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Trends in Radiation Protection of PET/CT Imaging

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Disclosure Statement

I have no relevant financial relationships with commercial interests to disclose.

PET/CT (Hybrid Imaging)

- It is a medical imaging technique using both PET & CT in a single gantry.
- PET scan shows areas with increased metabolic activity (functional), while the CT scan shows detailed locations (anatomical).
- PET/CT is the fastest-growing imaging modalities

- In 2011, > 5,000 PET/CT systems are installed worldwide

Ref: Thomas Beyer et al Nucl Med 2011; 52:303–310.

- In 2011, An estimated of 1.85 Million clinical PET patient studies were performed in the U.S.
- 44% of all PET imaging studies were performed using a mobile PET scanner
- 95% of PET patient studies used radiopharmaceuticals purchased from an outside supplier, & 5% were obtained from cyclotrons on site

Ref: IMV Medical Information Division, 2011

Advantages of PET/CT imaging

Å **Oncology Applications:**

(1) Diagnosis,

(2) Staging,

(3) Restaging,

(4) Early evaluation of therapy,

(5) Treatment planning,

(6) Evaluation of suspected recurrence.

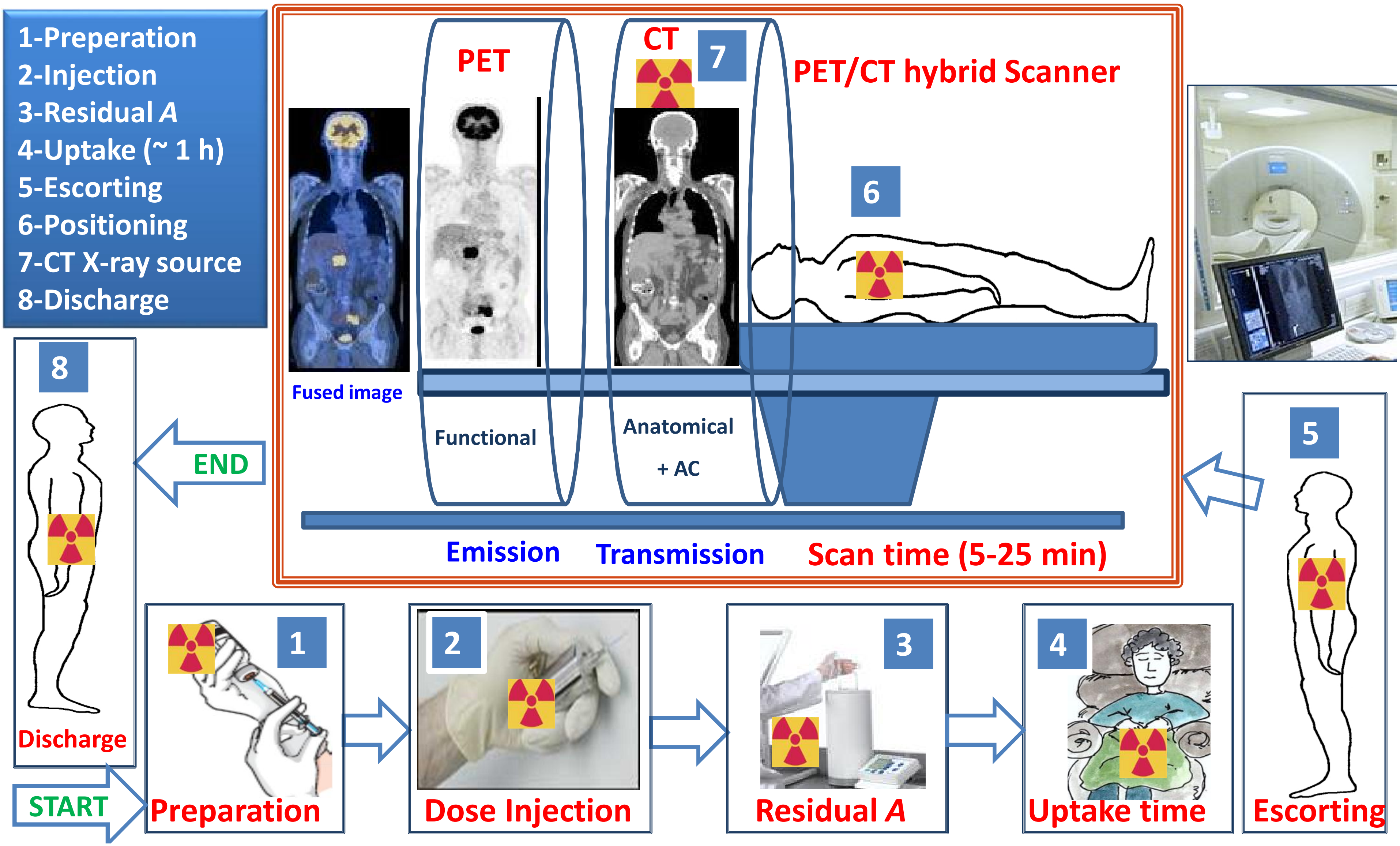
Å PET/CT is growing in use in the fields of Cardiology & Neurology

Å Better (Spatial Resolution, quantitation)

Å Potential for labeling of biological compounds with positron emitters including ^{11}C, ^{13}N, ^{15}O, ^{18}F.

Sources of Radiation Exposure

1-Preperation
2-Injection
3-Residual *A*
4-Uptake (~ 1 h)
5-Escorting
6-Positioning
7-CT X-ray source
8-Discharge



Radiation Protection in PET/CT

Å PET is based on High energy annihilation photons of ^{18}F (511 keV)

Å More photons escape from injected patient

Å Increases exposure rate from ^{18}F & patient

Å High dose to workers

Å High Energy photons are much harder to stop (More Shielding required)

	^{18}F	^{99m}Tc
Energy (keV)	511	140
Specific Gamma ray constant (R/hr/mCi at 1 cm)	6.0	0.78
HVL (mm of Lead)	4.1	0.3

Operational Radiation Dose

Å **Patient is exposed to radiation**

1-Internally: during PET (administered activity [^{18}F-FDG]

2-Externally: during CT

Å **Staff working in PET/CT**

1-Handling Radiopharmaceutical (^{18}F): Dose preparation, Transport of syringe to injection room , Injection of patient , Measure the residual activity, Handling of radioactive waste.

2-Close contact with the patient after the administration of ^{18}F: during the uptake stage, Escorting the patient to scanning room, during scanning stage, during release stage.

Å **59 %** of the operational related dose is due to direct handling of the ^{18}F & **41 %** of is from patient interactions.

Ref: Seierstad T. et al. Radiation Protection Dosimetry (2007).123 (2), pp. 246–249

ICRP

- The ICRP set out 3 fundamental principles for radiation protection:
  1) Justification, 2) Optimization of protection, 3) Dose limitation.

1) Justification :refers to the necessity to do more good than harm when deciding whether radiation use is necessary.

2) Optimization: (Time, Distance, Shielding)

3) Dose Limitation: The ICRP established dose limitations for occupational radiation to manage workers' exposure .

-Workers receive a maximum radiation effective dose of 20 mSv/y, 500 mSv each is the annual equivalent dose radiation limit to the skin, hands, and feet.

-For the lens of the eye, the dose limit was initially 150 mSv, but in 2011 the ICRP reduced this to 20 mSv/y

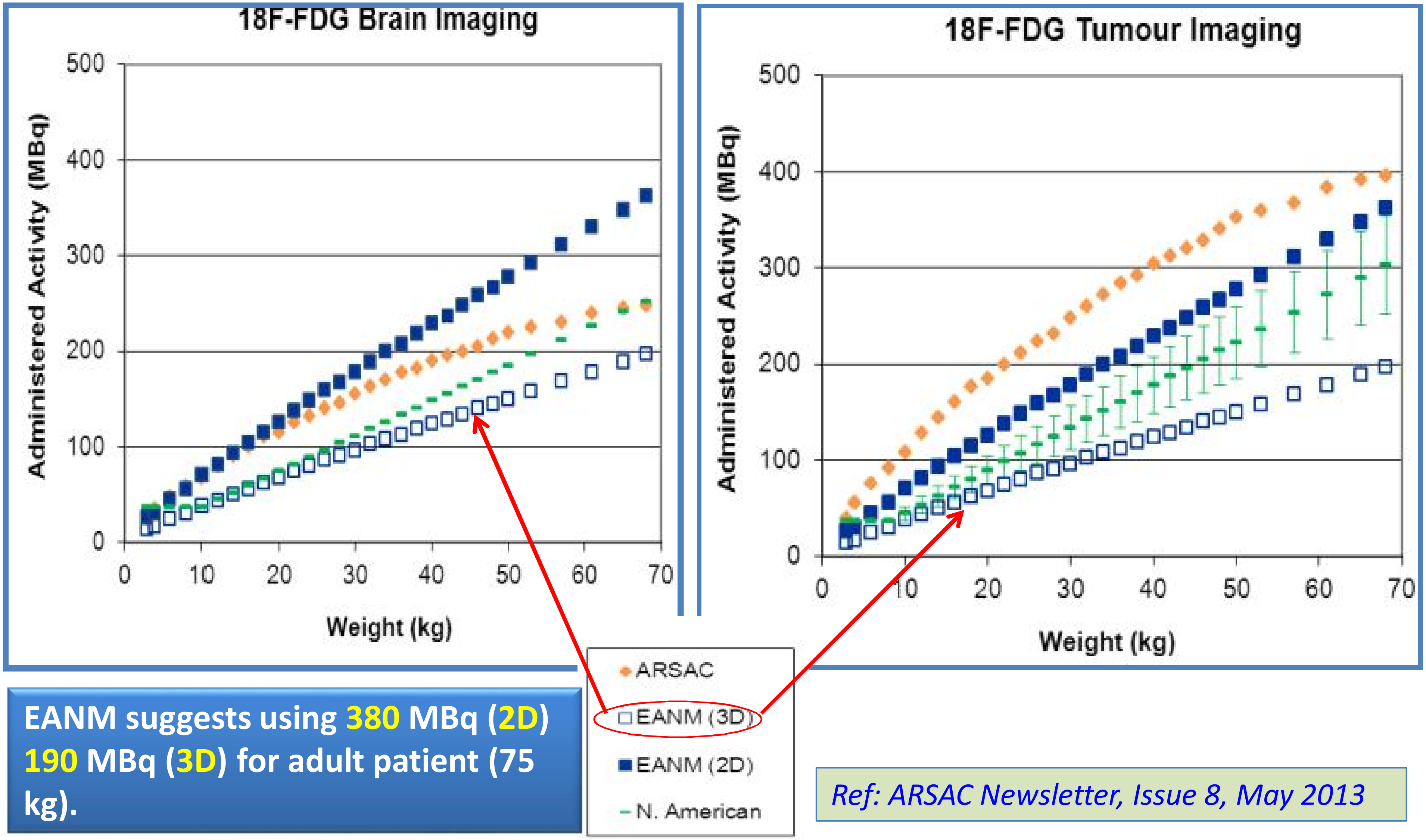
Administered Activity

- Radiation exposure to patients is directly proportional to the administered activity (*A*)
- Reducing the administered activity = ↓ Radiation dose to the patient
- Lower activity = Longer emission scan time (motion-induced misregistration) (patient throughput)
- *Administered Activity* depends on the (1) detector material (BGO, GSO or LSO), (2) count-rate behaviour of the PET scanner, (3) acquisition mode used (2D or 3D or ToF) and (4) patient weight.

- The recommended administered activity is 2.5 - 5 MBq/kg

Ref: Eur J Nucl Med Mol Imaging 2010, 37:181-200

Administered Activity



EANM suggests using 380 MBq (2D) 190 MBq (3D) for adult patient (75 kg).

Ref: ARSAC Newsletter, Issue 8, May 2013

Administered Activity (+ToF)

- Average ***Administered Activity*** was ↓ from 326.15 MBq (without TOF) to 211.04 MBq (with TOF) [Injected doses was ↓ by **34 %**.]
- ***Administered Activity*** can be ↓ from 5 to 3 MBq/Kg with TOF technology
- Whole Body dose/PET procedure was ↓from 2.6 to 1.7 µSv

Ref: Prevot S. Annual Congress of the EANM, 2012, Abstract P0232

" Average-specific activity was 4.3 MBq/kg (without TOF) and 3.5 MBq/kg (with TOF) " (↓ 20 %)

Ref: Etrad et al. Radiation Protection Dosimetry (2012), Vol. 152, No. 4, pp. 334–338

Administered Activity can be ↓ **30 %** with TOF technology

Ref: Philips Medical Systems. Gemini TF. Documento divulgativo. 4535 674 15481 Rev B; 2007

Dose Rate from Injected Patient

- Injected activity = 407 MBq FDG
- Radiation dose meter placed at 5 different heights, 8 different angles, 3 different distance (10 patients)

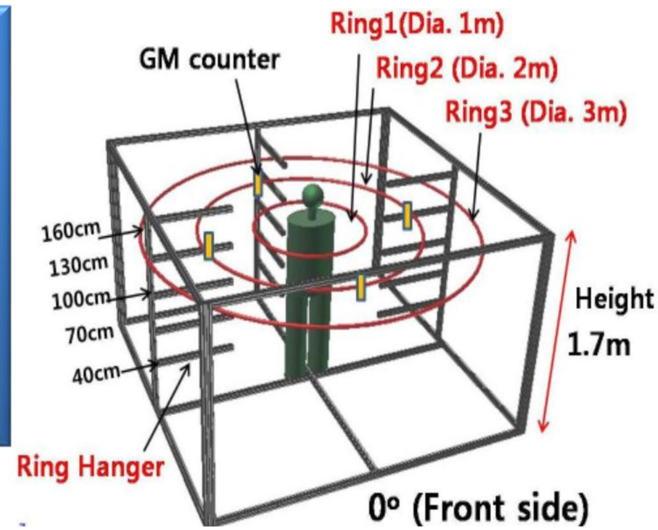
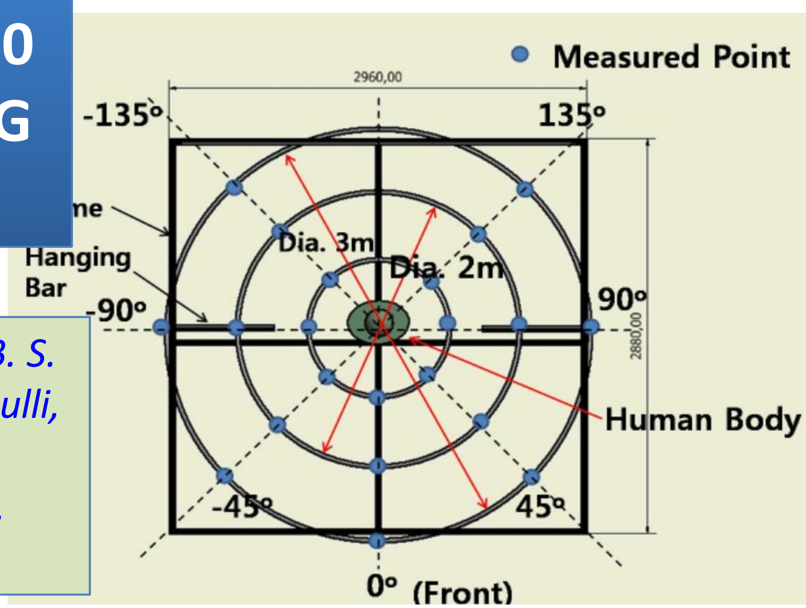


Table 1. Spatial dose rates (μSv/h) of 10 patients.

Patient	Angle -135°	-90°	-45°	0°(Front)	45°	90°	135°
1	17.9	15.8	16.6	18.1	16.4	18	17.4
2	21.7	22.0	20.7	22.4	21.6	21.6	20.4
3	17.8	17.3	17.1	18.1	16.7	17.8	17.6
4	18.4	17.8	16.9	18.8	17.9	18.9	18.2
5	18.8	18.1	17.4	19.9	17.8	19.6	18.7
6	20.2	21.0	19.0	22.3	21.7	21.9	20.6
7	17.9	17.0	17.6	18.8	17.7	18.0	17.9
8	19.0	18.9	19.1	21.1	19.7	19.9	18.6
9	17.1	17.4	17.3	18.5	16.9	17.9	17.6
10	19.4	18.8	17.6	20.8	18.5	19.7	19.2
Average	18.8 ± 1.2	18.4 ±1.4	17.9 ±1.1	19.9 ±1.3	18.5 ±1.4	19.3 ±1.2	18.6 ±1.1

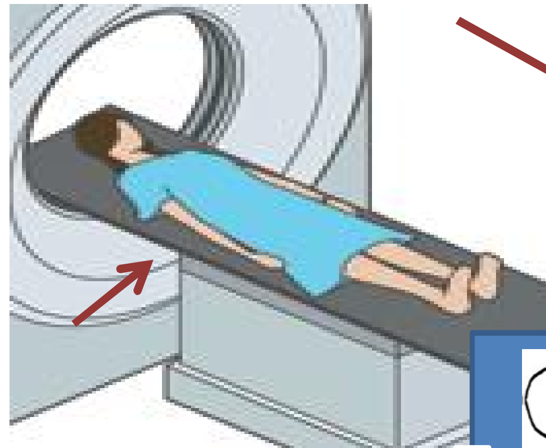
Dose rate was ±20µSV/h (60 min post FDG injection)



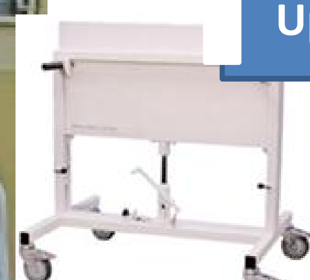
Ref: Chang et al. – B. S. New Physics: Sae Mulli, Vol. 62, No. 12, December 2012, pp. 1345-1350

Dose Rate from Injected Patient

- The position of the lead glass in front of the patient can be adjusted by the ceiling track or by the rotation of the glass barrier.
- The glass barrier is assisted in lifting up and down by an electrical actuator permitting simply by pressing the button up or down.
- The complete system is mounted in smooth bearings to move from left to right over the scanner bed



Uptake room



Extremity Dose Monitoring

- Dose-meter must be physically thin to avoid significant attenuation of the radiation.
- Dose-meter should be used to monitor the part of the extremity receiving the ***highest dose***
- Carried out by TLD-tapes or finger stalls.
- *Ring* dose-meters (middle finger) =underestimation of the highest dose
- *Wrist* dose-meter (wrist) =underestimation of the dose due to the distance between the wrist and the possible highest dose location
- These locations do not always represent higher doses compared with a convenient location on the other hand.

Extremity Dose Monitoring

-Belgium, Brussel (Over 1-y period, >500 manipulations of ^{99m}Tc & ^{18}FDG)

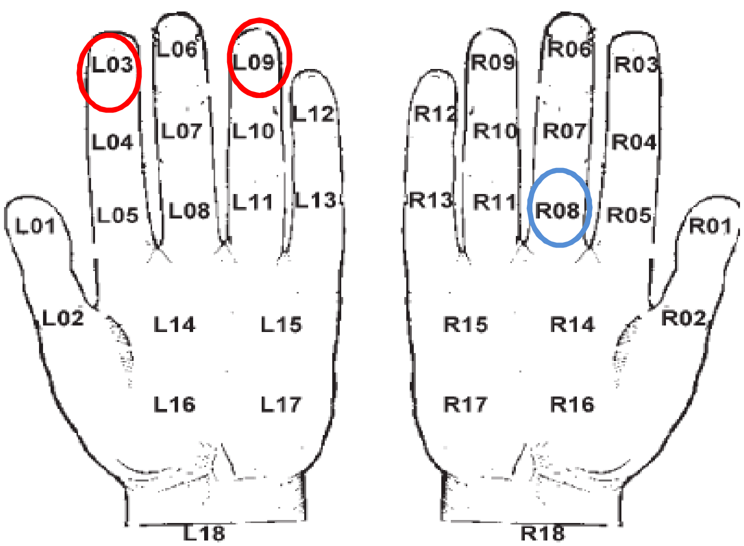
-7 workers, Right-handed (2 radiophramcists for dispensing & 5 technologists for administration)

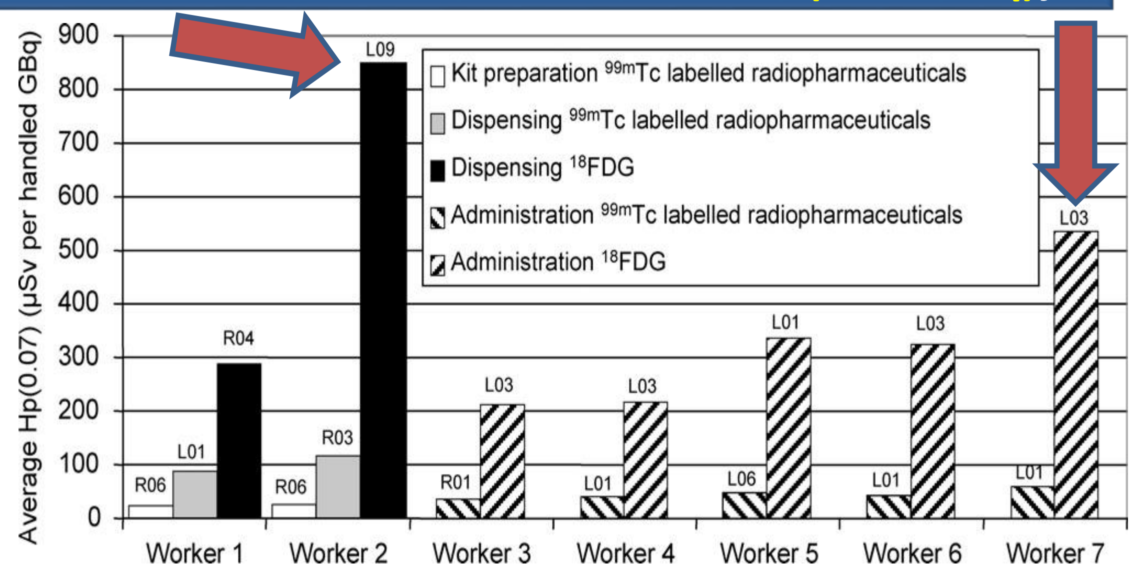
-Highest skin dose is often located on the left hand (support the syringes and needle)

-Highest skin doses range from 850 µSv per handled GBq of ^{18}FDG

-Dose to routine location (R08) can be multiplied by a factor to obtain the highest dose

{Worker 2 easily exceed the annual dose limit of 500 mSv at this location. (>588 GBq)}





Ref: P. Covens , Radiation Protection Dosimetry (2007), Vol. 124, No. 3, pp. 250–259

Automated System (Dispensing/Injection)

Use of Automatic infusion system ↓ 10-fold in staff extremity & body dose

Ref: Robert. A a J Nucl Med Technol 2012; 40:244–248

Å Collective finger dose ↓ by 39 %

Å *WB* exposure /PET procedure ↓ 19 %

Ref: Prevot S. Annual Congress of the EANM, 2012, Abstract P0232

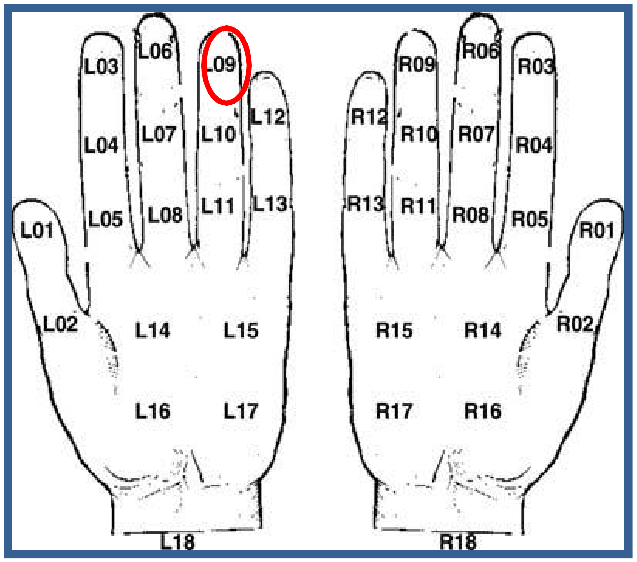
-WB doses of technologists are ↓by ½ during the injection step due to the lower dose rates at the position of the operator.

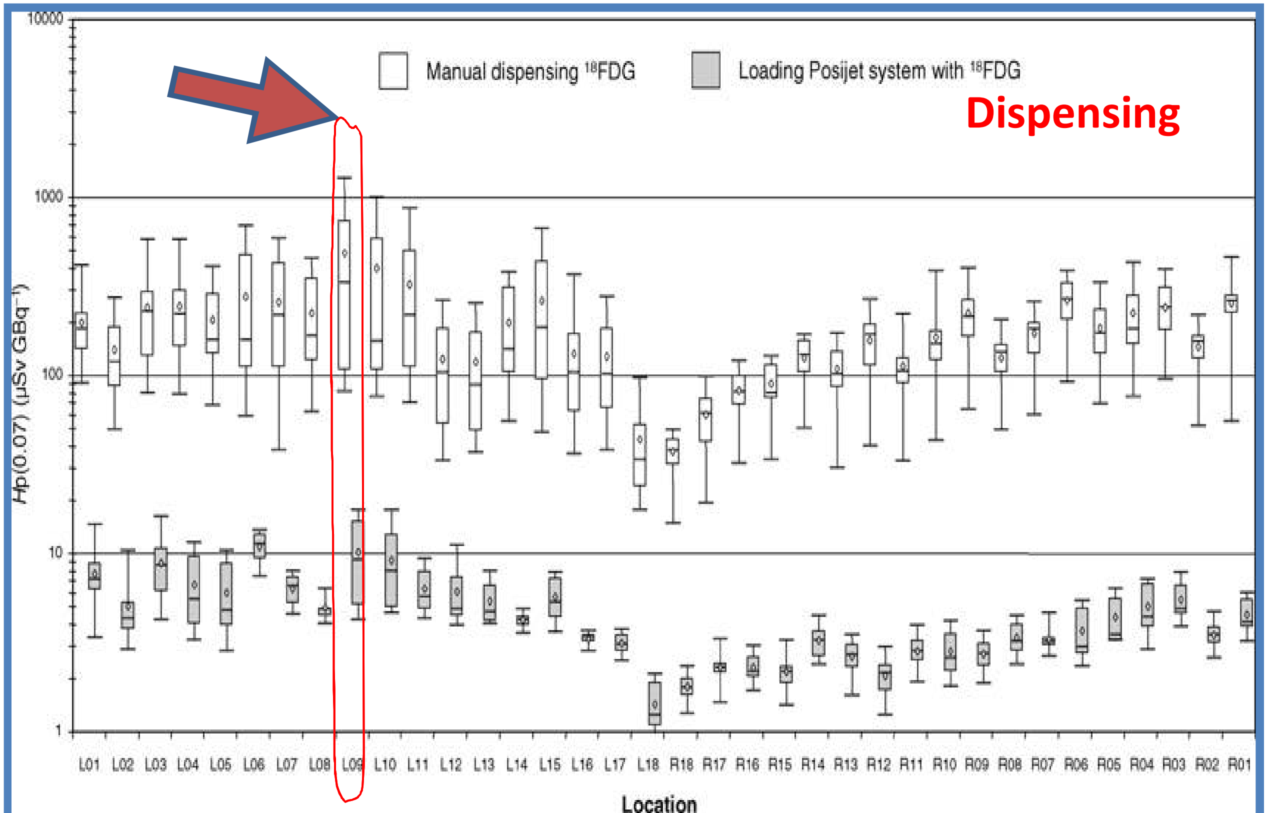
-The use of the Posijet® system ↓(>95 %)of extremity doses

Ref: Covens et al Radiation Protection Dosimetry (2010), Vol. 140, No. 3, pp. 250–258

Extremity Dose Monitoring

- The amount of residual activity (5 ± 0.6 MBq (i.e. 2 ± 0.2 % of the reference activity of 250 MBq. The contaminated kit can consequently act as small source of exposure to the hands.





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CT Dose Component

CT studies conducted in their own right (without PET) now account for 5 to 25% of all studies in large medical centres in the developed world, and contribute ½ to ⅔ of the effective dose received by patients from diagnostic radiology

IAEA SR No. 58

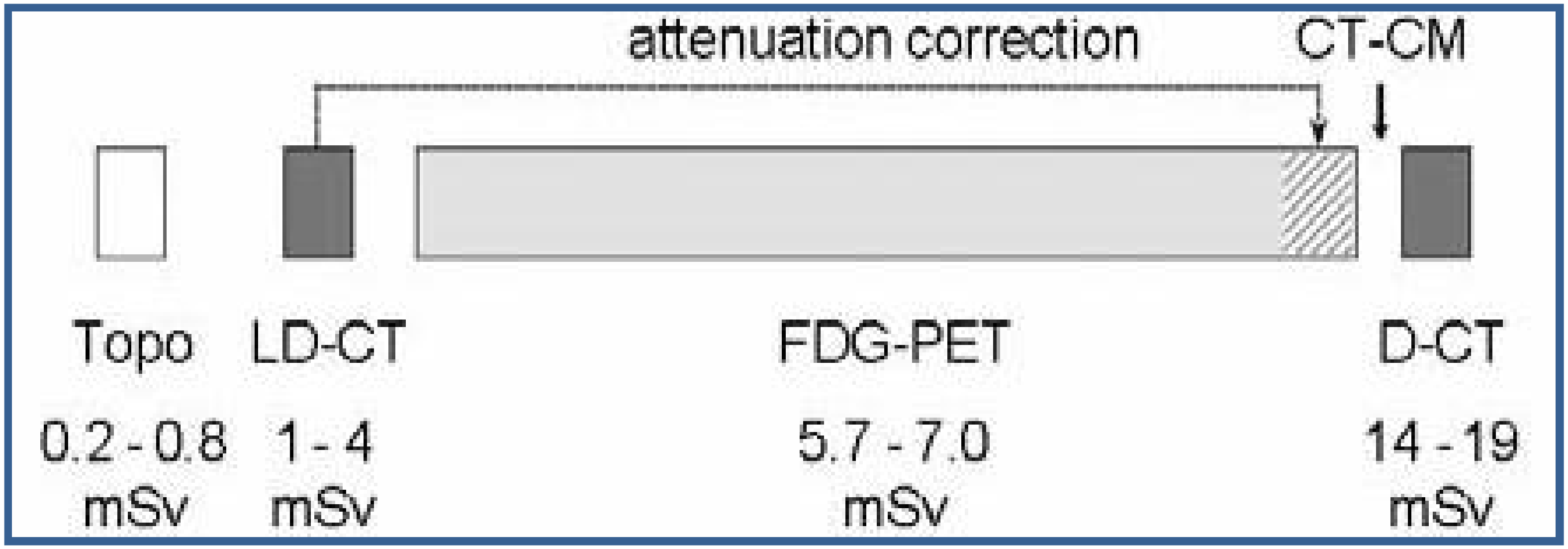
CT Exam Justification

Approximately 20 % of CT examinations were not justified.

Ref: National Survey on Justification of CT-examinations in Sweden, 2009

- Examination should be justified based on clinical referral criteria.
- Concerned medical bodies or organizations at the international level have to describe proper referral criteria.
- Medical doctors prescribing the exam must be aware of the referral criteria.
- Efforts must be deployed to apply the recommended referral criteria with close cooperation between clinicians, radiologist and medical physicists
- Annual audits of PET/CT exams justification is recommended.

3-CT Exam Optimization (LD CT vs FD CT)



- Low Dose CT (AC) ~ 2-4 mSV
- Full Diagnostic CT (oral & IV contrast) ~2-20 mSV

Ref: ICRP. Managing patient dose in Computed Tomography. ICRP Publication 87.Ann. ICRP 30(4) (2000)

Use LD CT (AC) only = ↓ dose by a factor of 2-3

Ref: Fahy FH. Dosimetry of pediatric PET/CT. J Nucl Med. 2009;50:1483-91

CT Dose Reduction Strategies (CT Scan Parameters Adjustment)

Å Improve operator's awareness about acquisition parameters affecting patient dose:

1. Tube current (current directly proportional to dose)
2. Tube voltage (exponential proportionality relationship)
3. Filtration (adequate filtration reduce the dose)
4. Collimation (dynamic collimator)
5. Reconstruction filter (post processing)
6. Slice thickness
7. Pitch
8. Scan length
9. Reconstruction Algorithm (iterative reconstruction)

CT Dose Component

"The CT component contributed **54-81**% of the total combined dose"

	kV	mA	PET only (mSV)	CT only (mSV)	PET/CT (mSV)
C (large patient)	140	150-350	6.23	25.68 (F) 25.95 (M)	31.91 (F) 32.18 (M)
A (commonly used)	120 ↓	100-300 ↓	6.23	7.22 (F) 7.42(M) ↓	13.45 (F) 13.65 (M) ↓

Ref: Huang et al. Radiology, 2009. 251, 166-174

A dummy simulation (10-y) with fixed current & **↓kV from 120 to 80 kV**= **67%** **↓**in measured dose

Ref: Fahy FH. Dosimetry of pediatric PET/CT. J Nucl Med. 2009;50:1483-91

CT Dose Reduction Strategies (Image Reconstruction Algorithm)

- Å FBP has been replaced by the **Iterative image reconstruction** techniques (with reported **dose savings of about 50%**)

Ref: Niu TY, et al.; AJNR Am J Neuroradiol. 33(6):1020-6, 2012

- Å Adaptive statistical Iterative reconstruction was used to scan ACR Phantom and the results support body CT dose index **reduction of 42 – 65 %**. Studies with larger samples are needed to confirm these findings

Ref: Amy K. Hara, et al. AJR;.(Abstract), 193:764-771, 2009

- Å Adaptive Iterative Dose Reduction (AIDR 3D) is an iterative reconstruction algorithm that reduce noise in both 3D reconstructed data & raw data. It provides a **dose reduction of up to 75%**.

www.toshiba-medical.eu./en/Our-Product-Range/CT/Technologies.

CT Dose Reduction Strategies (Automatic Exposure Control-AEC)

- AEC using tube current modulation has proven to reduce patient dose and image noise than the fixed mAs technique. (it preserves the image quality)
- Both tube current and voltage modulation are now available with modern scanners.
- Dose modulation are done based on patient diameter, shape and body attenuation profile.
- Modulation techniques insure that Image quality among patients are kept consistent., Increase tube lifetime and reduce image artefacts.
- Organ based Tube Current Modulation (TCM) has proven efficiency in comparison with bismuth shielding to radiosensitive organs.

Conclusion

1-Share information on RP for educational purpose (ICRP conference 2013)

2-Training & rotation scheme within workers (Divide responsibilities among staff)

3-FDG preparation & administration by a skilful worker

4-Vendors, workers and inventors should collaborate to develop equipment, software and protocols that delivers less radiation

5-Use of automated dispensing (or/and infusion) system

6- Reduce the administered activity

7-More communication between referring physician and NM physician to reduce unjustified procedures.

8-Harmonizing a Competency-based program for the certification of personnel in RP(dual certificate on PET/CT) (expected help from ICRP)

9-Regular QC and preventive maintenance of PET/CT scanner.

10-Optimisation of the individual workload is often used to restrict staff doses

11-Maximisation of distance and the minimization of close contact when escorting and positioning of the patient


Thank You