Design and performance of a miniature TDCR counting system

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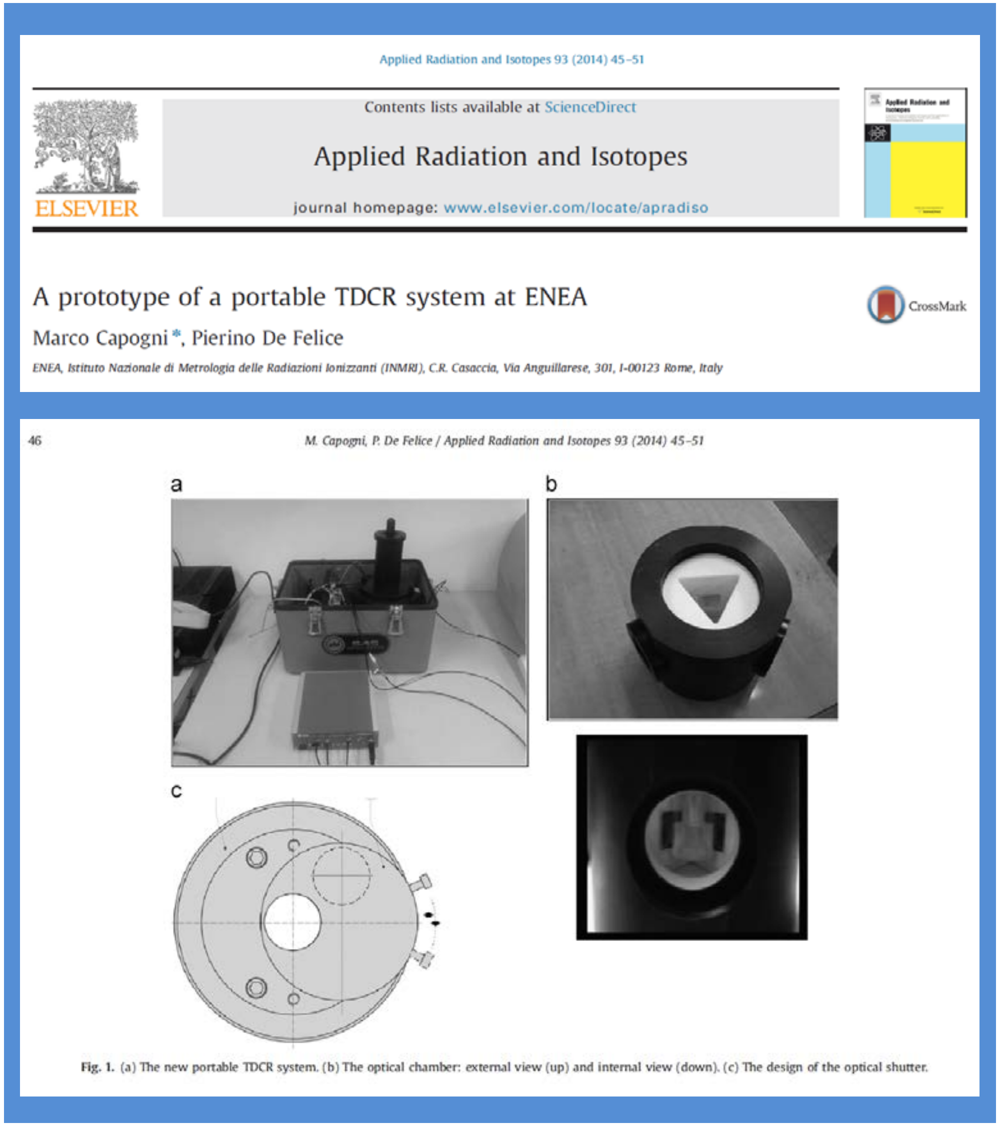
Overview

- Design of the TDCR counter;
- The new TDCR acquisition module, nanoTDCR: main features and functionality;
- Performance tests of the new miniature system (hereafter referred to as TDCR-SU). Results from comparisons with the LNHB's primary TDCR system on TDCR counting of ^{241}Am, ^{3}H, ^{14}C, ^{63}Ni.
- Conclusions

Design – the starting point



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A prototype of a portable TDCR system at ENEA

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Fig. 1. (a) The new portable TDCR system. (b) The optical chamber: external view (up) and internal view (down). (c) The design of the optical shutter.

The design of the optical chamber was inspired from the ENEA TDCR system (MetroFission European Project):

- **Hamamatsu R7600U-200 photo-multiplier tubes (PMTs);**

" ... – small dimensions 30x30 mm^2

– wide spectral response (300-600 nm)

– high quantum efficiency

– relatively low supply voltage (≈900 V)"

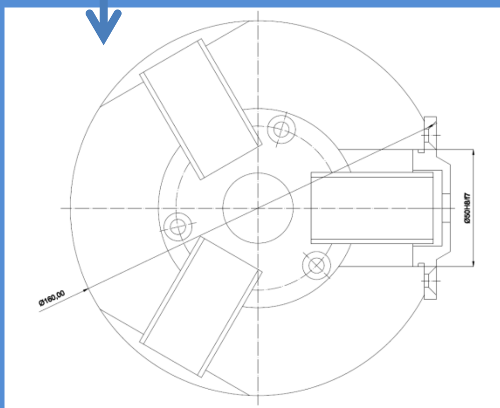
– grounded cathode to lower the dark noise

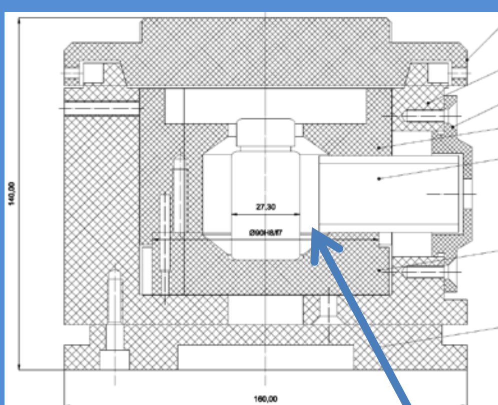
- **Optical chamber made of PTFE (Teflon®);**
- **Compact and portable TDCR device;**
- **Could be used as a traveling instrument for in-situ measurements**

TDCR-SU Design*

* The mechanical realization of the counter was perfomed by Mr. Nikolay Markov and Mr. Todor Todorov in Bulgaria

Cylindrical optical chamber made of PTFE (Teflon®) and mounted in housing made of Polyoxymethylene (POM)





The PMTs are mounted at a certain distance from the surface of the LS vial in order to allow full solid angle coverage of the volume of the vial

TDCR-SU system

TDCR-SU counter

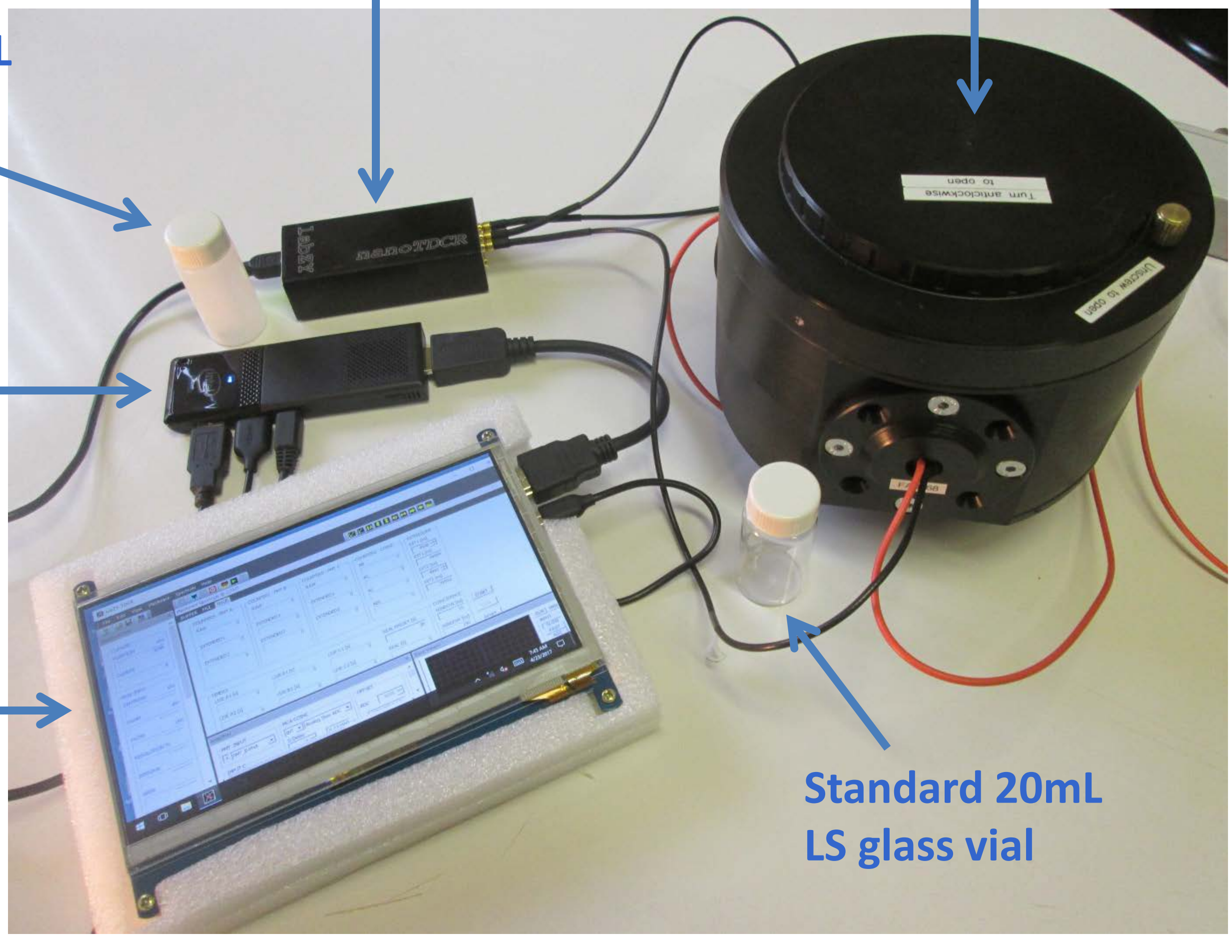
nanoTDCR acquisition module

Standard 20 mL
LS plastic vial

Computer

Display

Standard 20mL
LS glass vial



The nanoTDCR acquisition module

and associated acquisition software

Dedicated to TDCR measurements, developed by the labZY company

www.labzy.com

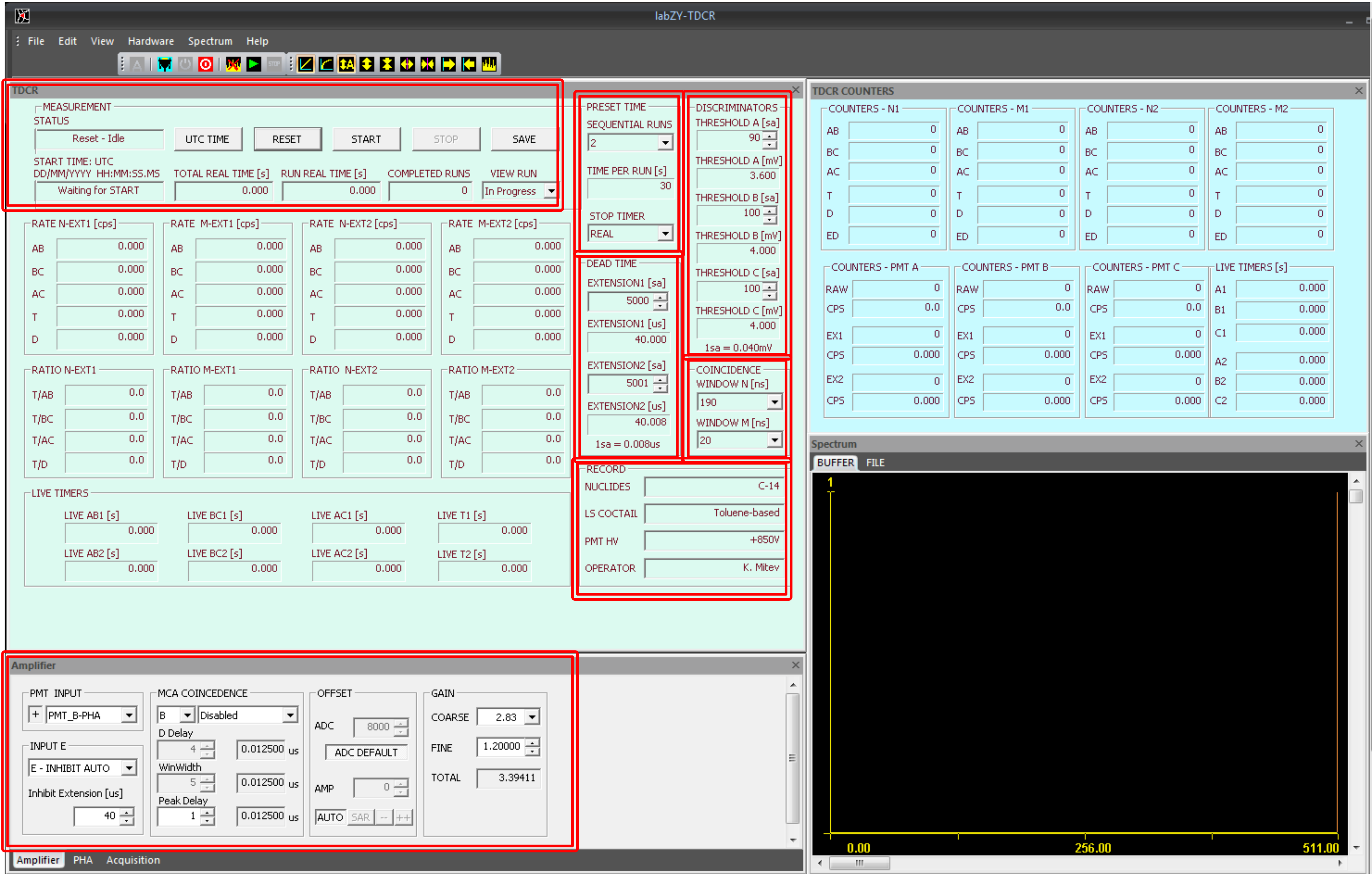
- **Fast input amplifiers, 50 Ω adapted, directly connected to the PMT's anodes**
- **Fast discriminators, software-adjustable thresholds, stable reference voltage;**
- **MCA spectra for threshold adjustment and radionuclide verification**
- **Routine to obtain UTC from NTP servers (NIST, European etc.) with standard metrology grade NTP accuracy of 30 to 50ms. The acquisition date/start time can be defined by the NTP server or by the computer time;**
- **Can perform consecutive (repetitive) runs of fixed real or live time with fixed 100 µs gap between runs**
- **External output of the clock for traceability to frequency unit**
- **1W consumption, can be powered directly from USB port.**
- **Weighs 135g and compact form factor (92 x 38 x 25mm^3)**

The nanoTDCR acquisition module

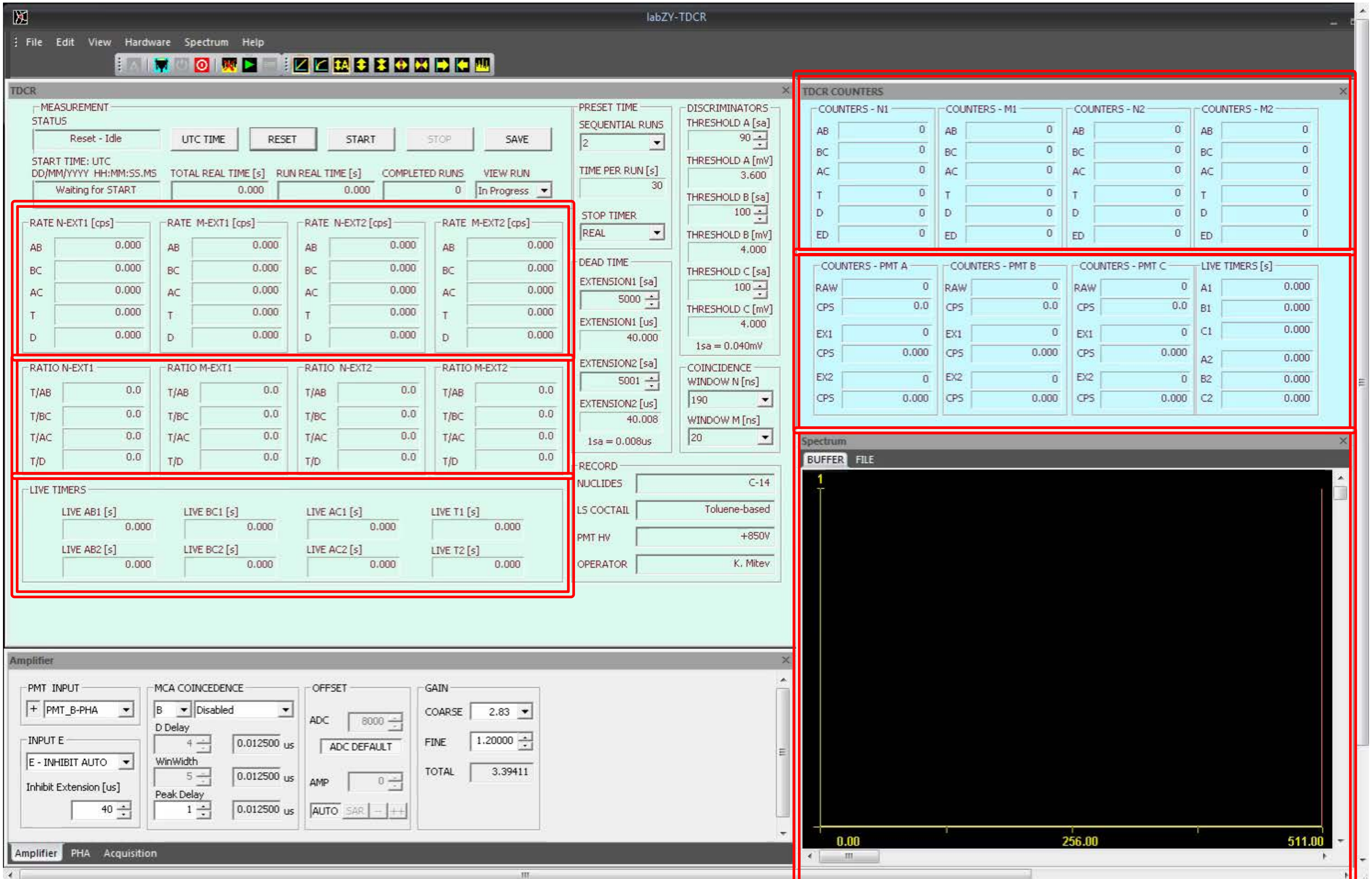
By design, the nanoTDCR module has similar functionality as the MAC3 TDCR counting module with some additional functions like:

- **individual extending-type dead-time in each channel**
- **capability of simultaneous counting with two different extendable dead-times (from 80ns to 500µs)**
- **capability of simultaneous coincidence counting with two different coincidence windows (from 8 to 190 ns)**
- **Live-time clocks in each channel (single and coincident) for each coincidence window and each dead-time duration**
- **Counters (pulses and associated live-time clocks) for A, B, C, AB, BC, AC, D and T for each coincidence window and each dead-time duration**
- **Online checksum calculation: AB+BC+AC = 2T+D**
- **Capability of simultaneous coincidence counting and spectrum acquisition from a PMT.**

Functionality of the nanoTDCR module



Functionality of the nanoTDCR module



Performance tests: nanoTDCR

As a first test, the nanoTDCR counting module was compared to the LNHB's MAC3 module, using the primary TDCR counter (RCTD1) of LNHB.

RCTD1 MAC3 nanoTDCR

Logical outputs of the constant fraction discriminator of RCTD1 were connected to the nanoTDCR inputs and simultaneous counting of 4 different ^{241}Am sources with activities in the 480 – 4600 Bq range was performed.

RCTD1 with Source:	Coincidences AB, s^{-1}			Coincidences BC, s^{-1}			Coincidences AC, s^{-1}			Coincidences ABC, s^{-1}		
	MAC3	nanoTDCR	Δ, %	MAC3	nanoTDCR	Δ, %	MAC3	nanoTDCR	Δ, %	MAC3	nanoTDCR	Δ, %
Am-241-NO.1	490	490.5	-0.11	490	490.2	-0.04	490	490.2	-0.03	490	490.0	0.00
Am-241-NO.2	1517	1519.7	-0.18	1516	1519.4	-0.22	1516	1519.3	-0.22	1516	1519.1	-0.21
Am-241-NO.3	2557	2563.0	-0.23	2557	2562.6	-0.22	2557	2562.6	-0.22	2557	2562.3	-0.21
Am-241-NO.4	4604	4599.7	0.09	4604	4599.4	0.10	4604	4598.8	0.11	4604	4599.1	0.11

- **Excellent agreement between MAC 3 and nanoTDCR counted events observed**
- **The relative differences are less than 0.3%, and can be attributed to the different live times of the two systems.**

TDCR-SU performance tests: TDCR counting of four ^{241}Am sources

- The ^{241}Am sources are measured on the RCTD1 TDCR counter at LNHB and then on the TDCR-SU counter;

^{241}Am Sources:	Logical sum of the net double coincidences (D) , s^{-1}			Net triple coincidences (T) , s^{-1}			Ratio T/D		
	RCTD1	TDCR-SU	Δ, %	RCTD1	TDCR-SU	Δ, %	RCTD1	TDCR-SU	Δ, %
# 1	487	486.4	0.12	487	486.1	0.18	1.0000	0.9994	0.06
# 2	1513	1515.2	-0.15	1513	1514.1	-0.07	1.0000	0.9993	0.07
# 3	2553	2559.5	-0.25	2554	2557.6	-0.14	1.0004	0.9992	0.11
# 4	4600	4591.2	0.19	4601	4588.0	0.28	1.0002	0.9993	0.09

- An excellent agreement between the two counting systems was observed with differences smaller than 0.3%

- No systematic trend in the differences, indicating a linear response of the TDCR-SU system for counting rates in the interval 480 – 4600 s^{-1}

TDCR-SU performance tests: TDCR counting of ^{3}H, ^{14}C and ^{63}Ni sources

- **The sources are measured on the RCTD1 TDCR counter at LNHB and then on the TDCR-SU counter;**

- **The activities are determined from the measured T/AB, T/BC and T/AC ratios using the TDCR07c program (http://www.nucleide.org/ICRM_LSC_WG/icrmsoftware.htm);**

- **Same kB values, cocktail and nuclide data are used for the calculations of A_{SU} and A_{RCTD1}**

Source:	Activity measured by RCTD1, LNHB , Bq	Activity measured by TDCR-SU, Bq	$\Delta = \frac{A_{RCTD1} - A_{SU}}{A_{RCTD1}}$
H-3 in toluene-based LSC	1010.7(2.1) [0.21%]	1010.9(5.1) [0.50%]	-0.02 %
C-14 in toluene-based LSC	1728.2(2.4) [0.14%]	1731.3(4.7) [0.27%]	-0.18 %
Ni-63 in Ultima Gold LSC	1325.9(4.1) [0.31%]	1313.9 ± 4.9 [0.37%]	0.91 %

Performance tests: TDCR-SU ^{14}C counting with different coincidence windows and dead-time base durations

A ^{14}C source in toluene-based LS cocktail used for the comparison. The source is measured on the RCTD1 TDCR counter at LNHB and then on the TDCR-SU counter using different coincidence windows and dead-time base durations.

- Notice that in a single measurement the nanoTDCR module can count with two coincidence windows and two dead-time base durations:

Coincidence window, ns	Dead time base, µs	TDCR-SU	RCTD1, LNHB	$\Delta = \frac{A_{RCTD1} - A_{SU}}{A_{RCTD1}}$
		A_{SU} , Bq	A_{LNHB}, Bq	
40	50	542.6 (1.2)	543.9 (1.1)	0.24 %
40	100	542.8 (1.2)		0.20 %
120	50	542.7 (1.2)		0.21 %
120	100	543.2 (1.2)		0.14 %

- Excellent agreement between the TDCR-SU and RCTD1 (LNHB) measurements
- Relative differences are less than 0.25% and are within the estimated uncertainties

Conclusions

- An innovative miniature TDCR counter was developed and validated
- New acquisition module and acquisition software for TDCR counting were developed. The module offers variety of very useful new features and allows measurements with traceability to time, date and frequency units. Adjustment of discriminator levels can be achieved easily by software
- The performance of the TDCR-SU counting system was benchmarked against the LHNB's primary TDCR system for measurements of ^{241}Am, ^{3}H, ^{14}C and ^{63}Ni. Excellent agreement is observed between the results of the two measurement systems

Overall, we believe that this miniature counter have outstanding metrological performances and can be used as a reference instrument for the standardization of radionuclides, but also for on-site measurements (e.g. for short half-life medical radionuclides calibration).
It can also be useful as a travelling instrument for international comparisons

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Thank you for your attention!

Future applications: Liquid scintillation counting of ^{222}Rn

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Standardization of ^{222}Rn by LSC and comparison with α- and γ-spectrometry

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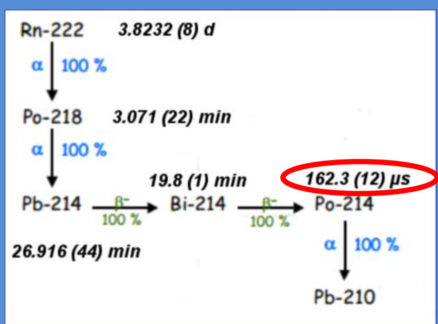
Abstract

Liquid scintillation counting (LSC) was used for the measurement of ^{222}Rn in equilibrium with its daughters, with detection efficiency close to 5. The appropriate corrections were considered, including one related to the probability that the 165-μs half-life ^{214}Po decays during the dead time of the counter initiated by the disintegration of his parent nuclide, ^{214}Bi. The dead-time determination of a commercial LS counter is also presented using a ^{222}Rn standard source.

The LSC ^{222}Rn sources were prepared by transfer of ^{222}Rn produced by a solid ^{226}Ra source into LSC cocktail frozen at 77 K, flame-sealed afterwards. They were measured using the LNHB triple coincidence counter with adjustable extending-type dead-time unit, between 8 and 100 μs; two different procedures were used to calculate an effective dead time and then to deduce the counting rate extrapolated to zero dead-time value. The LSC results were compared with those obtained by cryogenic α-particle spectrometry (LNHB system) and by γ-ray spectrometry for the same radon source in the LSC vial; the geometry transfer coefficient was calculated using the ETNA software. Measurement results and uncertainties are discussed.

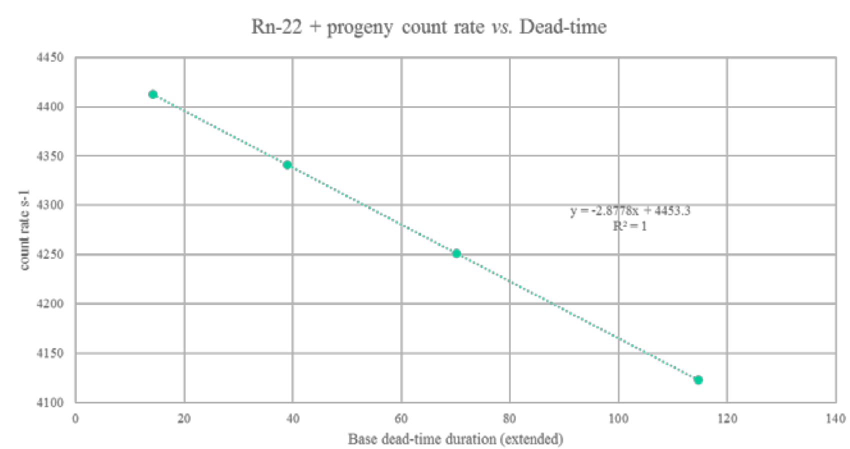
Keywords: ^{222}Rn; Standardization; LSC; Effective dead time; ^{214}Po decay correction

Simplified ^{222}Rn decay scheme:

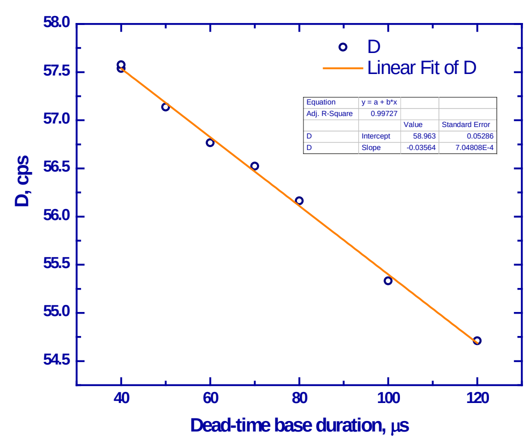


The detection loss of ^{214}Po can be calculated by varying the dead- time of the counter and extrapolating the count-rate to zero dead- time.

RCTD1, LNHB



TDCR-SU

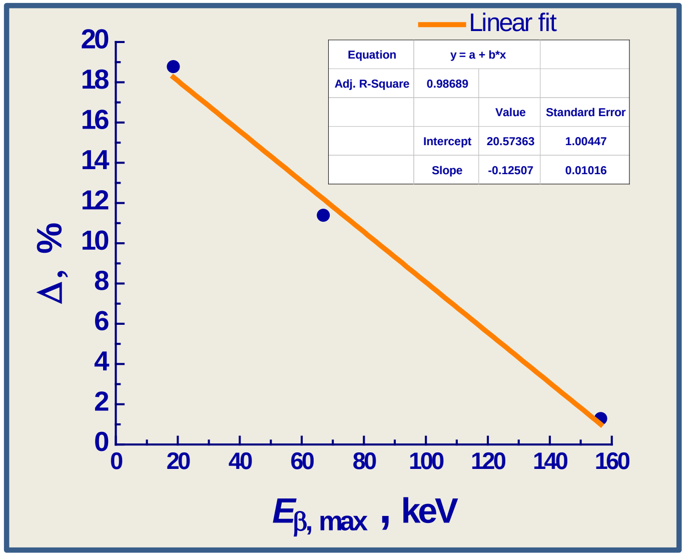


Equation	y = a + b*x		
Adj. R-Square	0.99727		
		Value	Standard Error
D	Intercept	58.963	0.05286
D	Slope	-0.03564	7.04808E-4

Work is in progress to apply TDCR-SU for standardization of ^{222}Rn by LSC.

Performance tests: Comparison of counting efficiency for logical sum of double coincidences for ^{3}H, ^{14}C and ^{63}Ni sources

Counter	Type and dimensions of the PMTS
TDCR-SU	Hamamtsu R7600-200, square PMTs, 30x30 mm
RCTD1	BURLE 8850, cylindrical PMTs, 51 mm diameter



Nuclide	$E_{\beta,max}$, keV	Counting efficiency for logical sum of double coincidences (ε_D)		$\Delta = \frac{\varepsilon_{D,RCDT1} - \varepsilon_{D,SU}}{A\varepsilon_{D,RCDT1}}$
		RCDT1, LNHB	TDCR-SU	
^{3}H	18.564 (3)	0.6982	0.5671	18.8 %
^{63}Ni	66.980 (15)	0.7965	0.7058	11.4 %
^{14}C	156.476 (4)	0.9634(8)	0.9510(9)	1.29 %