Performance evaluation of the EXPLORER Total-body PET/CT scanner based on NEMA NU-2 2018 standard with additional tests for extended geometry

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• UC Davis has a research agreement and a sales-based revenue sharing agreement with United Imaging Healthcare.
uEXPLORER Total-body PET/CT Scanner

- Eight rings of detector modules
- Axial FOV of 194 cm
- 57° acceptance angle

➢ Enhanced sensitivity
uEXPLORER Total-body PET/CT Scanner

- 510(k) approval (Dec. 2018)
- Installed at the EXPLORER Molecular Imaging Center (May 2019)
- First Total-body PET scanner used clinically (Aug. 2019)
Objectives

1. First post-installation characterization of the uEXPLORER scanner following NEMA NU 2-2018
   - Independent analysis software developed at UC Davis

2. Extended geometry measurements to characterize Total-body PET scanners
   - NEMA NU 2 suitable for scanners with <65 cm AFOV
   - Extended geometry: $\approx 175$ cm (world average human)
Sensitivity

NEMA NU 2-2018 Protocol

• **70 cm** $^{18}$F line source in attenuating aluminum sleeves

Extended Geometry

• **170 cm** $^{18}$F line source
• No aluminum sleeves
Sensitivity

- **NEMA NU 2-2018 (70 cm)**
  - Center: 174 kcps/MBq
  - 10 cm: 177 kcps/MBq

- **Extended Geometry (170 cm)**
  - Center: 147 kcps/MBq
  - 10 cm: 151 kcps/MBq

- Sensitivity 15 - 60 times higher than other scanners
Spatial Resolution

- Measured following the **NEMA NU 2-2018** protocol
  - FBP reconstruction, 0.6 mm isotropic voxels
  - Reduced acceptance angle
- Capillary tube with **1 mm** inner diameter
- \( \approx 8 \, \mu\text{Ci} \, ^{18}\text{F-FDG} \)
Spatial Resolution

FWHM (mm)
(radial, tangential, axial)

<table>
<thead>
<tr>
<th>Ring 1</th>
<th>Ring 2</th>
<th>Ring 3</th>
<th>Ring 4</th>
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<tr>
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(4.8, 4.6, 3.4)  (4.9, 3.2)
(3.4, 3.3, 3.3)  (3.5, 3.4, 3.2)
(3.3, 3.1, 3.0)  (3.3, 2.9, 3.2)

Axial Offset from the Center (cm)
Spatial Resolution – Iterative Reconstruction

• Measured using a **point source** reconstructed in a **warm background** with 3D-OSEM + PSF modeling

• Two separate scans:
  – $^{22}\text{Na}$ point source
  – $^{68}\text{Ge}$ uniform cylinder

• List-mode data combined with 10:1 image contrast

• 0.5 mm isotropic voxels, 20 iterations, 20 subsets
Spatial Resolution – Iterative Reconstruction

Center AFOV – 1 cm offset

1/8\textsuperscript{th} AFOV – 1 cm offset

Radial = 3.2 mm
Tangential = 2.6 mm
Axial = 2.8 mm

Radial = 2.9 mm
Tangential = 2.3 mm
Axial = 2.1 mm
Count Rate Performance

NEMA NU 2-2018

- 70 cm scatter phantom
- Activity ≈ 20 mCi
- Elevated 15 cm (bed to center)

Extended Geometry

- 175 cm scatter phantom
- Activity ≈ 20 mCi
- Elevated 15 cm (bed to center)
Noise Equivalent Count Rate (NECR)

NEMA NU 2-2018 (70 cm)

NECR_{peak} = 1.52 \text{ Mcps @ 17.3 kBq/cc}

Extended Geometry (175 cm)

NECR_{peak} = 1.86 \text{ Mcps @ 9.6 kBq/cc}

10.8 mCi (397.9 MBq)

14.9 mCi (552 MBq)
Scatter Fraction (SF)

NEMA NU 2-2018 (70 cm)
NECR_{peak} = 1.52 \text{ Mcps} @ 17.3 \text{ kBq/cc}

SF = 36.3%

Extended Geometry (175 cm)
NECR_{peak} = 1.86 \text{ Mcps} @ 9.6 \text{ kBq/cc}

SF = 37.4%
Time-of-Flight Resolution

NEMA NU 2-2018

- 70 cm scatter phantom with \(^{18}\text{F}\) line source

Additional TOF Measurements

- Additionally, using 70 cm scatter phantom measured TOF resolution of:
  - single detector ring
  - detector block-to-block
  - single crystal-to-crystal
Time-of-Flight Resolution

NEMA NU 2-2018

505 ps at 5.3 kBq/cc (low activity)

Additional TOF Measurements

Using counts from 0 - 12 kBq/cc

Single detector ring:
- 497 ps

Detector block-to-block:
- 461 ± 10 ps

Single crystal-to-crystal:
- 412 ± 35 ps
Activity distribution and scan protocol

- Sphere-to-background ratio: 4.07
- Bkg. activity conc.: 5.03 kBq/ml
- Total activity: 4.6 mCi
- Acquisition duration: 30 min
- 3D-TOF OSEM with all corrections, 4 iterations, 20 subsets

NEMA IQ Tool

- Semi-automated analysis tool in MATLAB
- Sphere centers found by parabolic fitting
- 2D ROIs defined automatically

Sphere diameters (mm): 10, 13, 17, 22, 28, 37
Using 1 mm voxels and PSF modelling:
- CRC >63% and background variability <4% achieved for all sphere sizes
Image Quality Throughout the AFOV

- NEMA image quality and scatter phantom scanned at **5 axial bed positions**
- Acquisition length adjusted for activity decay: **same total counts**

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<tr>
<th>Axial Offset from the Center (cm)</th>
<th>CRC_{37mm}</th>
<th>N_{37mm}</th>
<th>CRC_{17mm}</th>
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Duration: 7.6 min, 9.6 min, 11.7 min, 13 min
Image Quality at Reduced Dose or Scan Time

Scan Duration:
30 min

10 min

$T_0$
(4.8 mCi in FOV)

~3 hrs delayed
(32% dose)

~6 hrs delayed
(10% dose)

~9 hrs delayed
(3% dose)

~12 hrs delayed
(1% dose)
Contrast recovery not significantly affected by reducing scan time or dose to 10%
Image Quality at Reduced Dose and Reduced Scan Time

- Background variability still below 5% by reducing scan time or dose to 20%
Clinical Scan: **5 mCi** @90 min

Research Scan: **0.5 mCi** @90 min

Parameters: 3D-TOF OSEM, 4 it., 2.344 isotropic voxels, 20 min
Conclusion

• First physical characterization of the uEXPLORER total-body PET scanner has been performed
  – ~15-60 times higher sensitivity than other PET scanners
  – ~3 mm spatial resolution
  – Uniform IQ throughout AFOV, consistent CRC down to 10% activity

\[
T_0 \\
(4.8 \text{ mCi in FOV})
\]

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(1% dose)
Acknowledgments

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Thank you!