An Ultra-Sensitive Total Body PET Scanner for Biomedical Research

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Sensitivity – Every Count Counts

- PET provides the most sensitive non-invasive molecular assay of the human body
- All PET studies are limited by statistics, radiation dose, or both

Current scanners do not maximize the sensitivity for whole-body imaging
Total-Body PET: Maximizing Sensitivity

- x40 gain NEC!
- Higher statistics
  - Support higher spatial resolution
- Lower radiation dose
  - Whole body scans at ~ 100 µSv
- Higher dynamic range
  - Late imaging, 5 more $T_{1/2}$
- Whole-body kinetics
  - Better temporal resolution
  - All tissues/organs simultaneously
Not a New Idea!

Terry Jones, circa 1990


Applications

• Systemic disease and therapies:
  – Cancer: Ultra-staging and micrometastasis
  – Inflammation
  – Infection
  – Cellular therapy and trafficking
  – Mind-body interactions

• Total body pharmacokinetics
  – Drug development
  – Toxicology
  – Biomarker discovery

• Low Dose may enable:
  – Expanded use in pediatrics
  – Use in chronic disease
  – Studies of normal biology
Working Design

- Modular “Block” Detectors
- \( \sim 3.1 \times 3.1 \times 20 \text{ mm} \) L(Y)SO (16 x16)
- PMT (possibly SiPM) readout
- Time of flight and 1-bit DOI
- 40 rings, 48 detectors/ring
- \( \sim 78.6 \text{ cm} \) ring diameter
- 215 cm axial FOV
- OpenPET electronics
Predicted NEC\textsubscript{TOF} Gains versus Siemens Biograph mCT

**Adult Total Body Phantom:**
- 27 cm
- 200 cm
- **43.9 (10 mCi)**

**Pediatric Total Body Phantom:**
- 20 cm
- 70 cm
- **20.0 (0.3 mCi)**

**Brain:** (Voctiss 8, 6:1 brain to body)
- **4.2 (10 mCi)**

**Heart:** (Voxtiss 8, all in heart)
- **4.7 (20 mCi)**
Lesion Detectability - ALROC

Scan times are total for imaging a 100 cm x 35 cm dia. cylinder.
Spheres are 1.0 cm diameter with 3:1 uptake ratio.
Expected Counting Rates

Adult Total Body Phantom:

- Singles: 164 Mcps
- Prompts: 47 Mcps
- Randoms: 34 Mcps

Singles:Prompts ratio: 3.5

10 mCi in phantom

Optimal ring difference:
284 (~40% axial FOV)
Electronics

- Acquire singles
- Each detector crate writes singles to own disk
  - completely independent and scaleable
- Detector crates all synchronized in time
- Coincidences identified offline
  - complete flexibility in terms of energy window, timing windows etc…

OpenPET Meeting
18:30 Thursday ASEM 201
Why DOI-Encoding may be Necessary
Detector Development

• **Goal:**
  
  < 400 ps timing resolution with 1-bit DOI

• **Approaches:**
  Phosphor-coating, two-layer, monolithic…

3 x 3 x 20 mm LYSO with YAG phosphor
Image Reconstruction

- 2 meter extended NEMA IQ phantom
- Reconstruction:
  - OSEM (5 iterations/2 subsets)
  - 2 mm voxels, 160 x 160 x 1000 image matrix
  - dual 8-core CPUs @ 2.0 GHz,
  - ~10 mins/iteration per 1 billion events

Reconstructed image corresponding to 4-minute scan, 10 mCi in phantom.
Other Considerations

- **Mechanical design**
  - Scale
    - 491,520 crystals
    - 880 kg of L(Y)SO!
  - Thermal management (~30-40 kW)
  - Highly reliable & easily serviced
  - Efficient fabrication scale-up

- **Attenuation correction**
  - Low-dose CT?
  - Static transmission rods?
  - LSO background?

- **Respiratory Gating**

Current Status

- Project launched to build prototype total-body PET scanner with unprecedented sensitivity
  - Simulations are being used to evaluate design trade-offs
  - Initial design and feasibility studies underway
  - Conceptual applications in clinical medicine and research have been formulated

- Community input and participation encouraged
• Greatly increased utilization of available signal
  – Natural technical progression for the development of PET
  – Scans approaching background radiation dose, or,
  – High statistics scans at current radiation dose

• Assured unique novel human applications

• The need for advances which embrace the skill base of the IEEE imaging community:
  – Appropriate TOF/DOI detector technology
  – Optimal sorting and use of singles information
  – Accurate and fast detector normalization
  – Low dose attenuation correction
  – Efficient and accurate image reconstruction
  – …