PET in Norway an example

Julie Haglund

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Sweden/Norway

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Institute For Medical Physics (IFMP) Workshop
"PET Principles, PET use in hospital, and ongoing developments"
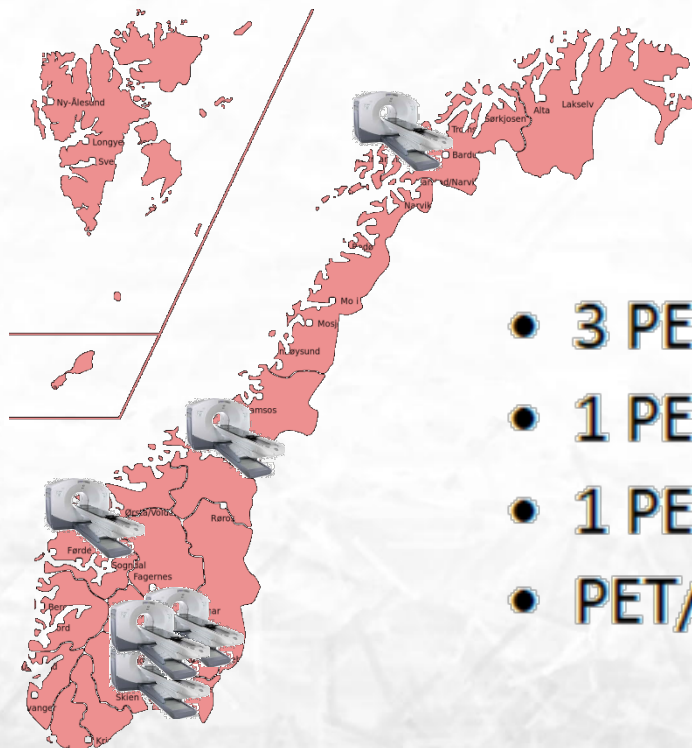Ohrid, Macedonia; 6-8 September 2015

Sykehuset Østfold

Norway
Population: 5 165 800

Area: 323,802 km²
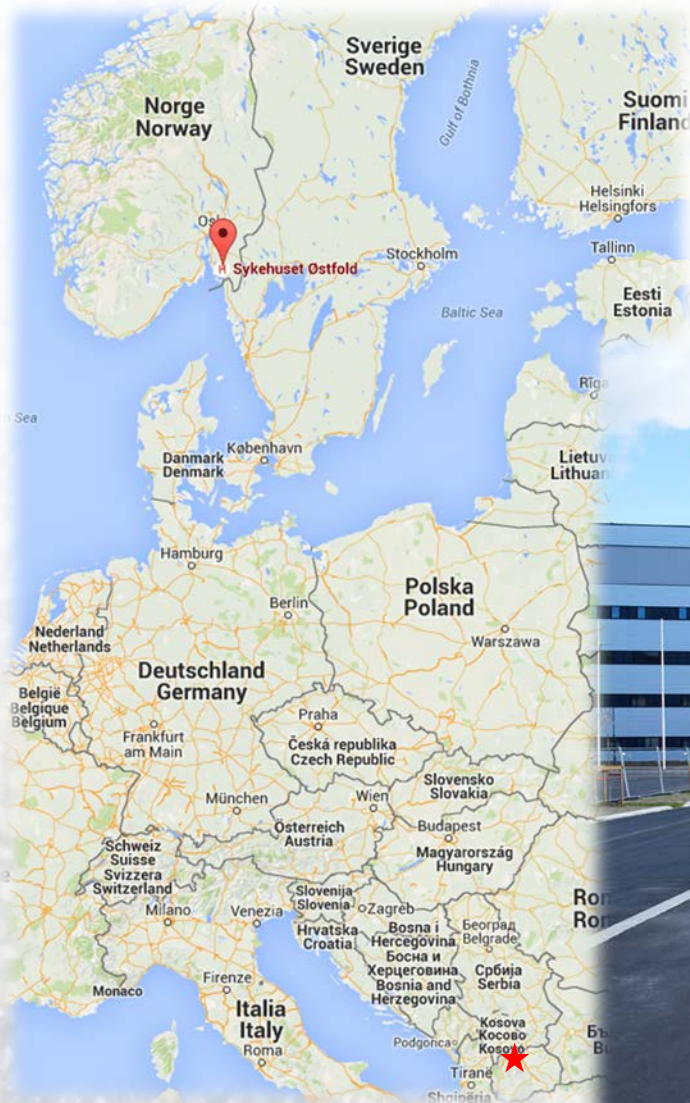

Sykehuset Østfold

PET i Norge

- 3 PET/CT Oslo Universitetssykehus
- 1 PET/CT Haukeland Universitetssykehus +1
- 1 PET/CT UNN
- PET/MR og PET/CT St.Olav høsten 2013

→ PET/CT Sykehuset Østfold Kalnes 2015

Sykehuset Østfold

New facility
Replaces 5 regional hospitals
Psychic and somatic health care
First departments: May 2015
Complete clinical operation: November 2015

Construction start: 2011

First clinical activities:
May 2015

Insert
PET/CT
here!

RØMNINGSPLAN

MR
MR
Røntgen
CT

SPECT/CT

PET/CT

What must we consider when installing a PET/CT?

- Which one to purchase?
- What will we do with it?
- What can we do with it?

- Where will it be?
- Who will use it?

Julie Haglund, haglundj@aol.com, augusti 2015

Sykehuset Østfold

Today, we have one SPECT/CT and 2 hotlabs.
We perform nuclear medicine studies and diagnostic CT.

The Mo/Tc99m generator is delivered every week.

Isotopes we use:
Tc99m
Ra-223 (therapy)
I-131 (therapy)
I-123

Julie Haglund, haglundj@aol.com, augusti 2015

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What do we need for PET/CT?

Positron emitting isotopes!

Our options: Positron emitting isotopes are produced in generators or cyclotrons.

Maybe, in the future, but also expensive.

Out of budget! Not spontaniously installed!
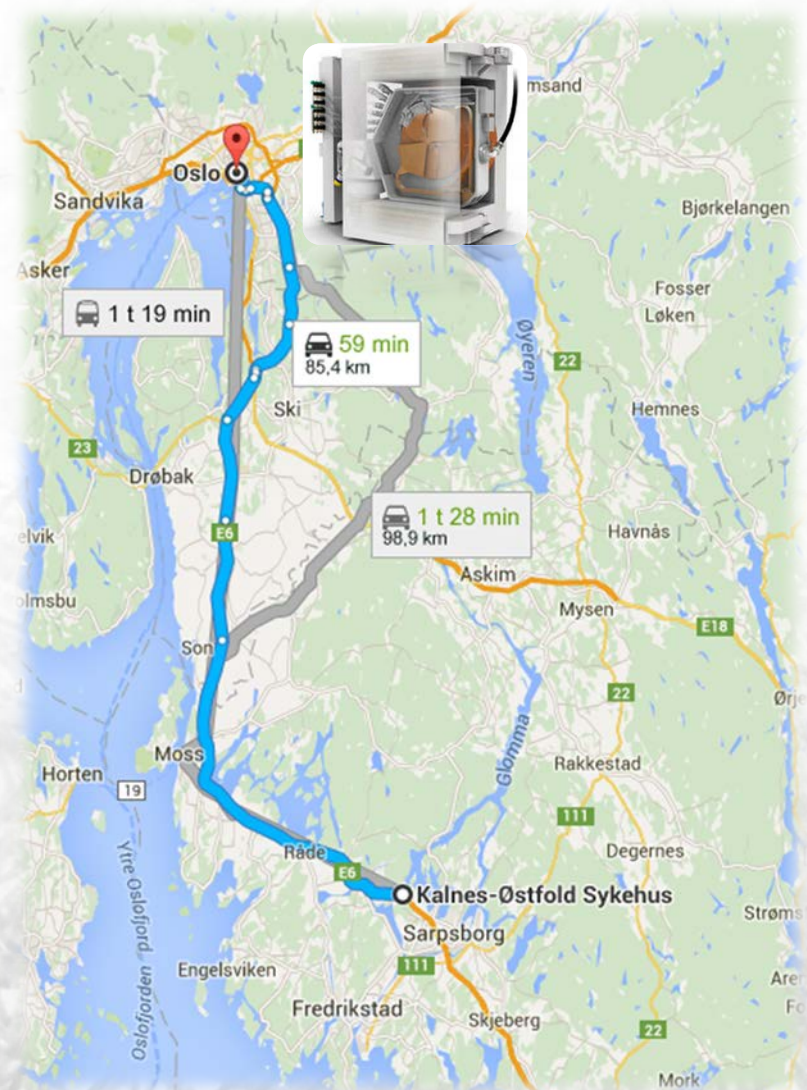
(Rubidium) generator

Cyclotron

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Solution: Oslo has cyclotron

Limitations:

- **What isotopes Oslo produces**
- **How often Oslo produces**
- **What can be transported (~1hr)**

Conclusion:

FDG delivery once daily

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Which PET/CT to purchase?
an investment now and for the future (~10-12 years)

What can we use with a PET/CT? → FDG
Rubidium

What will we do with a PET/CT?

→ Clinical patient studies/examinations
→ Research projects/Collaborations

Which PET/CT to purchase?

Requires extensive evaluation
by a multi-disciplinary team!

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The puchasing process includes research by a multi-disciplinary team including physicians, physicists, building/construction representatives, medical techncal personnel, radiographers/technicians who will work with the PET/CT.
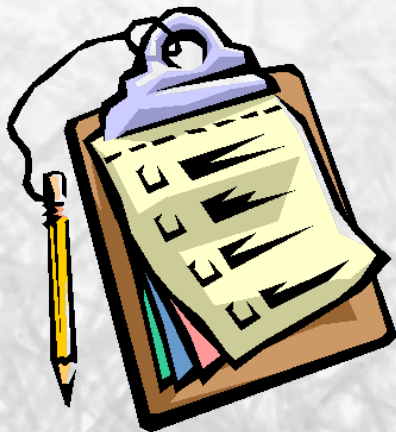
The group gathers information about available PET/CT systems and evaluates according to a list of desired and required characteristics of the machine that will be purchased.

Sykehuset Østfold

Specification of Requirements

- Big Excel document
- Given to each manufacturer
- Our demands and desires for the performance of the PET/CT
- Includes:
    - physics of the PET, physics of the CT, hardware, software, IT-solutions, reconstruction algorithms, protocols, energy use, heating/cooling requirements, area required for the scanner and additional equipment, education of personnel, equipment updates,...
- Each manufacturer states how or if thier machine meets our list of requirements

Julie Haglund, haglundj@aol.com, augusti 2015

Sykehuset Østfold

Specification of Requirements

	A	B	C	D	E
109	5.33	Effektivitet (geometrisk) i prosent	B	JA	0,93
110	5.34	Detektorbredde i aksialretning (mm)	B	JA	19,2 mm.
111	5.35	Oppgraderingsmuligheter	B		Siemens har som policy at våre nyvinninger også skal kunne bli tilgjengelig på eksisterende utstyr. Det betyr at man gis mulighet til å oppgradere systemet med ny funksjonalitet om det blir aktuelt.
112	**6.0**	**Scan**			
113	6.1	Oppgi minste mulige kollimering ved aksialt og helikalt opptak	B	JA	0.6 mm Merk! Oppløsning på 0.33 mm (x,y og z) oppnås ved overlappende utregninger av snitt.
114	6.2	Oppgi største mulige kollimering ved aksialt og helikalt opptak	B	JA	20 mm
115	6.3	Oppgi maksimal mAs på lengste scan.	B	JA	666 mAs
116	6.4	Oppgi detektordekning ved helikal og aksiale skann	B	JA	128 mm
117	6.5	Bordbevegelse mm/s min/max	B	JA	Table speed range 0.1-200 mm/sec ; gjelder mCT Flow (opsjon)
118	6.6	Oppgi pitch muligheter	B	JA	0,3 - 1,5 for Biograph mCT 64,
119	6.7	Rotasjonshastighet ved 360 grader	B	JA	mCT 64 : 0.33, 0.5, 1.0 s
120	6.8	Maksimal skanntid (sek)	B	JA	Max scantid på 100s ved spiral scann I praksis ingen begrensning.
121	6.9	Maksimal skannlengde (cm), både helikalt og aksialt	B	JA	2200 mm for CT only Maximum co-scan: 203cm with pallet extensions (3-ring) 198cm with pallet extensions (4-ring)
122	6.10	Maks antall bilder mulig i en serie	B	JA	Ingen praktisk begrensning. Man kan for eksempel kjøre hele kroppen, med 0.33 mm i romlig oppløsning. Etter dette kan dere rekonstruere så mange bilder dere ønsker i ønsket snittykkelse, alt etter hva slags kollimering dere har valgt. Og i tillegg kommer det an på hvor stort mellomrom dere ønsker mellom snittene. Fra én rotasjon med ett rør/én detektor kan systemet beregne 384 snitt (1mm).
123	6.11	Rekonstruksjonstid (bilder per sek)	B	JA	Opptil 40 bilder/sek for Biograph mCT 64
	6.12	Minste tidsoppløsning (ms)	B	JA	Ned til 83 ms (Biograph mCT 64)

Requirement

Importance scale

Fulfilled or not
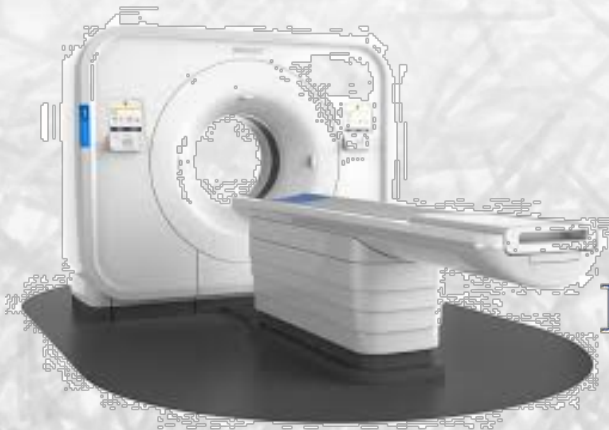
Details: how the requirement is fulfilled

Side 14

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Which PET/CT to purchase: 3 choices

GE Discovery 610

Siemens Biograph mCT

Philips Vereos PET/CT

Sykehuset Østfold

Which PET/CT to purchase: Evaluating the PET Physics

Characteristics we wanted:

The scanner shall be able to perform all types of PET examinations and come with protocols and equipment for performing all scan types.
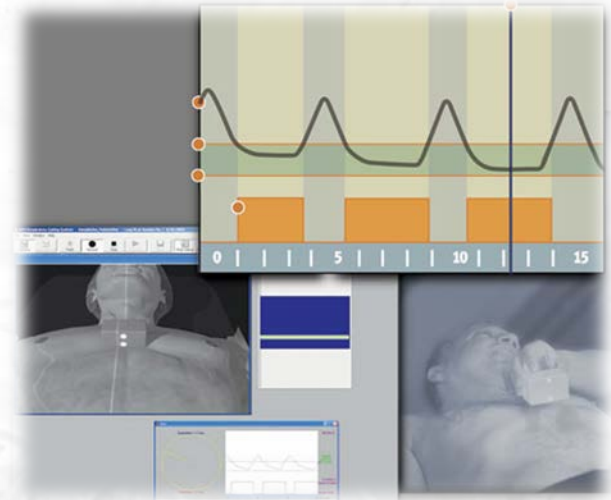
Evaluation:

- The machine from every manufacturer gives the possibility to perform all relevant examinations.
- Siemens & GE: requested software can be purchased as an option
- Philips: all requested software is included; protocols from our Ingenuity CT can be imported to the PET/CT

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Characteristics we wanted: EKG and respiratory gating

Evaluation:
- Each manufacturer has a unique solution for EKG and respiratory gating, and the solution is included in the purchasing of the PET/CT

- <u>Siemens</u>: a unique system for gating and triggering that makes possible the gating of CT and PET uptake; EKG triggering is possible; gating is prospective or retrospective
- <u>GE</u>: uses Varian RPM and IVY7800 trigger for cardiac gating
- <u>Philips</u>: is compatible with Varian RPM

Sykehuset Østfold

Evaluating the PET Physics means looking at the crystals, the detectors

Properties of the Ideal Scintillation Crystal for PET

Crystal property	Purpose
High density	High γ-ray detection efficiency
High atomic number	High γ-ray detection efficiency
Short decay time	Good coincidence timing
High light output	Allows large number of crystal elements per photodetector
Good energy resolution	Clear identification of full energy events
Emission wavelength near 400 nm	Good match to photomultiplier tube response
Transparent at emission wavelength	Allows light to travel unimpeded to photomultiplier tube
Index of refraction near 1.5	Good transmission of light from crystal to photomultiplier tube
Radiation hard	Stable crystal performance
Nonhygroscopic	Simplifies packaging
Rugged	Allows fabrication of smaller crystal elements
Economic growth process	Reasonable cost

Melcher, Charles L.; Scintillation Crystals for PET; J NuclMed2000;41:1051-1055

Julie Haglund, haglundj@aol.com, augusti 2015

Sykehuset Østfold

Characteristics: Scintillation crystals

Scintillator characteristics					
Manufacturer	Scintillator crystal	Light decay time (ns)	Attenuation coefficient (cm^{-1})	Light output (photons/MeV)	Density (g/cm^3)
GE	BGO	300	0,95	7000	7,13
Siemens, Philips	LSO, LYSO	40	0,86	26000	7,4
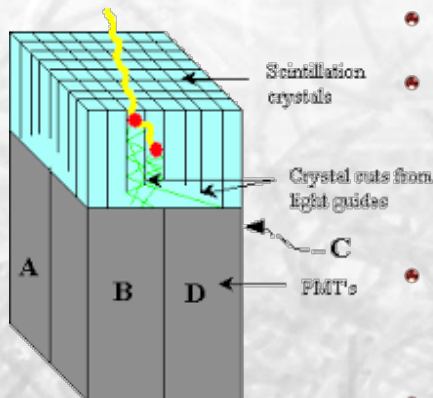
- Crystal density influences detection sensitivity
- Light decay time influences count rate; determines scanner deadtime and random coincidences rate; determines use of ToF or not
- Light output determines energy and spatial resolution
- Stopping power of LSO is slightly lower than BGO

Julie Haglund, haglundj@aol.com, augusti 2015

Sykehuset Østfold
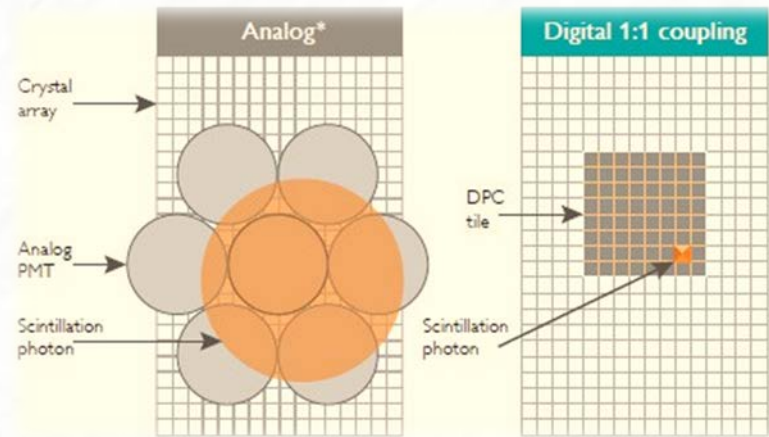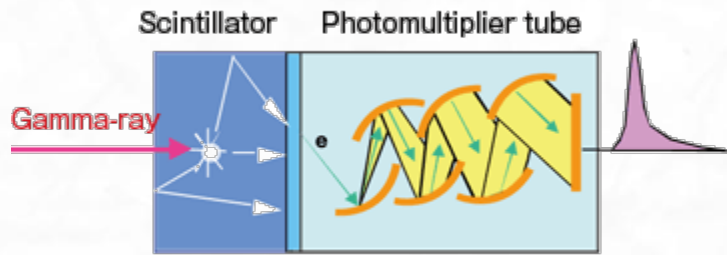
Manufacturer	Detector technology	Crystal size (mm)	# crystals / detector
GE	Analogue	4,7 x 6,3 x 30	12 crystals/PM-tube
Siemens	Analogue	4 x 4 x 20	42 crystals/PM-tube
Philips	Digital	4 x 4 x 19	1:1 coupling (23,040 digital detectors)

- Larger crystals → wider FWHM; worse spatial resolution
- Crystal elements coupled to PM-tubes → worse spatial resolution, even for a greater total number of detector elements
- Smaller crystal cross-sectional area → smaller pixel size; greater spatial resolution

Julie Haglund, haglundj@aol.com, augusti 2015

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Spatial Resolution (FWHM)

a measure of the ability of the device to faithfully reproduce the image of an object; the minimum distance between two points in an image; influenced by detector size & block configuration

Siemens

PET NEMA 2007 Spatial Resolution – Axial (Typical)	Standard Processing (256x256)	HI-REZ Processing (400x400)
FWHM @ 1 cm (mm)	5.5	4.5
FWHM @ 10 cm (mm)	6.0	5.9
PET NEMA 2007 Spatial Resolution – Transverse (Typical)	Standard Processing (256x256)	HI-REZ Processing (400x400)
FWHM @ 1 cm (mm)	5.9	4.4
FWHM @ 10 cm (mm)	6.0	4.9

Philips

Transverse spatial resolution @ 1 cm	4.1 mm FWHM
Transverse spatial resolution @ 10 cm	4.5 mm FWHM
Axial spatial resolution @ 1 cm	4.1 mm FWHM
Axial spatial resolution @ 10 cm	4.3 mm FWHM

GE

Spatial resolution FWHM[1]	NEMA performance standards[††]	VUE Point HD[1]
Axial @ 1 cm	5.6 mm	5.0 mm
Axial @ 10 cm	6.3 mm	5.0 mm
Transaxial @ 1 cm	5.0 mm	4.0 mm
Transaxial @ 10 cm	5.6 mm	4.5 mm

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System Sensitivity

- the number of counts per unit time detected by the PET/CT for each unit of activity present in a source
- depends on the geometric efficiency, detection efficiency, PHA window settings, and the dead time of the system
- detection efficiency of a detector depends on the scintillation decay time, density, atomic number, and thickness of the detector material

Manufacturer	System Sensitivity (cps/kBq)
GE	10
Siemens	9,5
Philips	22

System sensitivity increase as the square of the detector efficiency, which depends on scintillation decay time and stopping power of the detector → LSO/LYSO preferred to BGO

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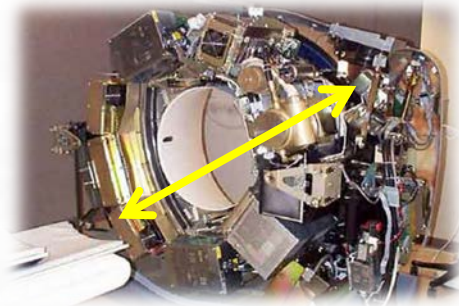
Axial detector width

More detector material across the FoV captures more information per bed position

Manufacturer	Axial FoV (cm)	Number of detector rings
GE	15,7	4
Siemens	21,6	4 (TrueV)
Philips	16,4	5

We desire as wide a detector as possible in the axial direction → fewer bed stops to cover the same patient volume

Without TrueV TrueV

Julie Haglund, haglundj@aol.com, augusti 2015

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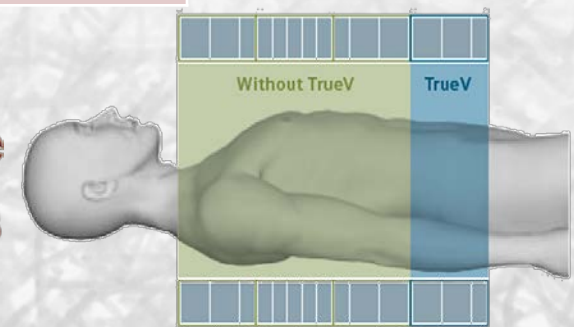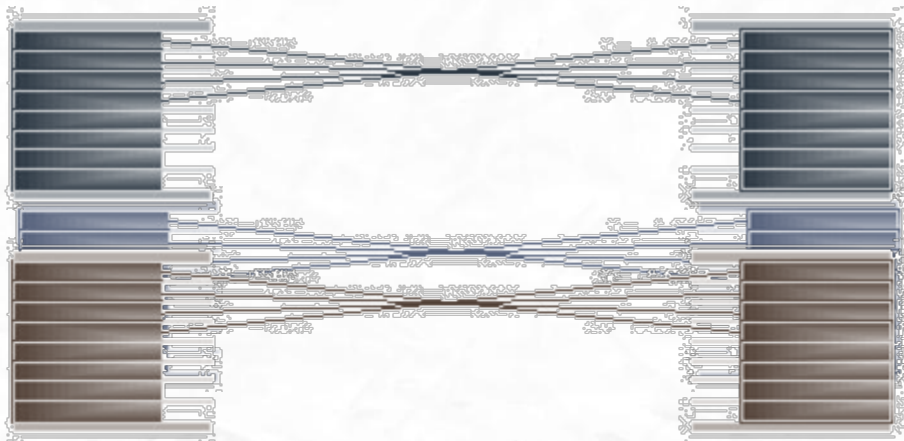
Bed overlap

PET/CT signal suffers from degradation from the center to the edge of the axial FoV

- Overlapping sequential bed positions compensates
- Can lead to axially varying noise sensitivity if there is not enough overlap

Manufacturer	Bed Overlap (%)	Options, Adjustments
GE	23% (standard 11 slices)	Overlap can be adjusted with respect to 1-23 slices
Siemens	43%	FlowMotion eliminates overlap; maintains uniform noise sensitivity across the entire scan
Philips	32%	Optimized for the scanner

Julie Haglund, haglundj@aol.com, augusti 2015

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Time of Flight

Smaller time resolution, coincidence window, and energy resolution → better time and spatial resolution
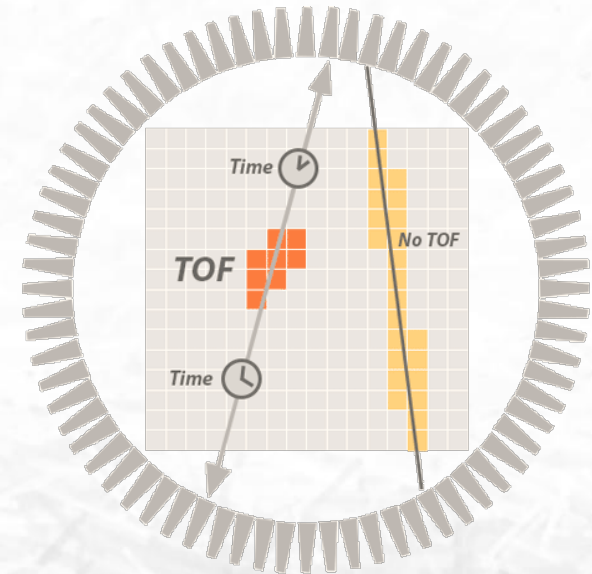
Manufacturer	Timing Resolution (ps)	Coincidence Window (ns)
GE	550	9,5
Siemens	540	4,1
Philips	345	4,0

GE offers a reconstruction method Q.Clear to process the data instead of measuring ToF

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Noise Equivalent Count Rate

Image noise is characterized by NECR

$$\text{Noise Equivalent Count Rate (NECR)} = \frac{\text{TRUES rate}^2}{\text{TRUES rate} + \text{RANDOMS rate} + \text{SCATTER rate}}$$

- NECR is proportional to SNR in the final reconstructed images
- NECR serves as a good parameter to compare the performances of different PET scanners
- Image noise can be minimized by maximizing NECR

Julie Haglund, haglundj@aol.com, augusti 2015

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Noise Equivalent Count Rate

COUNTS VS AKTIVITETSKURVE – VEREOS PET

SIEMENS

NEC – clinical performance

Effective NECR

90
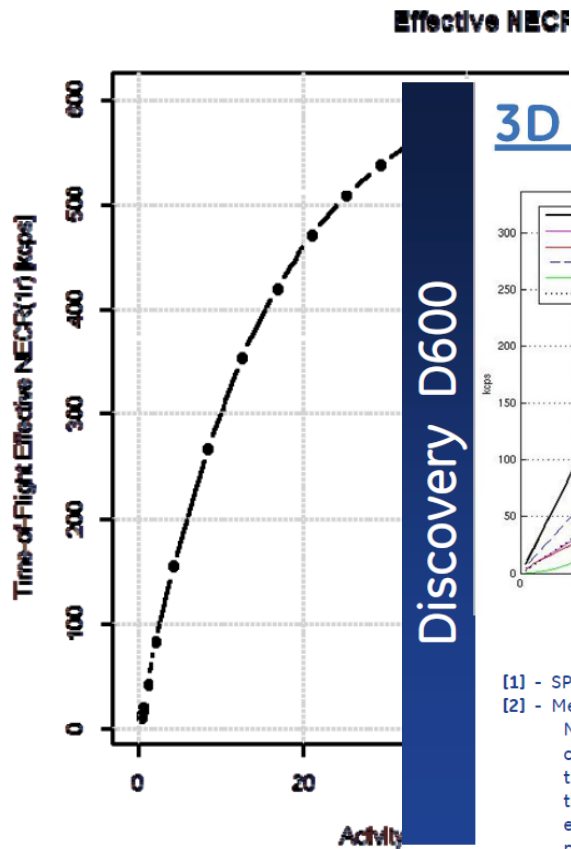
80

INJECTED DOSE RANGE
185 – 740 MBq
5 – 20 mCi
1 hour uptake

Biograph HI-REZ PICO

3D NECR Curves.

KING HAMAD UNIVERSITY HOSPITAL
مستشفى الملك حمد الجامعي

Discovery D600

Count Rate Curves

- Prompts
- NEC
- NEC-2R
- Trues
- Randoms
- Scatter
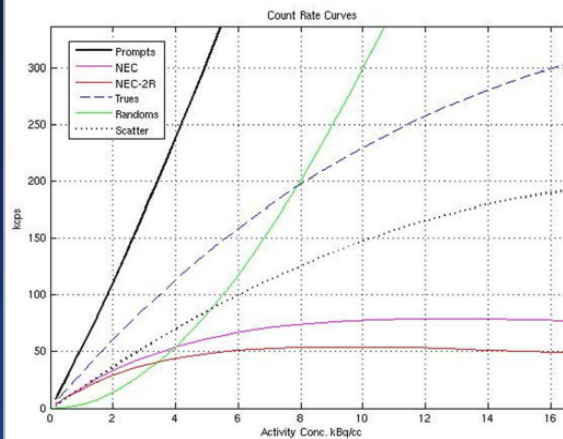
Diagnostic Acquisition
NU2-2007 3D SF and Cnt Rates Scan 1
nuclideName: 18F
data taken at 13/3/2012 16:19:00
report made at 29-Mar-2012 10:04:51

peak NECR is 79.6 KHz at 12.6 KBq/cc
SF at peak NECR is 39.17 %

[1] - SPEC : Lower Limits
[2] - Measured concentration at peak NECR depends on activity meter calibration and frame sampling time. More than 20% variation in the reported concentration is expected. This value is not a performance specification.

3D Peak NECR		
	Counts [kcps] [1]	Activity Conc [kBq/cc][2]
SPEC	68 kcps	15 kBq/cc
Measured	79.6 kcps	12.6 kBq/cc
Pass/Failed	Pass	N.A.

imagination at work

11 /
GE Bartholomé V. /
3/30/2012

Julie Haglund, haglun...

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Noise Equivalent Count Rate

- NECR describes the effective number of counts measured as a function of activity in the FoV
- NECR ☐ SNR
- Image noise can be minimized by maximizing NECR

Scatter Fraction

Lower SF → better scanner performance
Lower SF → better quality of images

$$SF = \frac{C_s}{C_p}$$

Scatter, Prompt count rates

Manufacturer	Peak NECR	Transaxial FoV/bore diameter (cm)	Scatter fraction (%)
GE	76kcps@15kBq/mL	70	38%
Siemens	175kcps@≤28kBq/mL	78	38%
Philips	650kcps@50kBbq/mL	67,6	31%

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Which PET/CT to purchase?

Our team members evaluated their parts of the specification of requirements and presented for the group, and the purchasing package from every manufacturer was evaluated on an equivalent basis

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Philips Vereos PET/CT received the highest evaluation and was purchased.

first digital PET/CT in Norway, third Vereos installation in Europe

Insert PET/CT here!

HELIKOPTERPLASS

AKUTTMOTTAK SOMATIKK

SENGEBYGG

SERVICEBYGG

BEHANDLINGSBYGG

SENGEBYGG

SENGEBYGG

SENGEBYGG

HOVEDINNGANG

PSYKIATRIBYGG

EKSPRESS BUSSTOPP

KOLLEKTIVTERMINAL

OSLO E6 S.BORG

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GE Discovery 610
11 450 000 NOK
(128slice): +400000NOK
Medrad Intego
939 000NOK

Siemens Biograph mCT 64
12 500 000NOK
Flow: 16 750 000NOK
True V: +1621250NOK
Intego: 836 600NOK

Philips Vereos PET/CT
(64slice): 17 825 000NOK
(128slice):+1200000NOK
Intego: 849 800NOK

Julie Haglund, haglundj@aol.com, augusti 2015

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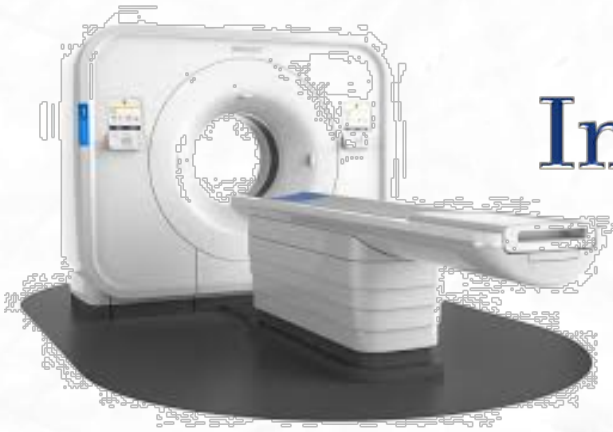
Install Vereos…

…but first install Gemini 64!
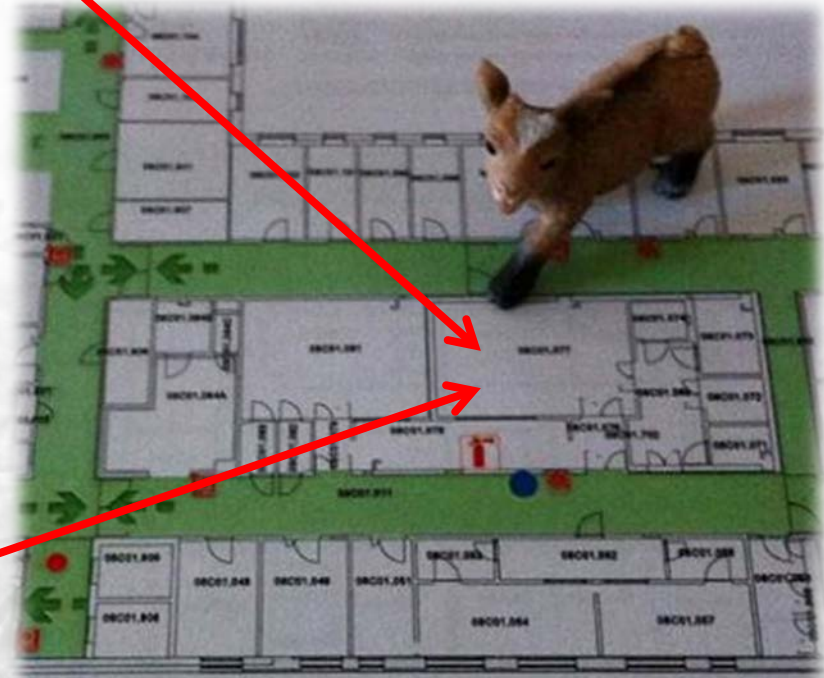
Gemini 64, September 2015
PET patients, October 2015
Vereos, April 2016(?)

Julie Haglund, haglundj@aol.com, augusti 2015

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What must we consider when installing a PET/CT?

Where will it be located?

We have a room (actually 2 rooms) shielded for SPECT/CT

Tc99m energy: 140keV
halflife: 6,02 hours

SPECT shielding is insufficient for PET/CT!

F-18 energy: 511keV
halflife: 109,8 min

ν

e^+ positron
e^- electron
ν neutrino
γ quantum/photon (511 keV)

$180° ± 0.5°$

Julie Haglund, haglundj@aol.com, augusti 2015

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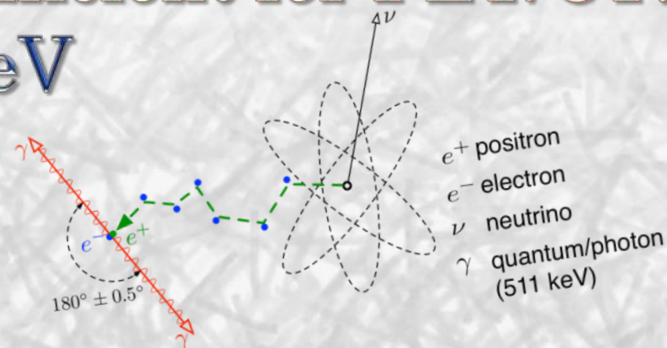
A disadvantage of deciding to install PET after building for SPECT:
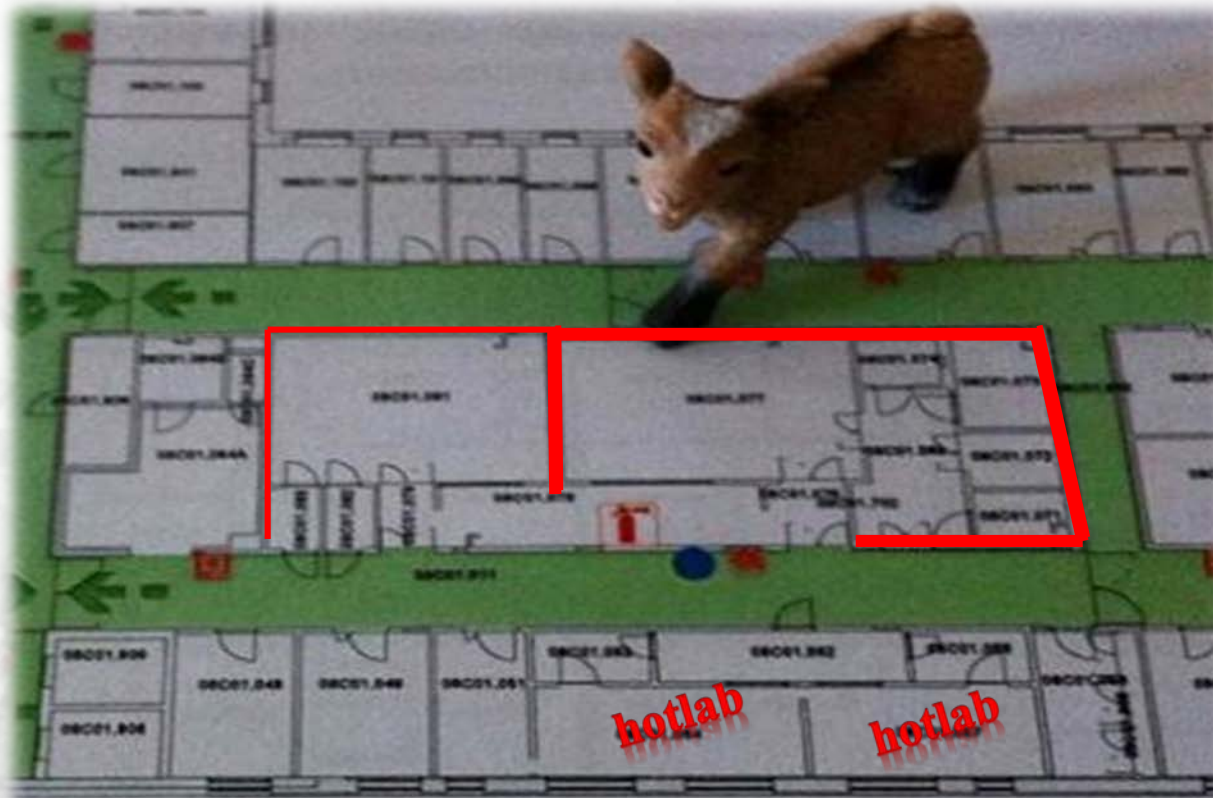
shielding for SPECT ≠ shielding for PET
→rooms get smaller

Julie Haglund, haglundj@aol.com, augusti 2015

Sykehuset Østfold

shielding for SPECT ≠ shielding for PET

3mm lead doors into the patient injection rooms

PET/CT | WC | 3 x injection
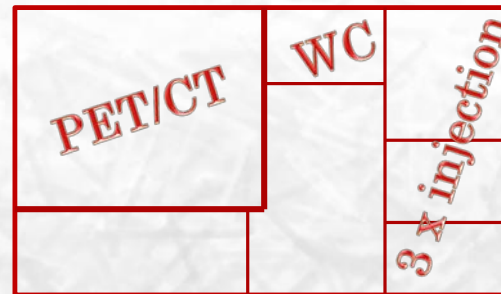
2mm lead SPECT/CT

4mm lead doors into the PET/CT camera room

Sykehuset Østfold

shielding for SPECT ≠ shielding for PET

PET/CT · WC · 3 x injection
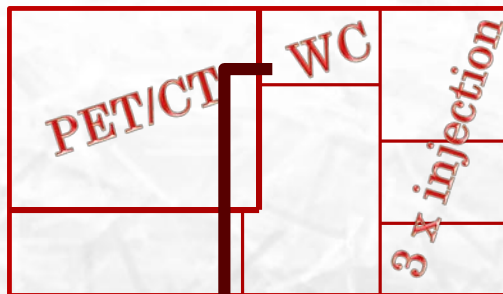
Østfold Hospital Kalnes has a delay tank in the basement

Emptied every 24 hours

Sykehuset Østfold

What must we consider when installing a PET/CT?

Who will use the PET/CT?

Our staff is well trained and routined in SPECT/CT:

 myocardial scintigraphy

 CBF

 heart stress/rest

 diagnostic CT with contrast

 I-131 thyroid therapy

 Ra-223 Xofigo therapy

 I-123

 Tc99m

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All staff are new to PET/CT!

Tc99m energy: 140keV
halflife: 6,02 hours

F-18 energy: 511keV
halflife: 109,8 min

Norway is relatively new to PET/CT

- 4 PET/CT Oslo Universitetssykehus
- 1 PET/CT Haukeland Universitetssykehus
- 1 PET/CT UNN
- PET/CT og PET/MR St. Olsv høsten 2013
- PET/CT Sykehuset Østfold Kalnes 2015

Survey March/April 2014:
How did other hospitals in Norway
educate their staff?

Sykehuset Østfold
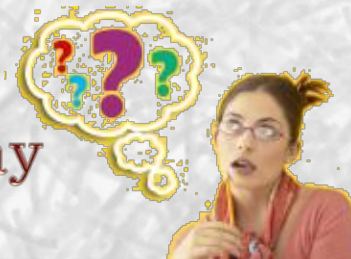
Survey: How did other hospitals educate their staff?

- EANM courses in Wien
- Manufacturer education upon installation
- Study visits to other hospitals
- Reading/studying articles
- Department seminars from colleagues who had been to other hospitals, physicists

Much emphasis on EANM guidelines and study visits

- We also sent out staff to other hospitals in Norway and Denmark
- Asked for protocols and patient letters used by other hospitals to be the guide for our own documents
- EANM guidelines
- Department seminars by the physicist
- Physicist went to many conferences, courses

Sykehuset Østfold

The SPECT/CT staff knows:
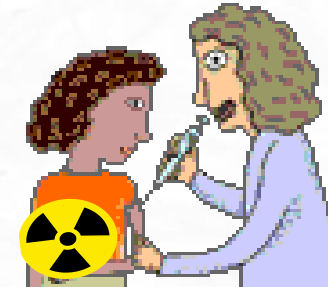
What is different with PET/CT:

EPD

Sykehuset Østfold

Learn examination protocol from EANM:

GUIDELINES

FDG PET and PET/CT: EANM procedure guidelines for tumour PET imaging: version 1.0

Ronald Boellaard · Mike J. O'Doherty · Wolfgang A. Weber · Felix M. Mottaghy ·
Markus N. Lonsdale · Sigrid G. Stroobants · Wim J. G. Oyen · Joerg Kotzerke ·
Otto S. Hoekstra · Jan Pruim · Paul K. Marsden · Klaus Tatsch ·
Corneline J. Hoekstra · Eric P. Visser · Bertjan Arends · Fred J. Verzijlbergen ·
Josee M. Zijlstra · Emile F. I. Comans · Adriaan A. Lammertsma · Anne M. Paans ·
Antoon T. Willemsen · Thomas Beyer · Andreas Bockisch ·
Cornelia Schaefer-Prokop · Dominique Delbeke · Richard P. Baum · Arturo Chiti ·
Bernd J. Krause

Abstract The aim of this guideline is to provide a minimum standard for the acquisition and interpretation of PET and PET/CT scans with [18F]-fluorodeoxyglucose (FDG). This guideline will therefore address general information about [18F]-fluorodeoxyglucose (FDG) positron emission tomography-computed tomography (PET/CT) and is provided to help the physician and physicist to assist to carrying out, interpret, and document quantitative FDG PET/CT examinations, but will concentrate on the optimisation of diagnostic quality and quantitative information.

This guideline is a joint project of the EANM Oncology Committee and the EANM Physics Committee. In addition, this guideline is based on the following three documents:

(1) DGN (Deutsche Gesellschaft für Nuklearmedizin) Leitlinie: "FDG-PET/CT in der Onkologie" by Krause BJ, Beyer T, Bockisch A, Delbeke D, Kotzerke J, Minkov V, Reiser M, Willich N, Arbeitsausschuss Positronenemissiontomographie der Deutschen Gesellschaft für Nuklearmedizin. 2007.

(2) SNM Guidelines: "Procedure Guidelines for tumour imaging with 18F-FDG PET/CT 1.0." by Delbeke D, Coleman RE, Guiberteau MF, Brown ML, Royal HD, Siegel BA, Townsend DW, Berland LL, Parker JA, Hubner K, Stabin MG, Zubal G, Kachelries M, Cronin V, Holbrook S. 2006.

(3) "Applications of F18-FDG-PET in Oncology and Standardisation for Multi-Centre Studies" by Boellaard R, Oyen WJG, Hoekstra CJ, Hoekstra OS, Visser EP, Willemsen AT, Arends AJ, Verzijlbergen JF, Paans AM, Comans EFI, Lugtenburg E, Stoker J, Schaefer-Prokop C, Zijlstra JM, Pruim J. HOVON Imaging workgroup and the Netherlands Society of Nuclear Medicine. 2007

Keywords Guideline · FDG · PET · PET/CT · Tumour · Oncology · Quantification · QC · QA

Introduction

The aim of this guideline is to provide a minimum standard for the acquisition and interpretation of PET

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W. A. Weber

Create a patient questionnaire based on examples from other hospitals

Sykehuset Østfold

EANM EARL Accreditation

Østfold Hospital Kalnes:
- regional hospital, not a university hospital
- new to PET/CT

EARL accreditation:
- demonstrates that we know what we are doing
- possibly facilitates research collaborations
- third EARL hospital in Norway
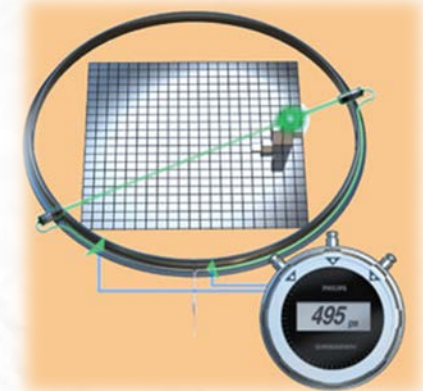
Means more work for the physicist!
- 4 quality control tests (image quality, recovery coefficients) to submit per year

Is your PET/CT centre accredited by the EANM Research Ltd. (EARL)?

Sykehuset Østfold

Takk!

Julie Haglund
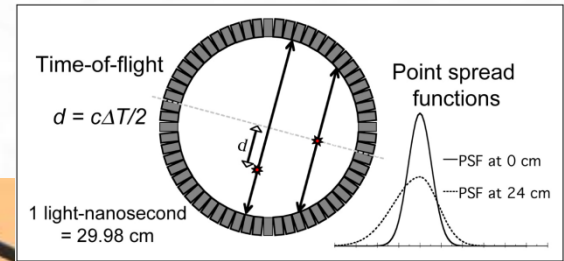Medical Physicist
haglundj@aol.com

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Characteristics: scan range and timing window for reconstruction

Manufacturer	Shortest frame-time	Maximum number of frames	Scan range
GE	1 second	250	120cm
Siemens	3 seconds	100	195cm with TrueV and pallet extensions
Philips	6 seconds randoms subtraction included	99	190cm

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http://www.ncbi.nlm.nih.gov/pmc/articles/PMC 3826954/

Time-of-flight
$d = c\Delta T/2$
Point spread functions
PSF at 0 cm
PSF at 24 cm
1 light-nanosecond = 29.98 cm

Time
TOF
No TOF
Time

TOF

Improvention...
...ossible to kn...
event has taken place on...line
of response, but not the actual
location of the event.

Time-of-Flight technology uses the actual time
difference between the detection of coincident
events to more accurately identify the origin of
the annihilation. Better identification leads to a
quantifiable improvement in image quality.

495 ps

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