New Activity Transfer Instrument

Can we improve the measurement of high-energy pure β^- emitters in the hospitals ?

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Teddington

Ionisation Chambers (IC)

- Used routinely in clinical practice (Radionuclide Calibrators) to measure activity before administration to the patient;
- Ionisation current proportional to the total energy deposited in the gas medium;
- High Stability;
- High Reproducibility;
- Easy to use;
- When calibrated for individual radionuclides and well-known geometries – good accuracy;

However, there are exceptions !

- High-energy β^- emitters: the IC current strongly depends on the detection of bremsstrahlung emitted in the container and its surroundings (vial walls)
- IC response is more sensitive to the variability of the geometry of the containers

Difficulties measuring ^{90}Y using ionisation chambers

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^{90}Y liquid form [1]

- Intercomparison exercise(2009): 40% of the participants reporting values within ±5% of the NPL certified value

^{90}Y SIR-Spheres [2,3]

- Large uncertainties associated with calibration factors: between 5% and 15% depending on the ionisation chamber used
- Reproducibility of calibration factors sensitive to the wall thickness of the vials

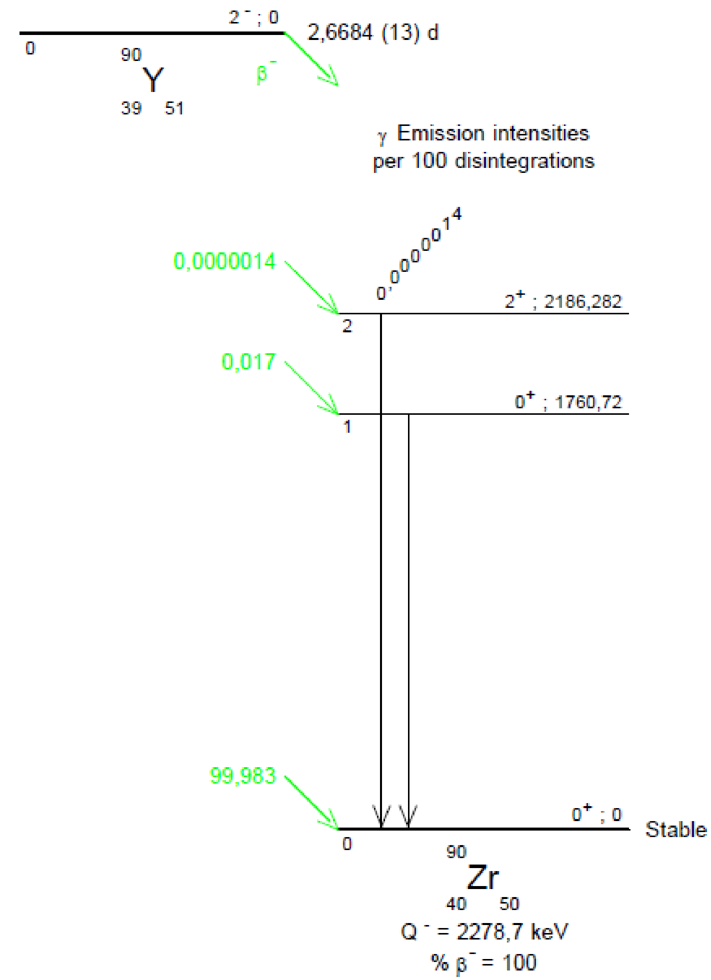

Figure 1: Decay scheme of ^{90}Y (from DDEP)

MRTDosimetry Project

Relevant Objective	Deliverable Number	Deliverable Description	Partners
1	D2	Validation report and recommendations for use of the transfer instrument for measurements of activity of high-energy beta-emitters in clinics and radiopharmaceutical companies with a target uncertainty of 2%	CEA, ENEA, BEV-PTP, NPL, OPBG

From JRP Protocol, WP1 deliverables

National measurement Institutes:

CEA: Commissariat à l'énergie atomique et aux énergies alternatives (France)

ENEA: Agenzia Nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (Italy)

BEV-PTP: Physikalisch- Technischer Pruefdienst des Bundesamt fuer Eich- und Vermessungwesen (Austria)

NPL: NPL Management Limited (United Kingdom)

Clinical Research Institution:

OPBG: Ospedale Pediatrico Bambino Gesù (Italy)

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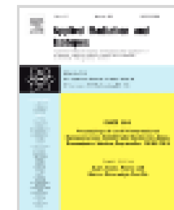

A radionuclide calibrator based on Cherenkov counting for activity measurements of high-energy pure β^--emitters

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Specifications of New Transfer Instrument

- Develop a new transfer instrument for the measurement of High Energy β^- emitters

  - Reduce standard uncertainty to less than 2 %
  - Activity measurements up to 10 GBq
  - Practical features close to classical ionisation chambers: quasi 4π geometry, use of containers for radioactive solutions such ampoules, vials, syringes, etc.
  - Applicable in radionuclide metrology laboratories, clinics and radiopharmaceutical companies

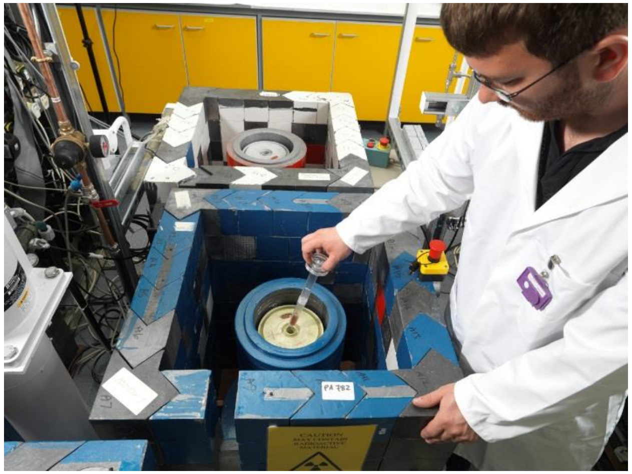


Figure 2: NPL Secondary Ionisation Chamber PA782+PA361

Characteristics of new instrument

Pulse-mode Counting [4]

✓ To lower the sensitivity to the energy distribution of bremsstrahlung

✓ Pulse-mode counting: only a fraction of the deposited energy is needed to exceed a detection threshold

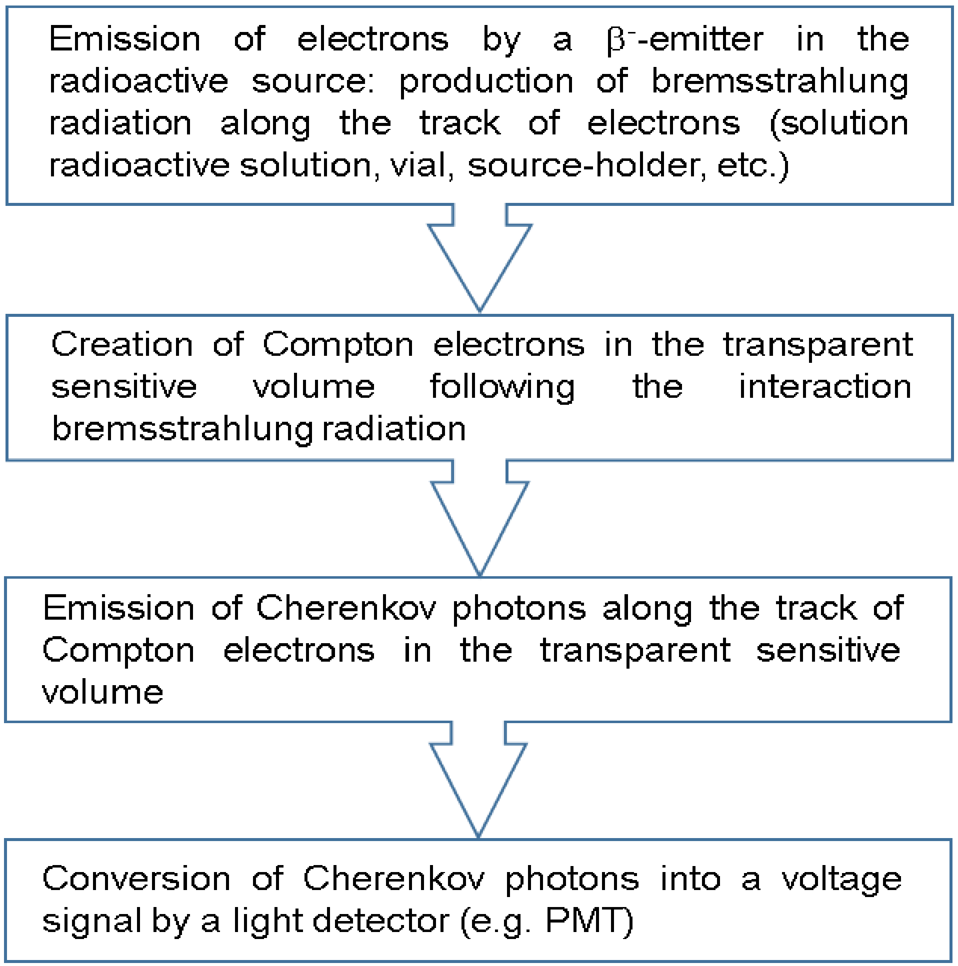
✗ Limited for high-activity measurements because of counting saturation

Low Sensitivity detector

✓ To measure high activity, up to 10 GBq (detection efficiency lower that 10^{-4})

- Replace the gas medium of IC by a transparent material to measure Cherenkov light
- Take advantage of the threshold effect to prevent counting saturation

New transfer instrument based on Cherenkov Counting



Instead of having the gas in the ionisation chamber replaced it by a transparent dielectric material and measure Cherenkov Photons.

Figure 5: Diagram describing the different interactions leading to the production of Cherenkov photons in a transparent material (from Bobin *et al.* 2017)

Validation by means of Monte Carlo Simulation

Using the Geant4 simulation toolkit [5]

Geometry close to the Vinten 671 type Ionisation Chamber (LNHB Secondary standard)

- Black plastic housing
- Reflective teflon layer: optimise the collection of Cherenkov photons
- Transparent material: fused silica
- Container similar to Sirtex vial (glass)and glass ampoule both filled with 5 mL of ^{90}Y aqueous solution
- Source holder: Delrin® (plastic)

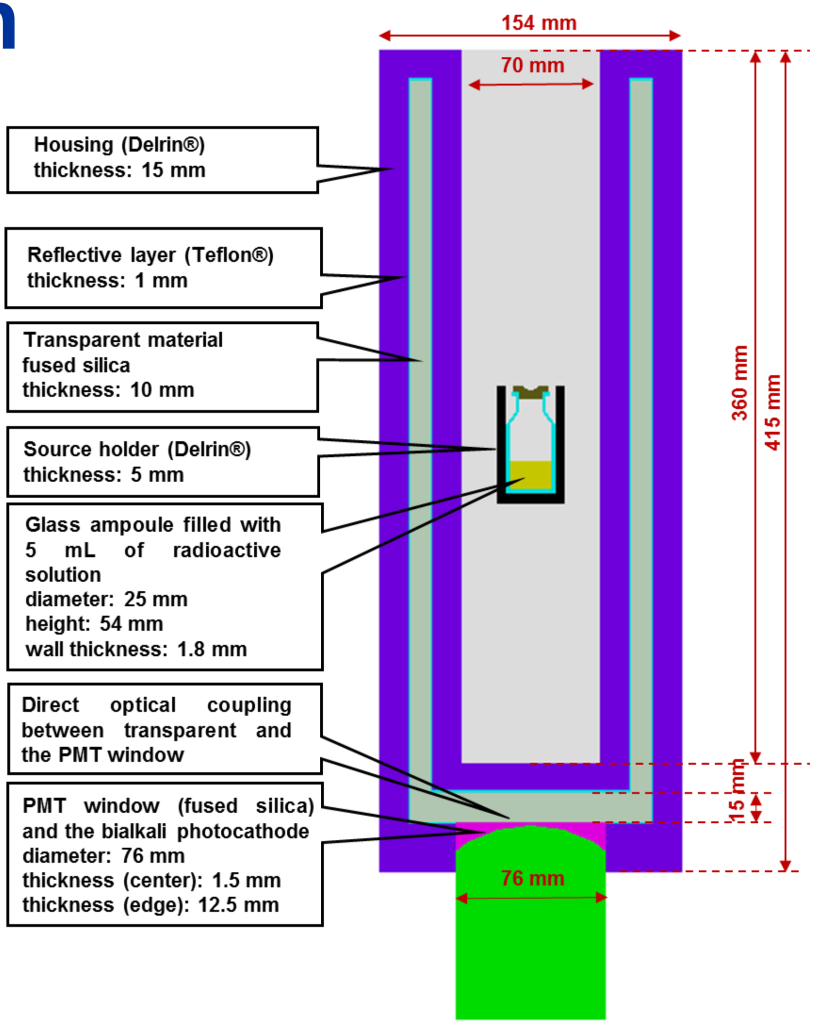


Figure 4: Geometry Modelling (from Bobin *et al.* 2017)

Simulated Efficiencies for Silica

Counting threshold Minimum number of PMT photoelectrons per counted pulse	Detection efficiency	
	Container wall thickness (Sirtex) 1.8 mm	Container wall thickness (LNHB) 0.6 mm
2	0.79×10^{-4}	0.79×10^{-4}
3	0.62×10^{-4}	0.61×10^{-4}
4	0.5×10^{-4}	0.49×10^{-4}
5	0.42×10^{-4}	0.41×10^{-4}

Table 1: Calculated detected efficiencies for glass vial and glass ampoule filled with ^{90}Y. Thickness of source holder: 5 mm (from Bobin et al. 2017)

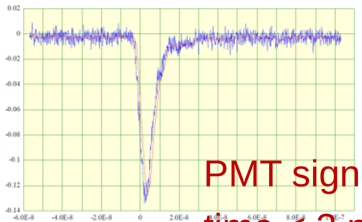
The table shows that Cherenkov counting is less sensitive to the wall thickness of the vials then Ionisation chambers (IC response 9 times higher for ampoule than vial [6])

Transfer Instrument

Mechanical drawings with SolidWorks

- Sensitive part (fused silica well)
- reduced dimensions: 80 mm diameter, 170 mm height

Digital acquisition



New front-end electronics

- Digital hardware
  - ✓ Fast ADC: ~ 2,5 GHz, 14 bits

    (adapted to fast photomultiplier signals with rise time < 3 ns)
  - ✓ Arria 10 FPGA
  - ✓ VHDL program for list-mode data acquisition

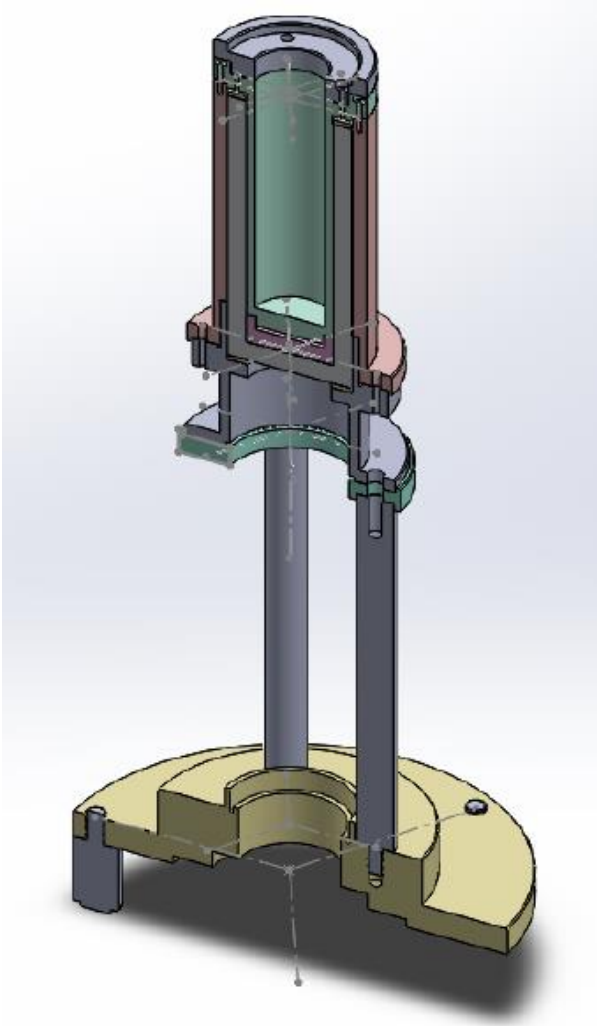


Figure 5: Drawing of the new instrument

First prototype

- First tests performed using a sensitive part made of transparent plexiglass
  - ✓ Weak Cherenkov signals: optical transmittance not optimised for Cherenkov counting

- Improvements needed to increase Cherenkov signals

  PMT window with Pyrex window
  (300 nm-650 nm) changed to fused silica
  (160 nm-650 nm)

- Delay in receiving fused silica part

Additional work is necessary

Perform measurements with the Silica detector
Measurements using other high-energy β^- emitters
Measurements using gamma emitters

Final considerations on Transfer Equipment

- A new transfer instrument (prototype) was developed for the measurement of high energy β^- emitters
  - Similar to ionisation chamber
  - Possibility to measure high activities (up to 10 GBq)
  - Pulse mode measurement instead of current
  - Fast electronics (paper will be published on this)
  - Gas replaced by transparent material
- Monte Carlo Simulations (using Geant4) showed the advantages of using Cherenkov for the measurement of β^- emitters
- Additional work is necessary to optimise the new transfer instrument
- Equipment is not available commercially and it is currently not cost-effective
- NMI applications: measurement of half-lives

But we still have Radionuclide Calibrators !

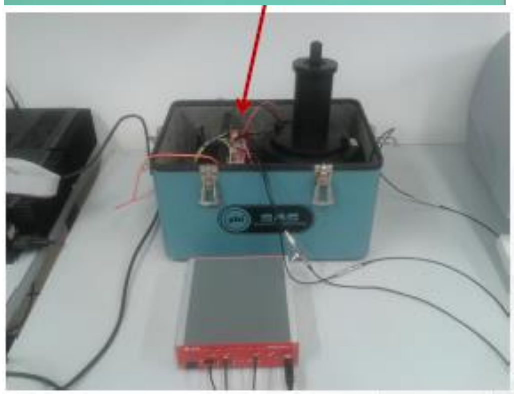
- QC program
- Understand the limitations of this instrument for the measurement of high-energy β^- emitters
- Assess realistic uncertainties for the measurements
- (Re)calibrate to confirm accuracy and traceability of measurements

    New vial type (change of supplier for eg.)

    Different sample volume

- Consider each ionisation chamber individually due to potential variations in the manufacturing process.

^{90}Y activity measurements using ENEA portable TDCR



^{90}Y activity measurement on site with an uncertainty ≤2%
Activity range 1 kBq to 10 kBq.
Measurements performed at Meldola and Gemelli Hospitals (M. Capogni and M. D’Arienzo)

The Triple-to-Double coincidence ratio (TDCR) method in liquid scintillation counting is a primary radionuclide standardisation method used in NMIs

^{90}Y on-site calibration of the OPBG ionisation chamber

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Abstract

The ENEA-INMRI TDCR portable instrument was used to carry out an extensive $^{90}YCl_3$ activity calibration of the OPBG Ionization Chamber. A ^{90}Y master solution was standardized by TDCR method using the portable TDCR, as transfer instrument, and the Hidex 300SL Metro-version counter both available at ENEA-INMRI. This work highlights some issues faced with on-site calibration of instruments, such as ionization chambers, usually used for activity measurements of short-lived radionuclides. The achieved results open interesting perspectives for Nuclear Medicine applications.

References

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Thank you for listening.

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