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Metrofission project: an overview of the ENEA contribution

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Abstract

The paper describes the progress made by ENEA-INMRI in the research carried out within the framework of the Joint Research Project (JRP) ENG08 Metrofission of the European Metrology Research Programme (EMRP). This JRP aims to solve important problems related to the development of the Generation IV (GenIV) nuclear power plants in Europe as required by new demands of energy supplies that must be secure, sustainable, of high quality and also able to reduce the green house gas emissions. In the Metrofission project the ENEA-INMRI is directly involved in three Working Packages (WPs): the WP6, that aims to develop a portable Triple-to-Double-Coincidence-Ratio (TDCR) system for measuring *in-situ* of pure beta radionuclides; the WP7, devoted to the development of modern acquisition techniques based on Digital Coincidence Counting (DCC) with high sampling speed for radionuclide standardization; the WP8, leaded by ENEA-INMRI, which takes into account the impact of the project toward the end-users and the nuclear industry. The new prototype of the ENEA-INMRI portable TDCR counter will be presented. The preliminary results obtained in the activity measurements of ^{14}C and ^{63}Ni standard sources carried out by the new counter equipped with the new front-end electronics based on the CAEN Digitizer DT5720 will be discussed.

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keywords: Radionuclide Metrology; GenIV nuclear reactors; TDCR technique; Digital Coincidence Counting;

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1. Introduction

Greenhouse gases such as CO_2 produce global warming and the reduction of this effect is one the biggest challenges facing mankind. The increasing in use of renewable may reduce the greenhouse gases, but unfortunately in Europe there is not a sufficient abundance of this kind of energy resources. Nuclear power is one of the way to meet the increasing demand for energy and to face to the greenhouse effect. The construction of new nuclear reactors is then a topical issue for many European countries that consider strategic the nuclear energy source for their energy program [1], [2], [3].

In particular there is in Europe an increasing interest for the Generation IV (GenIV) nuclear power plants. The reactors of the new generation will be "fast neutron" reactors with a closed ^{238}U fuel cycle or will work at very high temperature (i.e. 1000 °C). Less radioactive waste, more efficient use of natural resources and increasing resistance to proliferation of nuclear weapons will be the main advantages in using the GenIV reactors. Nevertheless "fast neutron" reactors will produce a much more aggressive radiation environment. Furthermore the so high working temperatures require new solutions to face to the problems concerning temperature measurement and kind of materials to be used.

The European project Metrofission, or Metrology for new generation nuclear power plants, jointly funded by the European Metrology Research Programme (EMRP) participating countries within EURAMET[†] and the European Union, aims to provide the necessary metrological support for the design of the new GenIV nuclear power plants. The project is structured in 9 Working Packages (WPs) [4]. The ENEA-INMRI is directly involved in three of them (WP6, WP7 and WP8). The WP6 has as objective the realization of a miniature self-calibrated primary TDCR system for measurements *in-situ* of low-energy beta emitters created in the fuel cycle (i.e. ^{241}Pu) and/or as activation products in the reactor and its enclosure (e.g. ^{35}S, ^{63}Ni, ^{41}Ca, ^{3}H, etc). The WP7 is entirely dedicated to the realization of the innovative electronics for signal acquisition coming from a TDCR counter making use of digital coincidence counting (DCC) with digital pulse processing (DPP) FPGA base systems at the GHz sampling rate. The WP8, leaded by ENEA-INMRI, is dedicated to the "Creating Impact" of the project by involving all the stakeholders interested for supporting the project as potential end-users of the research activities carried out by it.

This paper will stress the contribution given until now by the ENEA-INMRI to the Metrofission project focusing the attention on the new prototype of the portable TDCR detector and on its use for *in-situ* measurements. The acquisition electronics based on the new front-end technology of the digital pulse processing (DPP) developed in the framework of a scientific collaboration with the Italian CAEN firm will be also discussed. In particular the characteristics of the new detector, the selected photomultipliers (PMTs) and the of the CAEN Digitizer DT5720 used in the TDCR acquisition will be presented in the paper. The preliminary activity measurements results of two pure beta radionuclides, i.e.^{14}C and ^{63}Ni, obtained by the prototype of the new ENEA-INMRI portable TDCR system will be dealt and the next actions within the framework of the WP6 and WP7 will be also discussed.

Nomenclature

E_0	maximum kinetic energy of the beta particles emitted in a radioactive transition
$m(E)$	average value of the number of photons emitted in a liquid scintillator by an electron of energy E
ν	quantum efficiency of a photomultiplier (PMT)
Y	light yield of the liquid scintillator

[†] European Association of National Metrology Institutes

kB	Birks' constant
dE/dx	Linear Energy Transfer (LET)
S(E)	energy spectrum of the beta particles
QDC	Charge to Digital Converter
NIM	Nuclear Instrumentation Module

2. Metrology for New Generation Nuclear Power Plants

The Metrofission project, or Metrology for new generation nuclear power plants (NNPP), is a Joint Research Project (JRP) ENG08 of the EMRP Call 2009 – Energy. The aim of this call is to advance measurement science and technology in the field of energy. EMRP [5] is a long-term program for high quality joint metrology research and development amongst the European metrology community. It is supported by the European Commission (EC) through the Article 169 of the European Treaty and it is jointly funded by the EC and the EMRP participating European countries. The main challenges of EMRP are research and development in the Health, Environmental, Energy and New Technologies fields; it has a budget that covers a period of seven years starting since 2007 year.

Metrofission started in September 2010 and will be ended next September 2013. It is structured in 9 WPs and it is supported by 12 partners of 10 European countries. The project is coordinated by the National Physical Laboratory, NPL (UK). The main scientific and technical objectives [6] are summarized in the Table 1:

Table 1. Metrofission Working Packages

WP	Title
1	Temperature measurements and temperature sensors developments for the fission environment
2	Improved thermo-chemical data and modeling for nuclear design
3	Thermo-physical properties of advanced materials
4	Improved cross sections through neutron metrology
5	Improved nuclear decay data
6	Triple-to-Double-Coincidence-Ratio (TDCR)
7	Digital Coincidence Counting
8	Creating Impact
9	Management and coordination

The ENEA-INMRI is directed involved in the WP6 and WP7 and leads the WP8.

The WP6 is coordinated by the Laboratoire National Henri Becquerel (LNHB) of CEA (France) and the active JRP partners of this WP are NPL, PTB[‡], CMI[§], SMU[**] as well as ENEA. This Working Package aims at providing a world leading method for activity determination of pure beta emitters by developing a

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[‡] Physikalisch-Technische Bundesanstalt (Germany)

[§] Czech Metroloy Institute (Czech Republic)

[**] Slovak Institute of Metrology (Slovak Republic)

miniature size TDCR for measurements *in-situ*, that significantly improve the efficiency and reduce the costs of the plant operation as shown in previous experience working with nuclear power plants. The Triple-to-Double-Coincidence-Ratio (TDCR) method is a primary method for radionuclide standardization [7]-[8] well established in the European National Metrology Institutes (NMIs). Current TDCR systems are home-made metrology instruments not suitable for measurements *in-situ* for their dimensions and weight. The TDCR is the only available method for measuring beta emitters without calibration; the method can be also extended to other nuclides like alpha emitters and electron-capture decaying nuclides. This techniques is based on the $4\pi\beta$ liquid scintillation counting performed by 3 photomultipliers located in a symmetric 120° geometry around an optical chamber and wotking in coincidence. Inside the optical chamber is positioned a typical vial (glass or plastic material) containing the radioactive source in solution with the liquid scintillator. The use of fast PMTs for coincidence measurements needs also of an adequate electronics for signal processing.

The TDCR method is particularly useful for measuring low-energy beta emitters as ^{3}H and ^{241}Pu. In particular ^{3}H in a Light Water Reactor, due to the ternary fission of uranium and activation of lithium, boron and deuterium, is an important contaminant of the primary circuit of the reactor (about 10TBq/year for 10MWe of power produced).

The scientific and technological tasks of the WP6 and the active JRP partners are summarized in the Table 2.

Table 2. WP6 scientific and technological tasks

Tasks	Objectives and JRP active partners
1	Development of a protocol for the design of the transportable TDCR system for in-situ measurements (CEA, NPL, PTB, ENEA)
2	Construction of a joint prototype of a transportable TDCR system for in-situ measurements (CEA, NPL, PTB, ENEA)
3	Update of TDCR model in existing NMI software for relevant beta spectrum shapes (CEA, NPL, PTB, CMI)
4	Inter-laboratory comparison of two nuclides of relevance to new generation nuclear power plants, Pu-241 and H-3, with traceability to the International Reference System (NPL, CEA, PTB, CMI)
5	Report on in-situ TDCR instrument (CEA, NPL, PTB, ENEA, CMI)
6	Evaluation of the only available commercial TDCR system (Hidex) with associated validation for radioactivity measurements (PTB, ENEA)
7	Extension of the theoretical TDCR model to include nuclides with higher atomic number decaying by electron capture and nuclides with complex decay schemes including many gamma-rays (PTB, CEA)

The work consists in developing portable TDCR scintillation measuring system with joint design features drawn by the active JRP partners; a particular study of the PMTs and the electronics to be used is requested. Theoretical studies concerning the application of the TDCR technique to many electron-capture and gamma-ray decaying nuclides are also scientific tasks of the Working Package. The ENEA is direct involved in a bilateral comparison with the PTB to study the performance of the only one available transportable TDCR system, the HIDEX 300SL “Metro” version counter.

The WP7 is coordinated by the National Physical Laboratory that actively collaborates with LNHB, CIEMAT as well as ENEA. This Working Package aims to develop a high-sampling-speed digital system for radionuclide activity measurements by coincidence counting [9] in order to accomplish the portable TDCR system for measurements in-situ as required by WP6, to allow pulse shape discrimination for

measurements of different type of radiation (like alpha and beta or gamma-rays and neutron), to achieve higher-count rates of radioactive measurements. Until now digital acquisition systems developed at NMIs for the coincidence measurements of radioactive samples processed signals from radiation detectors by using classical shaping amplifiers and limited sampling rates of classical ADCs [10]. The WP7 intends to explore the advantages for radionuclide metrology obtained by coincidence techniques performed with digital signal processor (DSP) Field Programmable Gate Array (FPGA) based systems.
The scientific and technological tasks of the WP7 and the active JRP partners in this WP are summarized in the Table 3.

Table 3. WP7 scientific and technological tasks

Tasks	Objectives and JRP active partners
1	Development of a DCC suitable for radionuclide metrology (NPL, CEA, CIEMAT, ENEA)
2	Validation of DCC (NPL, CEA, CIEMAT, ENEA)
3	Knowledge transfer relating to DSP/DCC for radionuclide metrology (NPL, CEA, CIEMAT, ENEA)

The works consists in developing a high performance 2-channels (DCC) and 3-channels (TDCR) acquisition system with associated pulse characterisation and software that will be tested for both spectrometric and coincidence measurements to study count-rate dependence, pulse-height resolution, pulse-timing resolution and coincidence counting for variable resolving times. The ENEA is directly involved in all the tasks of this WP and to meet the scientific task of the WP6 and WP7 it started a scientific and technological collaboration with the CAEN firm [11]. The main goal of this collaboration is the implementation of the TDCR logic on the firmware of the new CAEN Digitizers belonging to the family DT57XX.
The WP8 is coordinated by ENEA-INMRI and all the JRP partners are involved in it. This Working Package aims to maximize the JRP impact by identifying the main stakeholders and keeping them aware of the Metrofission objectives and developments, by knowledge transfer among the JRP partners and toward the end-users and by training of young scientists achieved via EMRP funded *Researcher Excellence Grants* (REGs) and *Researcher Mobility Grant* (RMG) linked to this JRP.
The work consists in setting up all the instruments (website, meetings amongst JRP partners, etc) for dissemination of all the progress achieved during the period covered by the project. This WP will also promote the organisation of workshop open end-users and provide recommendation on future metrology needs in the field of nuclear fission.
All the WPs and the entire JRP are managed and coordinated following the main tasks of the WP9 leaded by NPL.
The scientific and technological tasks of this WP are summarized in Table 4.

Table 4. WP8 scientific and technological tasks

Tasks	Objectives and JRP active partners
1	Building awareness of the Metrofission project amongst stakeholders (NPL, all)
2	Training and development of JRP-Partner scientists (ENEA, all)
3	Scientific knowledge transfer (ENEA, all)
4	Knowledge transfer specifically aimed at end-user (ENEA, all)

3. ENEA contribution to the WP6 of Metrofission

The ENEA contributed actively with the others partners of the project in writing a protocol for defining the specific technical characteristics that must have a portable TDCR system for measurements *in-situ*. In particular an efficient optical chamber is required for low-energy beta emitters activity measurements and the counter must be equipped with efficient and sensitive photodetectors, fast front-end electronics, compact coincidence units based on the new FPGA technology; all the system must be portable (weight no greater than 10 Kg) and very compact.

The prototype of the ENEA portable TDCR detector is shown in Figure 1.

a) b)

Fig. 1. (a) ENEA portable TDCR prototype; (b) inside view of the optical chamber of the TDCR detector

To meet the portability and to have a compact portable system all the counter was made of PTFE (Teflon) (black color outside and white color inside, to prevent the external light from entering the optical chamber and to improve the efficiency of the counter respectively).

The main features of the ENEA-INMRI portable TDCR prototype are indicated in Table 5.

Table 5. Main features of the ENEA-INMRI portable TDCR prototype

Detector	Housing: dimensions: ϕ=150 mm, H= 150 mm ; weight: 4 K g
	Optical chamber: prismatic geometry with equilateral triangular basis (L= 60 mm; H= 73 mm)
Photomultipliers	Hamamatsu R7600U-200
	HV: + 900 V
HV supplier	C4900-50
Total dimension	350 x 150 x 200 mm^3 (WxHxD); weight 5 Kg

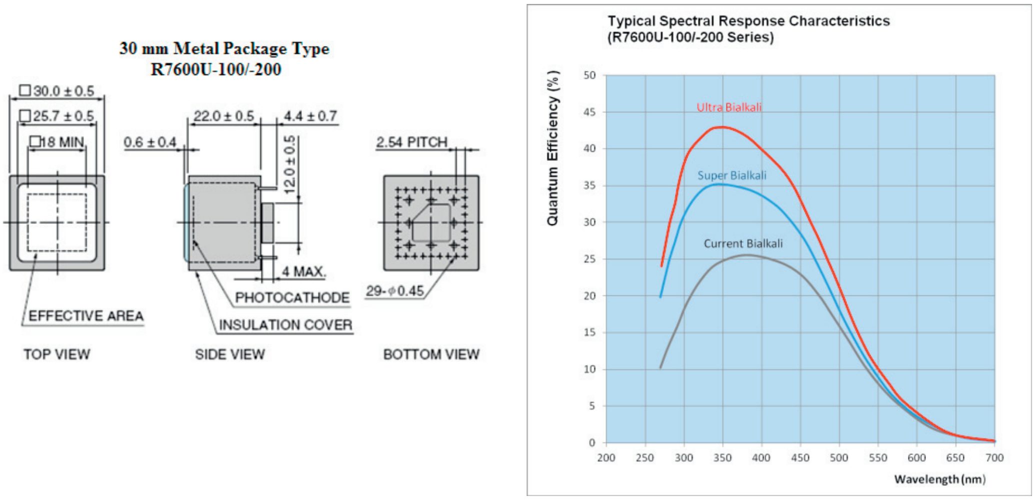
The detector is equipped with a lift for Liquid scintillation vial and an optical shutter in order to maintain the PMTs always powered.

The main characteristics of the photomultipliers selected are indicated in Figure 2. In particular in Figure 2 (b) is shown (red line) the typical spectral response of a single PMT.

The PMTs were selected for their small dimensions and high quantum efficiency. The relative low supply voltage (about +900 V) is a good requisite also for the portability of the counter.

The PMTs are powered by three high voltage power supply units C4900 series. These units are on-board type with a design that aims at providing compactness, high performance and low power consumption. The three C4900-50 HV units are powered by a 12 V battery. The maximum output voltage is +1250 V and can be regulated by a potentiometer. The dimensions of a single unit are: 46x24x12 mm^3 and the weight is 31g. In Figure 3 is shown a picture of a single C4900 unit.

All the components (TDCR detector, HV power supply units and battery) were assembled over a black table of PTFE (Teflon) as shown in Figure 1 (a) and (b).



a)

b)

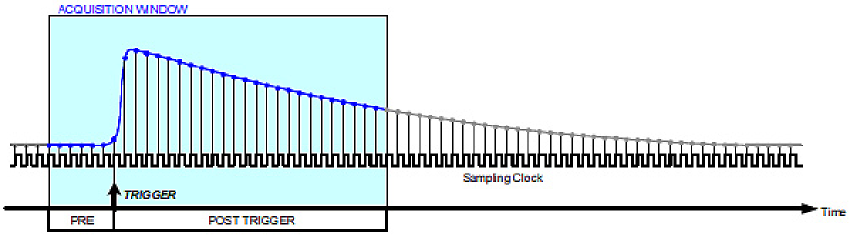
Fig. 2. (a) PMT dimensions; (b) PMT characteristics

Fig. 3. C4900 series HV power supply unit

4. ENEA contribution to the WP7 of Metrofission

An intensive scientific collaboration was established by ENEA-INMRI with the CAEN firm to meet the scientific and technological tasks of the WP7 of Metrofission in particular to develop digital coincidence counting systems to be used in the metrological application and in the specific case of the TDCR technique. The CAEN Digitizer DT5720, shown in Figure 4, was selected for preliminary tests carried out with the ENEA prototype of the portable TDCR counter. Some tests with the same digitizer are still ongoing with classical NaI(Tl) detectors for X-γ coincidence measurements particular useful for metrological applications.

a)



b)

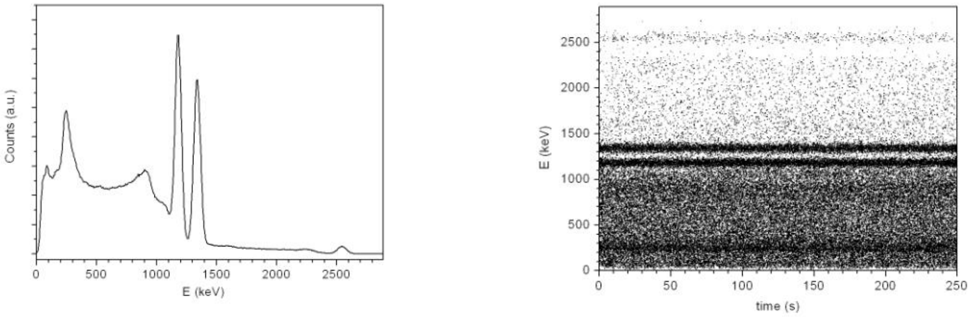
Table 6. Main characteristics of the CAEN DT5720 DPP-CI desktop digitizer used at ENEA-INMRI

Package	Desktop module: 154x50x164 mm^3 (WxHxD)
	Weight: 680 g
Analog Input	4 single-ended channels (MCX 50 Ohm)
	Input range: 2 Vpp
	Bandwidth: 125 MHz
Digital Conversion	Resolution: 12 bit
	Sampling rate: 250 MSamples/s simultaneously on each channel
Memory Buffer	1.25 MSamples/channel Multi Event Buffer
	Programmable event size and pre-post trigger
	Up to 1024 acquisition buffers
	Independent read/write access
FPGA	On-line Digital Pulse Processing (DPP) for digital charge integration
	Upgradeable via USB Link
Software	Tools for Windows and Linux
Readout	USB (30MB/s)
Electrical Power	Voltage range: 12±10% Vdc

The CAEN Digitizer DT5720 is a desktop waveform digitizer of relative small dimensions and weight that can be used as acquisition system of a portable counter. The principle of operation of a waveform digitizer is the same as the digital oscilloscope: when the triggers occurs, a certain number of samples (that define the acquisition window) is saved into one memory buffer (Figure 4.b). The digital pulse processing (DPP) is a feature of the CAEN waveform digitizers; DPP algorithm are implemented in FPGA and can be reprogrammed at any time. The DT5720 digitizer used at ENEA-INMRI runs DPP for charge integration (CI) and accepts signals directly from the detector; so this electronic device implements a digital replacement of QDC, discriminator and gate generator. The DT5720 characteristics are reported in Table 6.

The DPP-CI Control Software runs on Windows and Linux machine and gives the possibility to set all the acquisition parameters (DC offset, threshold level, pulse polarity, etc) for each channel. The software can work in oscilloscope acquisition mode and in histogram acquisition mode; the first one gives the possibility to visualize the pulse shape as in a normal oscilloscope, the last one permits to show on line the pulse height spectrum as a conventional multichannel analyser. The data are recorded in list mode format in binary or ASCII files where time and charge information for each digitized signal are stored.

Preliminary measurements were carried out with the Digitizer in single channel mode directly coupled to a NaI(Tl) cylindrical detector for studying the dynamic of the signals coming from a ^{137}Cs and a ^{60}Co source. These preliminary tests allowed to tune the acquisition electronics to the typical energy range useful for metrological applications. In Figure 5 are shown the typical energy spectrum of the ^{60}Co source and the bi-dimensional graph of the time-amplitude correlation obtained with the Digitizer for the recorded events.



a)

b)

Fig. 5. (a) ^{60}Co energy spectrum; with NaI(Tl) directed coupled to the Digitizer (b) time-amplitude spectrum of the recorded events

Successively some tests were performed with the PMTs of the TDCR counter. The 3 PMTs were directly coupled with the Digitizer, without any source inside the optical chamber, to tune the HV of each PMT and to set the threshold level for each channel in the valley before the single electron peak signal and after the noise. The acquisition of the 3 PMTs in TDCR mode was performed thanks to an acquisition program wrote by CAEN in C++ language that reproduce the philosophy of the MAC3 acquisition [12], a NIM electronic device developed at CEA-LNHB. All the details of the Digitizer acquisition in TDCR mode will be done in a dedicated paper by CAEN.

5. TDCR method and activity concentration of a beta pure radionuclide

A liquid scintillation counter made of 3 PMTs (A, B and C) (Fig. 6.a) gives the possibility to measure not only the single counting coming from each PMTs, but also the sum S=A+B+C of the counting coming from the 3 PMTs, the triple coincidences counting (T=ABC), the double coincidence counting between the three couples of PMTs (AB, BC and AC) and the logical sum of the double coincidences counting (D). In particular, as shown in Figure 6.b, the value of D is linked to the value of T and AB, BC and AC by the logical equation D=AB+BC+AC-2T. For a TDCR counter made by 3 PMTs must be verified also the other balance equation A+B+C=T+D+S as indicated in [7].

The software dedicated to the Digitizer acquisition in TDCR mode produces three binary files, in which the time and charge information of each channel are stored. By these files it is possible to build the energy histograms for the triple coincidences events; it is also possible to store in an ASCII file of data the time of acquisition, the dead time imposed on the measurements, the counts for each channel (A, B and C), the value of S=A+B+C, the triple (T) and the logical sum of the double (D) coincidences, the TDCR parameter, given by the ratio T/D, the double coincidences AB, BC, AC and the value in nanosecond imposed on the recorded events for the coincidence window (*cw*); in this file of data are also indicated the final results of the balance equations of the TDCR method that must be equal to zero if the TDCR counter worked properly [7].

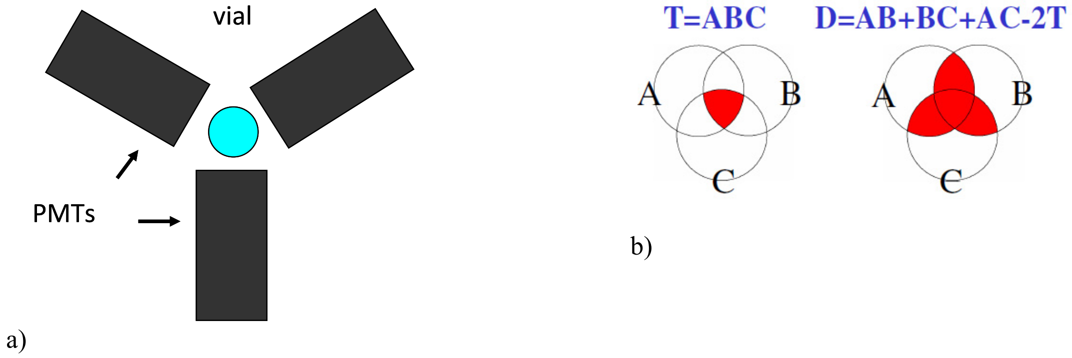


Fig. 6. (a) TDCR scheme; (b) TDCR logic

By taking into account the fundamental equations of the TDCR method [7] and by knowing the value of the ratios T/AB, T/BC and T/AC coming from the experimental data, it is possible to compute the efficiency for triple coincidences counting (ε_T) and the efficiency for the logical sum of the double coincidences counting (ε_D), given by the following equations:

$$\varepsilon_D = \int_0^{E_0} dE \;\; S(E) \cdot \left[3 \cdot \left(1 - e^{-\nu m(E)/3}\right)^2 - 2 \cdot \left(1 - e^{-\nu m(E)/3}\right)^3 \right] \qquad (1)$$

$$\varepsilon_T = \int_0^{E_0} dE \;\; S(E)\cdot\left(1-e^{-\nu m(E)/3}\right)^3 \qquad (2)$$

where the free parameter *νm(E)* is given by the third equation indicated below:

$$\nu m(E) = \nu Y \int_0^{E_0} \frac{dE}{1+kBdE/dx} \qquad (3)$$

The equation (1) and (2) are valid if the 3 PMTs have the same value of the quantum efficiency.

By the above three equations it is clear that both efficiencies depend on the value of the Birks constant (*kB*). The experimental data were analysed by a software code, TDCR07c.for, written in Fortan77 and provided by the CEA-LNHB. This program computes for a specific pure beta emitter the two efficiencies ε_T and ε_D by taking into account the Fermi's theory of the beta decay for the spectrum S(E) [13], the experimental ratios T/AB, T/BC and T/AC and different values of the Birks constant *kB* ranging between 0.007 cm MeV^{-1} till 0.015 cm MeV^{-1}. The activity concentration A_c of the radioactive solution of mass *m* is then obtained as

$$A_c = \frac{T}{\varepsilon_T \cdot m} = \frac{D}{\varepsilon_D \cdot m} \qquad (4)$$

6. Preliminary tests with the prototype of the ENEA-INMRI portable TDCR counter

Preliminary tests with the prototype of the ENEA-INMRI portable TDCR counter were performed during the months of May and June 2012. Many repeated counting at different starting time of two standard sources of ^{14}C and ^{63}Ni were carried out. The data were analysed by taking into account the basic equation of the TDCR method described in the previous section.

The sources are in 20 mL cylindrical glass vial usually used at ENEA-INRMI for liquid scintillation counting. The radioactive material is in solution with 10 mL of Ultima Gold liquid scintillator without any quenching agent. A count rate of about 2 kcounts/s was recorded in the counter for the ^{14}C source; a binary file of about 15 MB was then stored for each channel by measuring the same source for 600 s in the counter. The measured TDCR parameter for the unquenched ^{14}C source was 0.92 with a coincidence window of 40 ns.

The ^{14}C energy spectrum obtained by the triple coincidence counting is shown in Figure 7. The energy spectrum for triple coincidence counting of the unquenched standard source of ^{63}Ni recorded by the counter equipped with the CAEN Digitizer DT5720 is shown in Figure 8.

A TDCR parameter of 0.60 was measured for the ^{63}Ni source in the TDCR counter with a coincidence window of 40 ns. A particular effort was then dedicated to study the influence of the coincidence window *cw* on the measured activity. Different values for the coincidence window ranging between 20 to 80 ns were then automatically selected by the CAEN software code used to analyze the digitizer acquisition data. By knowing the experimental values of the ratios T/AB, T/BC, T/AC for each *cw*, the two efficiencies indicated in equation (1) and (2) were computed by the TDCR07c.for program for different *kB* values. The activity concentration was then obtained by applying the equation (4)

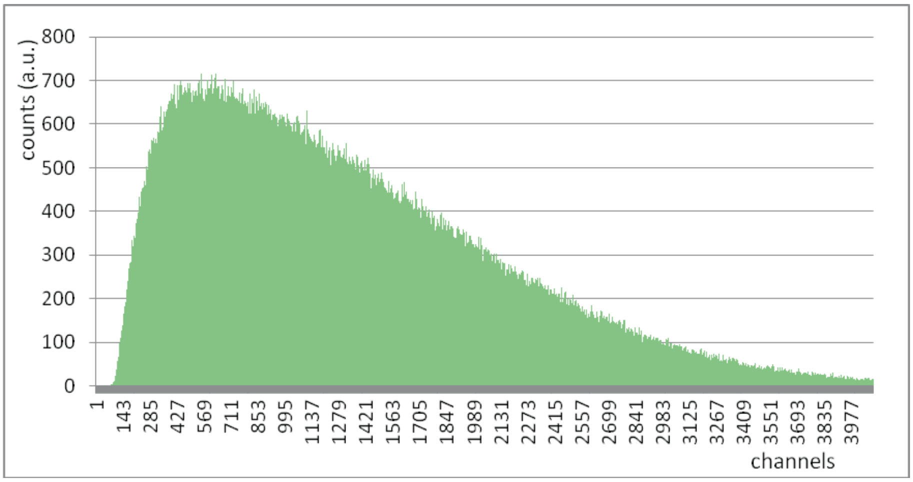


Fig. 7. ^{14}C energy spectrum recorded by the prototype of the ENEA-INMRI portable TDCR counter

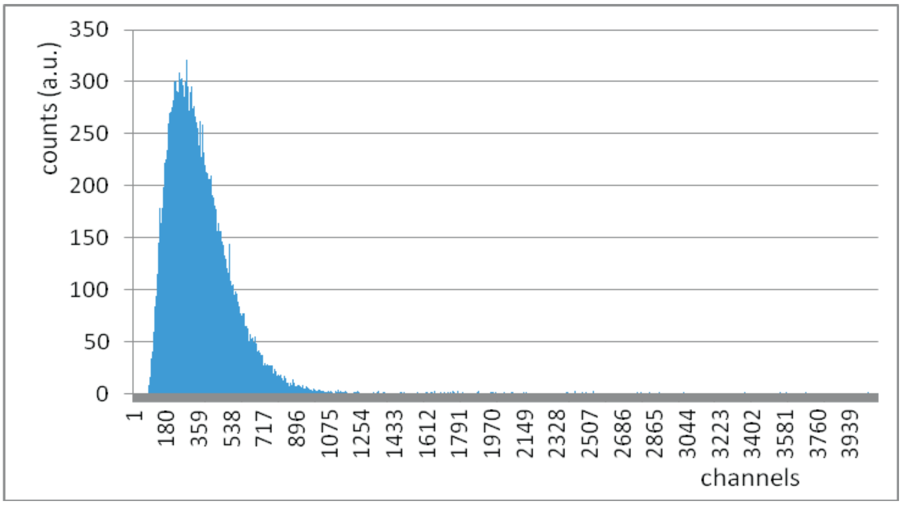


Fig. 8. ^{63}Ni energy spectrum recorded by the prototype of the ENEA-INMRI portable TDCR counter

The measured activity, A_c, for kB=0.011 cm MeV^{-1} was then compared with the reference value, A_r, and the deviation Δ(%) between the two values was then calculated by the formula:

$$\Delta(\%) = 100 \cdot \left(1 - \frac{A_c}{A_r}\right) \tag{5}$$

In Figure 9 the measured deviation Δ(%) given by the Eq. 5 is shown as function of the *cw* values

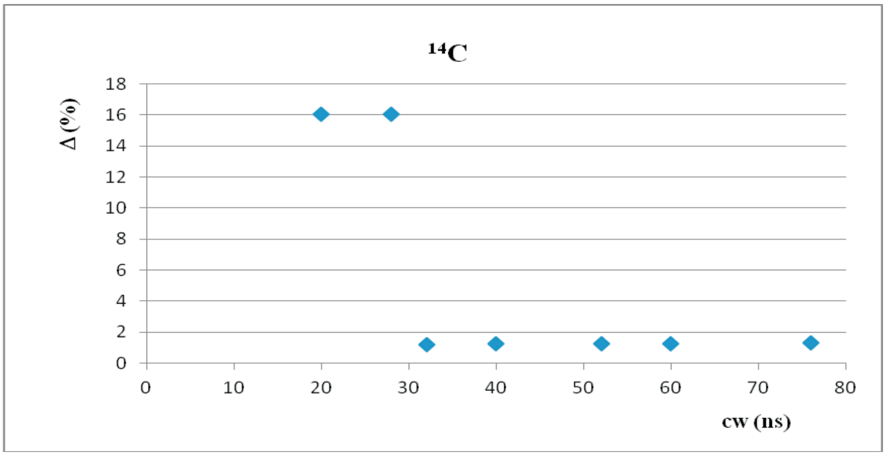


Fig. 9. Deviation Δ(%) between the measured activity value and the reference value as function of the cw

The obtained final results show a deviation Δ(%) lower than 2% for cw ≥ 35 ns. An analogous result was obtained for ^{63}Ni.

7. Progress in the WP8

The ENEA-INMRI leads this WP of Metrofission. Many actions were carried out in collaboration with the other JRP partners to meet the objectives of this WP. In particular the website of the project [4] is periodically updated for dissemination of progress made in the project and for highlighting workshop announcements, feedback from user community, etc. Many meetings were organized to share the information and the results achieved in the different topics of the project between the JRP partners. Metrofission was also presented at different meetings and conference to create awareness amongst stakeholders as indicated in the section News&Events of the website of the project. Some facilities for audio/video conferencing are now available for all JRP partners. An EMRP Researcher Mobility Grant (RMG) was awarded to a young scientist of the Istitutul National de Cercetare Dezvoltare pentru Fizica si Inginerie Nucleara “Horia Hulubei” (IFIN-HH) with the aim to train new scientists for the particular topic of the precise activity measurements performed by the TDCR technique. The ENEA-INMRI is the guestworking organization for this EMRP-RMG. The CAEN is until now the main Italian firm directly involved in the project for the nuclear electronics instrumentation and the development of the acquisition electronics used for the ENEA-INMRI portable TDCR detector.

8. Conclusions

The ENEA-INMRI is actively involved in three Working Packages (WP6, WP7 and WP8) of the EMRP ENG08 Metrofission project. More specifically to meet the tasks of the WP6 and WP7 a prototype of the portable TDCR counter was built and some preliminary tests were carried out by measuring two standard beta pure emitters (^{14}C and ^{63}Ni). High performance PMTs Hamamatsu of small dimensions and high quantum efficiency powered with relatively low HV were selected for the new TDCR counter. The new device is also equipped with the new FPGA based acquisition electronics of the CAEN Digitizer DT5720. The preliminary results obtained thanks also to an intensive scientific collaboration with the Italian CAEN firm are encouraging and show the possibility to study the effect of the coincidence resolving time in the activity measurements with the TDCR technique by using the new front-end electronics based on the DPP technology. An intensive work is still ongoing for studying the performances of the new counter by taking into account the effects of the threshold levels on the single PMT signal, the effect of the HV supplied to the PMTs in order to establish the best resolution between the single electron peak and the noise, the effect of the geometry of the optical chamber in order to understand its influence on the TDCR parameter for different beta pure emitters. Furthermore an intensive study is requested to understand all the physical effects related to the Birks constant in the activity measurements of low-energy and high-energy beta pure emitters with the TDCR technique. An international comparison between the different laboratories that take part in the Metrofission project is forecasted for the next year to validate the new prototype for low-energy beta emitters (as ^{3}H and ^{241}Pu) and link the results to the key comparison database of the Bureau International des Poids et Mesures (Sèvres, France).

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References

[1] European Commission, “The Sustainable Nuclear Energy Technology Platform”, *Strategic Research Agenda*, May, 2009, www.snetp.eu.

[2] European Commission, Directorate-General for Research, “World Energy Technology Outlook – 2050, WETO-H_2”, ©*European Communities*, ISBN 92-79-01636-9, 2006

[3] European Commission, Directorate-General for Research, Euratom, “The Sustainable Nuclear Energy Technology Platform”, ©*European Communities*, ISBN 978-92-79-05591-1, 2007

[4] http://projects.npl.co.uk/metrofission/work_package.html

[5] http://www.emrponline.eu

[6] L. Johansson, J-R. Filtz, P. De Felice, M. Sadli, A. Plompen, B. Hay, A. Dinsdale, S. Pommé, P. Cassette, J. Keightley, “Advanced Metrology for New Generation Nuclear Power Plants”, *Proceedings 2nd IMEKO TC 11 International Symposium METROLOGICAL INFRASTRUCTURE*, June 15-17, 2011, Cavtat, Bubrovnik Riviera, Croatia

[7] Cassette P., Bouchard J., “The design of a liquid scintillation counter based on the triple to double coincidence ratio method”, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Asssociated Equipment*, Volume 505, Issues 1-2, 2003, p.p. 72-75

[8] Broda R., “A review of the triple-to-double coincidence ratio (TDCR) method for standardazing radionuclides”, *Applied Radiation and Isotopes*, Volume 58, 2003, p.p. 585-594

[9] J. Keightley, P. Cassette, L. Johansson, “Radionuclide Metrology for New Generation Nuclear Power Plants”, Proceedings 2nd IMEKO TC 11 International Symposium METROLOGICAL INFRASTRUCTURE, June 15-17, 2011, Cavtat, Bubrovnik Riviera, Croatia

[10] J. Keightley and T.S. Park, “Digital coincidence counting for radionuclide standardization”, *Metrologia*, Volume 44, 2007, S32-S35. (Special issue on radionuclide metrology)

[11] http://www.caen.it

[12] Bouchard J., Cassette P., “MAC3: an electronic module for the processing of pulses delivered by a three photomultiplier liquid scintillation counting system”, *Applied Radiation and Isotopes* Volume 52, Issue 3, 2000, p.p. 669-72

[13] Daniel H., “Shapes of beta-ray spectra”, *Reviews of Modern Physics*, Volume 40, Issue 3, 1968, p.p. 659-71.