A temperature calibration method using dynamic energy windows for the online blood radioactivity meter

Presenter：QU，Huifan

01.08.2022

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

目录 Contents

1 Introduction

2 Method

3 Experiments & Results

4 Discussion & Conculsion

目录 Contents

1 Introduction

2 Method

3 Experiments & Results

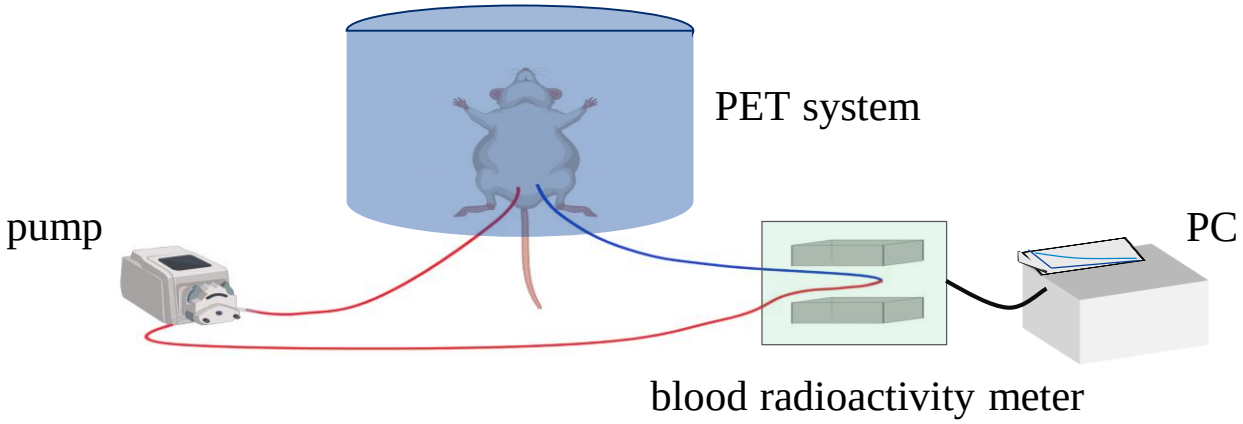
4 Discussion & Conclusion

Introduction

- Dynamic Positron Emission Tomography（PET）：
  - using **tracer kinetic modelling**
- Tracer kinetic modelling [1,2]：
  - needing calculated physiological parameters
- Physiological parameters：
  - arterial input function + output function
- **Arterial input function** (AIF)：
  - the concentration of tracer in arterial blood as a function of time
  - gold standard： arterial blood sampling + activity in plasma
  - **blood radioactivity meter**

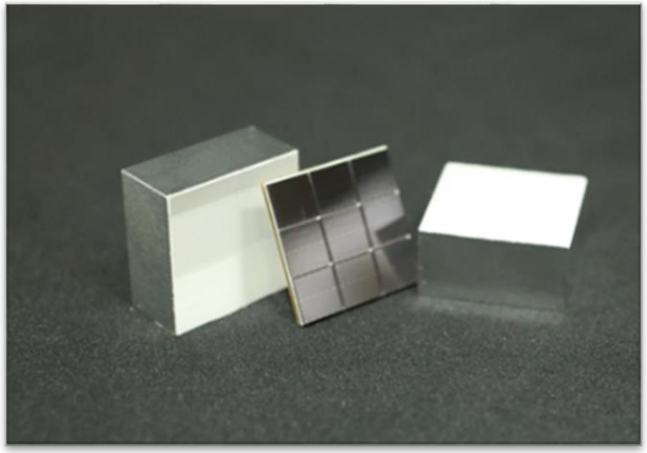
Introduction

- Disadvantages of blood sampling:
  - missing the important changing point
  - complicated sampling operation
  - radiation to operators
  - massive blood loss of animals
- Advantages of blood radioactivity meter:
  - **continuous** sampling
  - **automatic** operation
  - **protecting** operators from radiation
  - **minimizing** the blood loss



Introduction

- Blood radioactivity meter detector : scintillation crystals + SiPM
- Influence of temperature to scintillation crystals[3] :
  - the light output
  - the number of photons generated
  - the half-width pulse width of the energy spectrum
- Influence of temperature to SiPM[4-7] :
  - breakdown voltage
  - leakage current
  - dark event rate
  - internal gain



Scintillation crystals + SiPM

Introduction

- Methods to keep the output of the scintillation detector stable at different temperatures:
  - an efficient cooling system around the detector[8]
    - bring difficulty to the miniaturization of the device
  - fine-tuning the bias voltage of SiPM[9-12]
    - having challenge to know very accurately the temperature coefficient of the breakdown voltage of the SiPM and the conversion gain of the temperature sensor
  - adjusting the crystal light output according to the curve of light output and temperature[13]
- Our method : a temperature calibration method for the online blood radioactivity meter

目录 Contents

1 Introduction

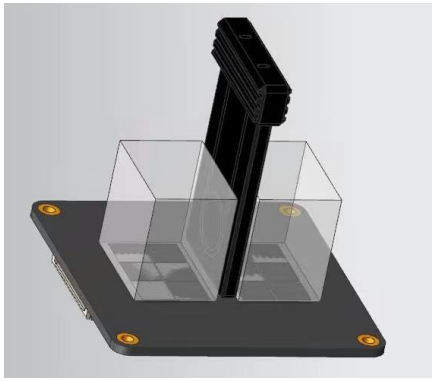
2 Method

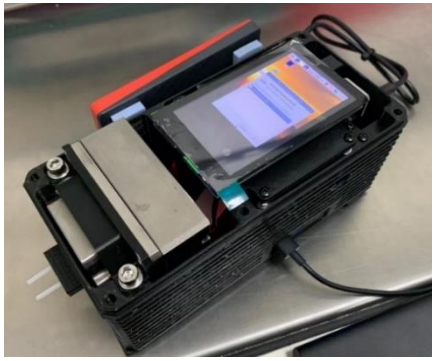
3 Experiments & Results

4 Discussion & Conclusion

Method——Hardware settings

- Prototype of the online blood radioactivity :
  - two pieces of monolithic LYSO coupled to two 2*3 SiPM array
  - a signal processing circuit using the time-over-threshold (TOT) method
    - converting the input waveform into a simple digital pulse via threshold comparison
    - using the pulse width as the energy
    - regarding the time of leading edge in the wave as the generation time for the input signal

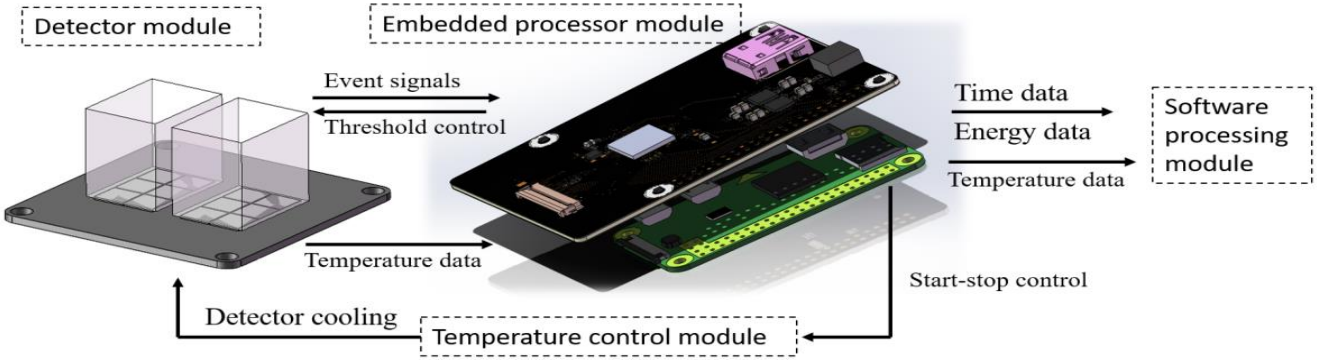




Detector of online blood radioactivity

Method——Hardware settings

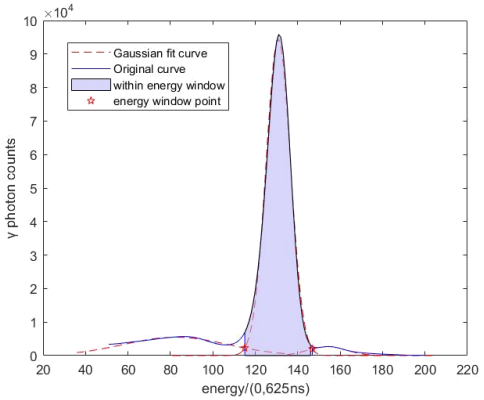
- Imbedded feedback temperature control module:
  - a temperature sensor installed in the detector to monitor the temperature of SiPMs.
  - a thermometric cooler installed adjacent to the SiPMs.
  - Raspberry Pi reading the temperature data from the temperature sensor and controling thethermometric cooler to operate when the temperature exceeds 24 ℃.



Temperature control system

Method——The floating energy window

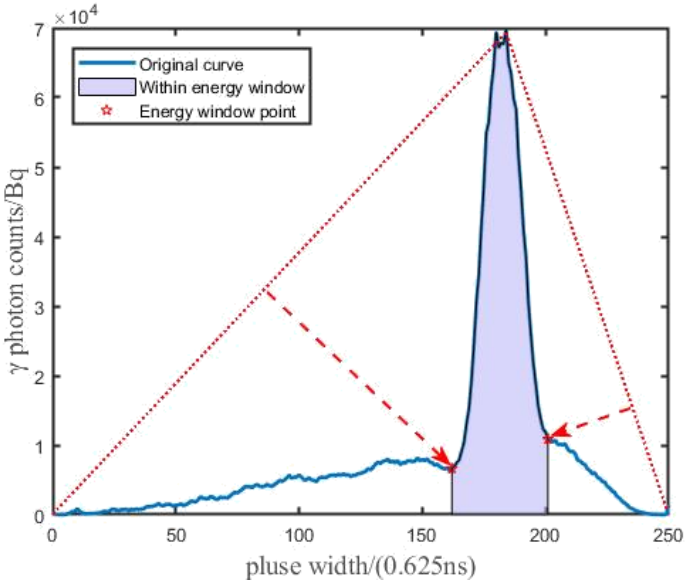
- Energy windows:
  - applying on the energy spectrum to remove the influence of background noise, scattering events, and high-energy events
- The energy spectrum of ^{18}F-FDG as an example to illustrate the algorithm :
  - three peaks in the energy spectrum of ^{18}F-FDG usually : compton scattering peak, the 511 keV peak, the piling peak
  - performing Gaussian fitting on these three peaks respectively
  - calculating the intersections of each two Gaussian functions
  - regarding the intersections as the energy windows



Floating energy window method

Method——The floating energy window

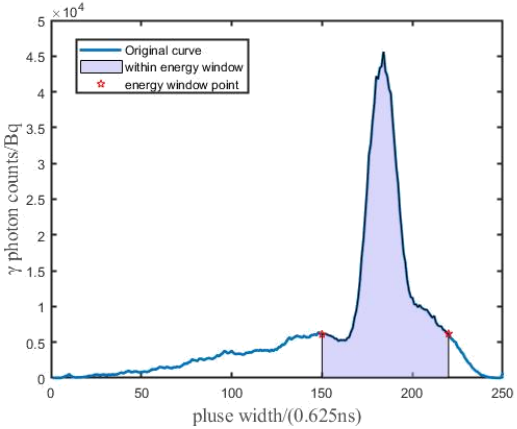
- Find valley：
  - the point which is the farthest one from the line between the peak and origin
  - enhancing the robustness of the algorithm



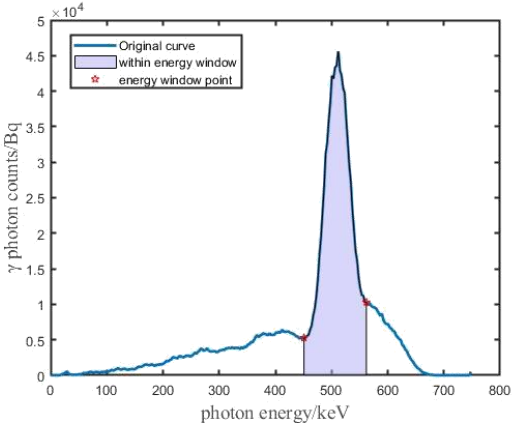
The point-line method

Method——Methods comparison

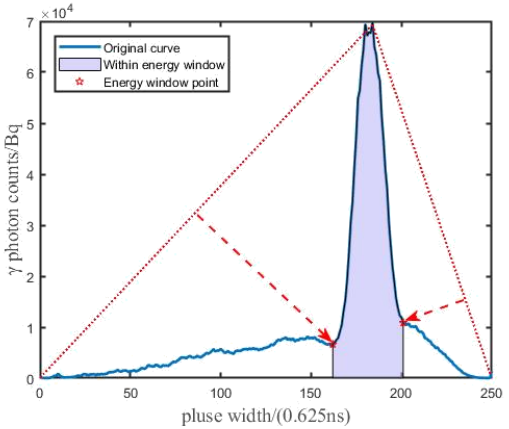
- Compared method :
  - fixed energy window method : 150-220 (0.625ns)
  - normalized energy window method : normalizing the main peak to 511 keV and sets the energy window around the 511 keV peak (451 keV - 561 keV)
  - floating energy window method （our method2）



Fix energy window method



Normalized energy window method



Floating energy window method

目录 Contents

1 Introduction

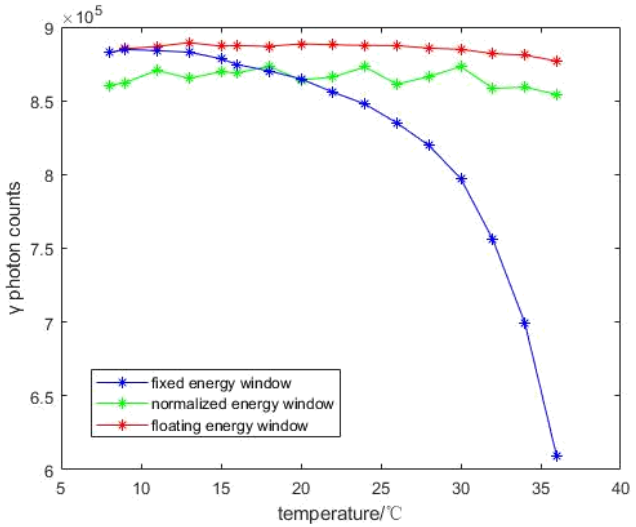
2 Method

3 Experiments & Results

4 Discussion & Conclusion

Experiments & Results —— ^{22}Na

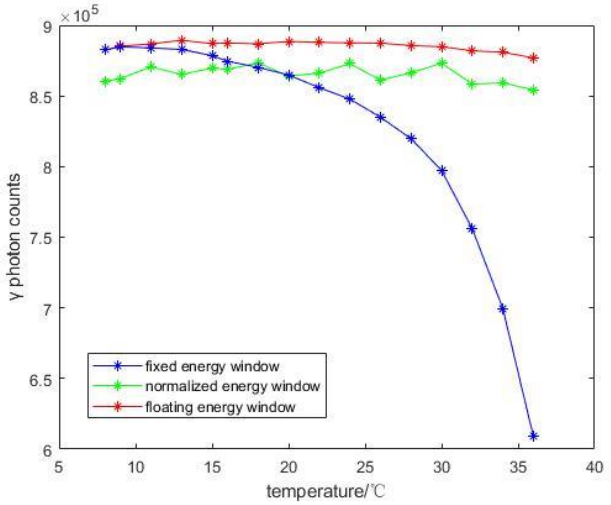
- Radioactive source with long half-life period :
  - radioactive source : ^{22}Na
  - temperature control : a separate water-cooling system
  - temperature set :
    - 16 different temperatures between 8℃ to 36℃
  - data acqusition : 10 minutes each
  - evaluation :
    - coefficient of variation = $\frac{\text{standard deviation}}{\text{mean}}$



Result of ^{22}Na experiment

Experiments & Results —— ^{22}Na

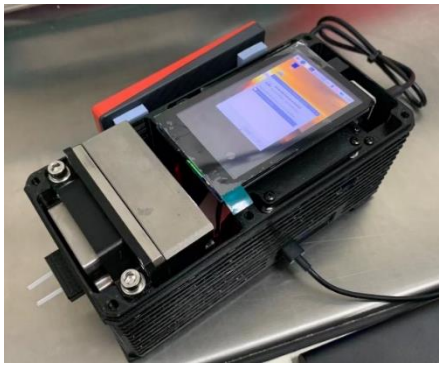
- Fixed energy window： obvious activity drop when the temperature increases
- Normalized energy window： can keep the activity stable but with some minor fluctuations
- Floating energy window： can keep the activity extremely stable
- Coefficients of variation：
  - fixed energy window : 0.0946
  - normalized energy window： 0.0067
  - floating energy window： 0.0037



Result of ^{22}Na experiment

Experiments & Results —— ^{18}F-FDG

- Radioactive source with short half-life period :
  - radioactive source : 18F-FDG
  - temperature control : temperature control module
  - temperature set : from 21℃ to 27℃
  - data acqusition : 24 hours each
  - evaluation : relative error to the true activity value



^{18}F-FDG data collecting

Dispensing the tracer

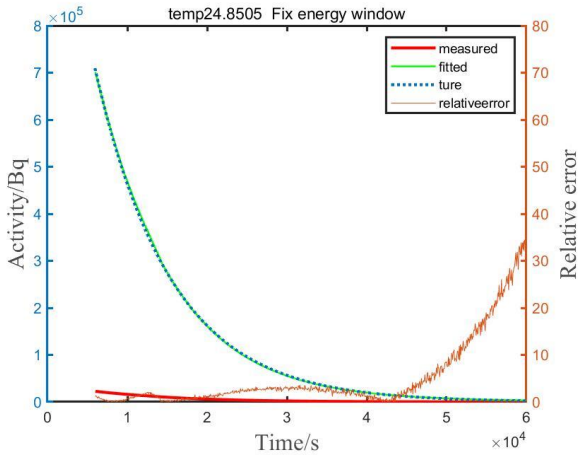
Experiments & Results —— ^{18}F-FDG

- Fitting function : calculated by the data acquired in 24.8506℃ （Exp1）
- Fitted by fitting function respectively：
  - fixed energy window： fitted data = 0.0002931*x^2 + 24.46*x + 848;
  - normalized energy window： fitted data = 0.0003451*x^2 + 25.96*x + 1132;
  - floating energy window： fitted data = 0.0001546*x^2 + 27.69*x - 174;

Experment	Temperature	Initial dose	Acquisition time
1	24.8506℃	35.8uCi	24h
2	25.3317℃	10.55uCi	24h
3	27.4181℃	11.34uCi	24h
4	26.1540℃	12.46uCi	24h
5	21.7164℃	15.66uCi	24h

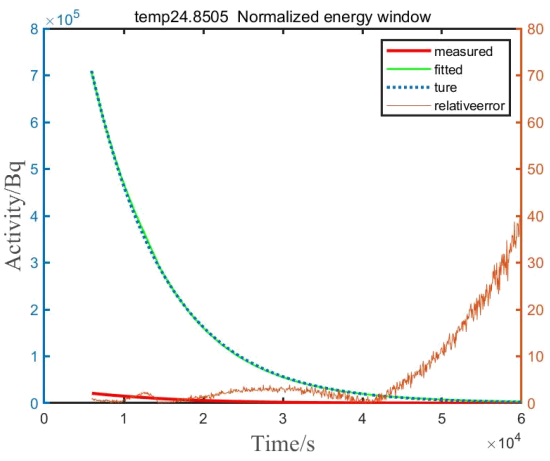
Experiments & Results —— ^{18}F-FDG

- Relative error in Exp1 （data which are used to calculate fitting function）
- Temperature： 24.8506℃



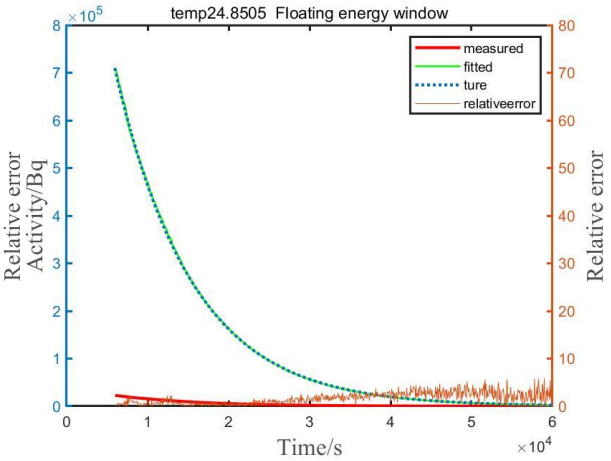
Fixed energy window

(relative error:0-35%)



Normalized energy window

(relative error:0-40%)

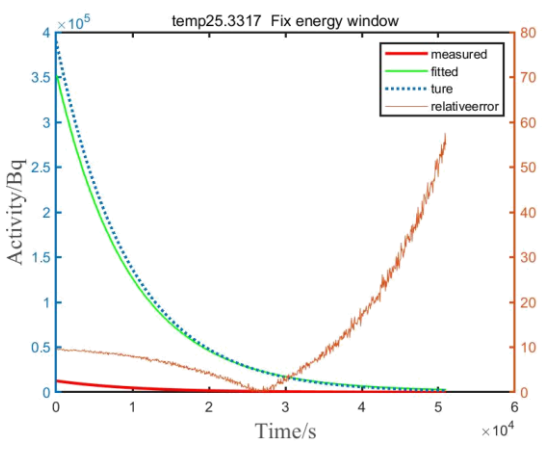


Floating energy window

(relative error:0-6%)

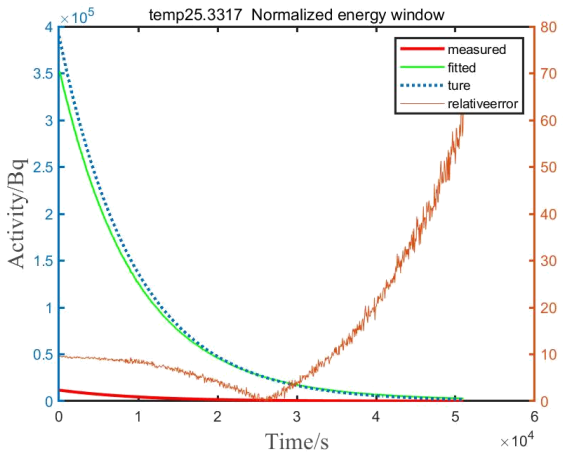
Experiments & Results —— ^{18}F-FDG

- Relative error in Exp2
- Temperature： 25.3317℃



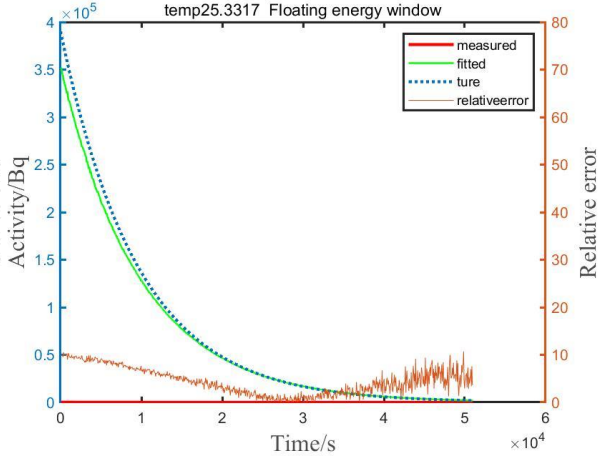
Fixed energy window

(relative error:0-60%)



Normalized energy window

(relative error:0-65%)

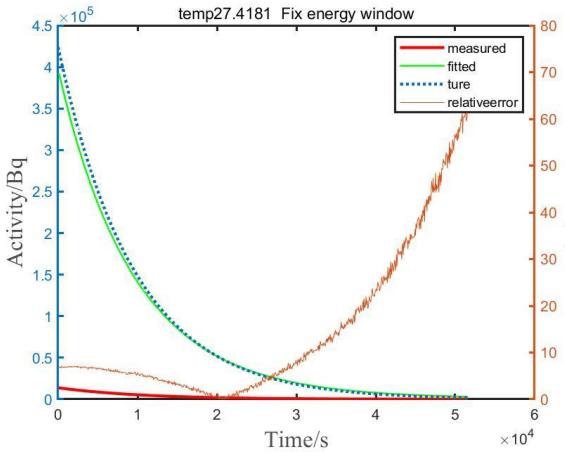


Floating energy window

(relative error:0-10%)

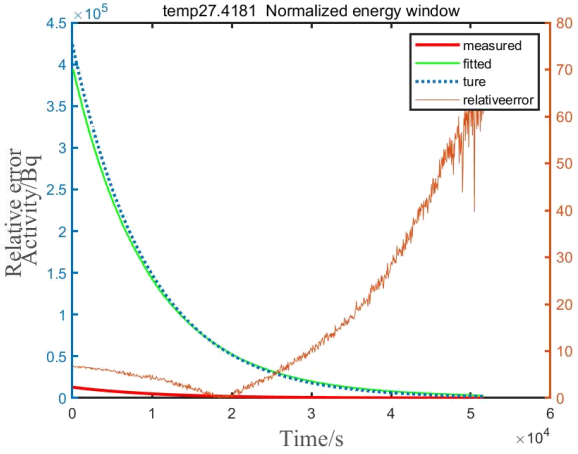
Experiments & Results —— ^{18}F-FDG

- Relative error in Exp3
- Temperature： 27.4181℃



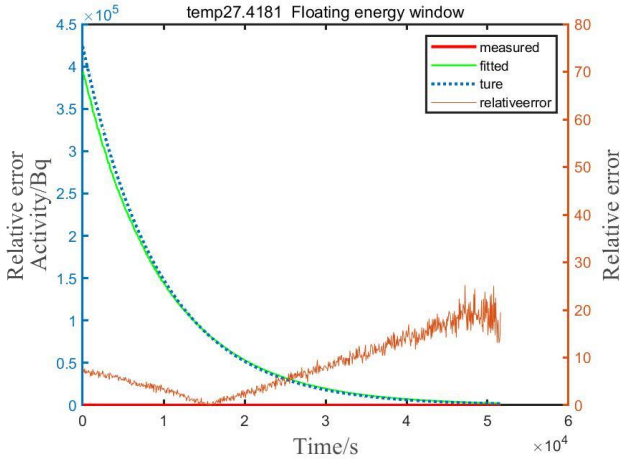
Fixed energy window

(relative error:0-70%)



Normalized energy window

(relative error:0-65%)

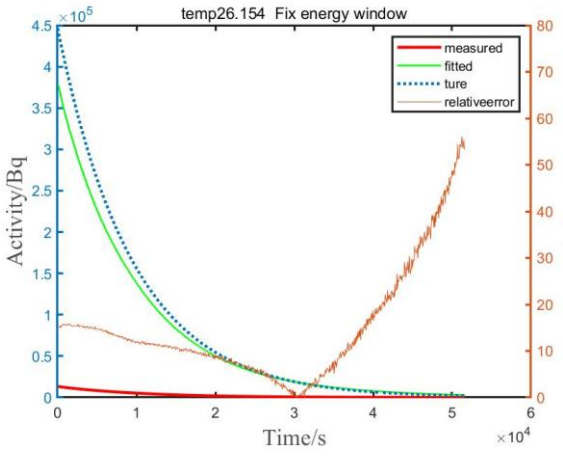


Floating energy window

(relative error:0-25%)

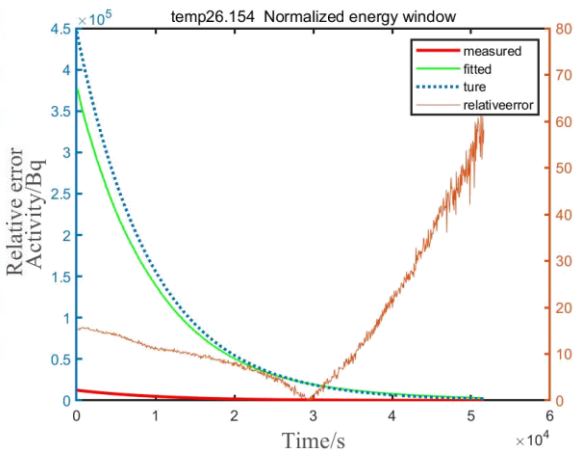
Experiments & Results —— ^{18}F-FDG

- Relative error in Exp4
- Temperature：26.1540℃



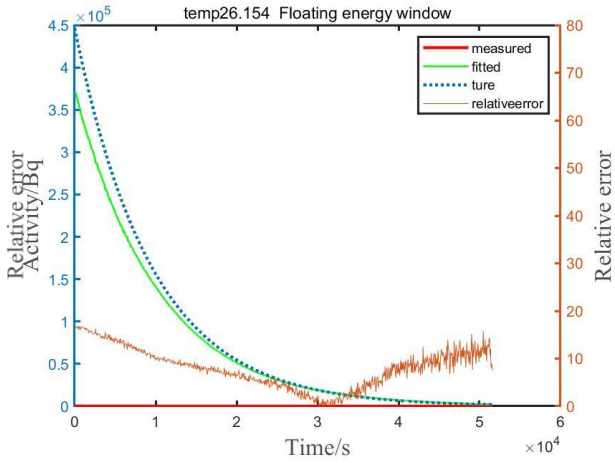
Fixed energy window

(relative error:0-55%)



Normalized energy window

(relative error:0-65%)

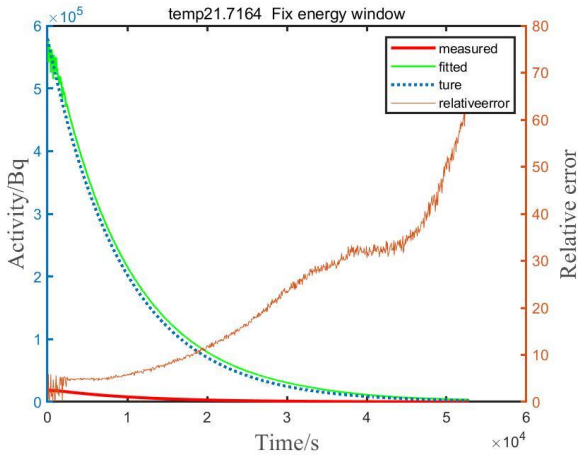


Floating energy window

(relative error:0-16%)

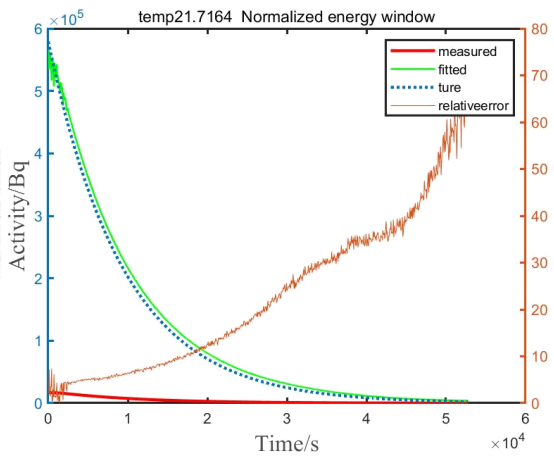
Experiments & Results —— ^{18}F-FDG

- Relative error in Exp5
- Temperature：21.7164℃



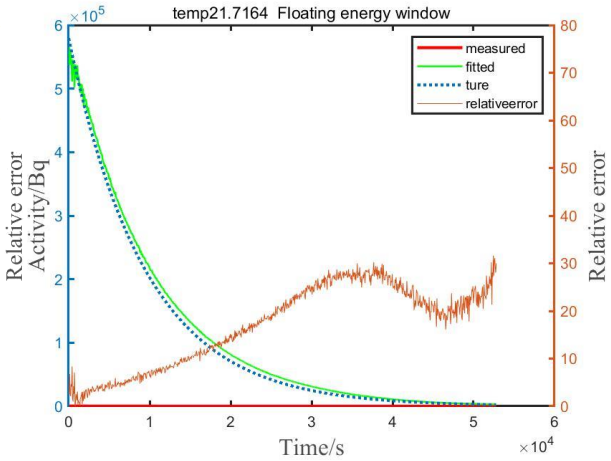
Fixed energy window

(relative error:0-65%)



Normalized energy window

(relative error:0-75%)



Floating energy window

(relative error:0-30%)

目录 Contents

1 Introduction

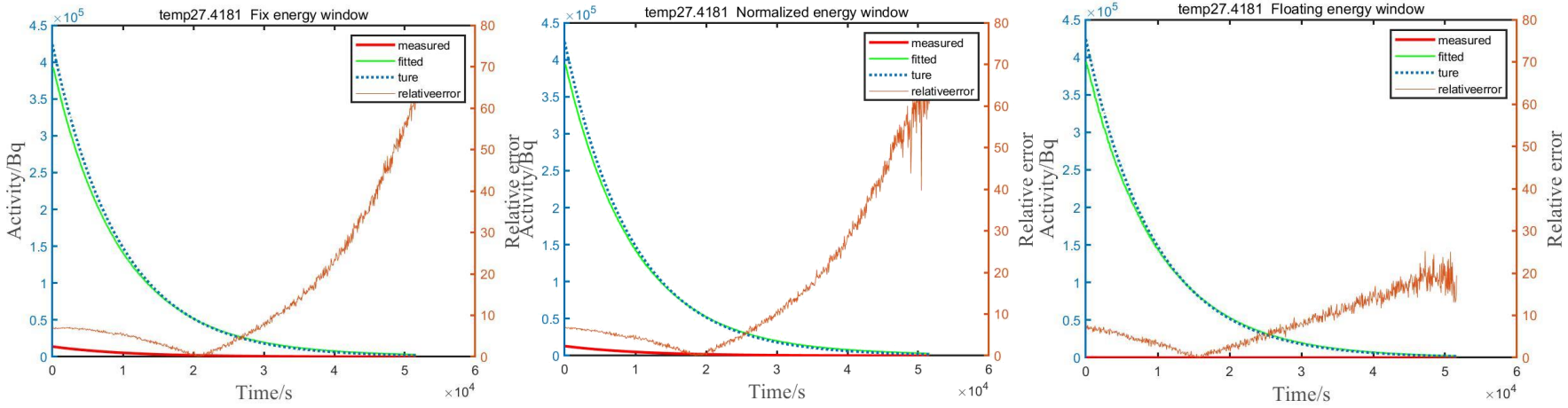
2 Method

3 Experiments & Results

4 Discussion & Conculsion

Discussion & Conculsion

- A lower signal-to-noise ratio may cause the rise of the relative error when the dose drops.
- Even when the dose of tracer becomes very low, the floating energy window method can keep the relative error at a relatively low level.



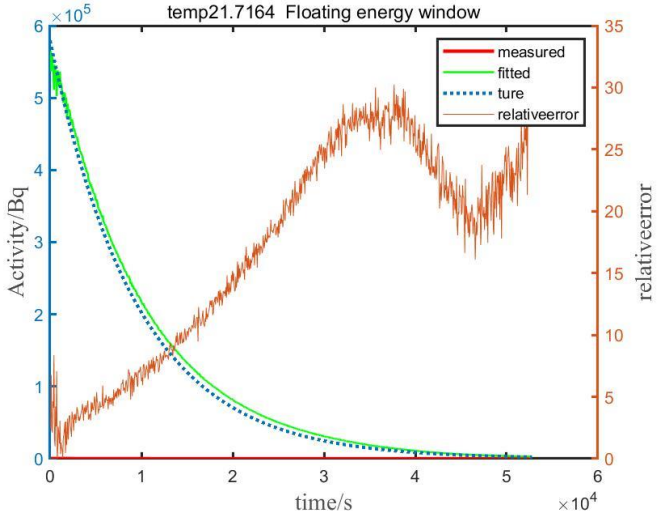
Discussion & Conculsion

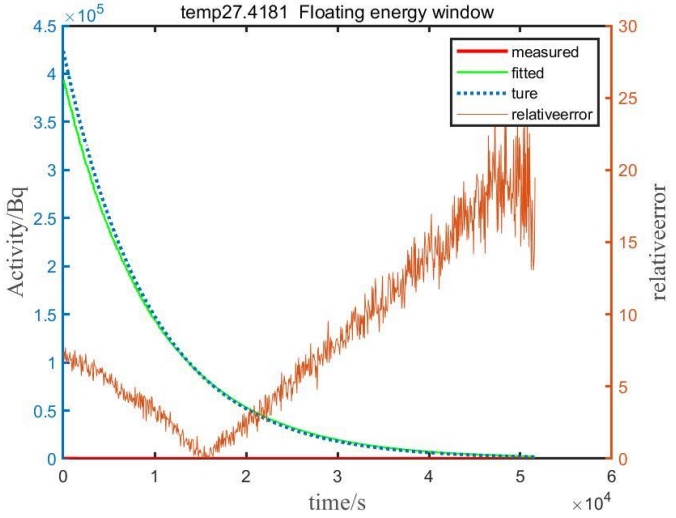
- Although the relative error will increase at later stage of the test, the blood radioactivity meter can keep the result accurate at a relatively low dose.

Experment	Temperature	Activity at the 10% relative error / uCi		
		Fix energy window	Normalized energy window	Floating energy window
1	24.8506℃	0.163	0.198	0.015
2	25.3317℃	0.225	0.300	0.056
3	27.4181℃	0.456	0.464	0.313
4	26.1540℃	0.290	0.329	0.113
5	21.7164℃	2.379	2.896	3.071

Discussion & Conculsion

- When temperature deviates from the normal temperature largely, the relative error will increase. The floating energy window method can decrease the error.
- We can see a increase number in calculated number when temperature decreases and an opposite trend when temperature increase. The algorithm can be improved by taking this trend into consideration.





References

- [1] T. Mann, J. Kurth, A. Möller, J. Förster, B. Vollmar, B.J. Krause, A. Wree, J. Stenzel, T. Lindner, Continuous Blood Sampling in Small Animal Positron Emission Tomography/Computed Tomography Enables the Measurement of the Arterial Input Function, JoVE (Journal of Visualized Experiments) (150) (2019) e59701.
- [2] H. Napieczynska, A. Kolb, P. Katiyar, M. Tonietto, M. Ud-Dean, R. Stumm, K. Herfert, C. Calaminus, B.J. Pichler, Impact of the arterial input function recording method on kinetic parameters in small-animal PET, Journal of Nuclear Medicine 59(7) (2018) 1159-1164.
- [3] Kim C L . A study on the temperature characteristics of LYSO PET detector[C]// Nuclear Science Symposium Conference Record, 2005 IEEE. IEEE, 2005.
- [4] M. Ramilli, Characterization of SiPM: temperature dependencies,in 2008 IEEE Nuclear Science Symposium Conference Record, 2008: IEEE, pp. 2467-2470.
- [5] N. Anfimov, D. Fedoseev, A. Rybnikov, A. Selyunin, S. Sokolov, and A. Sotnikov, Study of silicon photomultiplier performance at different temperatures, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 997, p. 165162, 2021.
- [6] E. Kuznetsov, Temperature-compensated silicon photomultiplier, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol.912, pp. 226-230, 2018.
- [7] M. Petasecca et al., Thermal and electrical characterization of silicon photomultiplier, IEEE Transactions on Nuclear Science, vol. 55, no. 3, pp. 1686-1690, 2008.
- [8] A. V. Stolin, S. Majewski, and R. R. Raylman, Novel method of temperature stabilization for SiPMBased detectors, IEEE Transactions on Nuclear Science, vol. 60, no. 5, pp. 3181-3187, 2013.
- [9] Z. Li et al., A gain control and stabilization technique for Silicon Photomultipliers in low-light-level applications around room temperature, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 695, pp. 222-225, 2012.
- [10] H. Miyamoto and M. Teshima, SiPM development for the imaging Cherenkov and fluorescence telescopes, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 623, no. 1, pp. 198-200, 2010.
- [11] R. Bencardino and J. E. Eberhardt, Development of a fast-neutron detector with silicon photomultiplier readout, IEEE Transactions on Nuclear Science, vol. 56, no. 3, pp. 1129-1134, 2009.
- [12] P. Marrocchesi et al., Active control of the gain of a 3mm× 3mm Silicon PhotoMultiplier, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 602, no. 2, pp. 391-395, 2009.
- [13] C. L. Kim, A study on the temperature characteristics of LYSO PET detector, in IEEE Nuclear Science Symposium Conference Record, 2005, 2005, vol. 4: IEEE, pp. 4 pp.-2016.

Thank you for listening!