NPL National Physical Laboratory

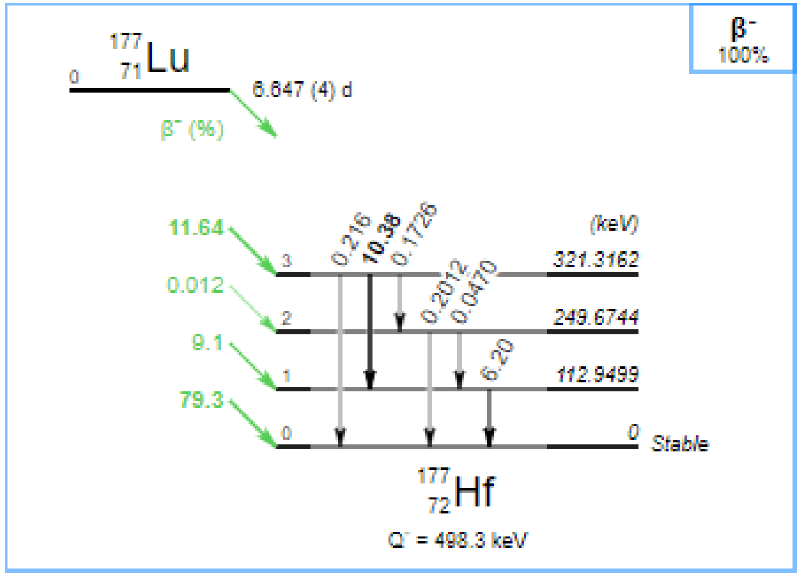
Decay Data: the importance and impact of metrology

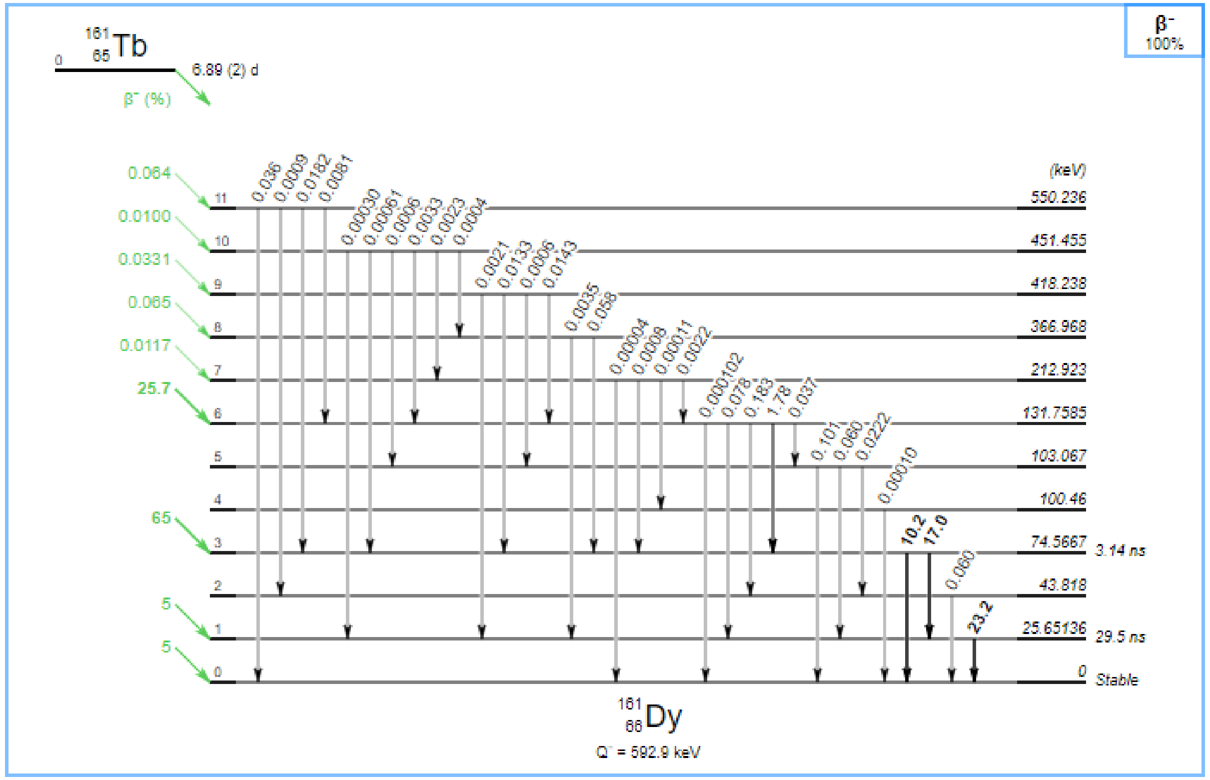
Seán Collins

PRISMAP Radiolanthanides Workshop, 3 September 2024

DECAY DATA

- A broad term that covers the unique values and arrangement associated with the decay process of a radionuclide
- Covers multiple parameters, such as:
  - Energy of excited states
  - Spin states (angular momentum)
  - Multipolarities
  - Emission probabilities
  - Half-lives

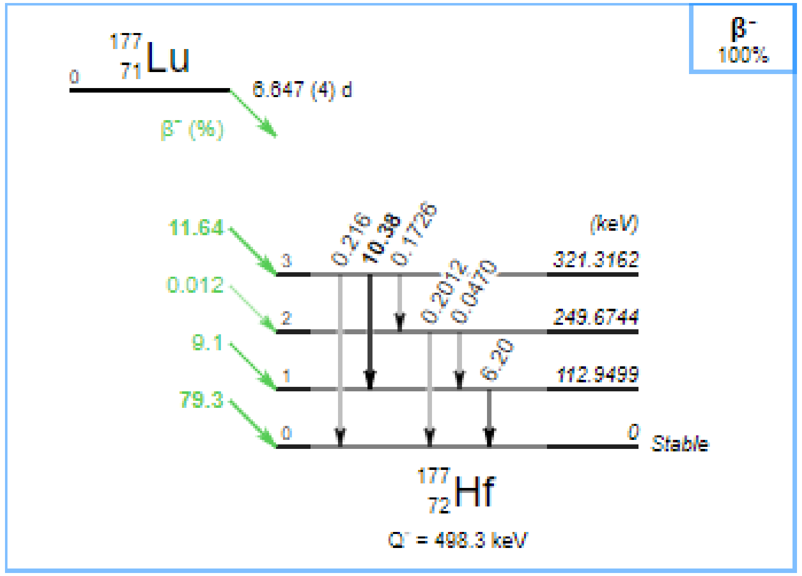


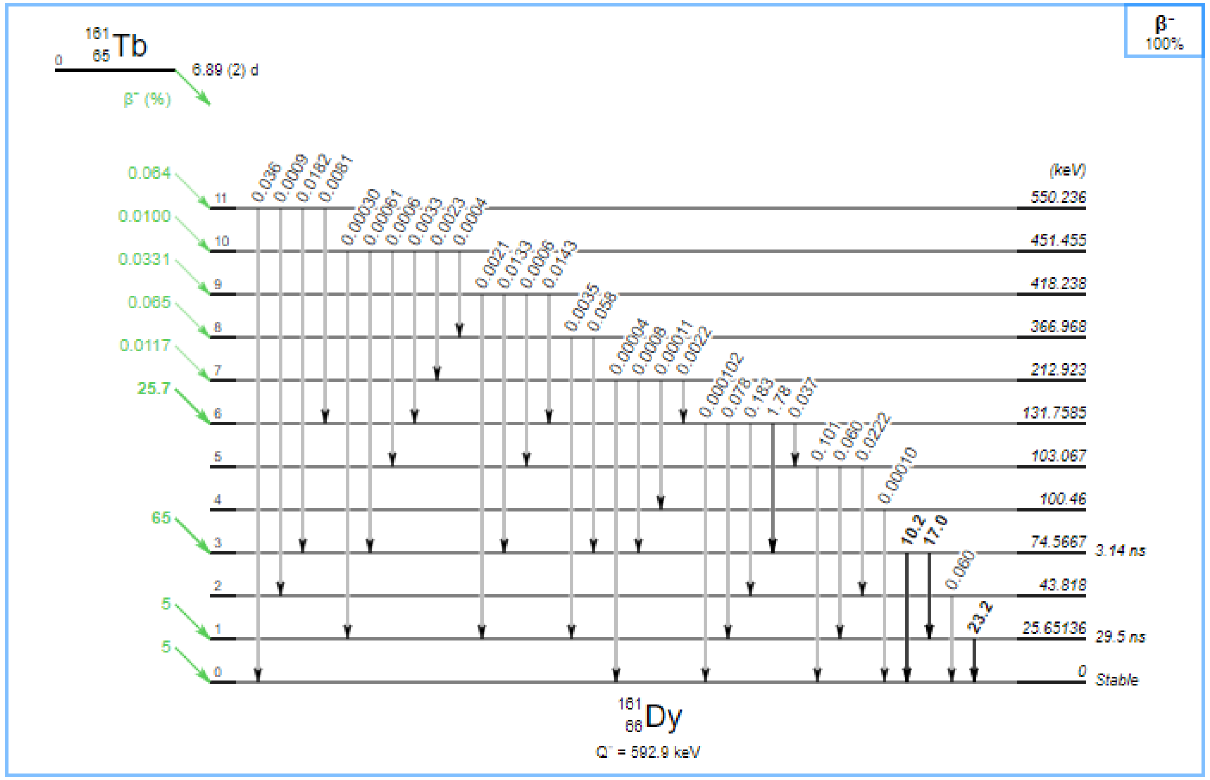


DECAY DATA

- A broad term that covers the unique values and arrangement associated with the decay process of a radionuclide

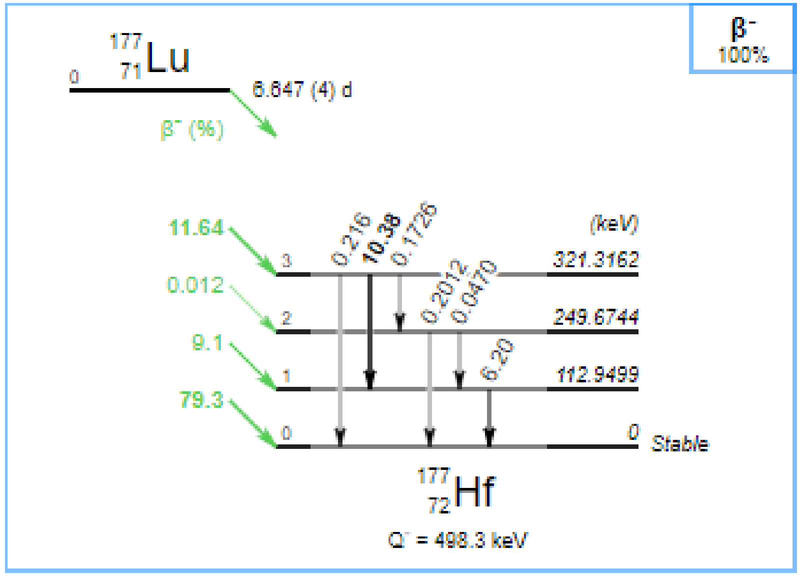
- Covers multiple parameters, such as:
  - Energy of excited states
  - Spin states (angular momentum)
  - Multipolarities
  - Emission probabilities
  - Half-lives
- Atomic data – e.g., X-ray emission intensities, Auger-electron emission intensities

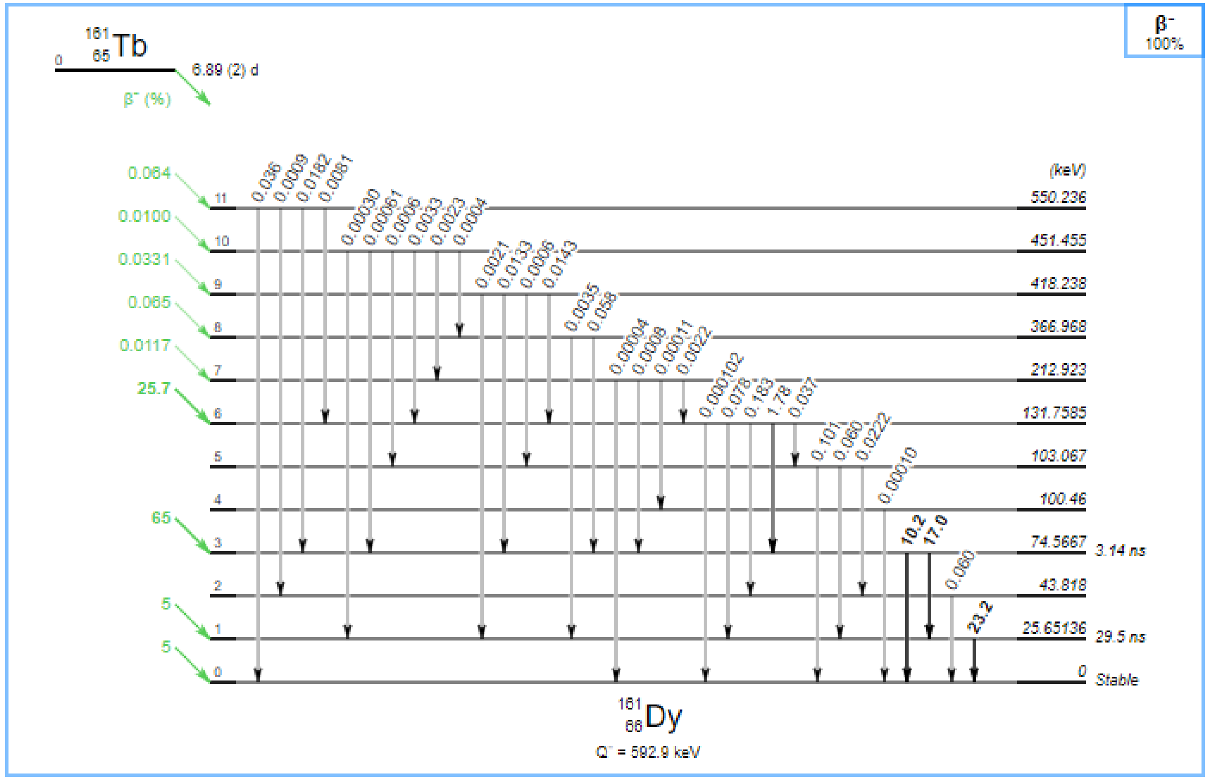




DECAY DATA

- A broad term that covers the unique values and arrangement associated with the decay process of a radionuclide
- Covers multiple parameters, such as:
    - Energy of excited states
    - Spin states (angular momentum)
    - Multipolarities
    - Emission probabilities
    - Half-lives
- Atomic data – e.g., X-ray emission intensities, Auger-electron emission intensities
- Cross-section data



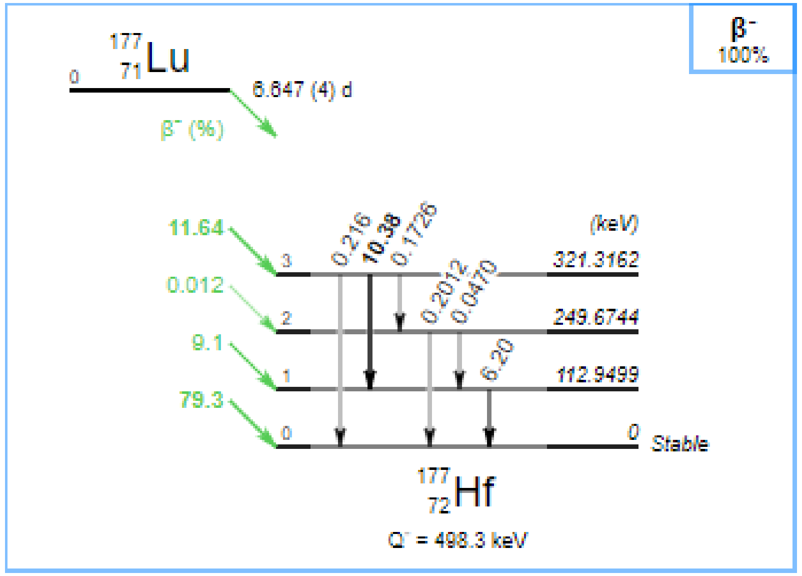


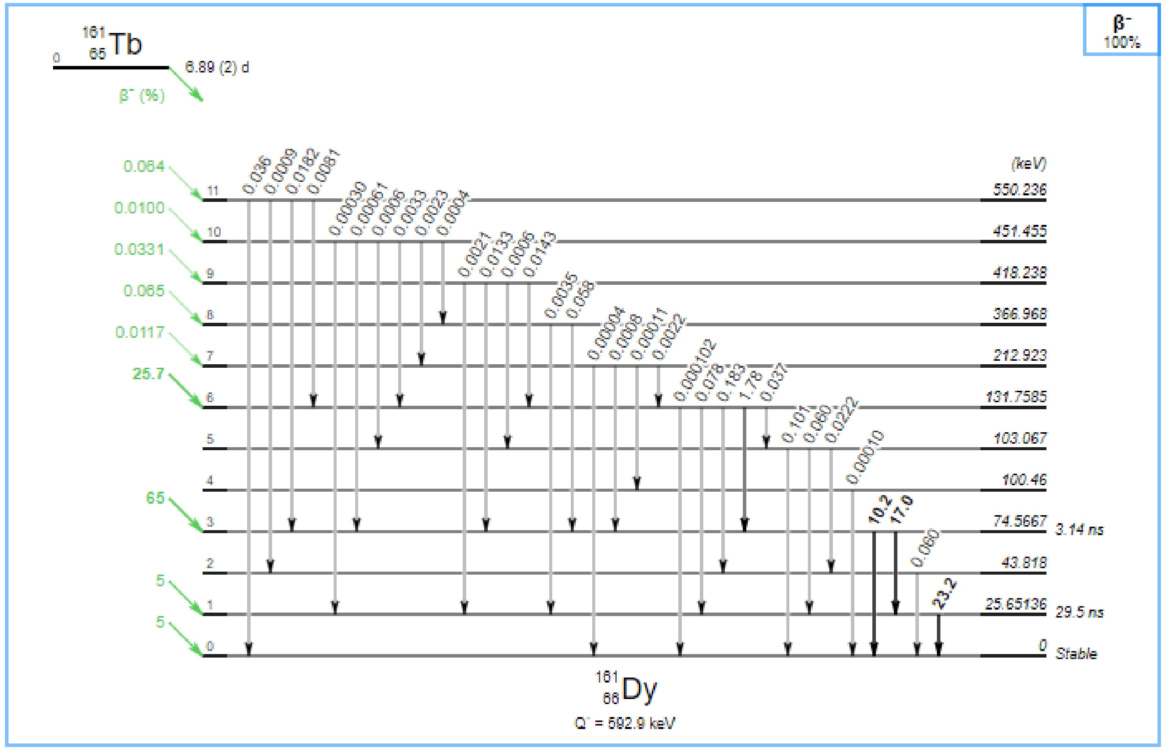
DECAY DATA

- Effectively the constants of radioactive decay of a radionuclide

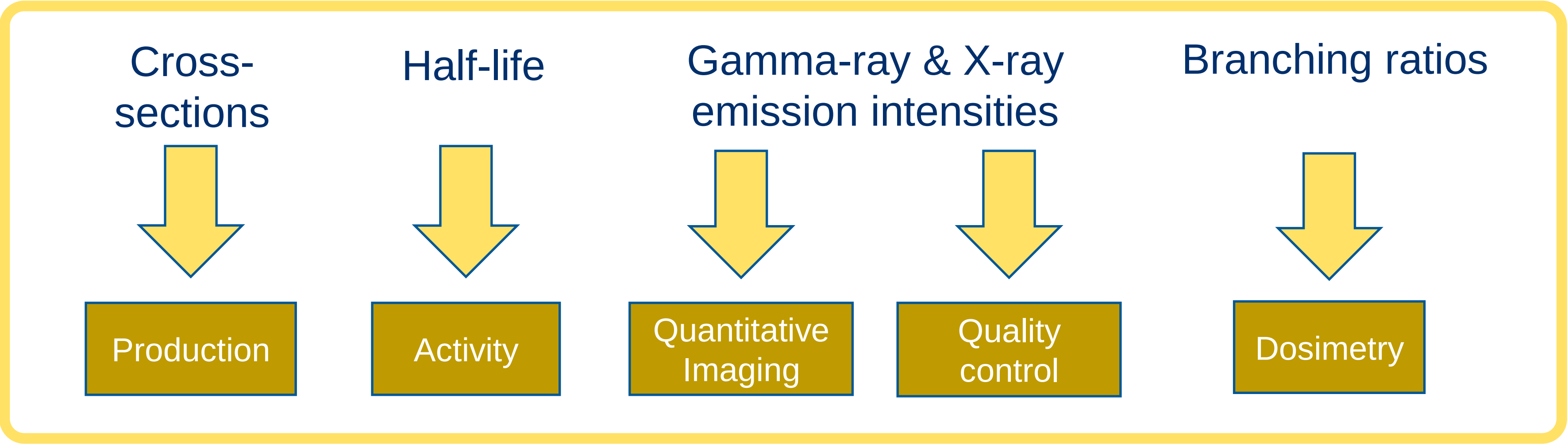
- These are all measurable quantities!

- They have uncertainties!





IMPORTANCE IN NUCLEAR MEDICINE



WHY CONFIDENCE IN DECAY DATA MATTERS

NPL

2010

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Standardization of radium-223 by liquid scintillation counting

J.T. Cessna *, B.E. Zimmerman

Ionizing Radiation Division, Physics Laboratory, National Institute of Standards and Technology, 100 Bureau Drive MS 8462, Gaithersburg, MD 20899-8462, USA

2015

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Standardisation of ^{223}Ra by liquid scintillation counting techniques and comparison with secondary measurements

John Keightley *, Andy Pearce, Andrew Fenwick, Sean Collins, Kelley Ferreira, Lena Johansson

National Physical Laboratory, Hampton Road, Teddington, Middlesex TW11 0LW, UK

2015

Volume 120 (2015) http://dx.doi.org/10.6028/jres.120.004
Journal of Research of the National Institute of Standards and Technology

10 %

Revision of the NIST Standard for ^{223}Ra: New Measurements and Review of 2008 Data

B. E. Zimmerman, D. E. Bergeron, J. T. Cessna, R. Fitzgerald, and L. Pibida

WHY CONFIDENCE IN DECAY DATA MATTERS

2010

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Standardization of radium-223 by liquid scintillation counting

J.T. Cessna *, B.E. Zimmerman

Ionizing Radiation Division, Physics Laboratory, National Institute of Standards and Technology, 100 Bureau Drive MS 8462, Gaithersburg, MD 20899-8462, USA

2015

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Standardisation of ^{223}Ra by liquid scintillation counting techniques and comparison with secondary measurements

John Keightley *, Andy Pearce, Andrew Fenwick, Sean Collins, Kelley Ferreira, Lena Johansson

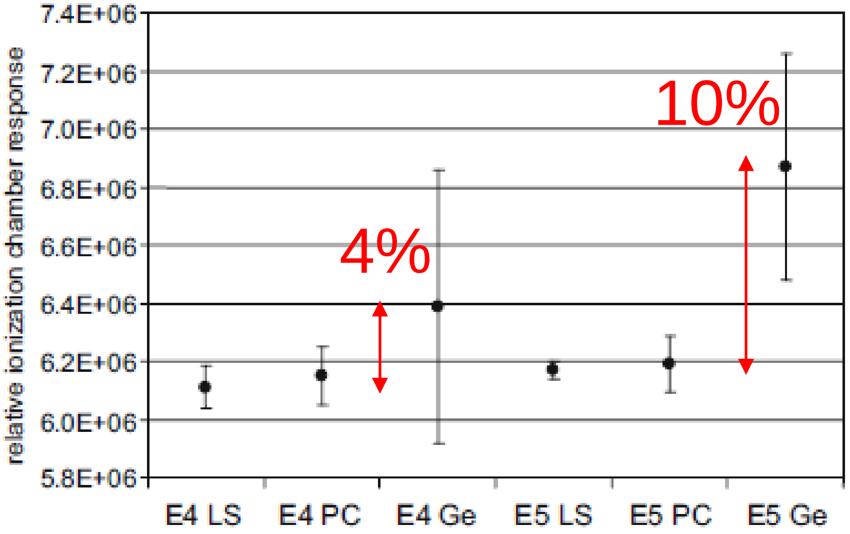
National Physical Laboratory, Hampton Road, Teddington, Middlesex TW11 0LW, UK

2015

Volume 120 (2015) http://dx.doi.org/10.6028/jres.120.004
Journal of Research of the National Institute of Standards and Technology

10 % *Revision of the NIST Standard for ^{223}Ra: New Measurements and Review of 2008 Data*

B. E. Zimmerman, D. E. Bergeron, J. T. Cessna, R. Fitzgerald, and L. Pibida



Cessna, J. T., Zimmerman, B.E. “Standardization of radum-223 by liquid scintillation counting“. *Applied Radiation and Isotopes 68* (2010): 1523-1528.

WHY CONFIDENCE IN DECAY DATA MATTERS

NPL

2010

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Standardization of radium-223 by liquid scintillation counting

J.T. Cessna *, B.E. Zimmerman

Ionizing Radiation Division, Physics Laboratory, National Institute of Standards and Technology, 100 Bureau Drive MS 8462, Gaithersburg, MD 20899-8462, USA

2015

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Standardisation of ^{223}Ra by liquid scintillation counting techniques and comparison with secondary measurements

John Keightley *, Andy Pearce, Andrew Fenwick, Sean Collins, Kelley Ferreira, Lena Johansson

National Physical Laboratory, Hampton Road, Teddington, Middlesex TW11 0LW, UK

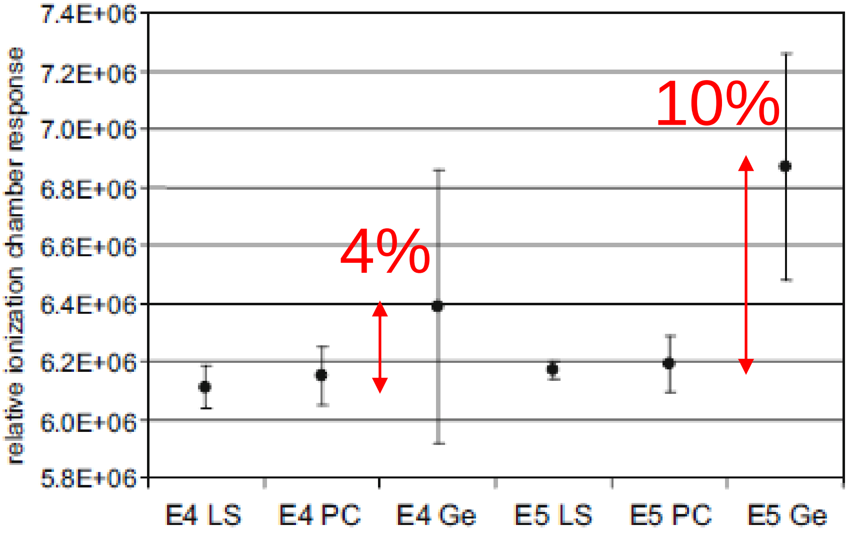
2015

Volume 120 (2015) http://dx.doi.org/10.6028/jres.120.004

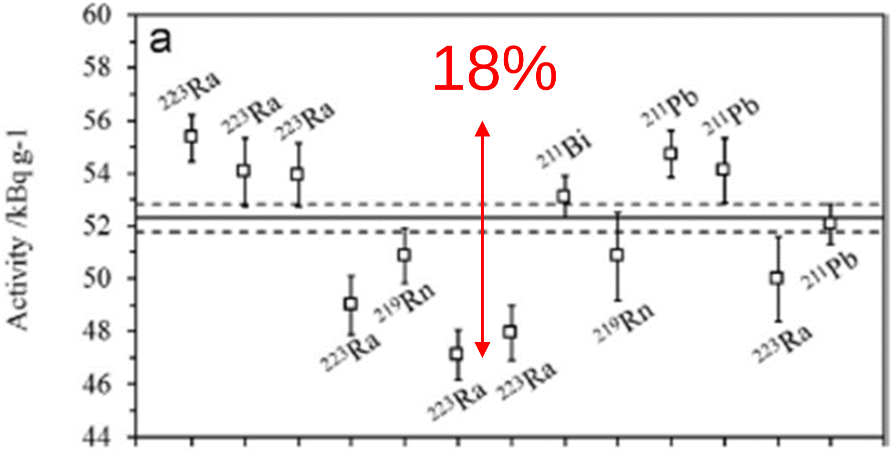
Journal of Research of the National Institute of Standards and Technology

10 % *Revision of the NIST Standard for ^{223}Ra: New Measurements and Review of 2008 Data*

B. E. Zimmerman, D. E. Bergeron, J. T. Cessna, R. Fitzgerald, and L. Pibida



Cessna, J. T., Zimmerman, B.E. “Standardization of radum-223 by liquid scintillation counting“. *Applied Radiation and Isotopes 68* (2010): 1523-1528.

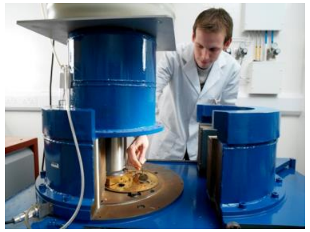


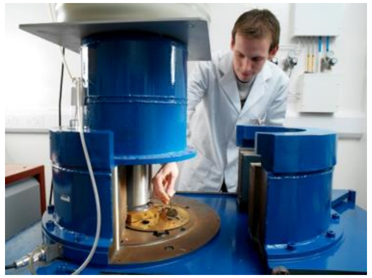
Collins, S. M., et al. “Precise measurements of the absolute γ-ray emission probabilities of ^{223}Ra and decay progeny in equilibrium“. *Applied Radiation and Isotopes* 102 (2015): 15-28.

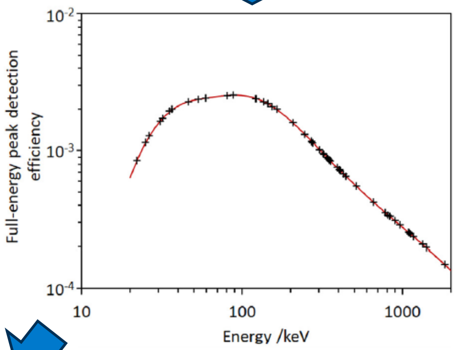
METROLOGY UNDERPINNING DECAY DATA

- Decay Data parameters are measurable quantities

- Traceability and standards can underpin these measurements







Absolute gamma-ray emission intensities

METROLOGY UNDERPINNING DECAY DATA

NPL

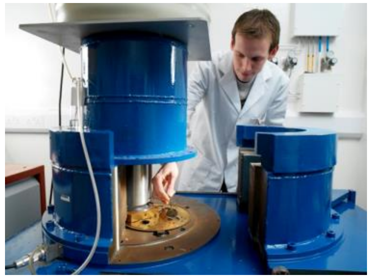
- Decay Data parameters are measurable quantities

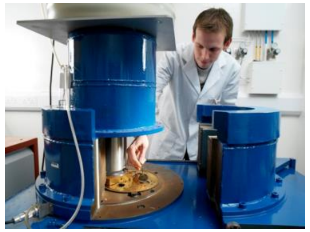
- Traceability and standards can underpin these measurements

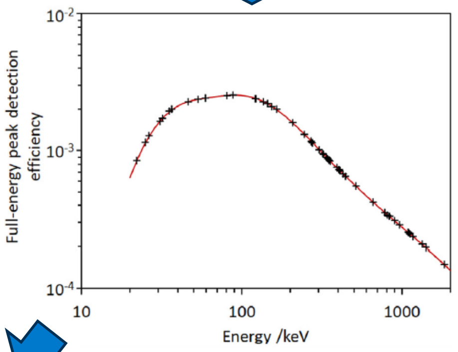
BIPM

SI

Radionuclide of interest







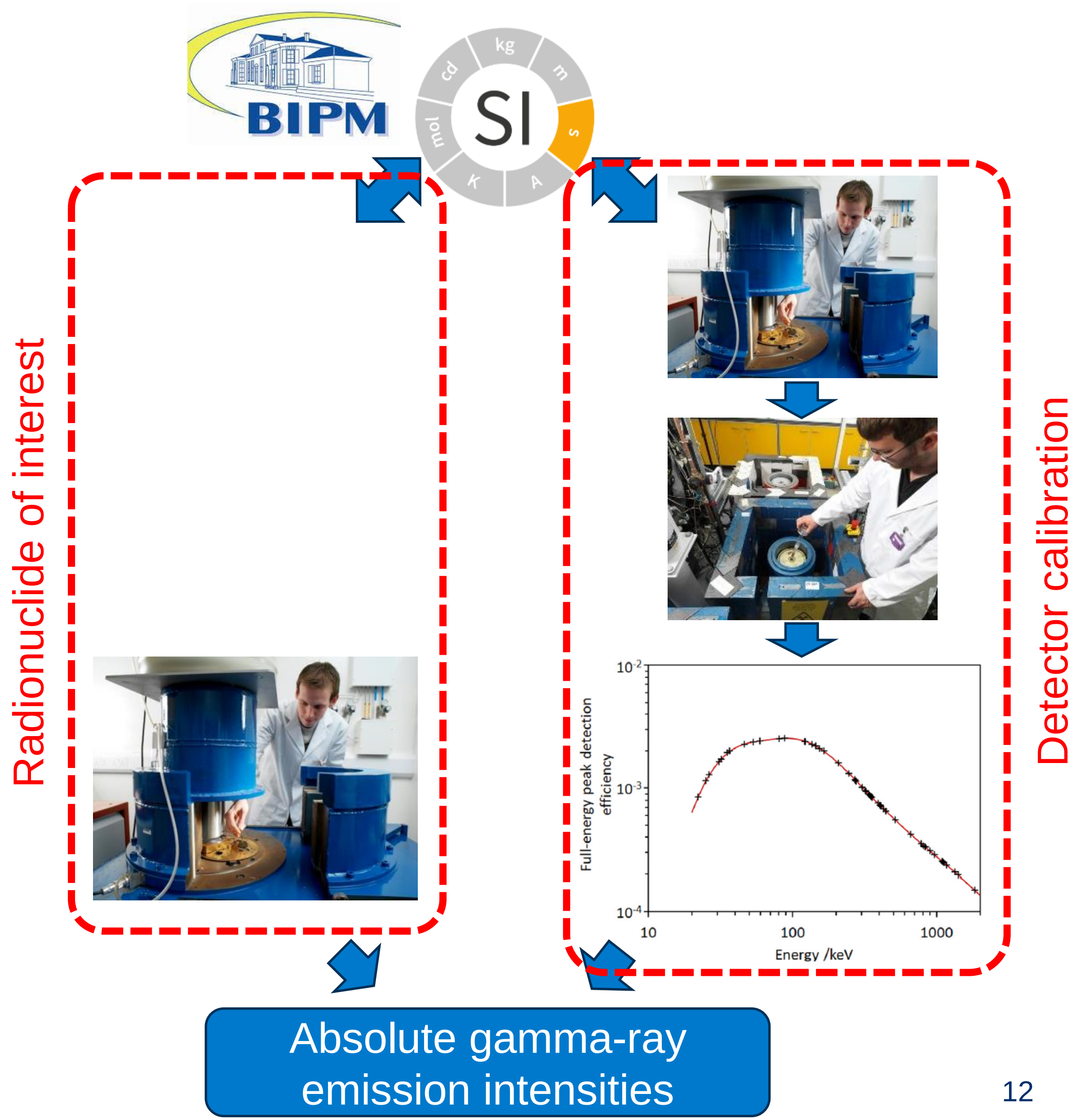
Absolute gamma-ray emission intensities

METROLOGY UNDERPINNING DECAY DATA

NPL

- Decay Data parameters are measurable quantities

- Traceability and standards can underpin these measurements

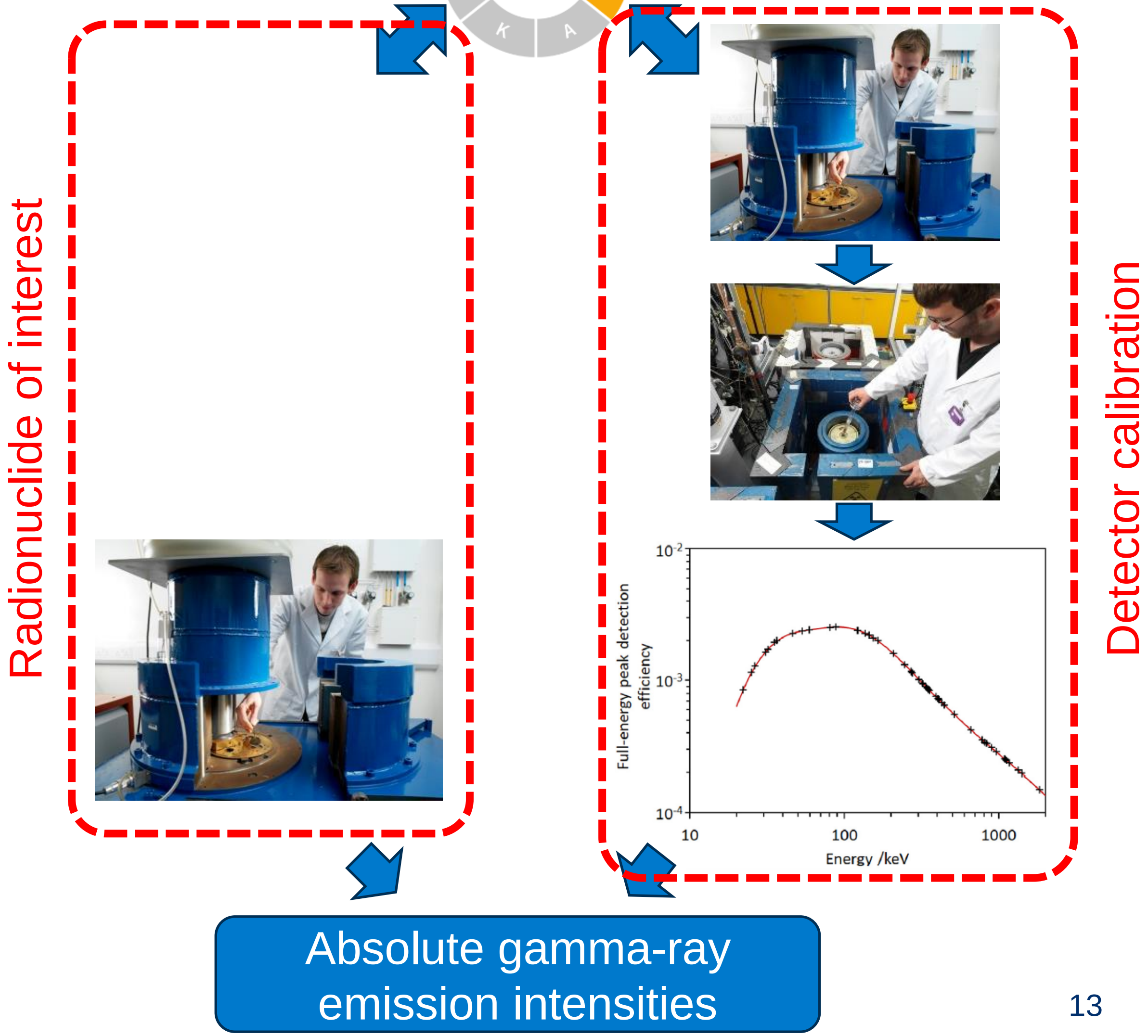


METROLOGY UNDERPINNING DECAY DATA

- Decay Data parameters are measurable quantities

- Traceability and standards can underpin these measurements

- Good metrology requires more:
  - Quality control
  - Validation of methods
  - Comparison of techniques (or to other laboratories)
  - Robust uncertainty analysis



DECAY DATA EVALUATIONS

NPL

- Evaluated datasets provide the decay data that most use on a routine basis
- There are several databases of evaluated decay data, e.g.,
    - NNDC
    - Decay Data Evaluation Project (DDEP)
- Evaluators rely on the data being robust!

National Nuclear Data Center

https://www.nndc.bnl.gov/

Laboratoire National LNHB Henri Becquerel

http://www.lnhb.fr/home/nuclear-data/nuclear-data-table/

PROBLEMS OF HALF-LIVES

NPL

ELSEVIER

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Applied Radiation and Isotopes 60 (2004) 257–262

Applied Radiation and Isotopes

www.elsevier.com/locate/apradiso

Half-life data—a critical review of TECDOC-619 update

M.J. Woods[a,*], S.M. Collins[b]

[a] Ionising Radiation Metrology Consultants Ltd, 152 Broom Road, Teddington, Middlesex TW11 9PQ, UK
[b] Centre for Acoustics and Ionising Radiation, National Physical Laboratory, Teddington, Middlesex TW11 0LW, UK

PROBLEMS OF HALF-LIVES

NPL

Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Applied Radiation and Isotopes 60 (2004) 257–262
Applied Radiation and Isotopes
www.elsevier.com/locate/apradisc

Half-life data—a critical review of TECDOC-619 update

M.J. Woods[a,*], S.M. Collins[b]
[a] Ionising Radiation Metrology Consultants Ltd, 152 Broom Road, Teddington, Middlesex TW11 9PQ, UK
[b] Centre for Acoustics and Ionising Radiation, National Physical Laboratory, Teddington, Middlesex TW11 0LW, UK

- 64 Radionuclides evaluated
- 48 recommendations for more measurements

Nuclide	Evaluated half-life (days)	Evaluated/required standard uncertainty	Observed/theoretical $\chi^2/(n-1)$	Number of data points: Used	Number of data points: Since 1968	More measurements required?
^{22}Na	950.57 (23)	0.84	2.15	3	3	Yes
^{24}Na	0.62329 (9)	0.50	1.22	13	13	Yes
^{40}K	4.563 (13) $\times 10^{11}$	<0.01	1.13	3	2	Yes
^{46}Sc	83.79 (4)	1.66	1.20	6	6	Yes
^{51}Cr	27.7009 (20)	0.25	0.62	6	6	No
^{54}Mn	312.29 (26)	2.89	19.59	8	8	Yes
^{55}Fe	1002.7 (23)	7.96	2.76	5	5	Yes
^{56}Co	77.20 (8) d	3.60	0.90	5	5	Yes
^{56}Mn	0.107449 (19)	0.61	5.29	6	6	Yes
^{57}Co	271.80 (5)	0.64	1.24	6	6	Yes
^{58}Co	70.86 (6)	2.94	1.19	6	6	Yes
^{59}Fe	44.494 (13)	1.01	1.40	5	5	Yes
^{60}Co	1925.23 (27)	0.49	0.09	5	5	No
^{64}Cu	0.52929 (18)	1.18	0.96	9	9	Yes
^{65}Zn	243.86 (20)	2.85	1.95	7	7	Yes
^{66}Ga	0.3909 (25)	22.21	0.38	4	0	Yes
^{67}Ga	3.2614 (4)	0.43	0.25	7	7	No
^{68}Ga	0.04703 (7)	5.17	1.11	3	3	Yes
^{75}Se	119.778 (29)	0.84	0.08	3	3	No

. . .

PROBLEMS OF HALF-LIVES

NPL

Available online at www.sciencedirect.com
SCIENCE DIRECT
Applied Radiation and Isotopes
Applied Radiation and Isotopes 60 (2004) 257–262
ELSEVIER
www.elsevier.com/locate/apradiso

Half-life data—a critical review of TECDOC-619 update

M.J. Woods[a],*, S.M. Collins[b]

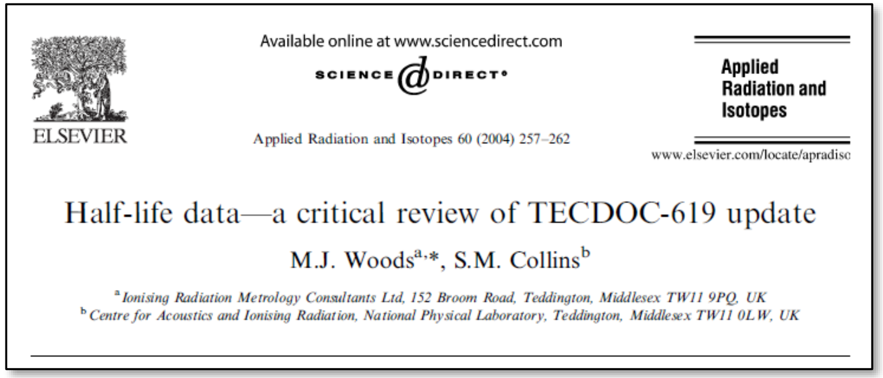
[a] Ionising Radiation Metrology Consultants Ltd, 152 Broom Road, Teddington, Middlesex TW11 9PQ, UK
[b] Centre for Acoustics and Ionising Radiation, National Physical Laboratory, Teddington, Middlesex TW11 0LW, UK

- 64 Radionuclides evaluated
- 48 recommendations for more measurements

Nuclide	Evaluated half-life (days)	Evaluated/required standard uncertainty	Observed/theoretical $\chi^2/(n-1)$	Number of data points		More measurements required?
				Used	Since 1968	
^{22}Na	950.57 (23)	0.84	2.15	3	3	Yes
^{24}Na	0.62329 (9)	0.50	1.22	13	13	Yes
^{40}K	$4.563\ (13) \times 10^{11}$	<0.01	1.13	3	2	Yes
^{46}Sc	83.79 (4)	1.66	1.20	6	6	Yes
^{51}Cr	27.7009 (20)	0.25	0.62	6	6	No
^{54}Mn	312.29 (26)	2.89	19.59	8	8	Yes
^{55}Fe	1002.7 (23)	7.96	2.76	5	5	Yes
^{56}Co	77.20 (8) d	3.60	0.90	5	5	Yes
^{56}Mn	0.107449 (19)	0.61	5.29	6	6	Yes
^{57}Co	271.80 (5)	0.64	1.24	6	6	Yes
^{58}Co	70.86 (6)	2.94	1.19	6	6	Yes
^{59}Fe	44.494 (13)	1.01	1.40	5	5	Yes
^{60}Co	1925.23 (27)	0.49	0.09	5	5	No
^{64}Cu	0.52929 (18)	1.18	0.96	9	9	Yes
^{65}Zn	243.86 (20)	2.85	1.95	7	7	Yes
^{66}Ga	0.3909 (25)	22.21	0.38	4	0	Yes
^{67}Ga	3.2614 (4)	0.43	0.25	7	7	No
^{68}Ga	0.04703 (7)	5.17	1.11	3	3	Yes
^{75}Se	119.778 (29)	0.84	0.08	3	3	No

. . .

PROBLEMS OF HALF-LIVES


Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

ELSEVIER

Applied Radiation and Isotopes 60 (2004) 257–262

Applied Radiation and Isotopes

www.elsevier.com/locate/apradiso

Half-life data—a critical review of TECDOC-619 update

M.J. Woods[a,*], S.M. Collins[b]

[a] Ionising Radiation Metrology Consultants Ltd, 152 Broom Road, Teddington, Middlesex TW11 9PQ, UK
[b] Centre for Acoustics and Ionising Radiation, National Physical Laboratory, Teddington, Middlesex TW11 0LW, UK

- 64 Radionuclides evaluated
- 48 recommendations for more measurements
- Many issues arising due to “precise” measurements disagreeing

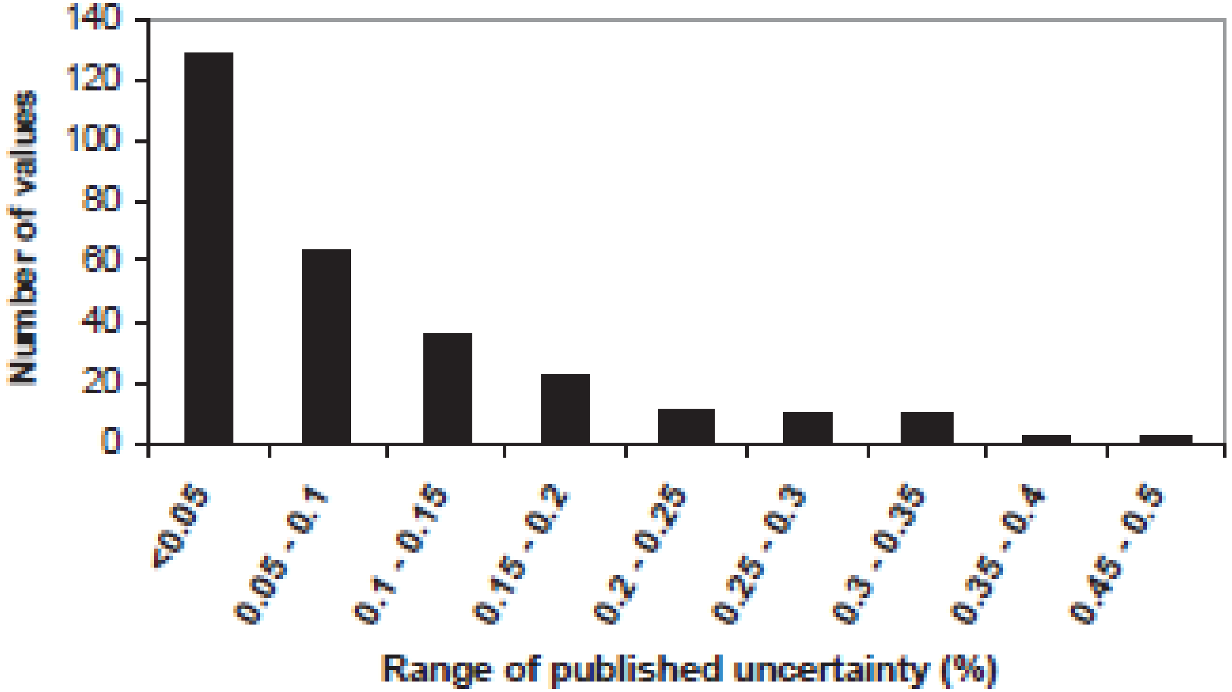


Fig. 1. Frequency of uncertainty range for published half-life values.

PROBLEMS OF HALF-LIVES

NPL

ELSEVIER
Available online at www.sciencedirect.com
SCIENCE @ DIRECT®
Applied Radiation and Isotopes 60 (2004) 257–262
Applied Radiation and Isotopes
www.elsevier.com/locate/apradiso

Half-life data—a critical review of TECDOC-619 update

M.J. Woods[a,*], S.M. Collins[b]
[a] Ionising Radiation Metrology Consultants Ltd, 152 Broom Road, Teddington, Middlesex TW11 9PQ, UK
[b] Centre for Acoustics and Ionising Radiation, National Physical Laboratory, Teddington, Middlesex TW11 0LW, UK

On several occasions, the decay of a radionuclide was monitored in order to validate the stability of some measurement device. Although a measured half-life value may have been published in this manner, such data cannot always be regarded as entirely valid.

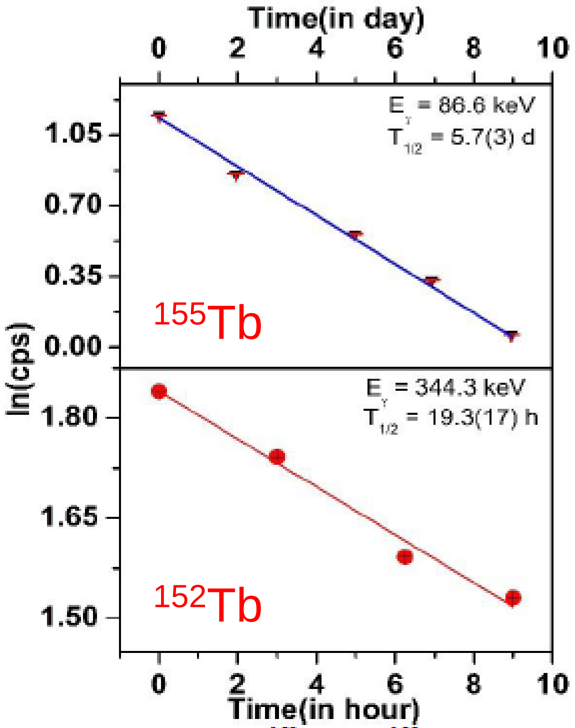


Fig. 2: Decay plots of ^{152}Tb and ^{155}Tb-isotopes.

Proceedings of the DAE Symp. on Nucl. Phys. 66 (2022) 184

Measurement of Decay Half Lives in Tb-Isotopes

A. Pal[1,3*], D. Banerjee[2], S. Basak[1,3], D. Kumar[1,3] and T. Bhattacharjee[1,3]
[1] *Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata – 700 064, India*
[2] *Radiochemistry Division (BARC), VECC, 1/AF, Bidhan Nagar, Kolkata-700064, India*
[3] *Homi Bhabha National Institute, Mumbai, India, PIN – 400094*
*ag.pal@vecc.gov.in

PROBLEMS OF HALF-LIVES

Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Applied Radiation and Isotopes 60 (2004) 257–262
Applied Radiation and Isotopes
www.elsevier.com/locate/apradiso

Half-life data—a critical review of TECDOC-619 update

M.J. Woods[a,]*, S.M. Collins[b]

[a] Ionising Radiation Metrology Consultants Ltd, 152 Broom Road, Teddington, Middlesex TW11 9PQ, UK
[b] Centre for Acoustics and Ionising Radiation, National Physical Laboratory, Teddington, Middlesex TW11 0LW, UK

On several occasions, the decay of a radionuclide was monitored in order to validate the stability of some measurement device. Although a measured half-life value may have been published in this manner, such data cannot always be regarded as entirely valid. Some

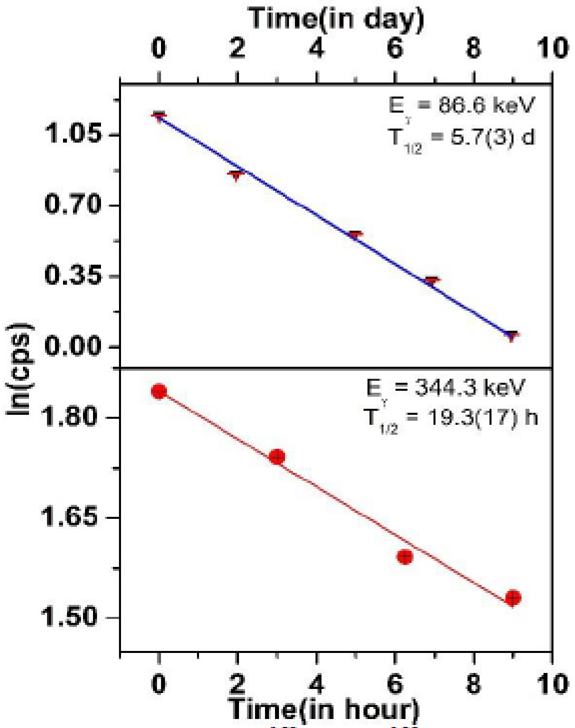
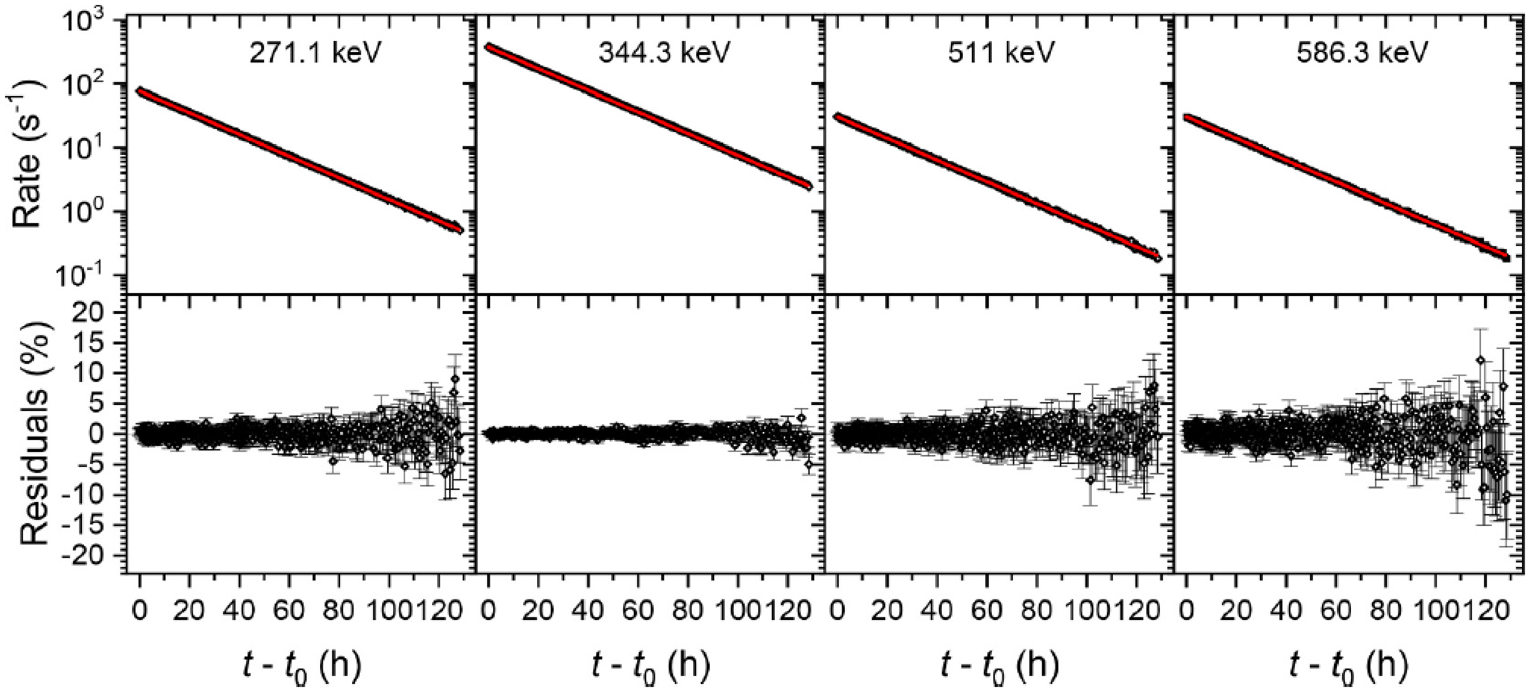


Fig. 2: Decay plots of ^{152}Tb and ^{155}Tb-isotopes.



HALF-LIFE UNCERTAINTY MODEL

OPEN ACCESS
IOP Publishing | Bureau International des Poids et Mesures Metrologia
Metrologia 52 (2015) S51–S65 doi:10.1088/0026-1394/52/3/S51

The uncertainty of the half-life

S Pommé

European Commission, Joint Research Centre, Institute for Reference Materials and Measurements, Retieseweg 111, B-2440 Geel, Belgium

E-mail: stefaan.pomme@ec.europa.eu

Received 2 September 2014, revised 23 October 2014
Accepted for publication 3 November 2014
Published 22 May 2015

CrossMark

Abstract
Half-life measurements of radionuclides are undeservedly perceived as 'easy' and the experimental uncertainties are commonly underestimated. Data evaluators, scanning the literature, are faced with bad documentation, lack of traceability, incomplete uncertainty budgets and discrepant results. Poor control of uncertainties has its implications for the end-user community, varying from limitations to the accuracy and reliability of nuclear-based analytical techniques to the fundamental question whether half-lives are invariable or not. This paper addresses some issues from the viewpoints of the user community and of the decay data provider. It addresses the propagation of the uncertainty of the half-life in activity measurements and discusses different types of half-life measurements, typical parameters influencing their uncertainty, a tool to propagate the uncertainties and suggestions for a more complete reporting style. Problems and solutions are illustrated with striking examples from literature.

$$\frac{\sigma_{T_{1/2}}}{T_{1/2}} \approx \frac{2}{\lambda T}\sqrt{\frac{3(n-1)}{n(n+1)}}\,\frac{\sigma_A}{A}$$

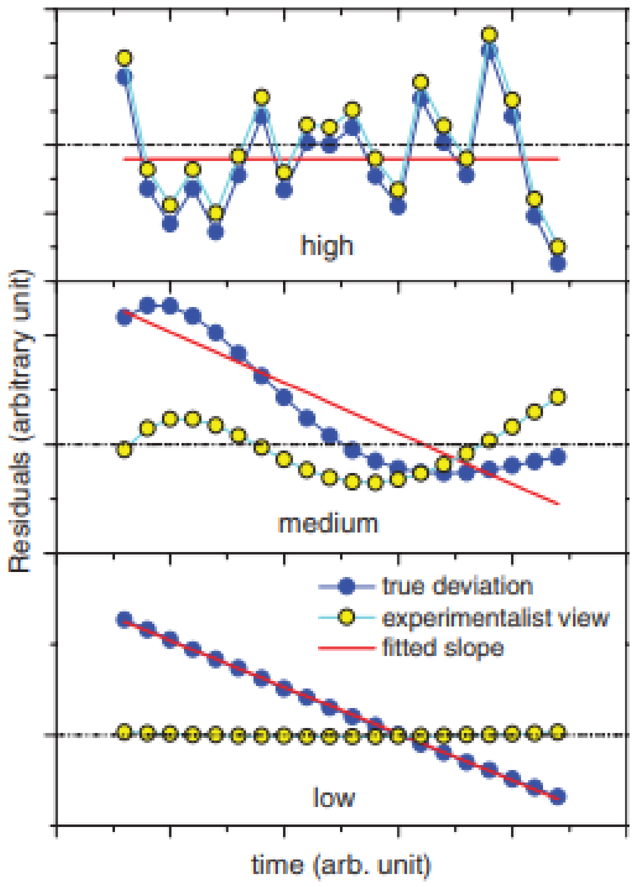


Figure 1. True (dark dots) and perceived (light dots) residuals from a fit of a decay curve through hypothetical data affected by high (top), medium (middle) and low (bottom) frequency instabilities. Systematic deviations are not fully observed by the experimentalist, as the fit tends to minimise them.

PROBLEMS OF HALF-LIVES

NPL

ELSEVIER

Available online at www.sciencedirect.com

SCIENCE DIRECT

Applied Radiation and Isotopes 60 (2004) 257–262

Applied Radiation and Isotopes

www.elsevier.com/locate/apradiso

Half-life data—a critical review of TECDOC-619 update

M.J. Woods[a,*], S.M. Collins[b]

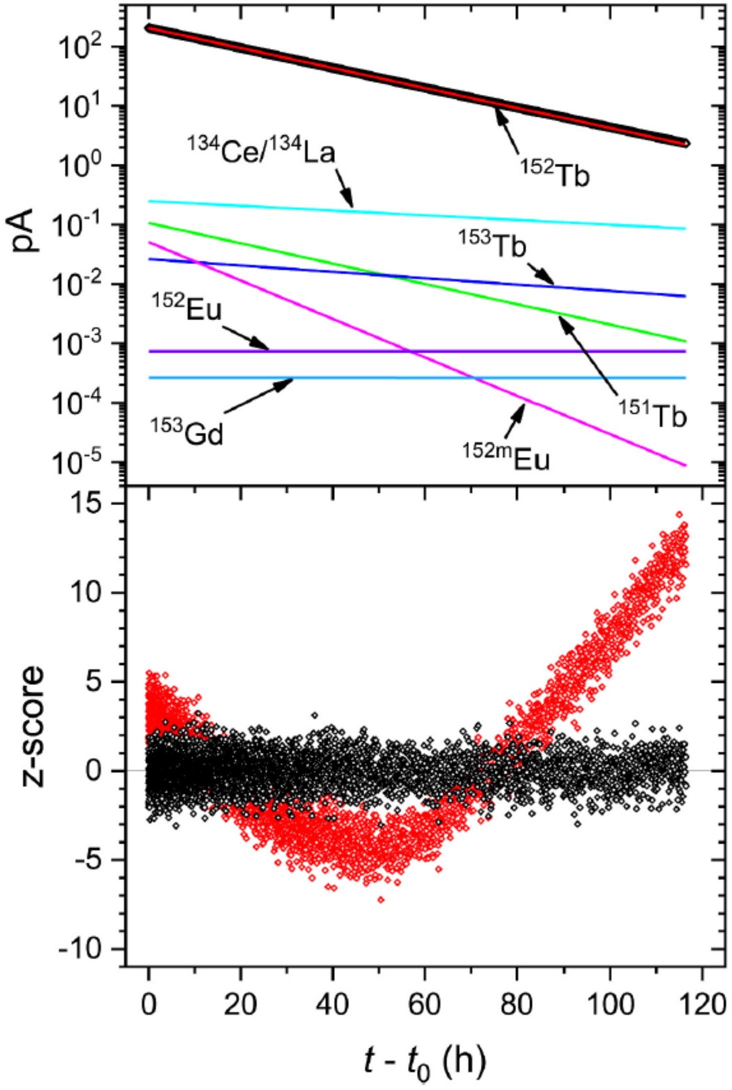
[a] Ionising Radiation Metrology Consultants Ltd, 152 Broom Road, Teddington, Middlesex TW11 9PQ, UK

[b] Centre for Acoustics and Ionising Radiation, National Physical Laboratory, Teddington, Middlesex TW11 0LW, UK

- 64 Radionuclides evaluated
- 48 recommendations for more measurements
- Many issues arising due to "precise" measurements disagreeing

Again, a closer examination of these new data is interesting. For many of the replacement data, the uncertainty quoted is larger than that previously published. This no doubt indicates that the relevant uncertainty budgets have been considered in more depth and more robustly than before. Some of these new data have uncertainties that are significantly larger than the rest of the data in the evaluation set for the radionuclide of concern. When the evaluation is conducted, the resulting weighting factor for these data mean that they have little or no significant impact on the final result. In essence, these values add little or nothing to the improvement in evaluated half-lives.

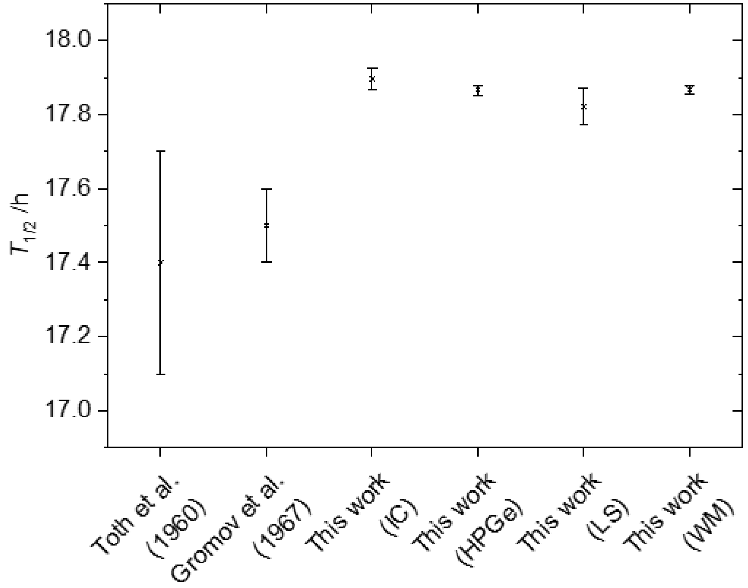
HALF-LIFE UNCERTAINTY MODEL – TB-152



$$\frac{\sigma_{T_{1/2}}}{T_{1/2}} \approx \frac{2}{\lambda T}\sqrt{\frac{3(n-1)}{n(n+1)}}\frac{\sigma_A}{A}$$

Uncertainty budget for the half-life of ^{152}Tb determined by the VINTEN 671 ionisation chamber.

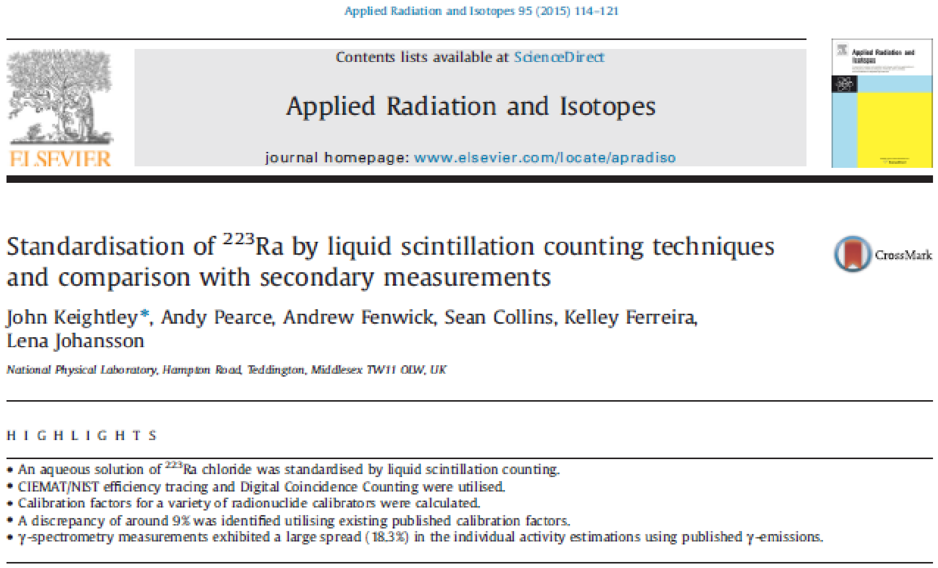
Component	$u(A)/A$ (%)	n	Propagation Factor	$u(T_{1/2})/T_{1/2}$ (%)
Statistical (C_1)	–	–	–	0.0030
Medium-frequency (C_2)	–	–	–	0.0017
Linearity	0.10	1	0.8639	0.086
Stability	0.020	1	0.8639	0.017
Background	0.0052	1	0.8639	0.0045
Contaminant (^{151}Tb)	0.0078	1	0.8639	0.0067
Contaminant (^{153}Tb)	0.0045	1	0.8639	0.0039
Contaminant (^{134}Ce)	0.15	1	0.8639	0.13
Contaminant (^{152m}Eu)	0.0035	1	0.8639	0.0030
Contaminant (^{152}Eu)	0.00012	1	0.8639	0.00011
Contaminant (^{153}Gd)	0.00016	1	0.8639	0.00014
Combined standard uncertainty				0.16



Collins, S. M., et al. "Determination of the Terbium-152 half-life from mass-separated samples from CERN-ISOLDE and assessment of the radionuclide purity". *Applied Radiation and Isotopes* 202 (2023): 111044.

RA-223 AND DECAY PROGENY GAMMA-RAY EMISSION INTENSITIES

- Total of 148 gamma-rays from the decay series
- No previous absolute gamma-ray emission measurements just normalised values available
- Absolute emission intensities calculated from decay scheme
- Gamma-ray spectrometry showed agreement with the primary techniques….so no problem?



Applied Radiation and Isotopes 95 (2015) 114–121

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

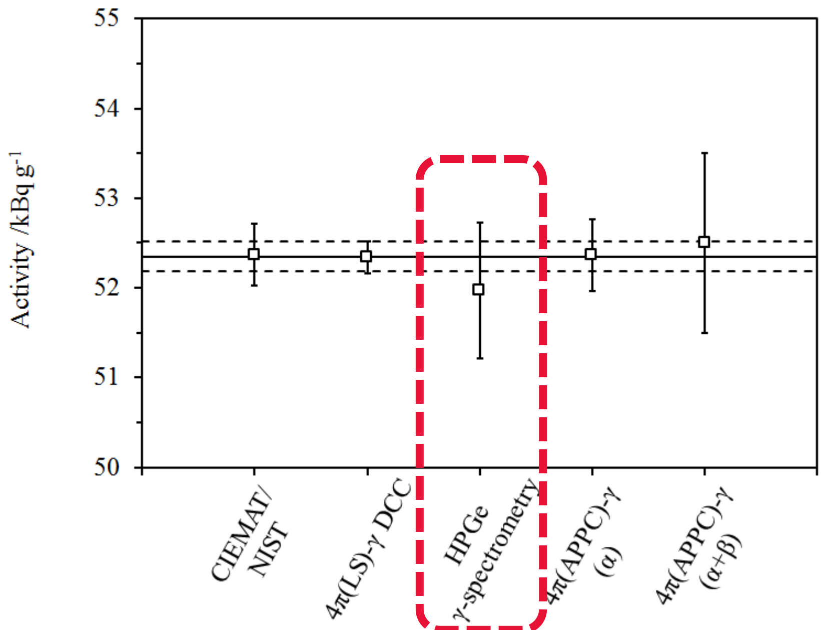
Standardisation of ^{223}Ra by liquid scintillation counting techniques and comparison with secondary measurements

John Keightley*, Andy Pearce, Andrew Fenwick, Sean Collins, Kelley Ferreira, Lena Johansson

National Physical Laboratory, Hampton Road, Teddington, Middlesex TW11 0LW, UK

HIGHLIGHTS

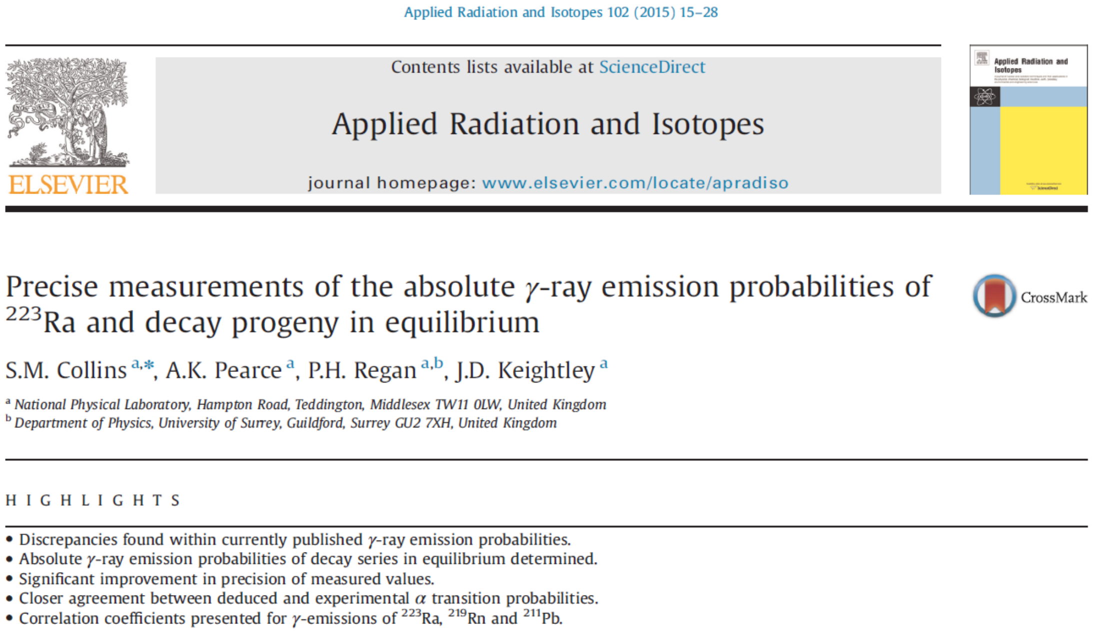
- An aqueous solution of ^{223}Ra chloride was standardised by liquid scintillation counting.
- CIEMAT/NIST efficiency tracing and Digital Coincidence Counting were utilised.
- Calibration factors for a variety of radionuclide calibrators were calculated.
- A discrepancy of around 9% was identified utilising existing published calibration factors.
- γ-spectrometry measurements exhibited a large spread (18.3%) in the individual activity estimations using published γ-emissions.



RA-223 AND DECAY PROGENY GAMMA-RAY EMISSION INTENSITIES

- 18% range in the activities determined from the main gamma-ray emissions

- No confidence in this data



Applied Radiation and Isotopes 102 (2015) 15–28

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

ELSEVIER

Precise measurements of the absolute γ-ray emission probabilities of ^{223}Ra and decay progeny in equilibrium

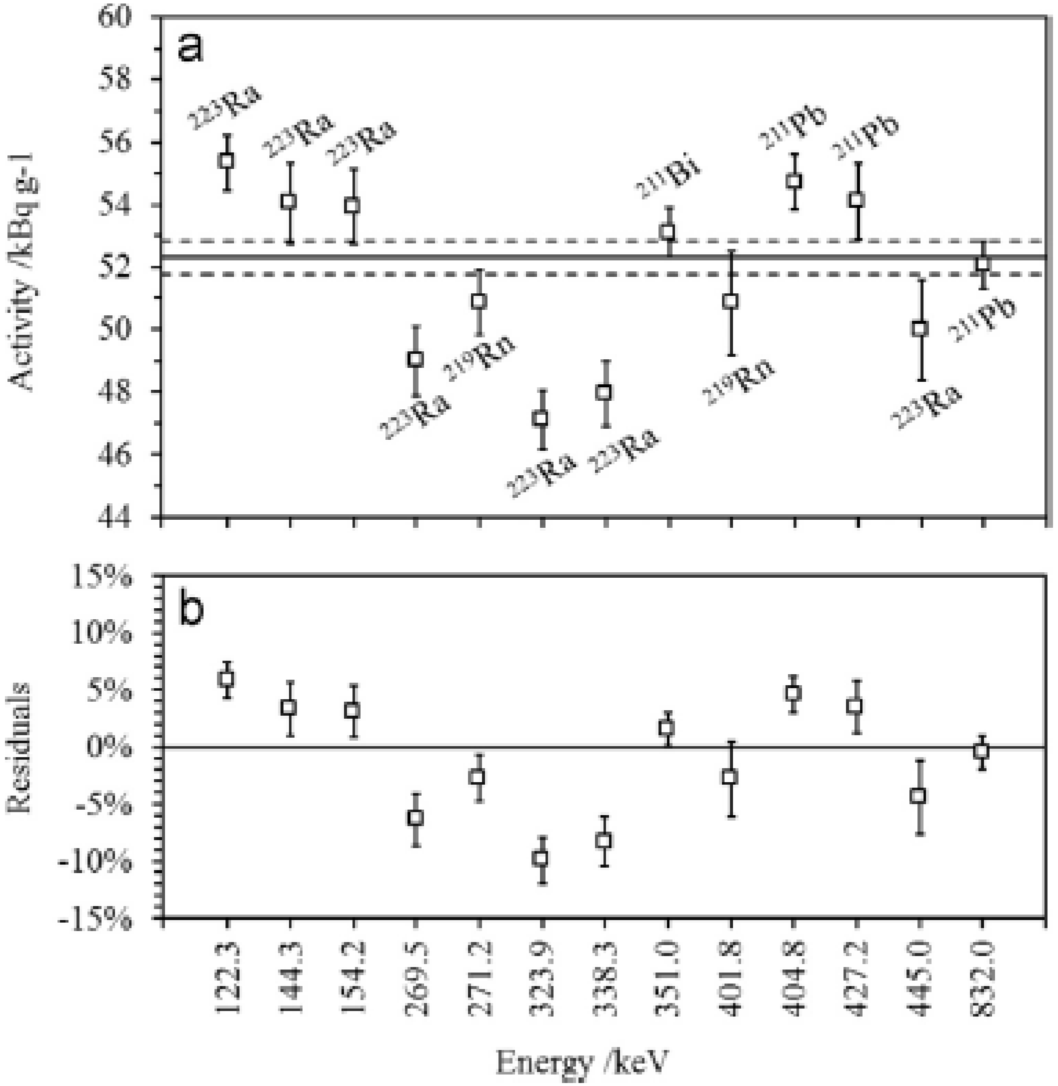
CrossMark

S.M. Collins[a,*], A.K. Pearce[a], P.H. Regan[a,b], J.D. Keightley[a]

[a] National Physical Laboratory, Hampton Road, Teddington, Middlesex TW11 0LW, United Kingdom
[b] Department of Physics, University of Surrey, Guildford, Surrey GU2 7XH, United Kingdom

HIGHLIGHTS

- Discrepancies found within currently published γ-ray emission probabilities.
- Absolute γ-ray emission probabilities of decay series in equilibrium determined.
- Significant improvement in precision of measured values.
- Closer agreement between deduced and experimental α transition probabilities.
- Correlation coefficients presented for γ-emissions of ^{223}Ra, ^{219}Rn and ^{211}Pb.



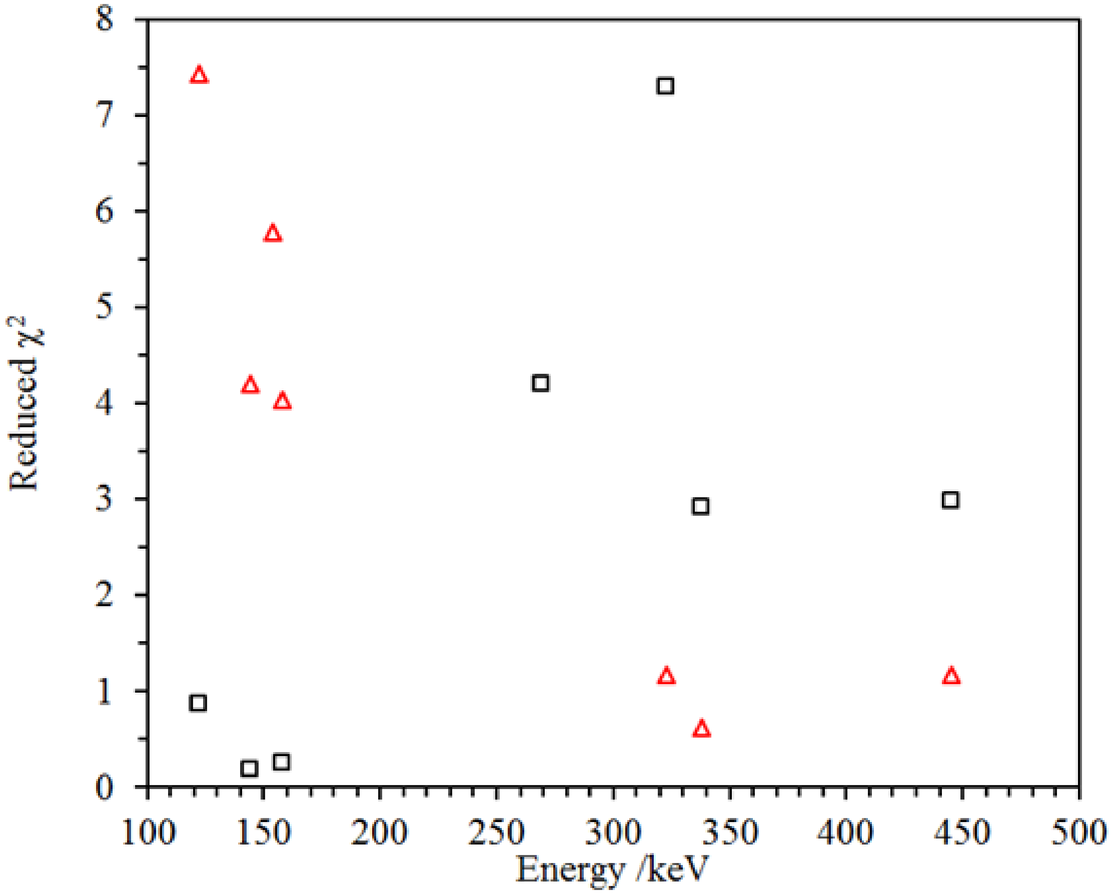
COMPARISON TO DDEP RECOMMENDED VALUES.

Radionuclide	Energy /keV	I_γ(This work) %	I_γ(DDEP) %	z-score	Difference %
^{223}Ra	269.5	13.37 (7)	14.23 (32)	-2.6	-6.0
^{219}Rn	271.2	10.75 (6)	11.07 (22)	-1.4	-2.9
^{215}Po	438.8	0.0533 (7)	0.058 (19)	-0.3	-8.1
^{211}Pb	404.8	4.011 (9)	3.83 (6)	3.0	4.7
^{211}Bi	351.0	13.17 (7)	13.00 (19)	0.8	1.3
^{207}Tl	897.7	0.2725 (15)	0.263 (9)	1.0	3.6

COMPARISON OF RA-223 RESULTS

△ normalised to the 154.2 keV γ-ray emission

□ normalised to the 269.5 keV γ-ray emission

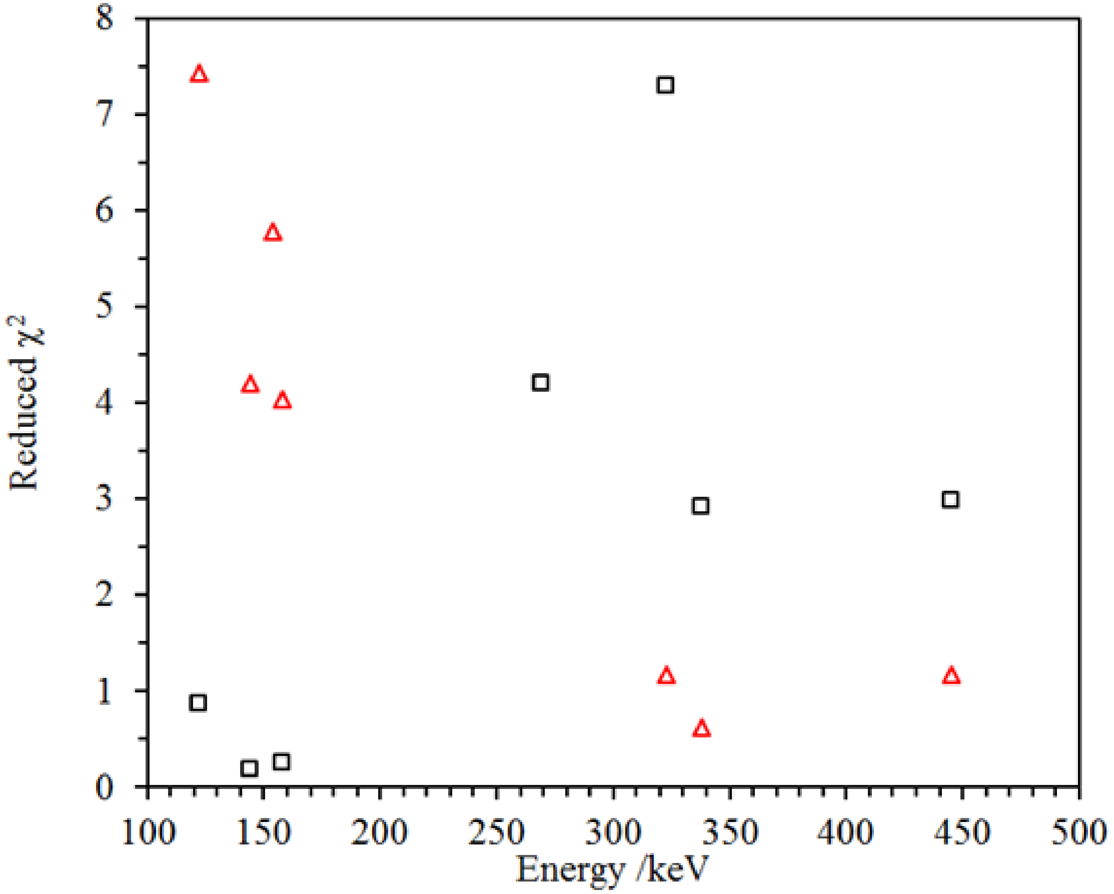


COMPARISON OF RA-223 RESULTS

NPL

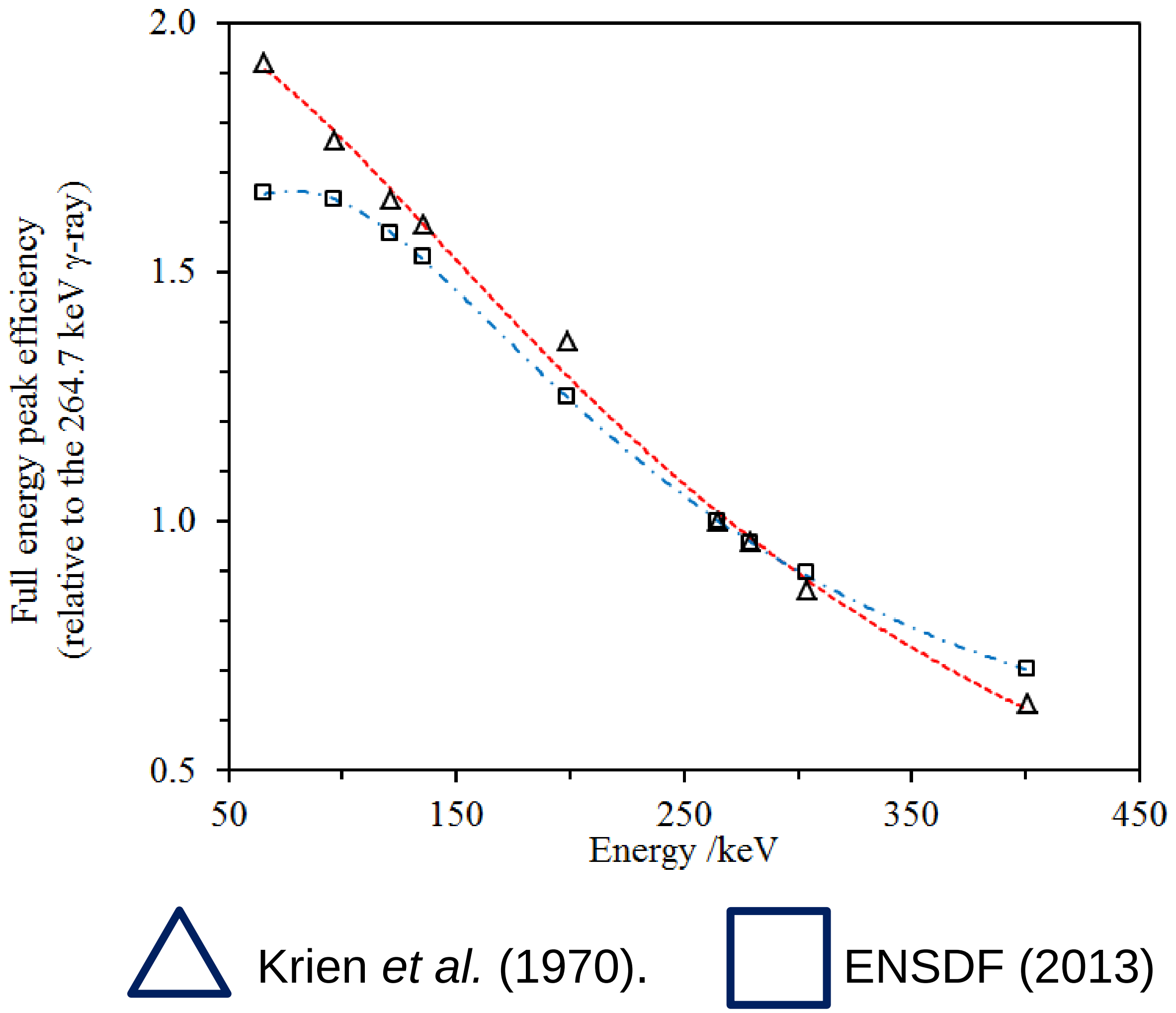
△ normalised to the 154.2 keV γ-ray emission

□ normalised to the 269.5 keV γ-ray emission



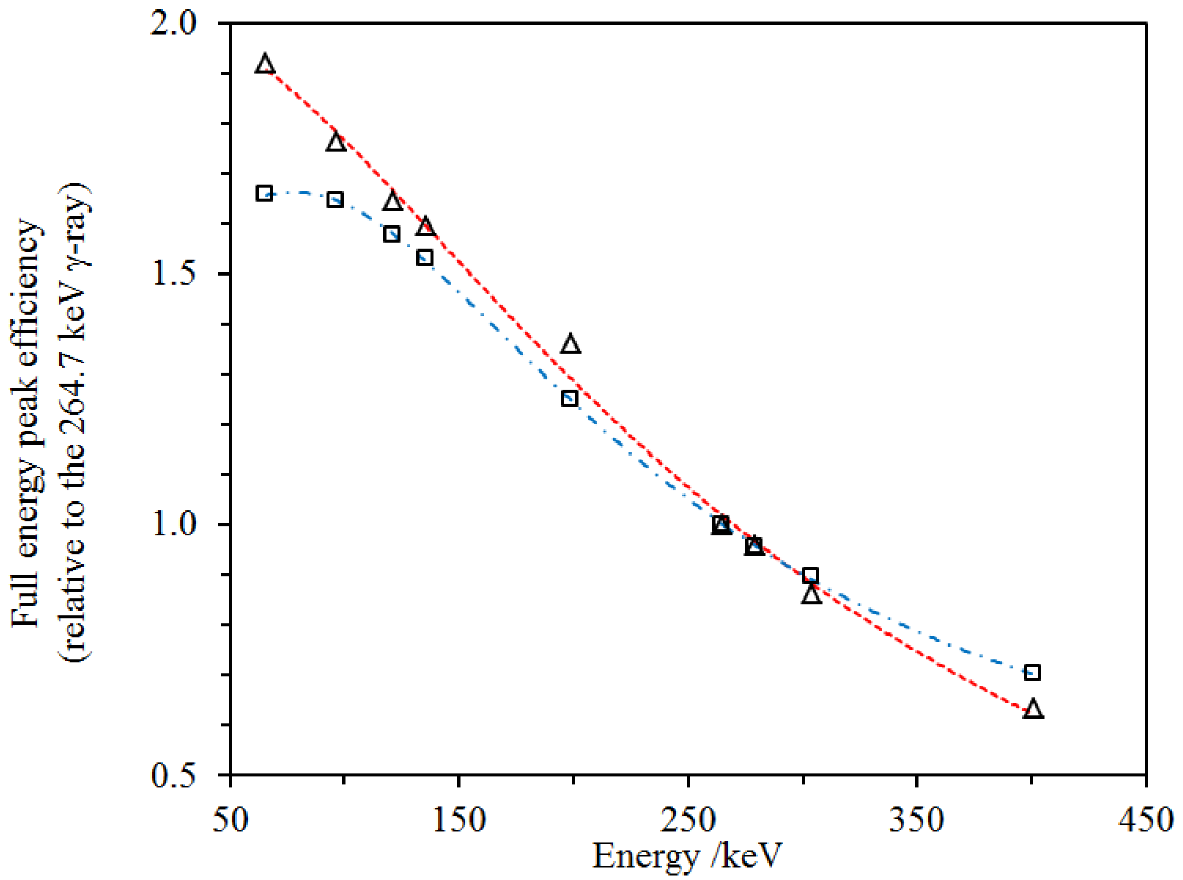
- There appears to be a ‘switching’ point in the discrepancies.
- What could cause this?
- Errors in efficiency calibrations?

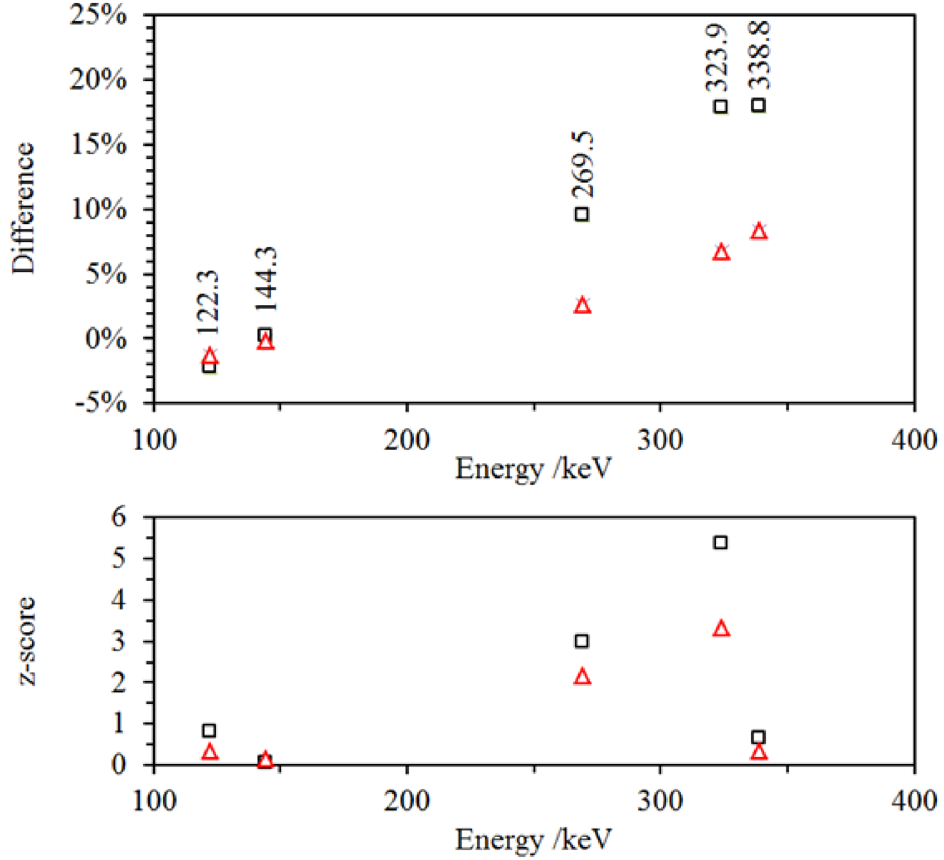
COMPARISON OF ^{75}Se DECAY DATA



- Only one publication (before 2015) provides any detector calibration details
- This also happens to be the one that quoted the best uncertainties
- Krien et al. (1970) used ^{75}Se to determine the full-energy peak efficiency calibration.
  - The γ-ray emission probabilities used at the time are provided.
  - These are significantly different from the recommended values now.
- This allowed us to do some investigation work….

COMPARISON OF ^{75}Se DECAY DATA

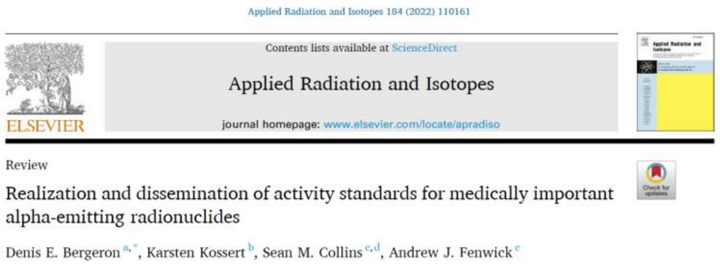




△ Krien *et al.* (1970). □ ENSDF (2013)

□ Before △ After

RA-223 AND DECAY PROGENY GAMMA-RAY EMISSION INTENSITIES


Applied Radiation and Isotopes 184 (2022) 110161
Contents lists available at ScienceDirect
Applied Radiation and Isotopes
journal homepage: www.elsevier.com/locate/apradiso
Review
Realization and dissemination of activity standards for medically important alpha-emitting radionuclides
Denis E. Bergeron[a,*], Karsten Kossert[b], Sean M. Collins[c,d], Andrew J. Fenwick[c]

Absolute emission intensities

Energy /keV	Radionuclide	DDEP (Bé et al., 2011) /I_γ	Pibida et al. (2015) (I_{ref}/I_{DDEP})/%	Collins et al. (2015a)	Kossert et al. (2015b)	Marouli et al. (2019)	Simões et al. (2021)	$\chi^2/(\nu\text{-}1)$
122.3	^{223}Ra	1.238(19)	5.0	6.0	5.3	12.3	−1.0	2.1
144.3	^{223}Ra	3.36(8)	4.5	3.6	3.2	10.4	−1.2	2.7
154.2	^{223}Ra	5.84(13)	4.1	3.1	3.3	10.1	−0.2	2.5
269.5	^{223}Ra	14.23(32)	−7.0	−6.0	−7.5	−0.9	−1.5	5.9
271.2	^{219}Rn	11.07(22)	−3.4	−2.9	−1.8	2.1	−4.0	1.1
323.9	^{223}Ra	4.06(8)	−10.6	−10.0	−9.8	−5.2	−6.2	2.4
338.3	^{223}Ra	2.85(6)	−9.1	−8.6	−8.3	−3.2	0.0	6.6
351.0	^{211}Bi	13.00(19)	0.9	1.3	1.9	6.9	3.62	1.2
401.8	^{219}Rn	6.75(22)	−2.8	−2.7	−1.9	3.4	−2.1	0.9
404.8	^{211}Pb	3.83(6)	4.7	4.7	5.7	9.7	10.2	0.9
427.2	^{211}Pb	1.81(4)	4.4	4.4	5.6	8.3	0.0	1.8
445.0	^{223}Ra	1.28(4)	−4.9	−4.8	−4.5	0.0	0.8	0.6
832.0	^{211}Pb	3.5(5)	−0.6	−1.5	−2.0	6.3	0.6	1.8

Pibida, L., Zimmerman, B., Fitzgerald, R., King, L., Cessna, J.T., Bergeron, D.E., 2015. Determination of photon emission probabilities for the main gamma-rays of ^{223}Ra in equilibrium with its progeny. Appl. Radiat. Isot. 101, 15–19.

Collins, S.M., Pearce, A.K., Regan, P.H., Keightley, J.D., 2015. Precise measurements of the absolute γ-ray emission probabilities of ^{223}Ra and decay progeny in equilibrium. Appl. Radiat. Isot. 102, 15–18.,

Kossert, K., Bokeloh, K., Dersch, R., N¨ahle, O.J., 2015. Activity determination of ^{227}Ac and ^{223}Ra by means of liquid scintillation counting and determination of nuclear decay data. Appl. Radiat. Isot. 95, 143–152.

Marouli, M., Lutter, G., Pomm´e, S., Van Ammel, R., Hult, M., Pierre, S., Dry´ak, P., Carconi, P., Fazio, A., Bruchertseifer, F., Morgenstern, A., 2019. Measurement of absolute γ-ray emission probabilities in the decay of ^{227}Ac in equilibrium with its progeny. Appl. Radiat. Isot. 144, 34–46.

Simoes, R.F.P., da Silva, C.J., da Silva, R.L., de S´a, L.V., Poledna, R., de Oliveira, A.E., Iwahara, A., da Cruz, P.A.L., Delgado, J.U., 2021. Standardization of ^{223}Ra by live-time anticoincidence counting and gamma-ray emission determination. Appl. Radiat. Isot. 170, 109559.

RA-223 AND DECAY PROGENY GAMMA-RAY EMISSION INTENSITIES

NPL

Applied Radiation and Isotopes 184 (2022) 110161

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

ELSEVIER

Review

Realization and dissemination of activity standards for medically important alpha-emitting radionuclides

Denis E. Bergeron[a,*], Karsten Kossert[b], Sean M. Collins[c,d], Andrew J. Fenwick[c]

Relative emission intensities

Energy /keV	Radionuclide	Pibida et al. (2015) $(I_\gamma/I_{\gamma,154\ keV})$/100 decays	Collins et al. (2015)	Kossert et al. (2015)	Marouli et al. (2019)	Simões et al. (2021)	$\chi^2/(\nu\text{-}1)$
122.3	^{223}Ra	21.38(27)	21.79(15)	21.63(27)	21.6(12)	21.03(68)	0.7
144.3	^{223}Ra	57.73(75)	57.82(39)	57.53(58)	57.7(31)	56.95(13)	0.1
269.5	^{223}Ra	217.8(29)	222.1(16)	218.2(31)	219(11)	240.5(42)	5.8
271.2	^{219}Rn	175.8(24)	178.6(13)	180.3(25)	175.7(88)	182.3(32)	0.8
323.9	^{223}Ra	59.70(67)	60.71(43)	60.71(61)	59.9(34)	65.4(14)	3.5
338.3	^{223}Ra	42.60(53)	43.27(31)	43.35(42)	42.9(22)	48.9(11)	7.0
351.0	^{211}Bi	215.6(26)	218.8(16)	219.6(21)	216(11)	231.1(51)	1.9
401.8	^{219}Rn	107.9(13)	109.14(74)	109.8(11)	108.6(56)	113.4(29)	0.9
404.8	^{211}Pb	65.95(82)	66.63(46)	67.2(10)	65.3(33)	72.4(29)	1.3
427.2	^{211}Pb	31.09(35)	31.40(22)	31.71(31)	30.5(15)	31.05(96)	0.6
445.0	^{223}Ra	20.02(24)	20.23(14)	20.27(20)	19.9(11)	22.1(14)	0.7
832.0	^{211}Pb	57.24(75)	57.28(39)	56.88(55)	57.9(30)	60.4(15)	1.3

Pibida, L., Zimmerman, B., Fitzgerald, R., King, L., Cessna, J.T., Bergeron, D.E., 2015. Determination of photon emission probabilities for the main gamma-rays of ^{223}Ra in equilibrium with its progeny. Appl. Radiat. Isot. 101, 15–19.

Collins, S.M., Pearce, A.K., Regan, P.H., Keightley, J.D., 2015. Precise measurements of the absolute γ-ray emission probabilities of ^{223}Ra and decay progeny in equilibrium. Appl. Radiat. Isot. 102, 15–18.,

Kossert, K., Bokeloh, K., Dersch, R., N¨ahle, O.J., 2015. Activity determination of ^{227}Ac and ^{223}Ra by means of liquid scintillation counting and determination of nuclear decay data. Appl. Radiat. Isot. 95, 143–152.

Marouli, M., Lutter, G., Pomm´e, S., Van Ammel, R., Hult, M., Pierre, S., Dry´ak, P., Carconi, P., Fazio, A., Bruchertseifer, F., Morgenstern, A., 2019. Measurement of absolute γ-ray emission probabilities in the decay of ^{227}Ac in equilibrium with its progeny. Appl. Radiat. Isot. 144, 34–46.

Simoes, R.F.P., da Silva, C.J., da Silva, R.L., de S´a, L.V., Poledna, R., de Oliveira, A.E., Iwahara, A., da Cruz, P.A.L., Delgado, J.U., 2021. Standardization of ^{223}Ra by live-time anticoincidence counting and gamma-ray emission determination. Appl. Radiat. Isot. 170, 109559.

RA-223 AND DECAY PROGENY GAMMA-RAY EMISSION INTENSITIES

Applied Radiation and Isotopes 184 (2022) 110161

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Review

Realization and dissemination of activity standards for medically important alpha-emitting radionuclides

Denis E. Bergeron[a,*], Karsten Kossert[b], Sean M. Collins[c,d], Andrew J. Fenwick[c]

Energy	DDEP (Bé et al., 2011)	ENSDF (Singh et al., 2021)	I_{DDEP}/I_{ENSDF}	Precision improvement factor $(u(I_{DDEP})/u(I_{ENSDF}))$
/keV	I_γ/per 100 decay	I_γ/per 100 decay	/%	
122.3	1.238(19)	1.3045(93)	5.4	2.1
144.3	3.36(8)	3.474(25)	3.4	3.2
154.2	5.84(13)	6.020(57)	3.1	2.3
269.5	14.23(32)	13.304(94)	−6.5	3.4
323.9	4.06(8)	3.642(26)	−10.3	3.1
338.3	2.85(6)	2.601(18)	−8.7	3.3
445.0	1.28(4)	1.2184(86)	−4.8	4.7

CONCLUSION

- Decay data has an important role in nuclear medicine
- ‘Good’ decay data relies on ‘good’ metrology practice
- Robust uncertainty analysis is key
- Historical data should be treated with caution
- Poor data in = Poor data out

National Physical Laboratory

npl.co.uk