Bio-medical Applications of Jefferson Lab’s Nuclear Physics Detector Technology

Drew Weisenberger
Radiation Detector and Imaging Group
Physics Division
Thomas Jefferson National Accelerator Facility
JLab’s Continuous Electron Beam Accelerator Facility
Radiation Detector & Imaging Group

◆ Support design and construction of new detector systems
◆ Technical consultants for the lab scientists and users
◆ Development and use of imaging and non-imaging detector systems
◆ Expertise in nuclear particle detection
  ➢ gas based detectors
  ➢ silicon photomultiplier (SiPMs)
  ➢ scintillation and light guide techniques
  ➢ standard and position-sensitive photomultiplier tubes (PSPMTs)
  ➢ fast analog readout electronics and data acquisition
  ➢ on-line image formation and analysis
  ➢ image reconstruction algorithms with motion correction
Detecting and Imaging Radioactive Decay (a nuclear process)

Scintillator: transparent material for detecting high energy photons (i.e. x-rays, gamma-rays)

A high energy photon deposits energy in the atoms of the scintillator resulting in the release of lower energy photons that can then be converted to an electrical signal by devices called photomultiplier tubes (PMTs).

**Compton Scattering**

before

after

**Photoelectric Absorption**

incident gamma-ray

\[ E_e = h\nu - E_b \]
Bio-Medical Imaging Modalities

Structural

Functional

Somatostatin receptors (neuroendocrine tumors)
Nuclear Medicine Imaging Basics

Functional imaging (vs structural): patient injected with a radiopharmaceutical that has a biological function in the body i.e. metabolism.

Radiopharmaceutical: radioactive isotope + bioactive tag

**Gamma Camera**
planar nuclear medicine images (also known as scintigraphy)

**Single-Photon Emission Computed Tomography (SPECT)**
technetium-99m (140 keV gamma-ray, 6 hour half-life)

**Positron Emission Tomography (PET)**
coincident radiation detection through positron-electron interaction fluorine-18 (positron emitter, 110 minute half-life) two 511 kev annihilation photons
Clinical SPECT System

Clinical PET System

End View

Rotating Gantry

Gamma Camera Module

Side View

Annihilation Point

Detector Ring

Detector Module

gamma ray

gamma ray
Latest photomultiplier technology allows modular detector construction.

Compact position sensitive PMTs and Silicon PMs

Pixelated Scintillator Crystal

Light Spreader

PSPMT  PSPMT  PSPMT  PSPMT  PSPMT
Breast-Specific Gamma Imaging

Need for a Detector Built for the Task
Dilon 6800 Gamma Camera

Smart Shield™ immobilizes the breast and prevents shine-through

Compact detector allows imaging close to the chest wall

Several patents licensed from JLab

www.dilon.com
Handheld Gamma Camera for Cancer Surgery

Imaging lymph nodes before surgery with JLab built **gantry mounted gamma camera**. Right: Imaging during surgery. University of Virginia surgeons.

SiPM based would be lighter and hand held.

patents pending
Awake Small Animal Imaging

A new tool for biological research under development:

JLab, ORNL and JHU

Several patents awarded and pending
Image of mouse injected with bone marker MDP-Tc99m

Using high resolution parallel hole collimator

Using 1mm pinhole ~2x magnification
Indications for awake animal SPECT imaging

- Addiction research
- Neuro-degeneration:
  - Alzheimer's Disease
  - Parkinson's Disease
- Brain inflammation (i.e. HIV, MS).
- Stem cell trafficking

- Avoid influence of anesthesia on: blood flow, metabolism, neural-vascular coupling
- Elucidate disease pathophysiology
- Drug/radiopharmaceutical development
- Mimic the human state
Awake Animal SPECT-CT Imaging System

An awake mouse with infrared reflectors for head tracking shown in imaging burrow.

Computer display illustrating real-time pose tracking via the stereo infrared CCD cameras.
SPECT Scan of Awake Mouse

Movie of Multiple SPECT Projections

Tc99m-MDP
Handheld Imaging Gamma Detector Development

Hand held gamma cameras for field work
SiPM based with tracking

Handheld detector with tungsten shell and tungsten collimators
Plant Biology Specific PET Detector Development

- Crop Pathogen
- Bio-fuels
- Photosynthesis Studies
- Subsurface radiation contamination to crops
- Carbon sequestration

Dual 15 cm x 20 cm Planar PET system
- 3.03 mm step pixelated, 10 mm thick LGSO (90% LSO, 10% GSO) array
- 6x8 array of Hamamatsu R7600-00-C8 PSPMTs

Dual 5 cm x 5 cm Planar PET system
- 1.5 mm step pixelated, 10 mm thick, LYSO array using 4ch PEM readout
- Single Hamamatsu H8500 PSPMT

Hordeum distichum L

Duke Forest FACE

Reach in EGC

Silicon Photomultiplier (SiPM)
- Compact
- MRI compatible
The model plant used for the experiment was barley (Hordeum distichum L.) grown in hydroponic fluid.
PET Imaging of Carbon Dioxide Utilization in Plant

Montage of root area reconstructed images. Time bin for each image was 20 minutes. Images are decay corrected for the half-life of $^{11}$C. Time bin was 20 minutes, images are decay corrected for the half-life of $^{11}$C.

Reconstruction montage of the leaf area of the image data obtained using a Plexiglass positron trap. Enhanced sensitivity is observed.
R3292 110mm diam. Hamamatsu PSPMT coupled to BC400 0.5mm thick plastic scintillator, 15 microns Mylar film and 25 micron Tedlar film were applied on top of the scintillating plastic. Detector ~600X more sensitive that dual planar PET.

"Detector on a stick"
Gamma-ray Imaging for Biological Systems

Partners:

- Oak Ridge National Laboratory (ORNL)
- Triangle Universities Nuclear Laboratory (TUNL)
- Los Alamos National Laboratory (LANL)
- West Virginia University
- Hampton University Proton Therapy Institute
- University of Virginia
- Johns Hopkins University
- Case Western Reserve University
- College of William and Mary
- Duke University
- Columbia University
- Dilon Technologies, Inc.
Detector Group Spin-Off Companies

Dilon Technologies
Ray Visions, Inc
Adaptive I/O
NeoMed

JLab CTO: Roy Whitney
757-269-7536
https://www.jlab.org/exp_prog/techtransfer/