = 0.156% ± 0.0023% $\varepsilon_{1332keV}$ = 0.138% ± 0.0021%

A_{Fe} = 49.19 Bq ± 0.11 Bq ± 0.74 Bq

A_{Co} = 0.207 Bq ± 0.006 Bq ± 0.003 Bq

Other Fit Possibilities



Sensitivity of Non-Linear Fit

param	value	uncert.	value	uncert.	value	uncert.
A_{Fe}	35.381	fixed	35.381	fixed	256.2	92984.9
A_{Co}	0.00289	fixed	0.00289	fixed	0.21	75.4
δ	1.0008	0.0012	1	fixed	1	fixed
ϕ	0.0573	0.0018	0.056	0.001	0.0594	fixed

Number of ^{60}Fe Atoms

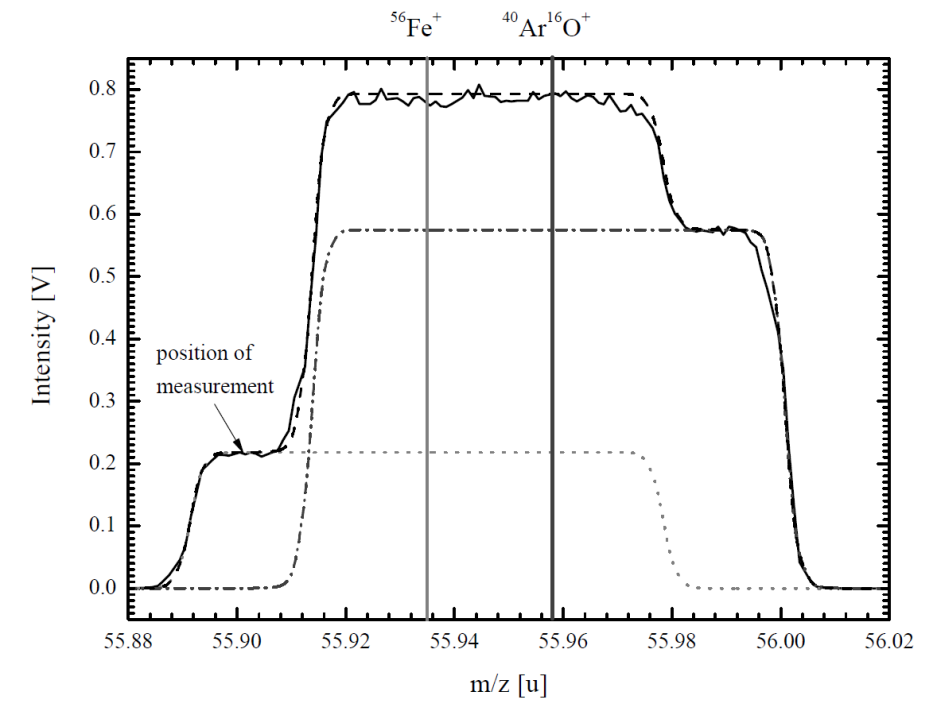
Neptune MC-ICP-MS

Thermo Fisher Scientific, Germany

- Double focusing sector field
  (Nier-Johnson-geometry)
- Ar-plasma torch (27 MHz RF)
  - *95% ionisation yield of Fe*
- APEX HF spray chamber
  - *high efficient desolvating system*
  - *custom made sampler & skimmer (Al)*
- PFA-ST micro flow nebulizer 65 µl/min
- Entrance slit
  - *50 µm (medium resolution)*
  - *Resolution ~2400*
- Focal-plane detectors
  - *9x Faraday cup*
  - *1x Secondary electron multiplier*
    (can replace central Faraday cup)
- Acquisition time 4.196 s

Neptune MC-ICP-MS at HOT-Lab PSI

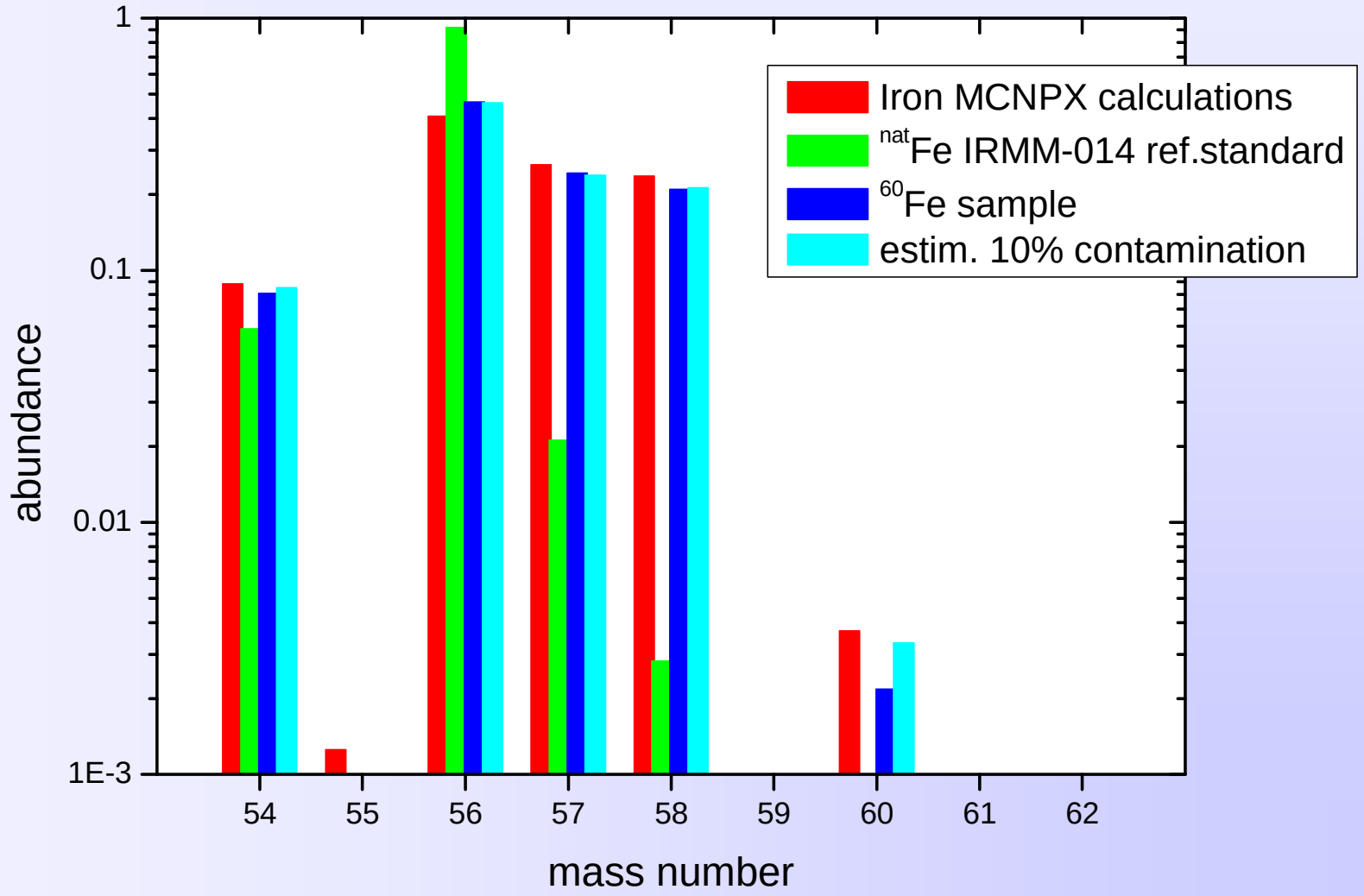
Mass Scan with ICP-MS



isotope	abundance	uncert.
^{54}Fe	0.08100	0.00033
^{56}Fe	0.46466	0.00035
^{57}Fe	0.24302	0.00021
^{58}Fe	0.20915	0.00046

N. Kivel, et al.: Phys. Rev C (to be published)

Isotopic Ratios of ^{60}Fe Sample



Results

- Non carrier added samples
  - *all stable isotopes present*
  - *isotopic ratio not natural*
  - *typical amount of stable isotopes higher than wanted*
  - *composition can be forecast by MCNPX calculations*

- total mass ^{60}Fe
  - IRMM-014 certified iron reference material
  - *only one short test measurement performed*
  - *0.36 μg/g ± 0.04 μg/g*

Results

- $N_0 = (3.6 \pm 0.4) \cdot 10^{15}$ atoms
- $A_{Fe} = 35.4$ Bq $\pm$ 1.8 Bq
- $t_{1/2} = 2.26$ Ma $\pm$ 0.28 Ma (k=2)

- G. Rugel, et al.: Phys. Rev. Lett. 103 (2009) 072502
  $t_{1/2} = 2.62$ Ma $\pm$ 0.04 Ma (k=1)

Next Steps

- continue the γ-measurement for 1 year
- more precise ^{60}Co reference-source
  PTB standard: 1831 Bq ± 13 Bq (k=2)
- determination of peak to total efficiency
- final determination of total Fe content
  in used γ-source (open vial!)

Non-Linear Fit ^{60}Co 2505 keV