“Beside the comfort of knowledge, every science is auxiliary to every other.”

Thomas Jefferson

August 26, 1786
JLab Detector and Imaging Group

Support design and construction of new detector systems
Technical consultants for the lab scientists and users
Development and use of radiation detection systems
Expertise in nuclear particle detection

Stan Majewski (Group Leader) - detector concepts/design applications
Brian Kross - mechanical design and construction / gas systems
John McKisson- software / data acquisition / electronics
James Proffitt - high speed electronics
Sasha Stolin - medical physics post doc
Drew Weisenberger - data acquisition / applications / photo multipliers
Carl Zorn - scintillators / photo multipliers / optics
Detector Physics
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

Photoelectric Absorption

\[ \text{dN/dE} \]

\[ \Theta = \pi \]

\[ E_c \]

\[ \text{hv} \]

\[ \text{photo peak} \]

\[ \text{Compton continuum} \]

\[ E (\text{energy}) \]

\[ \Theta = 0 \]

\[ \Theta = \pi \]

\[ E_c = \text{hv} - E_b \]
Nuclear Medicine
Medical Imaging Modalities

Structural

Functional

Somatostatin receptors (neuroendocrine tumors)

www.radswiki.net
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
<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life</th>
<th>Photon energies (keV) (photon abundance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>technetium-99m</td>
<td>6.02 hours</td>
<td>140 (89%)</td>
</tr>
<tr>
<td>indium-111</td>
<td>2.83 days</td>
<td>170 (94%), 240 (90%)</td>
</tr>
<tr>
<td>gallium-67</td>
<td>3.25 days</td>
<td>93 (37%), 185 (20%), 300 (17%), and 394 (4%)</td>
</tr>
<tr>
<td>iodine-123</td>
<td>13.3 hours</td>
<td>159 (84%)</td>
</tr>
</tbody>
</table>

**99mTc-sestamibi**

<table>
<thead>
<tr>
<th>Positron Emitting Isotope</th>
<th>Half-life (minutes)</th>
<th>Positron $E_{\text{max}}$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>oxygen-15 ($^{15}\text{O}$)</td>
<td>2.07</td>
<td>1.72</td>
</tr>
<tr>
<td>nitrogen-13 ($^{13}\text{N}$)</td>
<td>9.96</td>
<td>1.19</td>
</tr>
<tr>
<td>carbon-11 ($^{11}\text{C}$)</td>
<td>20.4</td>
<td>0.96</td>
</tr>
<tr>
<td>fluorine-18 ($^{18}\text{F}$)</td>
<td>109.7</td>
<td>0.64</td>
</tr>
</tbody>
</table>

**$^{18}\text{F}$ -fluoro-2- deoxyglucose (FDG)**
Typical Clinical Gamma Camera

- Matrix of photomultiplier tubes
- NaI crystal scintillator
- Light guide
- Parallel hole lead collimator
- Circuit to determine X,Y of interaction
- Host Computer
- X
- Y
- SUM

Matrix of photomultiplier tubes
Nal crystal scintillator
Light guide
Parallel hole lead collimator
Circuit to determine X,Y of interaction
Host Computer
X
Y
SUM
Clinical SPECT System

Clinical PET System
Latest photomultiplier tube technology allows modular detector construction

Compact position sensitive PMTs:

Hamamatsu’s R7600, H8500/H8900, and Burle’s 85001.
Light Distribution
Slab vs. Pixellated

Simple light guide light is sufficient to bypass the cracks

Tapered light guides are required to recover light loss in the cracks
Scintillator Array
Need for a Detector Built for the Task
Breast-Specific Gamma Imaging (BSGI):
Functional imaging to complement mammography
Uses Tc99m-sestibibi
Compact Detector Allows for Improved Imaging
System is being used in centers all across the US, from Seattle to Houston, CA to FL, and there are many in the North & Eastern states/cities- such as in NYC, Philadelphia, Pittsburgh, Washington, DC, Boston, Newport News, Raleigh

Lahey Clinic in Burlington, MA

Since the first camera installation about 3 years ago, there have been about 60,000 patients imaged with the Dilon 6800
X-ray mammogram: The patient returned 8 weeks later reporting increased perception of dimpling. No palpable area noted in the clinical examination.

Follow-up Ultrasound: Right breast - fibrocystic change with a large number of cysts. No discrete mass is found.
BSGI: Left breast – normal uniform distribution. Right breast – a large area of asymmetric focal area of increased uptake in the upper-inner quadrant of the breast, measuring approximately 2 cm. A second, smaller and more intense focus located retroareolar, measuring about 1 cm at the 6 o’clock position. In addition, there are areas of increased activity in the right axilla which may be node activity. Multifocal positive in the right breast and possible positive findings in the right axilla.
Awake Small Animal Imaging

A new tool for biological research under development:
JLab, ORNL and JHU
Image of mouse injected with bone marker MDP-Tc99m

Using high resolution parallel hole collimator

Using 1mm pinhole ~2x magnification
Why anesthesia in Small Animal SPECT imaging?

Eliminate motion artifacts while taking multiple projections

Clinical SPECT
### Effects of anesthesia on cerebral blood flow

<table>
<thead>
<tr>
<th>anesthetic</th>
<th>effect on CBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>isoflurane</td>
<td>↑↑</td>
</tr>
<tr>
<td>chloral hydrate</td>
<td>=</td>
</tr>
<tr>
<td>(\alpha)-chloralose</td>
<td>↓</td>
</tr>
<tr>
<td>propofol</td>
<td>↓</td>
</tr>
<tr>
<td>sevoflurane</td>
<td>↓</td>
</tr>
<tr>
<td>pentobarbital</td>
<td>↓↓</td>
</tr>
</tbody>
</table>
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
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.

Modified SPECT/CT gantry with X-ray shield removed at JHU
Head Pose Measurement Approach

Cameras

Segmentation & Correspondence

3D Pose Calculation

Time-stamped Pose Parameters
Awake Animal SPECT-CT Imaging System Presently at JHU
SPECT Scan of Awake Mouse

Movie of Multiple SPECT Projections

Tc99m-MDP
SPECT and Tracking Reference Frames
Motion Correction for 6 Degrees of Freedom

Three translations \( (t_p) \):
- \( X \)
- \( Y \)
- \( Z \)

Three rotations \( (R_p) \):
- roll
- pitch
- yaw

Mouse head pose parameters:
- translation \( t_p \), rotation \( R_p = R_y \ R_x \ R_z \) (yaw, pitch, roll)

Transformation from tracking coordinate system to gamma camera coordinate system \( R_{TG}, t_{TG} \)

Motion of a point in gamma camera reference frame

\[
X(\text{GRF};t) = R_{TG} \left[ R_p(t)R_p^{-1}(t_0) \left\{ R_{TG}^{-1} \left[ X(\text{GRF};t_0) - t_{TG} \right] - t_p(t_0) \right\} + t_p(t) \right] + t_{TG}
\]
Computer Iterative Reconstruction of all 6 degrees of freedom on Simulated Data
SPECT Reconstruction of Moving Phantom with Roll Change

Latest Results!
Final Words

• Radiation therapy monitoring
• Prostate cancer detection
• Brain imaging AD, PD
In 2004, federal funding of research in the physical sciences as a fraction of GDP was 54% less than in 1970. In engineering, it was 51% less.

...

In 2005, only four American companies were among the top 10 in receiving US patents.

...

Federal annual investment in research in the physical sciences, mathematics, and engineering combined is equal to the increase in US health care costs experienced every 6 weeks.
Acknowledgements

This work is supported by the U.S. Department of Energy Office of Biological and Environmental Research in the Office of Science through the DOE Medical Imaging program and from the DOE Office of Nuclear Physics.
"I have never heard before such support for the physical sciences from a President of the United States. But if the FY 09 enacted budget proves similar to FY 07 and FY 08 a "three-peat," the future of the physical sciences will be in jeopardy. Opportunities will be lost forever: for science, and our country."

Dr. Ray Orbach, Director of the Department of Energy Office of Science, and Under Secretary for Science commenting on the State of the Union Address.

The American Institute of Physics and two of its Member Societies, the American Physical Society and the American Association of Physicists in Medicine, have joined 50 scientific societies and associations, universities, and corporations in endorsing a letter requesting $300 million "to prevent serious damage to vital U.S. scientific efforts supported by the Department of Energy (DOE) Office of Science."

Letter sent January 28th by the Energy Sciences Coalition, to which AIP and several of its Member Societies belong, the President, DOE and select members of Congress requesting emergency funding.