Medical application of nuclear physics: development of dedicated PET systems

Taiga Yamaya, Ph. D

National Institute of Radiological Sciences (NIRS),
National Institutes for Quantum and Radiological Science and Technology (QST)
(Visiting Professors in Chiba University and Yokohama City University)
Where am I coming from?

Kyoto

Asakusa (in Tokyo)

Yokohama

“Ryokan”
National Institute of Radiological Sciences (NIRS-QST)
Carbon ion therapy

[Graph showing the depth-dose curves for different radiation types including X rays, gamma rays, neutron beam, proton beam, and charged particle beam (carbon).]
HIMAC
(Heavy Ion Medical Accelerator in Chiba)

Synchrotron

Ion Source

Linac

Room C

Room B

Room A

Room E

Room F

Room G

New Facility

S.C. Gantry

Room A, B, C (Bolus)

Room G

(Spot scanning + Rotation gantry)

Room E, F

(Spot scanning)
Demand for range verification by PET

Why in-beam?
- Short half-lives
- Biological washout
- Positioning
- Patient time
Principal of FDG-PET imaging

1. **Glucose** and **FDG** (Fluorine-18 Fluorodeoxyglucose)

2. Injection of Positron emitters (185MBq - 370MBq) into Cancer

3. Typical count rate: ~$10^6$ count/sec.
Principal of in-beam PET imaging

Typical count rate ~10^6 count/sec.
“OpenPET”: our idea for 3D in-beam PET

Conventional in-beam PET

- GSI
- Pawelke et al, 1996
- Partial detectors
- Non isotropic res.
- Limited sensitivity

OpenPET

- 3D imaging
- Full-ring detectors
- High sensitivity

Yamaya PMB 2008
- DROP
- beam

Tashima PMB 2012
- SROP
Depth-of-interaction (DOI) detector

Conventional detector

 DOI detector

3-4 mm square

30 mm length

Scintillator (crystal) array

Photomultiplier tube (PMT)

Sensitivity and resolution are incompatible

Both sensitivity and resolution can be improved

従来技術 放医研独自技術

Both sensitivity and resolution can be improved
4-Layer DOI Detector

GSO (Gd$_2$SiO$_5$:Ce)
2.9 x 2.9 x 7.5mm$^3$ (Hitachi Chemical)

Extension to
- LGSO, LYSO, BGO
- Smaller size (1.5 x 1.5 x 5.0 mm$^3$)
- H8500 PMT

H. Murayama et al 1998 IEEE TNS p 1152
N. Inadama et al 2002 IEEE TNS p 629
T. Tsuda et al 2004 IEEE TNS p 2537

Flat panel PS-PMT
(Hamamatsu, H9500)
4-layer DOI measurement

1st layer

2nd layer

3rd layer

4th layer

Patterns of reflector insertion

Air

Reflector

2D position histogram (Flood images)
4-layer DOI measurement

Each crystal can be identified by the conventional Anger type calculation.
DOI enables OpenPET

Tilted PET

Non-DOI

DOI

Too large for therapy room

Degraded resolution

Keep resolution in the gap

Beam nozzle

(1/10 scale mode)
HIMAC test (\(^{12}\text{C}\) beam)

- Beam
  - \(^{12}\text{C}\)
  - 3 spill
- PET measurement
  - 23 min
- Target
  - PMMA phantom (10x10x30 cm\(^3\))
HIMAC test ($^{12}$C beam)

- $10^7$ pps
  - Dose (meas.)
  - PET (meas.)
  - $\beta^+$ (Phits)
  - Depth in target (mm): 7.6 mm

- $10^9$ pps
  - Dose (meas.)
  - PET (meas.)
  - $\beta^+$ (Phits)
  - Depth in target (mm): 7.6 mm

- $10^7$ pps
- $10^9$ pps

Spill off + beam off (23 min)
MAP-EM
1.5 mm$^3$ voxel

PET (meas.)

QST
Secondary beam line at HIMAC

RI beams

$^{11}$C ($6 \times 10^6$ pps)
- Half life: ~20 min
- 3 spills
- Scan time: 23 min

$^{15}$O ($7 \times 10^6$ pps)
- Half life: ~2 min
- 2 spills
- Scan time: 13 min

Mohammadi, ..., Yamaya, NIMA (2017) p76
Mohammadi, ..., Yamaya, PMB 64 (2019) 145014
Helmet-type PET: toward the best brain PET in the world
Brain PET for early diagnosis of AD


NIRS press release
Cylinder vs. Hemisphere
Cylinder vs. Hemisphere

Conventional PET

Surface area (Relative num. of detectors)

\[ 2\pi r \times r = 2\pi r^2 \]

PET geometrical sensitivity

\[ 4\pi r^2 / 2 = 2\pi r^2 \]

1.5x sensitivity gain with the same num. of detectors
First prototype (2015)

The total num. of detectors: ~only 1/5 of whole body PET (potential cost reduction)
Comparison with Siemens mCT

**mCT**

- 9.3 MBq $^{18}$F
- 20 min
- List-mode PSF-TOF-OSEM (3 itr. 21 sub.)

**Helmet-Chin PET**

- 8.8 MBq $^{18}$F
- 22 min
- List-mode OSEM (10 itr. 8 sub.)
Summary

PET innovation being made at NIRS

New technologies
- DOI detector

Unusual systems
- OpenPET
- Helmet PET

Clinical impact
- Therapy guide
- Earlier diagnosis of dementia
IEEE Nuclear Science Symposium and Medical Imaging Conference (IEEE NSS-MIC) 2021

Proposed Date: 16th ~ 23rd October, 2021