
BIPM.RI(II)-K5.Tc-99 (2026 update)

Activity of radionuclide Tc-99

KEY COMPARISON

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BIPM comparison BIPM.RI(II).K5.Tc-99 of activity measurements of the radionuclide ^{99}Tc with results from LNE-LNHB (France) and NRC (Canada)

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Abstract

The Extended International System of Reference (ESIR) was established at the BIPM to evaluate the international equivalence of standardization capabilities for radionuclide solutions. This service supports National Metrology Institutes (NMIs) and Designated Institutes (DIs) under the CIPM MRA framework. The ESIR specifically addresses radionuclides that cannot be measured using the International System of Reference (SIR). This report details the key comparison BIPM.RI(II).K5 of ^{99}Tc , featuring results from the LNE-LNHB and NRC.

1 Introduction

The International Reference System (SIR) provides a streamlined framework for National Metrology Institutes (NMIs) and Designated Institutes (DIs) to demonstrate the international equivalence of primary standards for gamma-ray emitting radionuclides. Under this system, standard solutions are transferred to the BIPM and measured using a high-stability ionization chamber and a specific procedure [1]. These results, published in the BIPM Key Comparison Database (KCDB), serve as essential evidence for the validation of Calibration and Measurement Capabilities (CMCs). However, the traditional SIR has technical limitations. Radionuclides that emit no gamma radiation, or emissions insufficient for ionization chamber detection, fall outside the SIR's scope. To address this gap, the Extended International System of Reference (ESIR) was established in 2024. Designed specifically for pure beta-particle emitters as well as certain electron-capture and alpha-particle emitters, the ESIR utilizes a liquid scintillation counter employing the Triple-to-Double Coincidence Ratio (TDCR) method [2].

The ESIR provides NMIs/DIs with a means to verify the reliability of their activity measurements, A_i , through a continuous comparison framework. This is achieved by defining a comparison indicator, k_i , as:

$$k_i = \frac{A_i}{A_{\text{ESIR},i}}, \quad (1)$$

where $A_{\text{ESIR},i}$ denotes the reference activity determined by the ESIR system.¹ This ratio serves as a stable comparison indicator, k_i , provided by the unique system established at the BIPM.

The associated standard uncertainty, $u(k_i)$, is obtained from the standard uncertainties $u(A_i)$ and $u(A_{\text{ESIR},i})$ of the two independent measurements, as follows:

$$u(k_i) = k_i \sqrt{\left(\frac{u(A_i)}{A_i}\right)^2 + \left(\frac{u(A_{\text{ESIR},i})}{A_{\text{ESIR},i}}\right)^2}, \quad (2)$$

To ensure a reproducible reference that remains robust against variations in detection efficiency, the ESIR employs a fixed TDCR model in the estimation of $A_{\text{ESIR},i}$. The reference activity provided by the ESIR, $A_{\text{ESIR},i}$, is not intended to yield an accurate estimate of the true activity; rather, it serves as a stable reference parameter that is insensitive to changes in detection efficiency, including, to some extent, detector asymmetry.

The principle of the ESIR method was demonstrated in a preliminary study [3], followed by a pilot study involving 13 NMIs/DIs, in which the ESIR was benchmarked against the SIR using ^{60}Co standard solutions [4].

The k_i values derived from primary measurements are subsequently used to estimate the Key Comparison Reference Value (KCRV), denoted μ , for a given radionuclide by averaging, using the Power Moderated Mean (PMM) method [5].

The relative degrees of equivalence, D_i , are defined as the relative difference between the comparison indicator k_i and the KCRV value μ , such that:

$$D_i = \frac{k_i - \mu}{\mu}. \quad (3)$$

The expanded uncertainty, $U(D_i)$, is given by:

$$U(D_i) = 2 \sqrt{\frac{1 - 2w_i \frac{k_i}{\mu}}{\mu^2} u^2(k_i) + \frac{k_i^2}{\mu^4} u^2(\mu)}, \quad (4)$$

where $u(k_i)$ and $u(\mu)$ are the standard uncertainties associated with the indicator k_i and the KCRV value μ , respectively, and w_i is the weight assigned to measurement i in the KCRV calculation.²

These exercises are classified as BIPM continuous comparisons, and the resulting data contribute to the BIPM Key Comparison Database (KCDB) within the framework of the CIPM Mutual Recognition Arrangement (CIPM MRA) [6]. The specific comparison described in this report is designated as the BIPM.RI(II)-K5.Tc-99 key comparison.

Successful participation in this comparison by a laboratory may provide evidential support for Calibration and Measurement Capability (CMC) claims for ^{99}Tc measured using the laboratory's method(s) used in the comparison or methods calibrated by those used for the comparison. This comparison may also be used to support CMC claims for those radionuclides measured in the laboratory using the same method and having a degree of difficulty at or below that of the radionuclide measured in this comparison as indicated in the current Measurement Methods Matrix (MMM) [7].

2 Participants

Laboratory details are given in Table 1 with the date of the measurement in the ESIR.

¹This quantity is referred to as $I_{2,i}$ in reference [4], where k_i has the same meaning.

²See [5] for details on the calculation of μ and w_i .

Table 1: Details of the participants.

Laboratory	Measurement date	Full name	Country
LNE-LNHB	2024-12-16	Université Paris-Saclay, CEA, List, Laboratoire National Henri Becquerel	France
NRC	2026-4-29	National Research Council	Canada

3 Standardization methods

Each NMI that submits ampoules to the ESIR has measured the activity either by a primary standardization method or by using a secondary method. In the latter case, the traceability of the calibration needs to be clearly identified to ensure that appropriate correlations are taken into account. Table 2 summarizes the standardization details for each participating laboratory, including the measurement date, reference date, method, measurement system, and half-life used. It also provides the participants' activity measurements along with their standard deviations.

The details on the measurements including system information, measurement model implementation and uncertainty budget are provided in Appendix A.

Table 2: Summary of the participant standardizations.

Laboratory	Measurement date (UTC)	Reference date (UTC)	Method	System	A_i (kBq/g)	$T_{1/2}$ (days)
LNE-LNHB	2024-09-02	2024-07-15	TDCR	RCTD1 MAC3	60.17(18)	$(7.725 \pm 0.040) \times 10^7$ [11]
LNE-LNHB	2024-11-13	2024-07-15	TDCR	Hidex 300 SL Metrology	60.19(19)	$(7.725 \pm 0.040) \times 10^7$ [11]
NRC	2026-02-20	2026-01-15	TDCR	Hidex 300 SL Metrology	181.0(10)	$(7.725 \pm 0.040) \times 10^7$ [11]

4 Standard solutions

The details of the solutions submitted are presented in Table 3, including any identified impurities reported by the participating laboratories.

When relevant, additional information concerning the liquid scintillation sources prepared by participants for their standardization procedures is included in Appendix A.

Table 3: Details of each solution of ^{99}Tc submitted.

Laboratory year	Chemical composition	Solvent concentration (mol/dm ³)	Carrier concentration ($\mu\text{g/g}$)	Density (g/cm ³)	Relative activity of impurity ^a
LNE-LNHB 2024	water	-	-	0.998	none detected
NRC 2026	NH ₄ OH	0.1	-	0.997	none detected

^a The ratio of the activity of the impurity to the activity of ^{99}Tc at the reference date

5 Results

All ESIR measurements were performed using the nanoTDCR TD9010 electronic module [9] (serial number 10150), configured with a fixed dead time of 50.0 μs and a coincidence resolving time of 50 ns.

The ESIR reference activities were calculated with the analytical TDCR model implemented in the TDCRPy code, version 2.18.2 [10], using a Birks constant of 0.01 cm MeV^{-1} . The half-life adopted by the BIPM is $(7.725 \pm 0.040) \times 10^7$ days [11]. Stopping power values were taken from the ICRU Report 37 above 10 keV and from Z. Tan *et al.* [12] below 10 keV. The beta spectrum of ^{99}Tc was obtained from

M. Paulsen *et al.* [13].

Table 4 presents the participant's activity, A_i , the ESIR reference activity, $A_{\text{ESIR},i}$, and the resulting comparison indicator, k_i , for each submission. The obtained KCRV, $\mu = \mathbf{1.0014(21)}$, was calculated using the values shown in bold in the table (one value per laboratory).

Table 4: Comparison indicators of ^{99}Tc obtained from ESIR measurements.

Laboratory year	Method	System	A_i (kBq/g)	$A_{\text{ESIR},i}$ (kBq/g)	k_i
LNE-LNHB 2024	TDCR	RCTD1 MAC3	60.17(18)	60.074(42)	1.0016(31)
LNE-LNHB 2024	TDCR	Hidex 300 SL Metrology	60.19(19)	60.074(42)	1.0019(32)
NRC 2026	TDCR	Hidex 300 SL Metrology	181.0(10)	181.01(12)	0.9999(57)
μ					1.0014(21)

Table 5 presents the relative degrees of equivalence, D_i , and their associated expanded uncertainties, $U(D_i)$. The values shown in red are those reported to the KCDB. The relative standard uncertainties associated with the participant activity measurements, $u(A_i)/A_i$, and the BIPM ESIR measurements, $u(A_{\text{ESIR},i})/A_{\text{ESIR},i}$, are also reported, highlighting the minimal contribution of the ESIR measurements to the final results.

Table 5: Relative degrees of equivalence for the ^{99}Tc obtained from ESIR measurements.

Laboratory year	Method	System	$u(A_i)/A_i$ (%)	$u(A_{\text{ESIR},i})/A_{\text{ESIR},i}$ (%)	D_i (%) ($k = 2$)
LNE-LNHB 2024	TDCR	RCTD1 MAC3	0.30	0.070	0.02 ± 0.50
LNE-LNHB 2024	TDCR	Hidex 300 SL Metrology	0.31	0.070	0.06 ± 0.52
NRC 2026	TDCR	Hidex 300 SL Metrology	0.57	0.065	-0.14 ± 0.96

A graphical representation of the relative degrees of equivalence is shown in Figure 1.

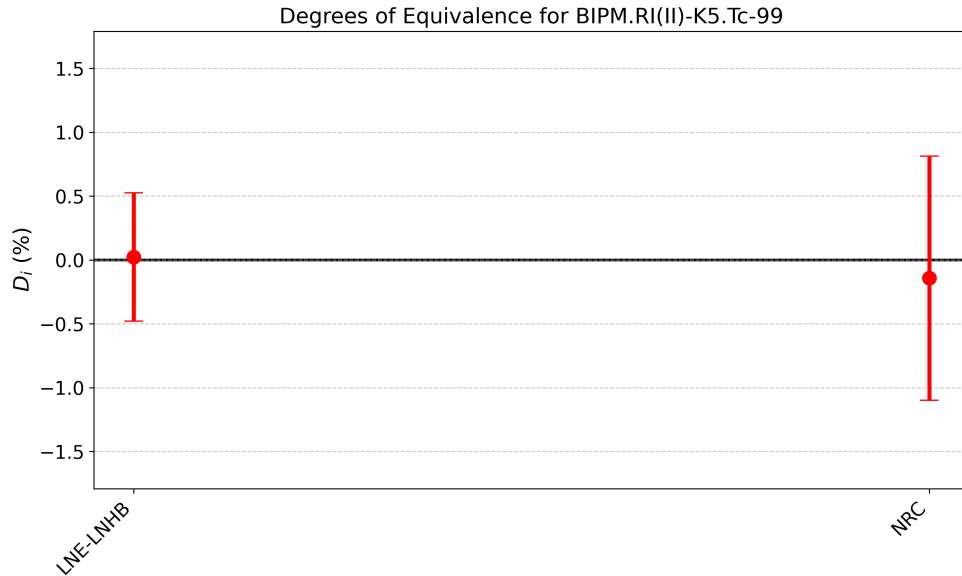


Figure 1: Relative degrees of equivalence for BIPM.RI(II).K5.Tc-99 key comparison.

Detailed information on the ESIR measurements and their uncertainty budgets is provided in Appendix B. Evidence for the robustness of the ESIR comparison results with the TDCR model, the scintillation cocktail and signal processing parameters are presented in Appendices D and E. The control chart used to monitor the long-term stability of the ESIR response is presented in Appendix C.

6 Conclusion

The BIPM continuous key comparison for ^{99}Tc , BIPM.RI(II)-K5.Tc-99, currently includes 2 results. The KCRV has been established from the results submitted by LNE-LNHB (2024) and NRC (2026). The comparison results have been evaluated against this KCRV, providing relative degrees of equivalence for the 2 participating NMIs/DIs. These relative degrees of equivalence have been approved by CCRI(II) and are published in the BIPM key comparison database. Further results may be added as additional NMIs/DIs contribute ^{99}Tc activity measurements to the comparison or take part in related linked comparisons.

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A Details on laboratory measurements and uncertainty budgets

A.1 Details on the measurement carried out by the LNE-LNHB in 2024 for method RCTD1 MAC3

The TDCR system is equipped with 3 BURLE 8850 photomultipliers. The counting is implemented using the home-made module MAC3 based on a extendable dead-time circuitry and the live-time technique [8]. The activity concentration is obtained from the measurements of 6 LS sources (10 mL of Ultima Gold AB in standard 20 mL glass vials).

Table 6: Details on the experimental setup established by the LNE-LNHB for method RCTD1 MAC3

Component	Information
Name of the measurement system	RCTD1 MAC3
Type of PMTs	BURLE 8850
Coincidence resolving time (ns)	40
Type of dead time	Extended
Dead time base duration (μ s)	50
Technique for efficiency variation	Grey filters
Name of the acquisition system	MAC 3
TDCR value	0.9694
Double coincidence efficiency	0.9654
Count rate of double coincidences (s^{-1})	1500

Table 7: Details on the measurement model used by the LNE-LNHB for method RCTD1 MAC3

Component	Information
Code for efficiency calculation	Specific calculation code implemented with the Python language
Birks constant	0.008 cm/MeV to 0.012 cm/MeV
Stopping power model	ICRU37
Statistical model	Poisson
Quenching model	Birks
Lower integration bound (eV)	10
Asymmetry considered	Yes
Accidental coincidences considered	No (considered as negligible with the experimental settings)
Beta spectrum	Experimental MMC spectrum [13]

Table 8: Details on the sources prepared by the LNE-LNHB for method RCTD1 MAC3

Component	Information
Type of vials	Glass
Scintillation cocktail	UGAB
Scintillation source volume (mL)	10
Mass of aliquot of standard solution (mg)	Ranging from 20 mg to 40 mg
Number of scintillation sources prepared	6

Table 9: Uncertainty budget from LNE-LNHB for method RCTD1 MAC3

Component	Relative standard uncertainty (%)	Evaluation type	Comment
Counting statistics	0.05	A	Standard deviation calculated from the measurement of 6 LS vials
Background	0.05	B	
Weighing	0.1	B	
Dead time	0.02	B	
			Live time technique using extendable dead-times
TDCR Modeling	0.14	B	
Beta spectrum	0.24	B	
Combined	0.3		

A.2 Details on the measurement carried out by the LNE-LNHB in 2024 for method Hidex 300 SL Metrology

The activity concentration is obtained using a commercial TDCR Hidex 300SL system purchased at LNHB in June 2023. The measurements were performed in the Metrology mode using a resolving time equal to 40 ns. The activity concentration is obtained from the measurements of 6 LS sources (10 mL of Ultima Gold AB in standard 20 mL glass vials).

Table 10: Details on the experimental setup established by the LNE-LNHB for method Hidex 300 SL Metrology

Component	Information
Name of the measurement system	Hidex 300 SL Metrology
Type of PMTs	ET9102
Coincidence resolving time (ns)	40
Type of dead time	Non-extended + compensation
Dead time base duration (μ s)	40
Technique for efficiency variation	No efficiency variation
Name of the acquisition system	Hidex 300 SL Metrology
TDCR value	0.976
Double coincidence efficiency	0.972
Count rate of double coincidences (s^{-1})	1500

Table 11: Details on the measurement model used by the LNE-LNHB for method Hidex 300 SL Metrology

Component	Information
Code for efficiency calculation	Specific calculation code implemented with the Python language
Birks constant	0.008 cm/MeV to 0.012 cm/MeV
Stopping power model	ICRU37
Statistical model	Poisson
Quenching model	Birks
Lower integration bound (eV)	10
Asymmetry considered	Yes
Accidental coincidences considered	No (considered as negligible with the experimental settings)
Beta spectrum	Experimental MMC spectrum [13]

Table 12: Details on the sources prepared by the LNE-LNHB for method Hidex 300 SL Metrology

Component	Information
Type of vials	Glass
Scintillation cocktail	UGAB
Scintillation source volume (mL)	10
Mass of aliquot of standard solution (mg)	Ranging from 20 mg to 40 mg
Number of scintillation sources prepared	6

Table 13: Uncertainty budget from LNE-LNHB for method Hidex 300 SL Metrology

Component	Relative standard uncertainty (%)	Evaluation type	Comment
Counting statistics	0.08	A	Standard deviation calculated from the measurement of 6 LS vials Hidex dead-time management verified at LNHB
Background	0.01	B	
Weighing	0.1	B	
Dead time	0.05	B	
TDCR Modeling	0.14	B	
Beta spectrum	0.24	B	
Combined	0.31		

A.3 Details on the measurement carried out by the NRC in 2026 for method Hidex 300 SL Metrology

Table 14: Details on the experimental setup established by the NRC for method Hidex 300 SL Metrology

Component	Information
Name of the measurement system	Hidex 300 SL Metrology
Coincidence resolving time (ns)	50
Type of dead time	Non-extended + compensation
Dead time base duration (μ s)	30
Name of the acquisition system	Hidex 300 SL MikroWin
TDCR value	0.9696 to 0.9011
Double coincidence efficiency	0.97 to 0.91
Count rate of double coincidences (s^{-1})	417

Table 15: Details on the measurement model used by the NRC for method Hidex 300 SL Metrology

Component	Information
Code for efficiency calculation	TDICRPy (2.16.3)
Birks constant	0.001 cm/MeV to 0.009 cm/MeV
Stopping power model	ICRU37
Statistical model	Poisson
Quenching model	Birks
Asymmetry considered	No
Accidental coincidences considered	No
Beta spectrum	Beta Shape

Table 16: Details on the sources prepared by the NRC for method Hidex 300 SL Metrology

Component	Information
Type of vials	Glass
Scintillation cocktail	UG
Scintillation source volume (mL)	15
Mass of aliquot of standard solution (mg)	15.7
Number of scintillation sources prepared	12

Table 17: Uncertainty budget from NRC for method Hidex 300 SL Metrology

Component	Relative standard uncertainty (%)	Evaluation type	Comment
Counting statistics	0.04	A	Standard deviation of 12 measurements
Background	0.001	B	Propagation of the uncertainty in the background
Weighing	0.03	B	Balance calibration
Dilution	0.00037	B	
Resolving time	0.16	B	Uncertainty from variation of the resolving time (value of resolving time 35-100 ns)
Decay correction	2.7e-06	B	
Quenching, kB value	0.52	B	kB selected and method for selection
Reproducibility	0.15	B	Standard deviation between different date of measurement and detector
Combined	0.57		

B Details on ESIR measurements and uncertainty budgets

Since the ESIR approach defines the BIPM instrument as the international reference, the uncertainty budgets exclude any components arising from the TDCR model itself. This enables the ESIR results to contribute minimally to the uncertainty of the relative degrees of equivalence, $U(D_i)$, thereby better reflecting the measurement capabilities of the participating laboratories.

However, a long-term process component is included in the uncertainty budgets. This component was evaluated through quality-control measurements assessing the reproducibility of the ESIR response based on monthly tests using highly stable toluene-based liquid scintillation ^{14}C sources, as detailed in Appendix C [14].

B.1 Details on the ESIR measurements related to submission from the LNE-LNHB in 2024

Table 18: Details on the ESIR measurement

Acquisition System	
Hardware name	nanoTDCR TD9010
Serial number	10150
Firmware version	50.20
FPGA version	107.1
Threshold PMT A (mV)	-6.98
Threshold PMT B (mV)	-6.98
Threshold PMT C (mV)	-6.98
Extended dead time (μ s)	50.0
Coincidence resolving time (ns)	50
Number of measurement per source	10
Duration of individual measurement (s)	720.0
Measurement date	16/12/2024 17:17:13 UTC
Liquid Scintillation Sources	
Number of sources	4 for each LS cocktail
LS cocktail	UG and PS
LS cocktail volume (mL)	15.0
LS batch	2024
Aqueous volume (mL)	0.91
Complexing agent (mL)	0.00
TDCR Model	
Software name	TDCRPy
Software version	2.18.2
kB (cm/MeV)	0.01
Half-life (s)	6674432400000(34713360000)
Measurement Results	
Dead time of the measurements (%)	32.9(34)
Rate of accidental coincidences (%) (Signal)	0.018
Rate of accidental coincidences (%) (Background)	5.202
Free parameter global (keV^{-1})	5.27(10)
Free parameter channel A (keV^{-1})	5.27(28)
Free parameter channel B (keV^{-1})	5.35(21)
Free parameter channel C (keV^{-1})	5.30(24)
Decay factor	1.0000013507(35)
Double coincidence efficiency	0.97347(30)
$A_{\text{ESIR},i}$ (kBq/g)	60.074(42)
Uncertainty Budget	
Counting statistics (from type A evaluation) (%)	0.058
Background component (%)	0.0016
Decay correction component (from type B evaluation) (%)	7e-07
Weighing component (from drift analysis) (%)	5.6e-05
Long term process component (%)	0.031
Combined uncertainty (%)	0.07

B.2 Details on the ESIR measurements related to submission from the NRC in 2026

Table 19: Details on the ESIR measurement

Acquisition System	
Hardware name	nanoTDCR TD9010
Serial number	10150
Firmware version	50.20
FPGA version	107.1
Threshold PMT A (mV)	-5.00
Threshold PMT B (mV)	-5.00
Threshold PMT C (mV)	-5.00
Extended dead time (μ s)	50.0
Coincidence resolving time (ns)	50
Number of measurement per source	10
Duration of individual measurement (s)	720.0
Measurement date	29/4/2026 11:52:40 UTC
Liquid Scintillation Sources	
Number of sources	2 for each LS cocktail
LS cocktail	UG, PS, LLT, AB, HF
LS cocktail volume (mL)	15.0
LS batch	2026
Aqueous volume (mL)	1.06
Complexing agent (mL)	0.00
TDCR Model	
Software name	TDCRPy
Software version	2.18.2
kB (cm/MeV)	0.01
Half-life (s)	6674432400000(34713360000)
Measurement Results	
Dead time of the measurements (%)	37.0(13)
Rate of accidental coincidences (%) (Signal)	0.016
Rate of accidental coincidences (%) (Background)	4.490
Free parameter global (keV^{-1})	5.87(16)
Free parameter channel A (keV^{-1})	5.874(57)
Free parameter channel B (keV^{-1})	5.94(30)
Free parameter channel C (keV^{-1})	5.96(14)
Decay factor	1.0000009437(35)
Double coincidence efficiency	0.97534(46)
$A_{\text{ESIR},i}$ (kBq/g)	181.01(12)
Uncertainty Budget	
Counting statistics (from type A evaluation) (%)	0.06
Background component (%)	0.0059
Decay correction component (from type B evaluation) (%)	4.9e-07
Weighing component (from drift analysis) (%)	0.0028
Long term process component (%)	0.031
Combined uncertainty (%)	0.065

C Control chart of the ESIR measurement using toluene-based liquid scintillation sources of ^{14}C .

The control chart of the ESIR obtained using toluene-based liquid sources of ^{14}C is presented in Figure 2. The normalized ESIR reference activities, $A_{\text{ESIR},j}/\bar{A}_{\text{ESIR},j}$, where j denotes an individual measurement periodically performed over time, are shown for the ^{14}C sources CCT, CMF and 14C-117TOL. Several acquisition modules are also included to account for continuity with the back-up electronics: Device 10150 is the currently used nanoTDCR TD9010, and Device 10030 is another nanoTDCR TD9010 used as back-up.

Figure 2 shows that the dispersion of the measurement data is contained within $\pm 0.1\%$ over six years of observation, demonstrating the overall good stability of the ESIR system.

The uncertainty component associated with long-term process fluctuation is evaluated through the estimation of the dark uncertainty τ^3 , which increases the data point uncertainties to ensuring consistency of the overall measurement dataset. The Table 20 summarizes the results obtained using two methods: the Power Moderated Mean (PMM) [5] and the DerSimonian-Laird (DSL) procedure [15]. The average of the DSL estimates yields a relative standard uncertainty associated with long-term process noise of 0.03117 %.

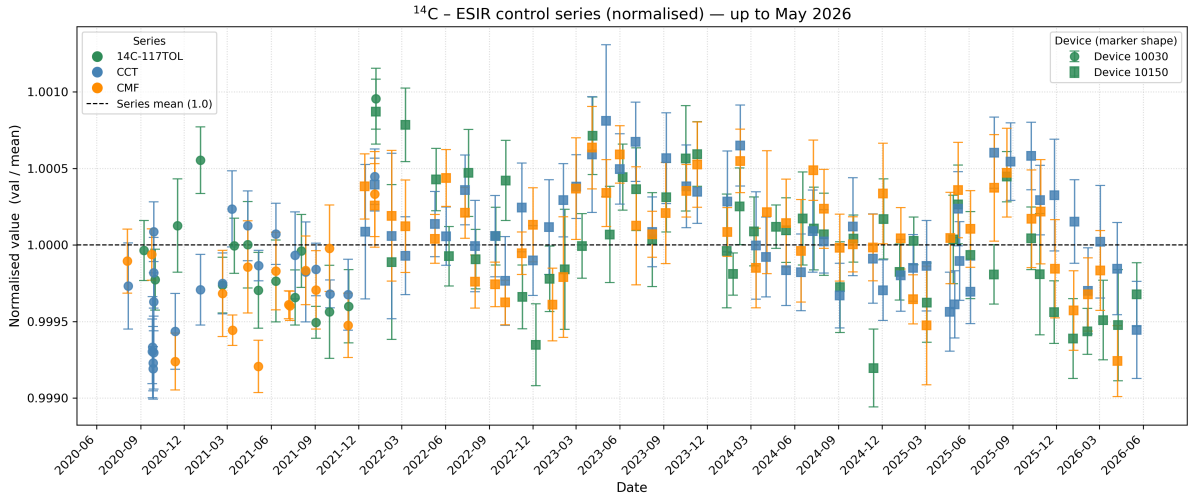


Figure 2: Control charts of the ESIR using toluene-based liquid scintillation sources of ^{14}C .

Table 20: Evaluation of the long-term process noise of the ESIR

Source	$u(\bar{A}_{\text{ESIR},j})/\bar{A}_{\text{ESIR},j}$ (%)	$u(\bar{A}_{\text{ESIR},j})/\bar{A}_{\text{ESIR},j}$ (%)	$\tau/\bar{A}_{\text{ESIR},j}$ (%)	$\tau/\bar{A}_{\text{ESIR},j}$ (%)
Method	PMM	DSL	PMM	DSL
14C-117TOL	0.00472	0.00488	0.03005	0.03163
CCT	0.00423	0.00441	0.02677	0.02880
CMF	0.00441	0.00491	0.02653	0.03149

³Dark uncertainty refers to the unrecognized or unexplained component of measurement variation that causes actual data points to disperse much more widely than their reported uncertainty budgets predict. In consensus value calculations, dark uncertainty is mathematically treated as a variance-inflating random effect (τ^2) added to the stated laboratory variances to bring mutually inconsistent data into statistical agreement [16].

D Robustness of the ESIR with TDCR models and LS cocktails

The comparison indicators derived from the ESIR measurements are summarized in Table 21 for two types of scintillation cocktails, Ultima Gold (UG) from PerkinElmer and ProSafe+ (PS) from Hidex, and for three Birks constants, $kB = 0.01 \text{ cm MeV}^{-1}$, $kB = 0.007 \text{ cm MeV}^{-1}$ and $kB = 0.013 \text{ cm MeV}^{-1}$. The values retained for the key comparison reference value (KCRV) are shown in bold, and the KCRV itself is highlighted in red.

Table 21: Comparison indicators of ^{99}Tc obtained from ESIR measurements using different LS cocktails and TDCR models.

Laboratory year	k_i	k_i	k_i	k_i	k_i	k_i
	UG, $kB = 0.01 \text{ cm/MeV}$	PS, $kB = 0.01 \text{ cm/MeV}$	UG, $kB = 0.007 \text{ cm/MeV}$	PS, $kB = 0.007 \text{ cm/MeV}$	UG, $kB = 0.013 \text{ cm/MeV}$	PS, $kB = 0.013 \text{ cm/MeV}$
LNE-LNHB 2024	1.0016(31)	1.0016(31)	1.0027(31)	1.0029(31)	1.0007(31)	1.0006(31)
LNE-LNHB 2024	1.0019(32)	1.0020(32)	1.0030(32)	1.0032(32)	1.0010(32)	1.0010(32)
NRC 2026	0.9999(57)	0.9997(57)	1.0010(57)	1.0009(57)	0.9991(57)	0.9987(57)
μ	1.0014(21)	1.0013(21)	1.0025(21)	1.0026(21)	1.0005(21)	1.0004(21)

The relative degrees of equivalence calculated from the ESIR results are presented in Table 22 for both scintillation cocktails and Birks constants. Values reported to the KCDB are shown in red color.

Table 22: Relative degrees of equivalence for the ^{99}Tc obtained from ESIR measurements using different LS cocktails and TDCR models.

Laboratory year	D_i (%)	D_i (%)	D_i (%)	D_i (%)	D_i (%)	D_i (%)
	UG, $kB = 0.01 \text{ cm/MeV}$	PS, $kB = 0.01 \text{ cm/MeV}$	UG, $kB = 0.007 \text{ cm/MeV}$	PS, $kB = 0.007 \text{ cm/MeV}$	UG, $kB = 0.013 \text{ cm/MeV}$	PS, $kB = 0.013 \text{ cm/MeV}$
LNE-LNHB 2024	0.02 ± 0.50	0.03 ± 0.50	0.02 ± 0.50	0.03 ± 0.50	0.02 ± 0.50	0.03 ± 0.50
LNE-LNHB 2024	0.06 ± 0.52	0.06 ± 0.52	0.06 ± 0.52	0.06 ± 0.52	0.05 ± 0.52	0.06 ± 0.52
NRC 2026	-0.14 ± 0.96	-0.16 ± 0.95	-0.15 ± 0.96	-0.16 ± 0.95	-0.14 ± 0.96	-0.16 ± 0.95

The results demonstrate the independence of the relative degrees of equivalence from the choice of scintillation cocktail or TDCR model parameters, confirming the robustness and reliability of the ESIR approach.

E Robustness of the ESIR with respect to signal processing parameters

The comparison indicators derived from the ESIR measurements are summarized in Table 23 for four combinations of the TDCR signal processing parameters: the coincidence resolving time, τ_c , and the imposed dead time per event, τ_d . The values selected for the key comparison reference value (KCRV) are highlighted in bold, while the KCRV itself is indicated in red.

Table 23: Comparison indicators of ^{99}Tc obtained from ESIR measurements using different signal processing parameters.

Laboratory year	k_i	k_i	k_i	k_i
	$\tau_c = 50 \text{ ns}$	$\tau_c = 100 \text{ ns}$	$\tau_c = 50 \text{ ns}$	$\tau_c = 100 \text{ ns}$
	$\tau_d = 50 \text{ }\mu\text{s}$	$\tau_d = 50 \text{ }\mu\text{s}$	$\tau_d = 10 \text{ }\mu\text{s}$	$\tau_d = 10 \text{ }\mu\text{s}$
LNE-LNHB 2024	1.0016(31)	1.0015(31)	1.0015(31)	1.0014(31)
LNE-LNHB 2024	1.0019(32)	1.0018(32)	1.0019(32)	1.0017(32)
NRC 2026	0.9999(57)	0.9998(57)	0.9998(57)	0.9997(57)
μ (KCRV)	1.0014(21)	1.0012(21)	1.0013(21)	1.0012(21)
meas. dead time	37.0 %	37.0 %	9.1 %	9.1 %
accidental. coinc rate [17]	1.56e-02 %	3.10e-02 %	1.59e-02 %	3.16e-02 %

The relative degrees of equivalence derived from the ESIR results are presented in Table 24 for the different TDCR signal processing configurations. The values reported to the KCDB are highlighted in red color.

Table 24: Relative degrees of equivalence for the ^{99}Tc obtained from ESIR measurements using different signal processing parameters.

Laboratory year	k_i	k_i	k_i	k_i
	$\tau_c = 50 \text{ ns}$	$\tau_c = 100 \text{ ns}$	$\tau_c = 50 \text{ ns}$	$\tau_c = 100 \text{ ns}$
	$\tau_d = 50 \text{ }\mu\text{s}$	$\tau_d = 50 \text{ }\mu\text{s}$	$\tau_d = 10 \text{ }\mu\text{s}$	$\tau_d = 10 \text{ }\mu\text{s}$
LNE-LNHB 2024	0.02 ± 0.50	0.02 ± 0.50	0.02 ± 0.50	0.02 ± 0.50
LNE-LNHB 2024	0.06 ± 0.52	0.06 ± 0.52	0.06 ± 0.51	0.06 ± 0.51
NRC 2026	-0.14 ± 0.96	-0.14 ± 0.96	-0.15 ± 0.95	-0.15 ± 0.95
meas. dead time	37.0 %	37.0 %	9.1 %	9.1 %
accidental. coinc rate [17]	1.56e-02 %	3.10e-02 %	1.59e-02 %	3.16e-02 %

The results demonstrate that the relative degrees of equivalence are independent of the selected TDCR signal processing parameters, thereby confirming the robustness and reliability of the ESIR approach.