

Half-life measurement of the medical radioisotope ^{177}Lu

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Overview

- Overview of ^{177}Lu
 - Decay Scheme
 - Application
 - Production method
- Overview of current published values
- Experimental conditions
 - Source preparation
 - Ionisation chamber
 - Measurements
- Results
 - Recommended half-life of ^{177}Lu
- Uncertainties
- Conclusions

Introduction

^{177}Lu Decay Scheme

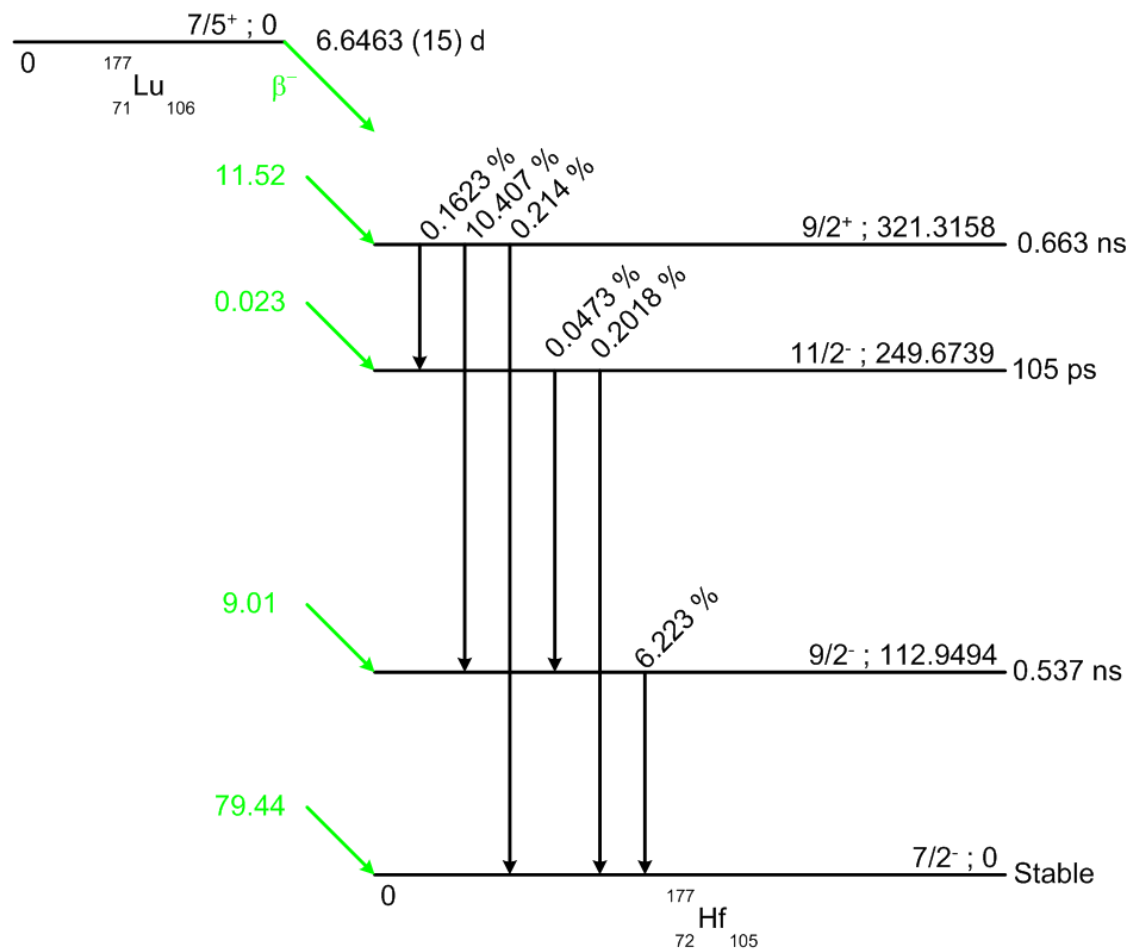


Figure 1: Decay scheme of ^{177}Lu

Introduction

^{177}Lu applications

- Medium-energy beta emitter with a maximum tissue penetration of ~ 1-2 mm
- Gamma emissions with the most abundant peaks being 112.9 keV and 208.4 keV – useful for treatment planning and follow-up;

^{177}Lu is used in Nuclear Medicine:

- ^{177}Lu -DOTATATE used for the Treatment of Neuroendocrine Tumours or metastatic lesions (see figure 1);
- ^{177}Lu -Betalutin used for the treatment of Relapsed non-Hodgkin Lymphoma.

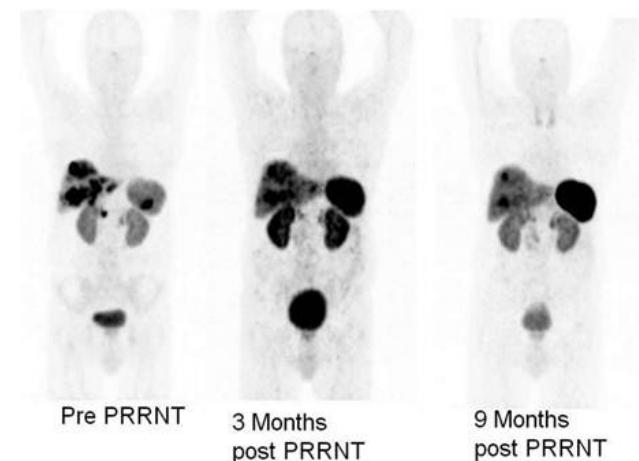


Figure 2: ^{177}Lu –DOTATE scan before and after peptide radionuclide therapy.

Introduction

^{177}Lu Production

- Produced by Irradiation of ^{176}Lu (n, γ) to ^{177}Lu
 - $^{177\text{m}}\text{Lu}$ present as impurity ($T_{1/2} = 160.44$ (6) days)
 - Partly (21.7 %) to ^{177}Lu by isomeric transition
 - Partly (78.3 %) to ^{177}Hf .

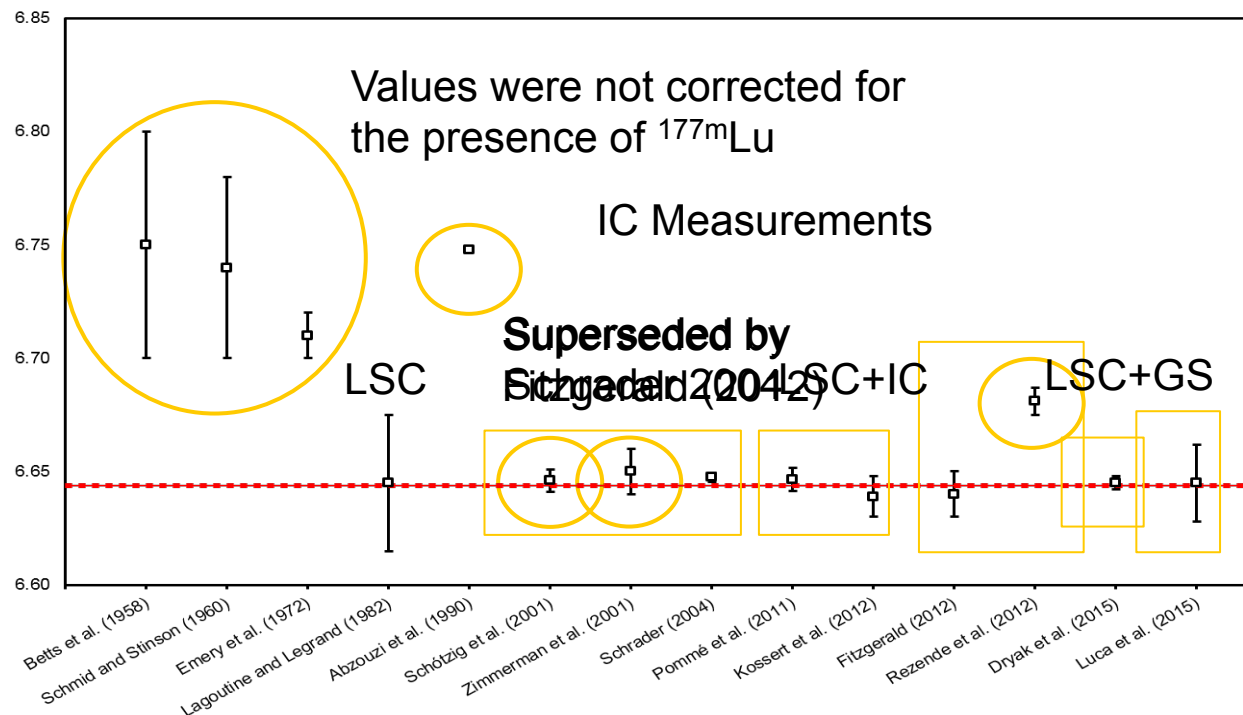
or

- Irradiation of ^{176}Yb (n, γ) to ^{177}Yb followed by beta decay to ^{177}Lu
 - non-carrier added (n.c.a.)
 - No impurities expected by this method

^{177}Lu half-life measurements

Current published values

- Ionisation chamber (IC) measurements: 6
- Other methods: Liquid Scintillation (LSC), or combination of methods (Gamma Spectrometry, IC, LSC)



Graph 1: Published values for the half-life of ^{177}Lu . 14 measurement results have been reported since 1958.

Source Preparation

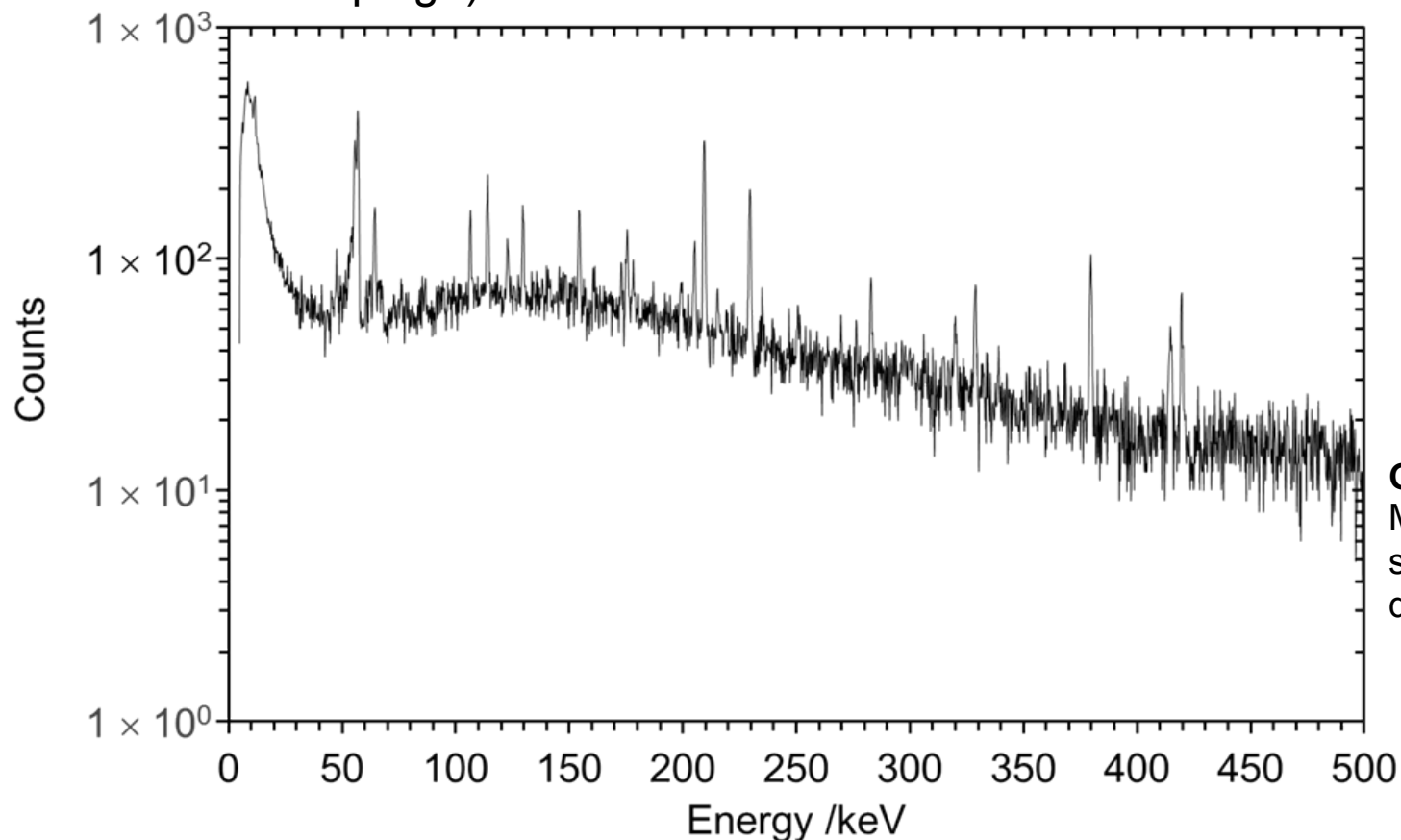
- The solution was received from ITG and diluted at NPL using an aqueous solution of 0.04 mol dm^{-3} hydrochloric acid also containing inactive lutetium at a concentration of $100 \mu\text{g g}^{-1}$;
- ^{177}Lu n.c.a was used in source preparation;
- 10.02 g of solution dispensed to a 10 ml flame sealed glass ampoule;
- Total activity at the start of the measurement campaign was $\sim 200 \text{ MBq}$.

Measurements (1/6)

Gamma spectrometry

The presence of ^{177m}Lu was checked using HPGe gamma spectrometry;

- Activity per unit mass ^{177m}Lu : 0.793 (23) Bq g⁻¹ (start of measurement campaign)



Graph 2:
Measurement spectrum after the decay of ^{177}Lu .

Measurements (2/6)

Ionisation Chamber

- The half-life of ^{177}Lu was measured using a re-entrant ionisation chamber;
- The system comprised of two identical chambers of the same type TPA Mk II connected in a “back-to-back formation;
- Dual lead shield (5cm thick lead ring and 1mx1m bunker (10 cm thick lead blocks) ;
 - reduced background noise
- The sample was placed in a plastic dedicated holder – reproducible positioning;

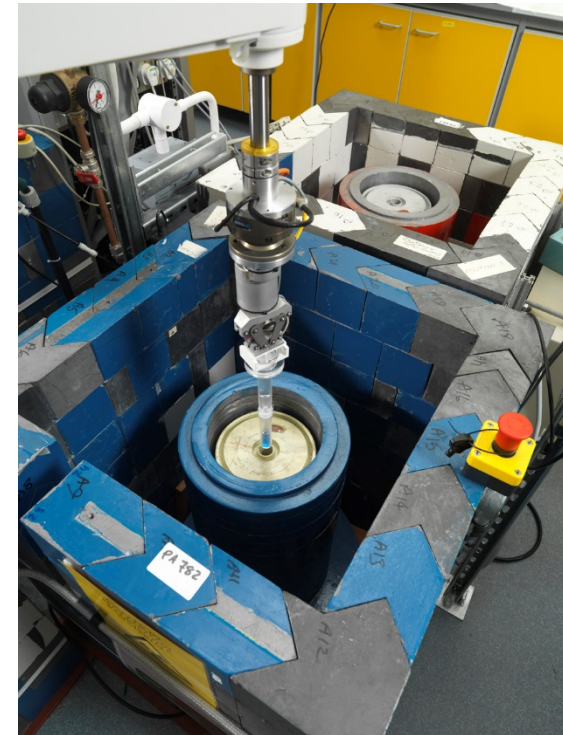
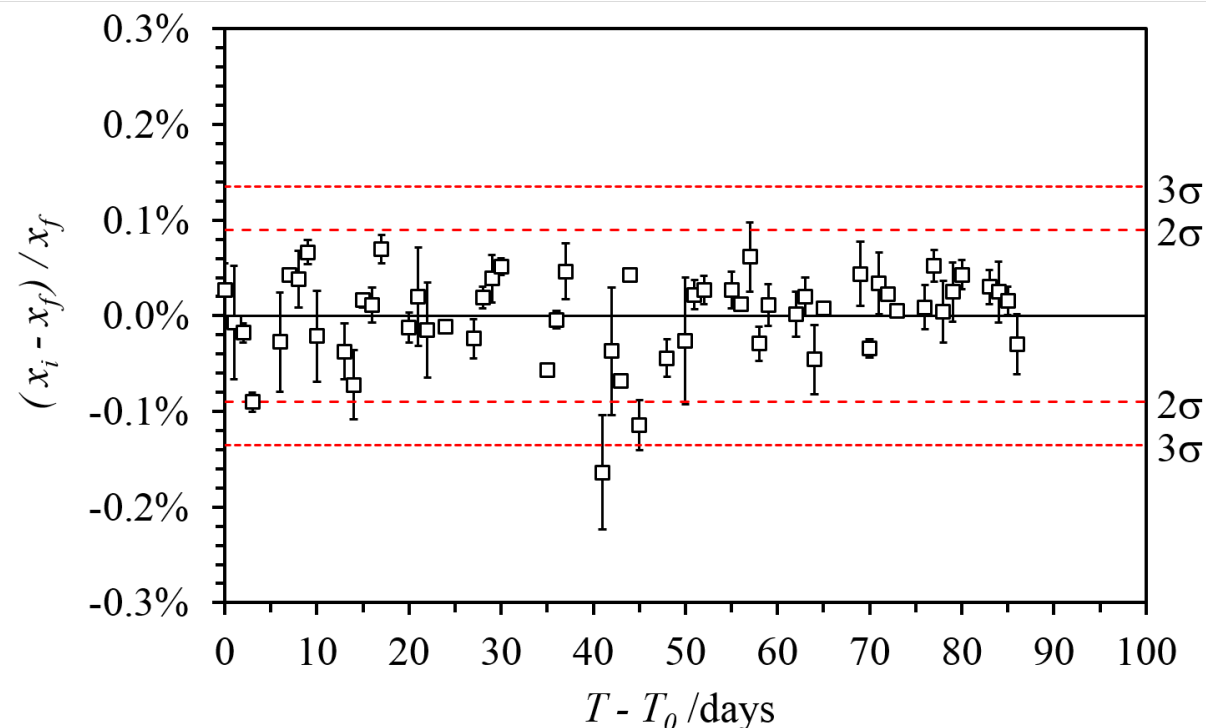


Figure 3: Measurement geometry of the ^{177}Lu ampoule

Measurements (3/6)

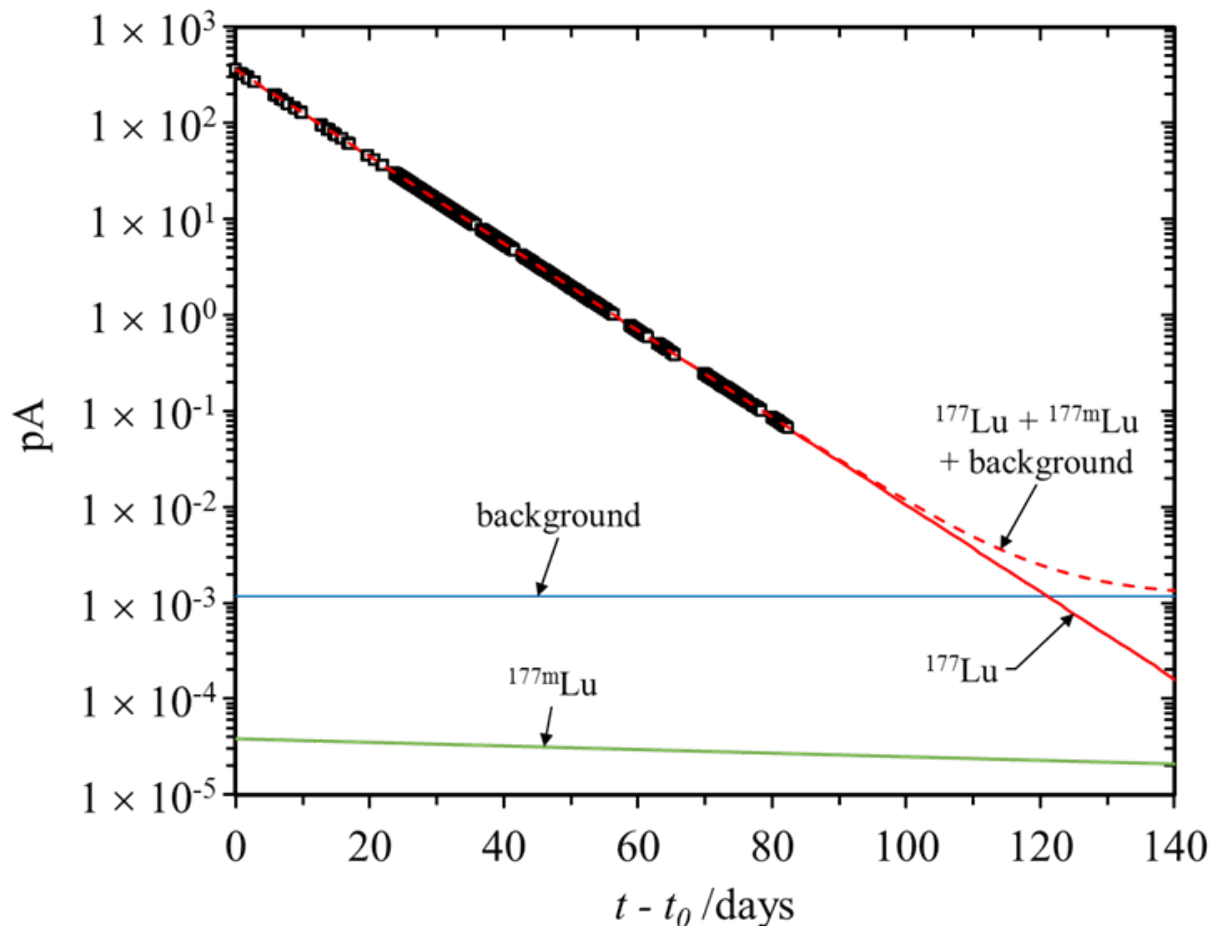
- Stability tracked using ^{226}Ra check source;
 - Measurements corrected for decay using half-life of 1600 (7) years.
- Background was also measured everyday;
 - Mean value was calculated and subtracted from the measurements.



Graph 3: Stability check using ^{226}Ra source. The measurements are within 2 standard deviations.

Measurements (4/6)

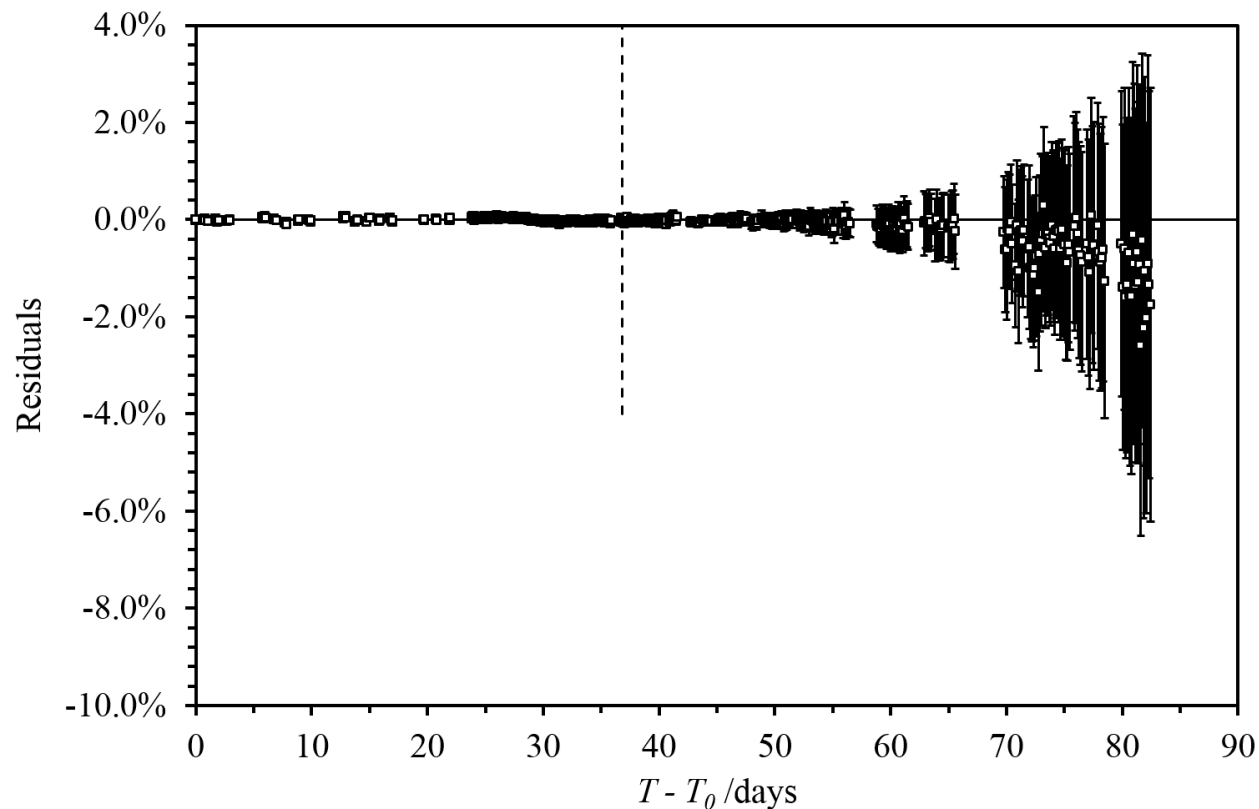
- The ^{177}Lu half-life calculated using least squares fit of exponential decay for 38.1 days.



Graph 4: Ionisation chamber current (pA) as a function of time for a Lu-177 source (dots); the mean background current (blue line); fitted decay exponential curve (dashed red); fitted exponential decay curve for ^{177}Lu (red line); Ionisation current (pA) as a function of time for $^{177\text{m}}\text{Lu}$ (green)

Measurements (5/6)

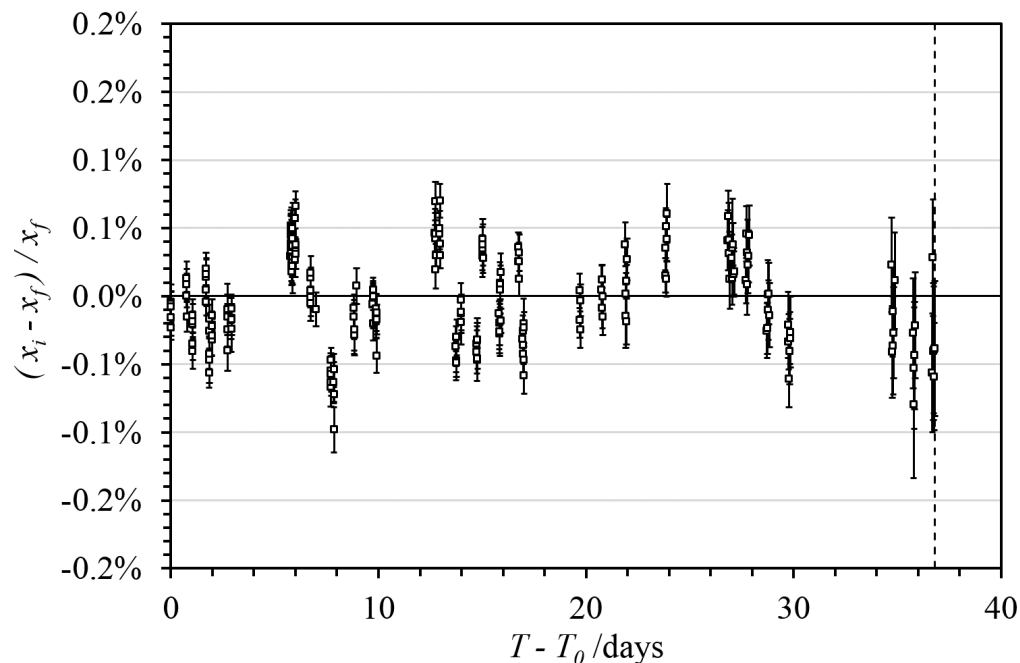
- Measurement campaign over 80 days (~ 12 half-lives);
 - Approximately 11000 individual data points grouped in sets of 10.
 - Start of campaign: 357 pA (end of campaign: 0.1 pA)



Graph 5: Residuals of all collected points.

Measurements (6/6)

- Only data up to 36.8 days (~ 5.5 half-lives) was accepted
 - Shown to be the optimal period for assessing the uncertainty;
 - Periods of time where the source was not repositioned (overnight measurements and weekends) were not considered – non-random error;
 - Data grouped in sets of 10 cycles (n=230).



Graph 6: Residuals of the data points used to determine the half-life for this work.

Uncertainty (1/2)

The uncertainty components have been evaluated using the uncertainty propagation formula (Pommé 2015)

$$\frac{\sigma(T_{1/2})}{T_{1/2}} \approx \left\{ \frac{2}{\lambda T} \sqrt{\frac{2}{n+1}} \right\} \frac{\sigma(A)}{A}$$

Where,

λ – decay constant

T – duration of the measurement campaign

n – frequency of the occurrences of the uncertainty component

σ_A/A – relative uncertainty component of the activity due to the considered component.

The uncertainty components are grouped in 3 categories: low, medium and high frequencies accordingly to the rate of occurrence.

Uncertainty (2/2)

Components	$u(A)/A$	n	factor	$u(T_{1/2})/T_{1/2}$
High Frequency				
Standard Deviation of Residuals	0.034%	230	0.05	0.00164%
Medium Frequency				
Reproducibility	0.050%	24	0.15	0.0074%
Low Frequency				
Stability	0.020%	1	0.52	0.010%
Background	0.018%	1	0.52	0.009%
Linearity	0.010%	1	0.52	0.0052%
Impurity	0.000026%	1	0.52	0.000014%
$T_{1/2}$ (^{177}Lu) result	6.6430 (11)			0.0017 %

New Evaluation of ^{177}Lu half-life

A new evaluation of the half-life of ^{177}Lu has been performed using the **power moderated mean** described by Pommé (2012).

Reference	$T_{1/2}$ /d	$\sigma(T_{1/2})$ /d
Betts et al. (1958)	6.75	0.05
Schmid and Stinson (1960)	6.74	0.04
Emery et al. (1972)	6.71	0.01
Lagoutine and Legrand (1982)* ←	6.645	0.030
Abzouzi et al. (1990)	6.7479	0.0007
Schötzig et al. (2001)	6.646	0.005
Schrader (2004)* ←	6.6475	0.0020
Pommé et al. (2011)* ←	6.6465	0.0050
Kossert et al. (2012)* ←	6.639	0.009
Fitzgerald (2012)* ←	6.640	0.010
Rezende et al. (2012)	6.681	0.006
Dryak et al. (2015)* ←	6.645	0.003
Luca et al. (2015)*	6.645	0.017
This work*	6.6430	0.0011
Recommended $T_{1/2}$ (^{177}Lu)	6.6443	0.0010
DDEP Evaluation (Kellett 2015)	6.6463	0.0015

- The asterisk (*) denotes the values included in the new evaluation.
- The recommended value determined in this work is in good agreement with the previously published value by DDEP – **but with greater accuracy.**
 - Low background;
 - Presence of $^{177\text{m}}\text{Lu}$ is negligible;
 - Using first 6 half-lives.

Conclusion

- The half-life of ^{177}Lu has been measured using a re-entrant ionisation chamber;
- The obtained value is in good agreement with previous evaluated value published by DDEP;
 - This work: 6.6430 (11) days
 - DDEP evaluation: 6.6463 (15) days
- Obtained result has a greater accuracy;
 - the presence of $^{177\text{m}}\text{Lu}$ is negligible;
- A new evaluation has been performed using the power moderated mean.

Thank you for your attention.

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