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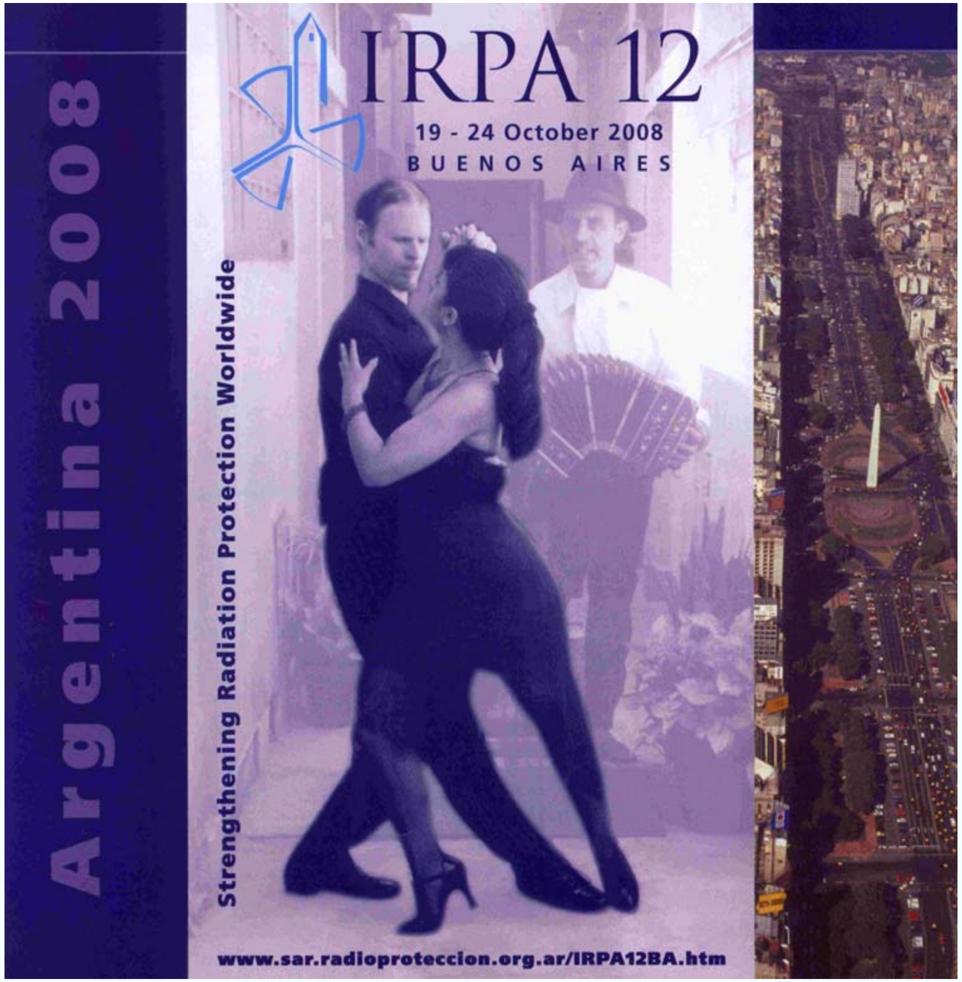

Refresher Course 18

Shielding Of Medical Facilities. Shielding Design Considerations For PET-CT Facilities

Juan Angel Cruzate and Adrián Pablo Discacciatti

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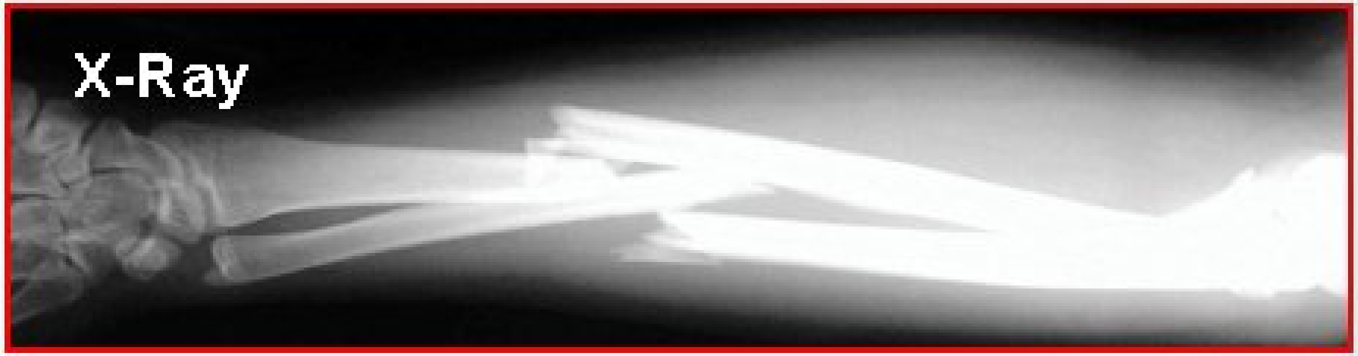
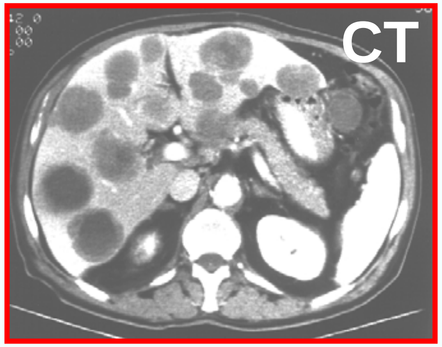
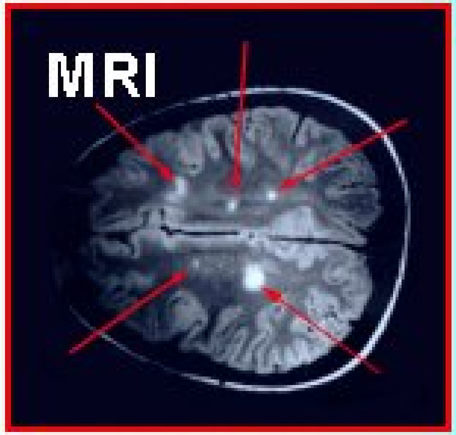
Non-invasive Medical Imaging Techniques

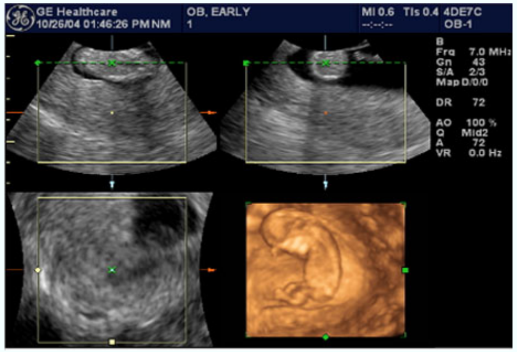


Anatomical

- X-rays
- CT (Computed Tomography)
- MRI (Magnetic Resonance Imaging)
- Ultrasound







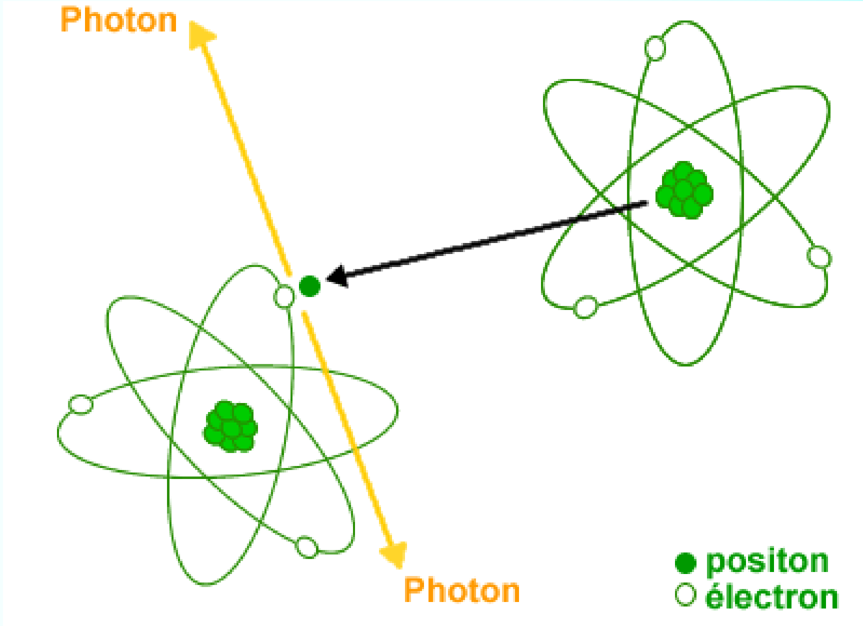
Functional

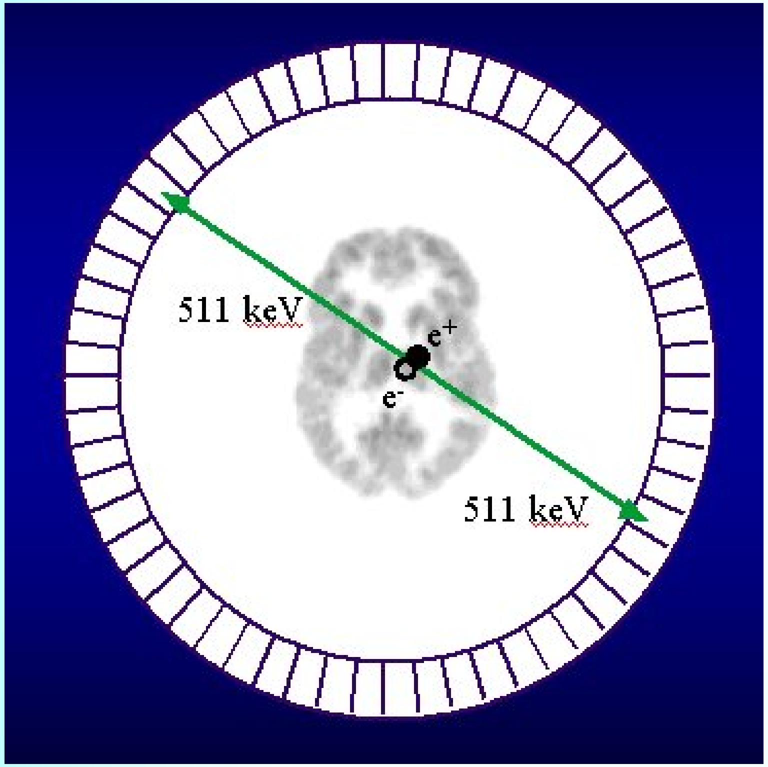
- Nuclear Medicine

PET

Positron Emission Tomography

Positron Decay (β+)





Gamma coincidence detection

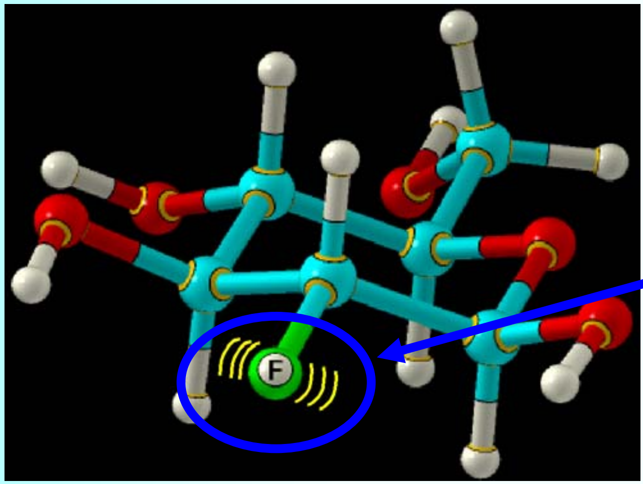
Positron Emission Tomography

Diagnostic technique ⇒ Radiotracer must have short half-life

Typical radiotracer used in PET

^{18}F	109.8 min
^{15}O	2 min
^{11}C	20.4 min
^{13}N	10 min

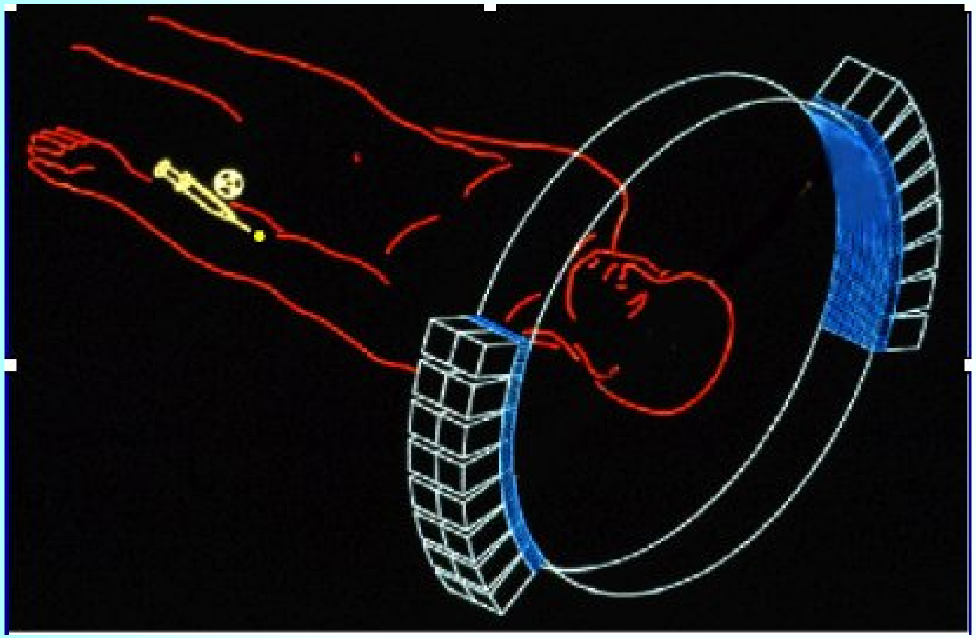
^{18}F – the most used

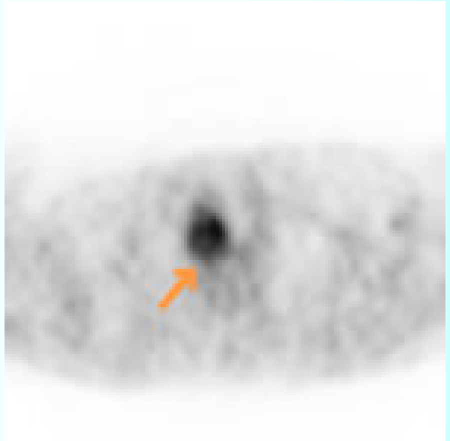


F-18 FDG Fluoro-2-deoxyglucose

Positron Emission Tomography

what about the images from PET scanner ?



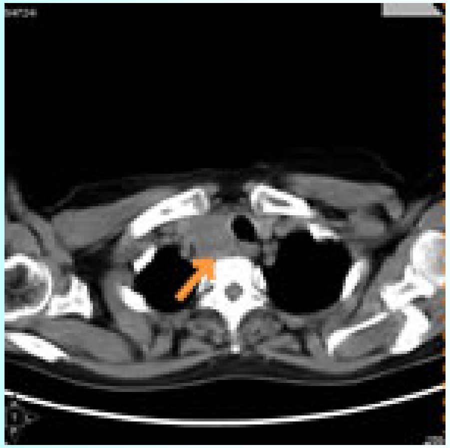
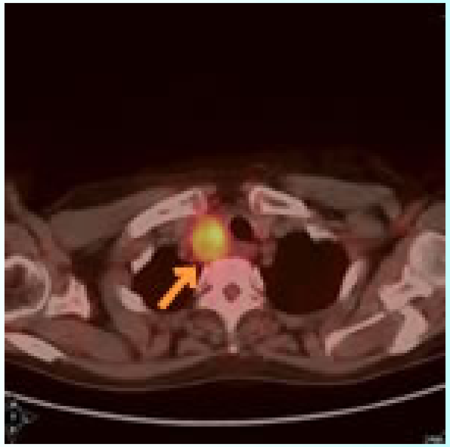


so, we can see the tumour, but no anatomy details

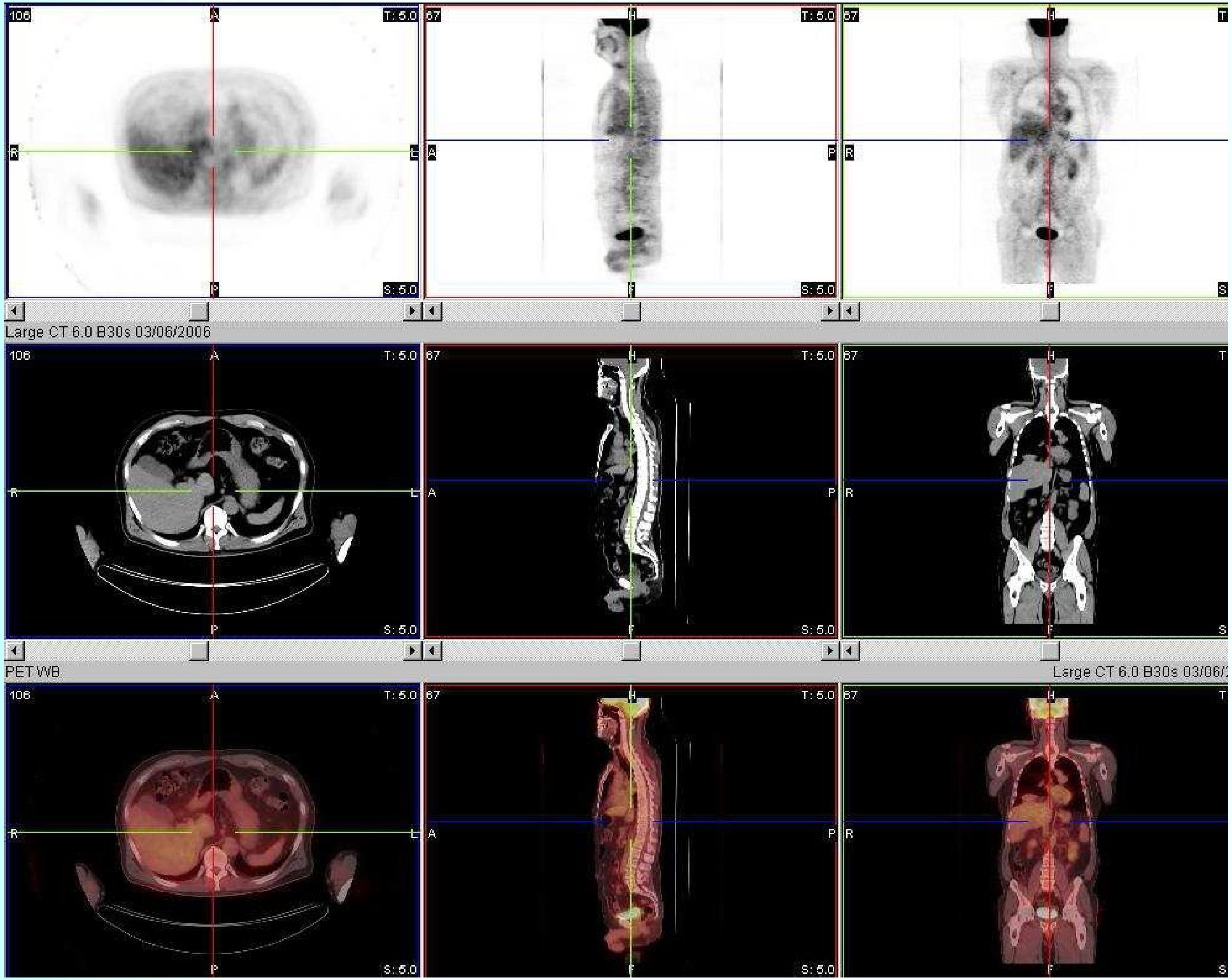
Positron Emission Tomography

then, how can a physician make a diagnosis ?

IMAGE FUSION

CT	PET	IMAGE FUSION
		

here we have other examples of image fusion



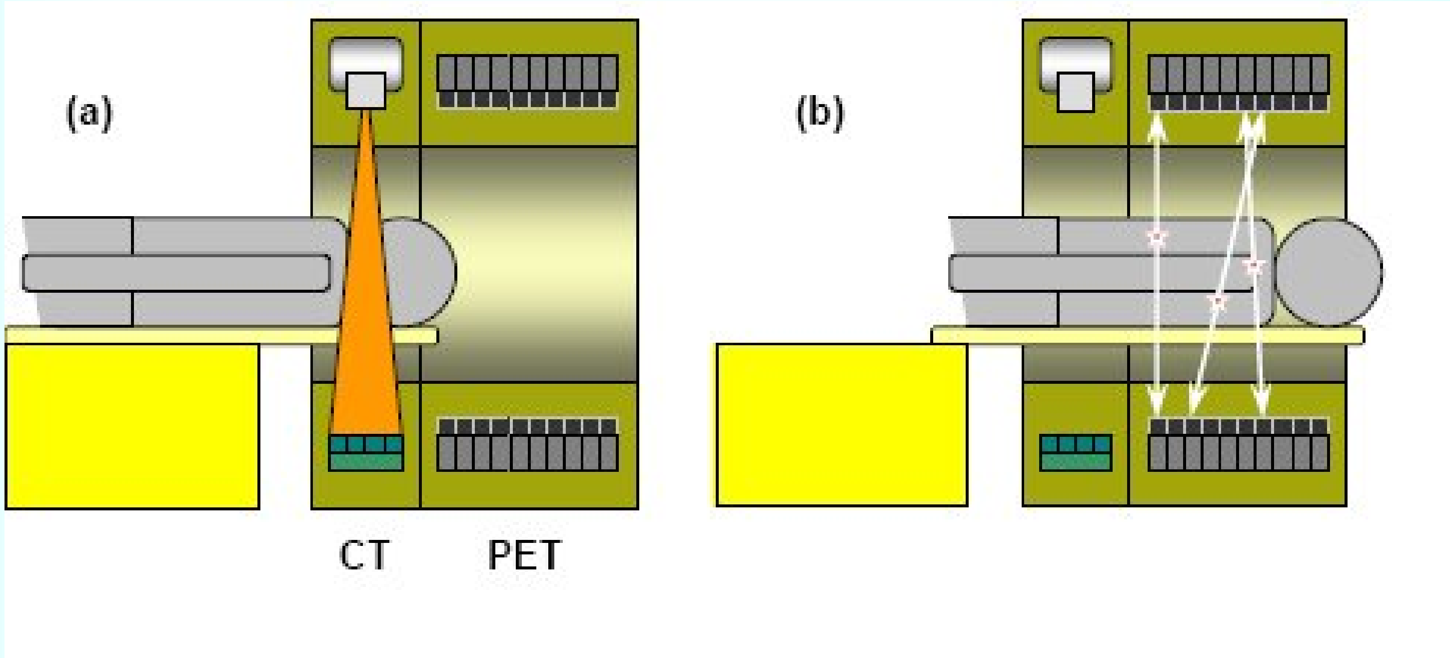
PET

CT

IMAGE FUSION

Positron Emission Tomography

IMAGE FUSION ⇒ **PET/CT units**



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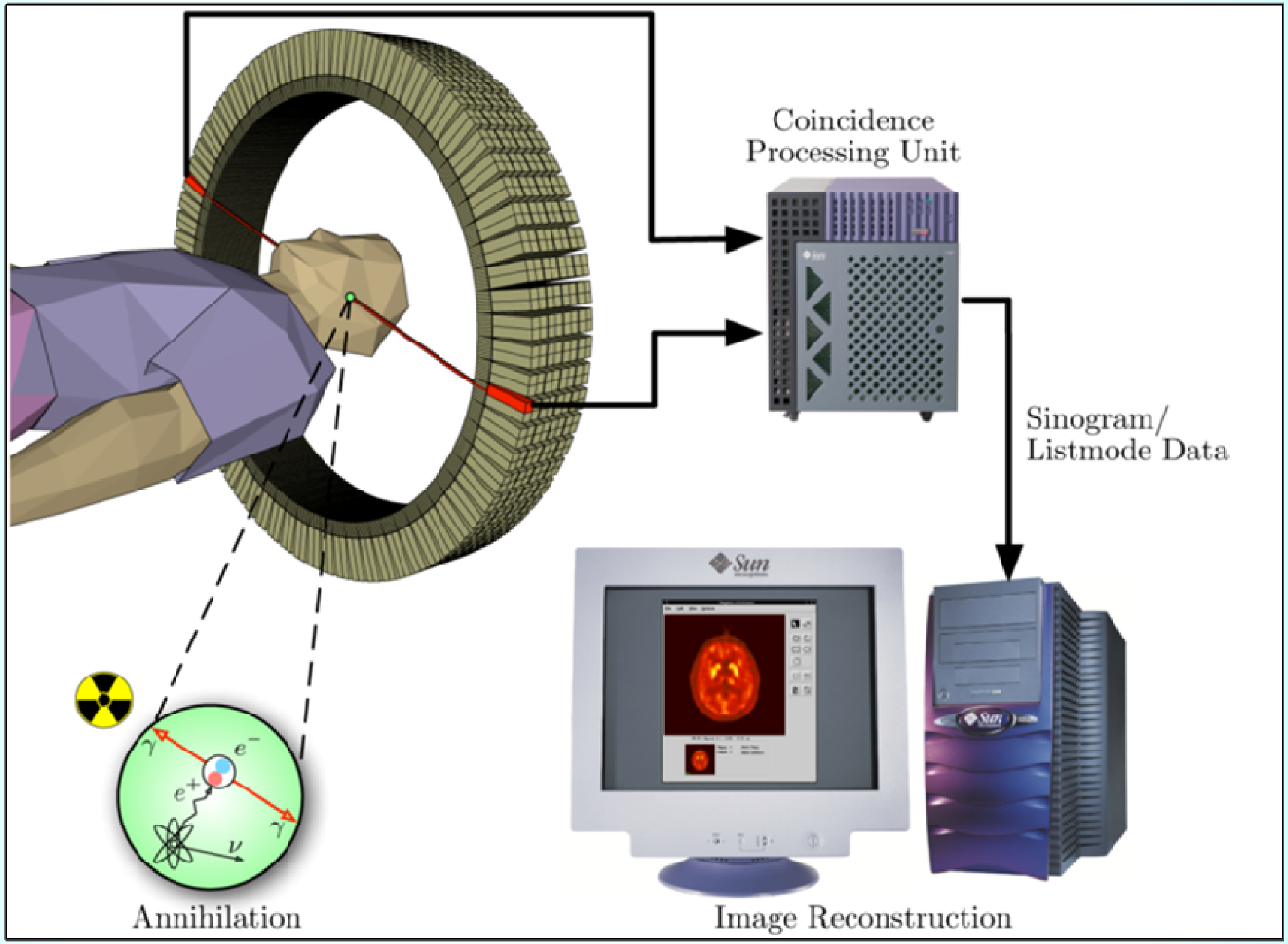
PET/CT units



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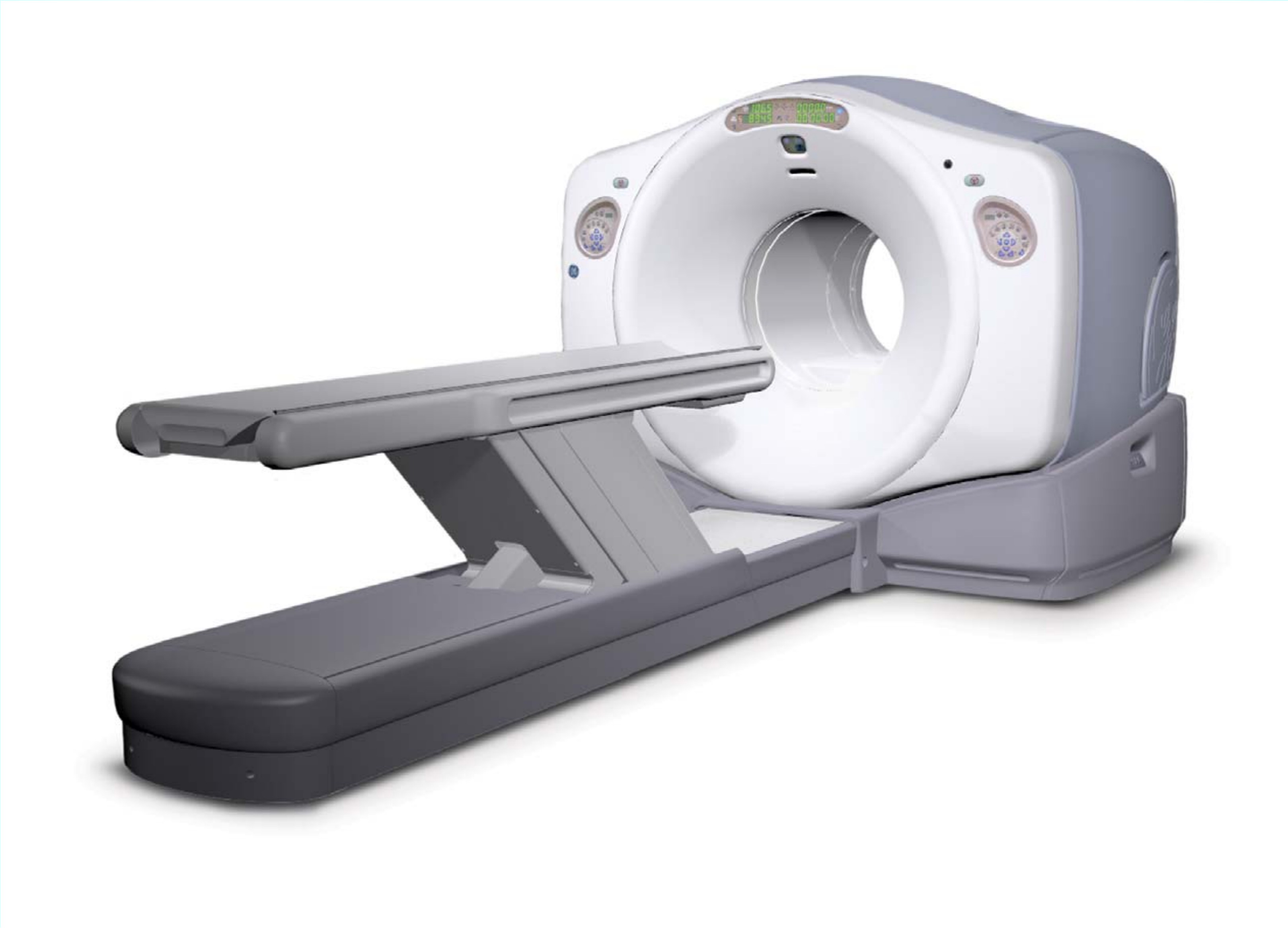
PET/CT units



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PET/CT units

CONTROL CONSOLE

Radiation Protection

the longest half-life

typical radiotracer used in PET

^{18}F	109.8 min
^{15}O	2 min
^{11}C	20.4 min
^{13}N	10 min

the most used

consequently, radiation protection measures are drew out assuming only studies with ^{18}F

Typical practice

radionuclide reception

The vial with the radionuclide is received and stored in the “hot lab”

Typical practice

“dose” preparation

Prior to injection to the patient, the radioactive aliquot has to be transferred from the vial to the syringe.

Typical practice

syringe transportation

Then, syringe is transported up to the place of injection to patient (injection room)

Typical practice

injection

patients are injected with an average ^{18}F activity of about 555 MBq (15 mCi)

Typical practice

uptake

patients lie down in the uptake room for about 45-60 minutes (uptake time)

- to allow *distribution of radionuclide throughout the body*
- *for reduction of uptake in the skeletal muscles*

generally injection room and uptake room are the same

Typical practice

stretcher

Typical practice

uptake

patients are instructed to void their bladder of urine accumulation (about 15 % of administered activity) before scanning

- to reduce gamma dose in the bladder
- to avoid signal interference due to gamma emission from bladder

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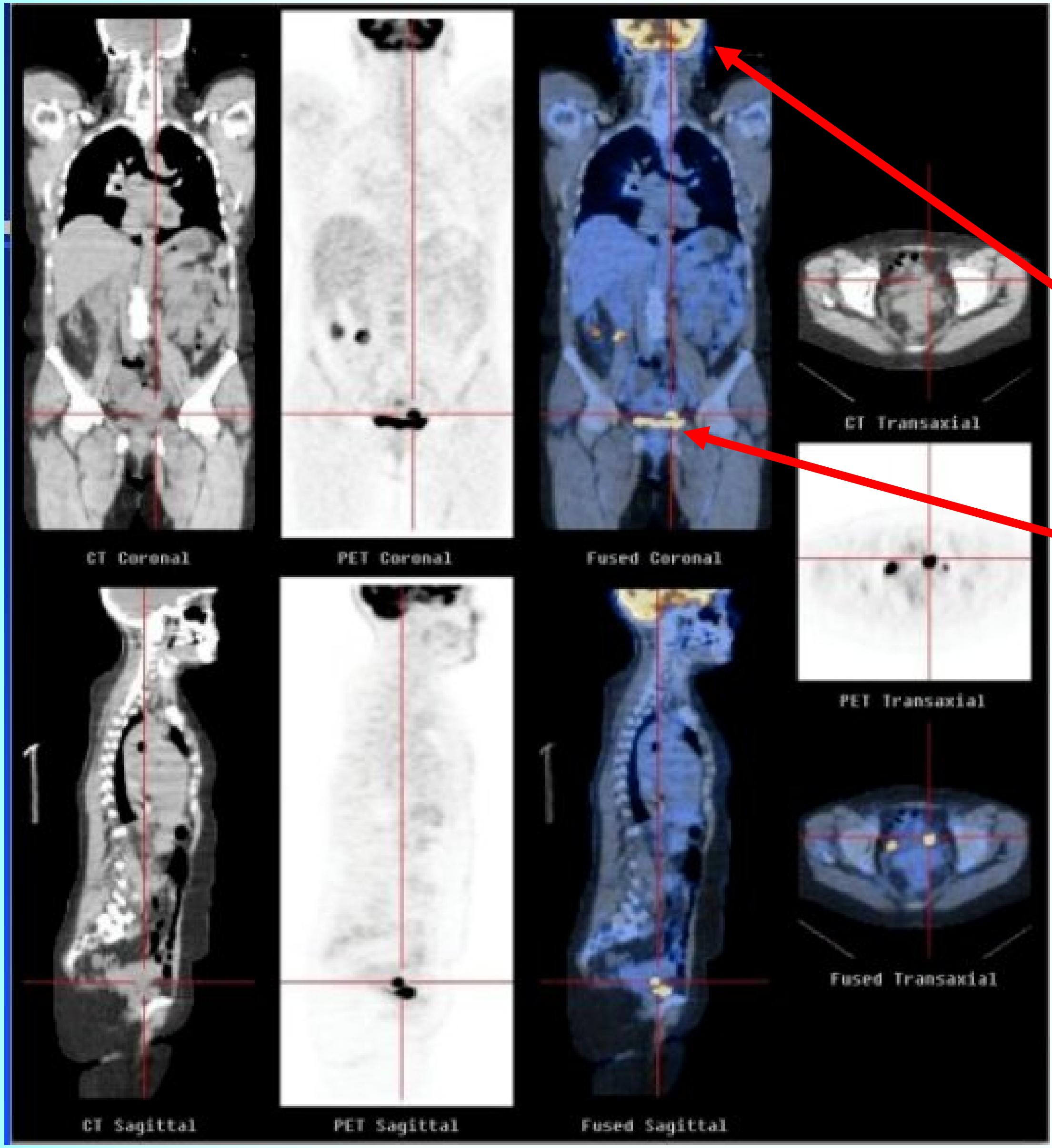

main gamma emission
from annihilation photons
(not from tumours)

Typical practice

scanning

patients are given an approximately 20-30 minutes scan (acquisition time)

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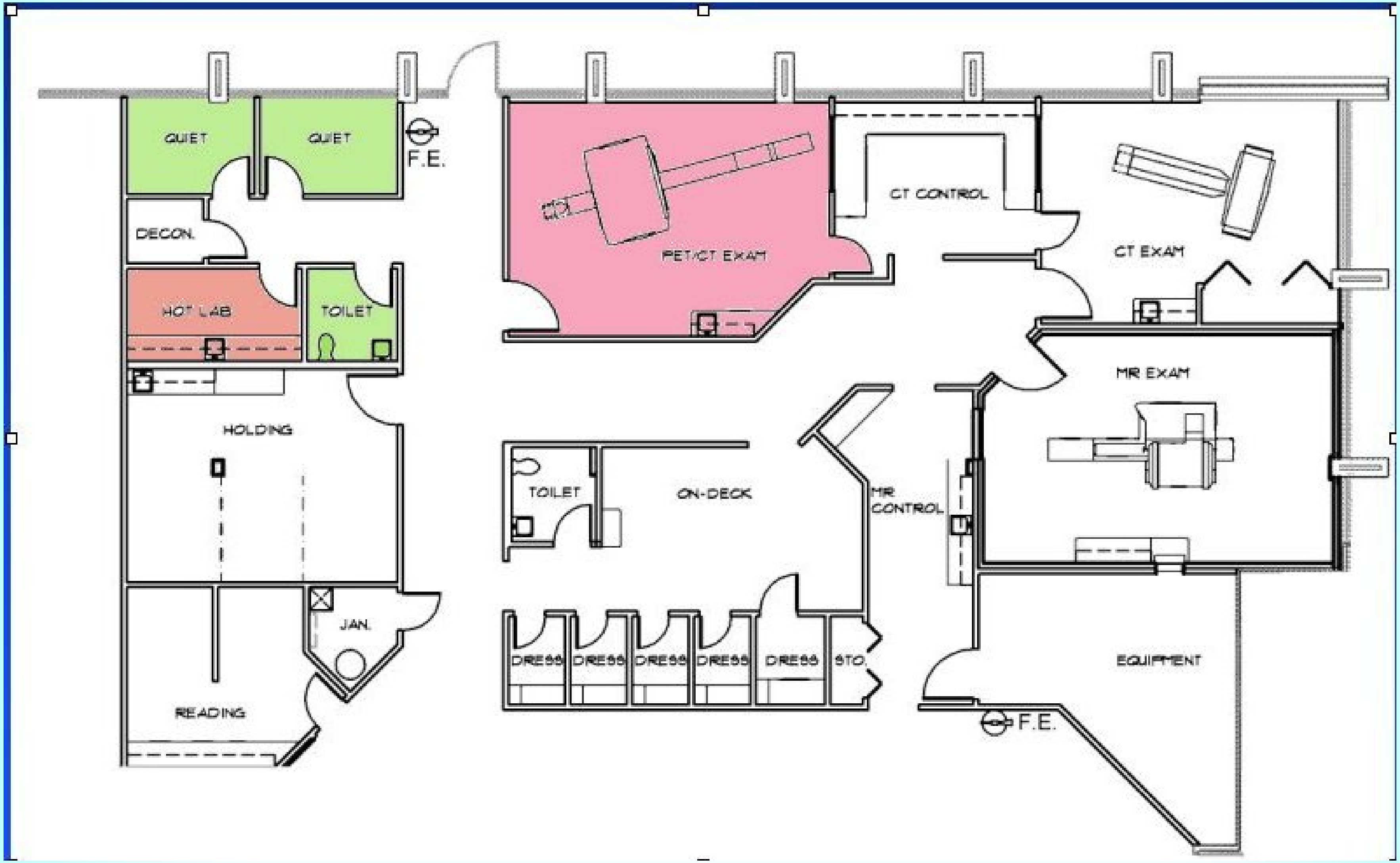
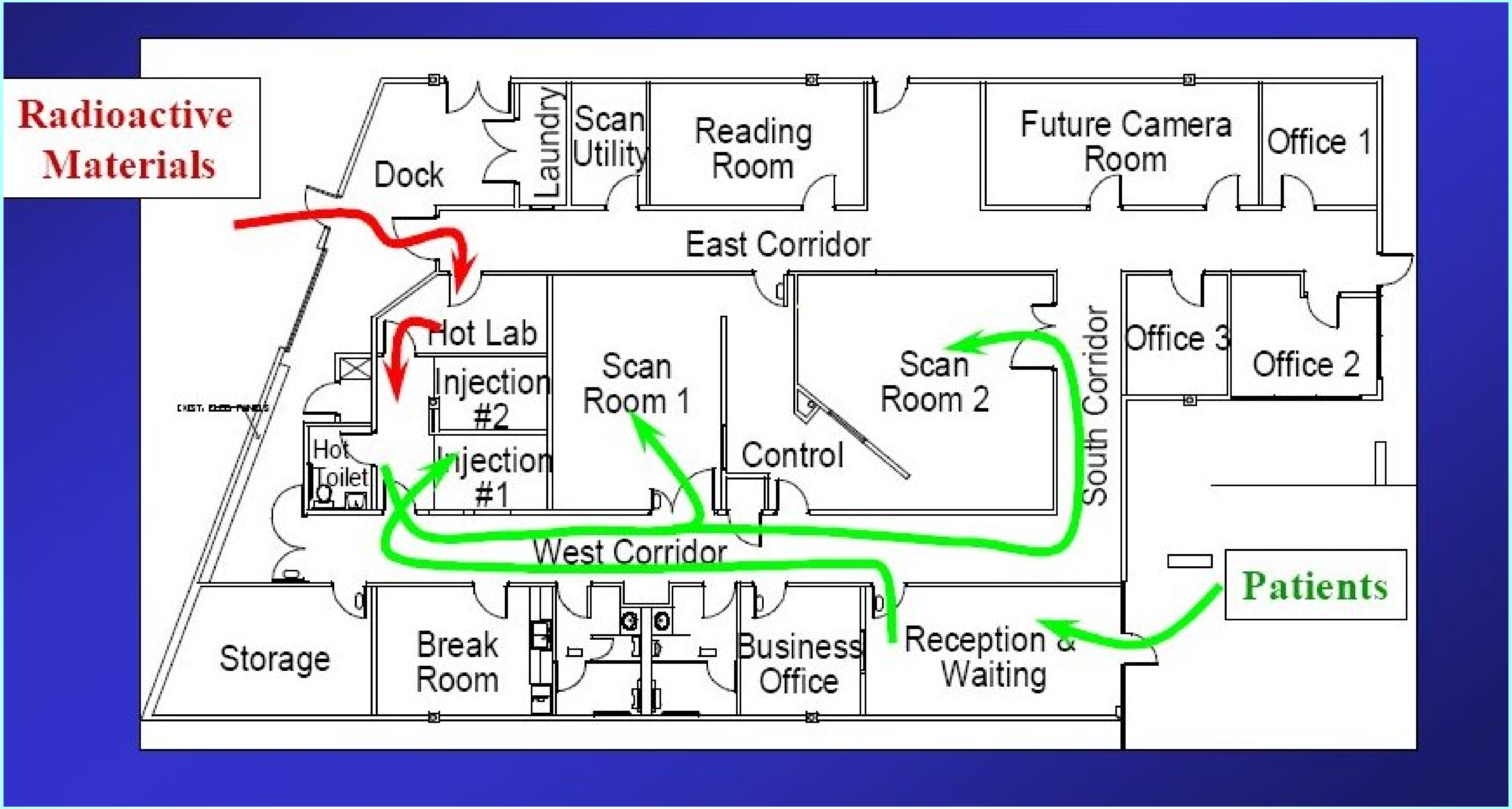
but, what are the radiation sources ?



Why is PET shielding different ?

- The 511 keV photons from ^{18}F and the mobile nature of the source (source itself and patient) create some unique shielding design problems for a PET clinic.

Why is PET shielding different ?



Why is PET shielding different ?

- New clinics are commonly sandwiched into existing imaging centers that are densely populated. Areas above and below the clinics are routinely occupied by other offices.

Radiological evaluation

⇓

Assesment of the annual effective dose

- *to exposed workers*
- *to members of the public*

Radiological evaluation

- *radionuclide involved*
- *layout of the facility*
- *shieldings*
- *use of spaces in and out the facility*
- *expected number of patients per year*
- *working procedures*
    - *administered activity*
    - *uptake time*
    - *acquisition time*

Radiological evaluation

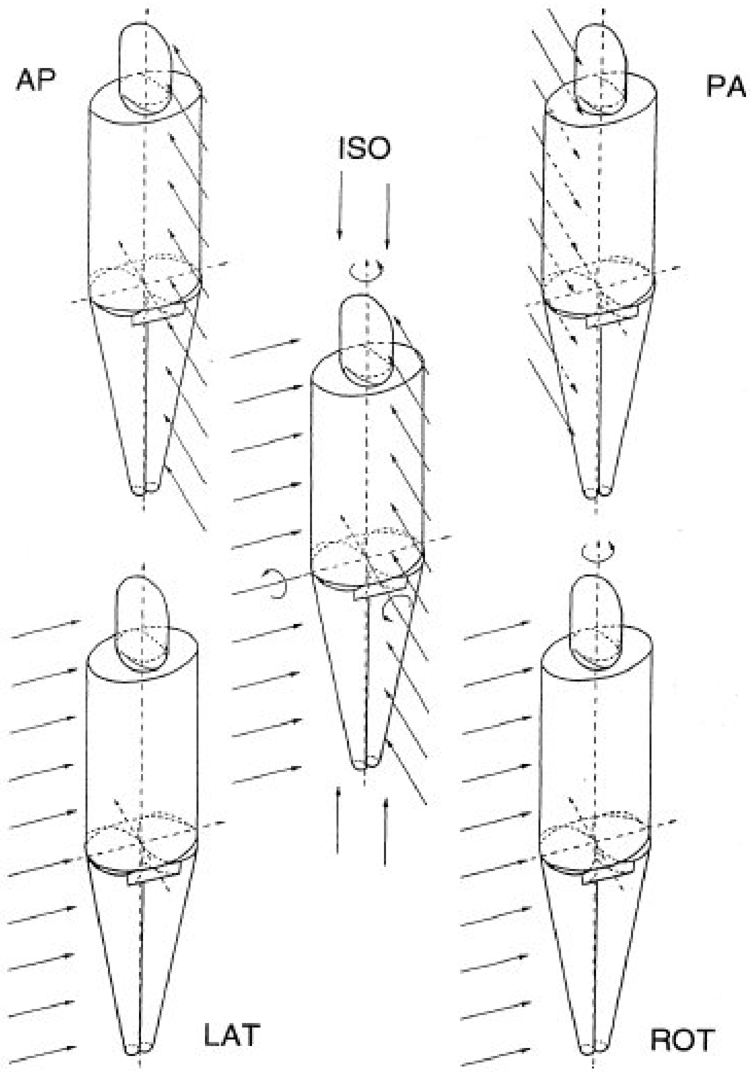
- *PET facility must comply with regulatory standards from its country*
- *Then, assessed annual effective dose must be compared with dose constrains from those standards*
- *And, obviously, must be less than those constrains*

radiation protection ⇒ **effective dose**

effective dose depends on

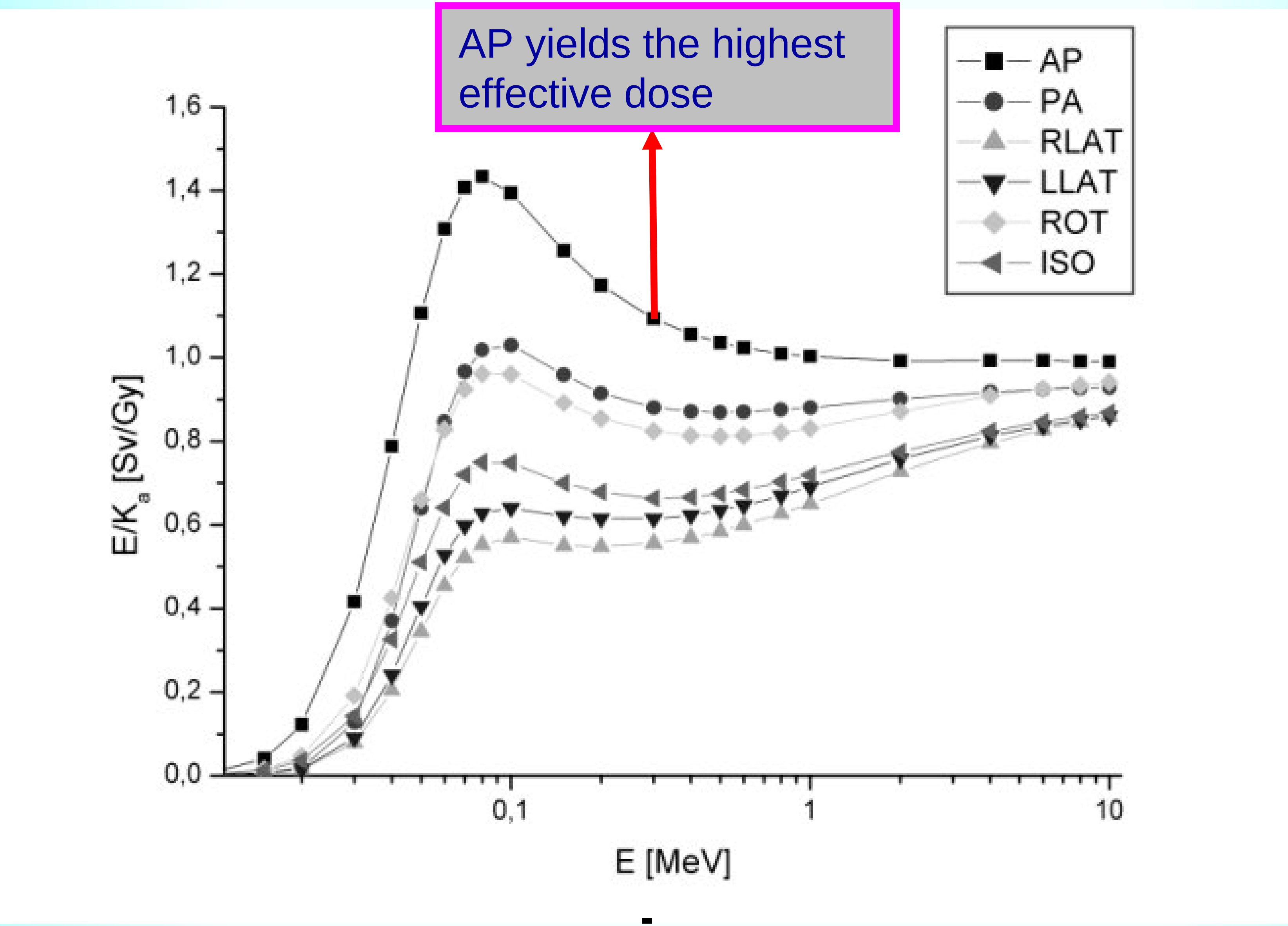
- *incident photon energy*
- *irradiation geometry*

common irradiation geometries



but, in general, during a given practice we have a combination of geometries

effective dose dependence



Effective dose rate constant (Γ)

the effective dose per unit time and per unit activity at 1m from an "unshielded" source

*In radiation protection we are interested in **antero-posterior geometry**, because it shields the **most conservative** value*

Effective dose rate constant (Γ)

Table 1: Dosimetric properties of commonly radionuclides used at PET.

Radionuclide	Energy [MeV]	Emissivity	Half-life
^{11}C	0.511	2.00	20.4 min
^{13}N	0.511	2.00	10.0 min
^{15}O	0.511	2.00	2.0 min
^{18}F	0.511	1.93	109.8 min
^{64}Cu	0.511 – 1.346	0.38 – 0.005	12.7 h
^{68}Ga	0.511	1.84	68.3 min
^{82}Rb	0.511 – 0.776	1.90 – 0.13	76 s
^{124}I	0.511 – 0.603 – 1.693	0.5 – 0.62 – 0.3	4.2 d

Table 3: Positron emitters radionuclides used in PET studies.
Half life ($T_{1/2}$), emissivity (ε),and effective dose rate constant (Γ).

Radionuclide	$T_{1/2}$	Photon energy [MeV]	ε	Γ [mSv m²/h.MBq]
^{11}C	20.4 min	0.511	2.00	1.44E-04
^{13}N	10.0 min	0.511	2.00	1.44E-04
^{15}O	2.0 min	0.511	2.00	1.44E-04
^{18}F	109.8 min	0.511	1.93	1.39E-04
^{64}Cu	12.7 h	0.511 / 1.346	0.38 / 0.005	2.70E-05
^{68}Ga	68.3 min	0.511	1.84	1.33E-04
^{82}Rb	76 s	0.511 / 0.776	1.90 / 0.13	1.50E-04
^{124}I	4.2 d	0.511 / 0.603 / 1.693	0.5 / 0.62 / 0.3	1.45E-04

$1.39\ 10^{-4}$ mSv m^2 / h MBq

Administered activity decay

Adults ≈ 370-740 MBq (10-20 mCi)

children ≈ 4-5 MBq (108-135 μCi) per Kg

$$A(t_{up}) = A_0\, e^{-\lambda\, t_{up}} - \alpha\, A_0$$

≈ 45 - 60 minutes

≈ 10 - 15 %

Transmission Factor

$$k = \frac{D(r_o)}{D_o(r_o)}$$

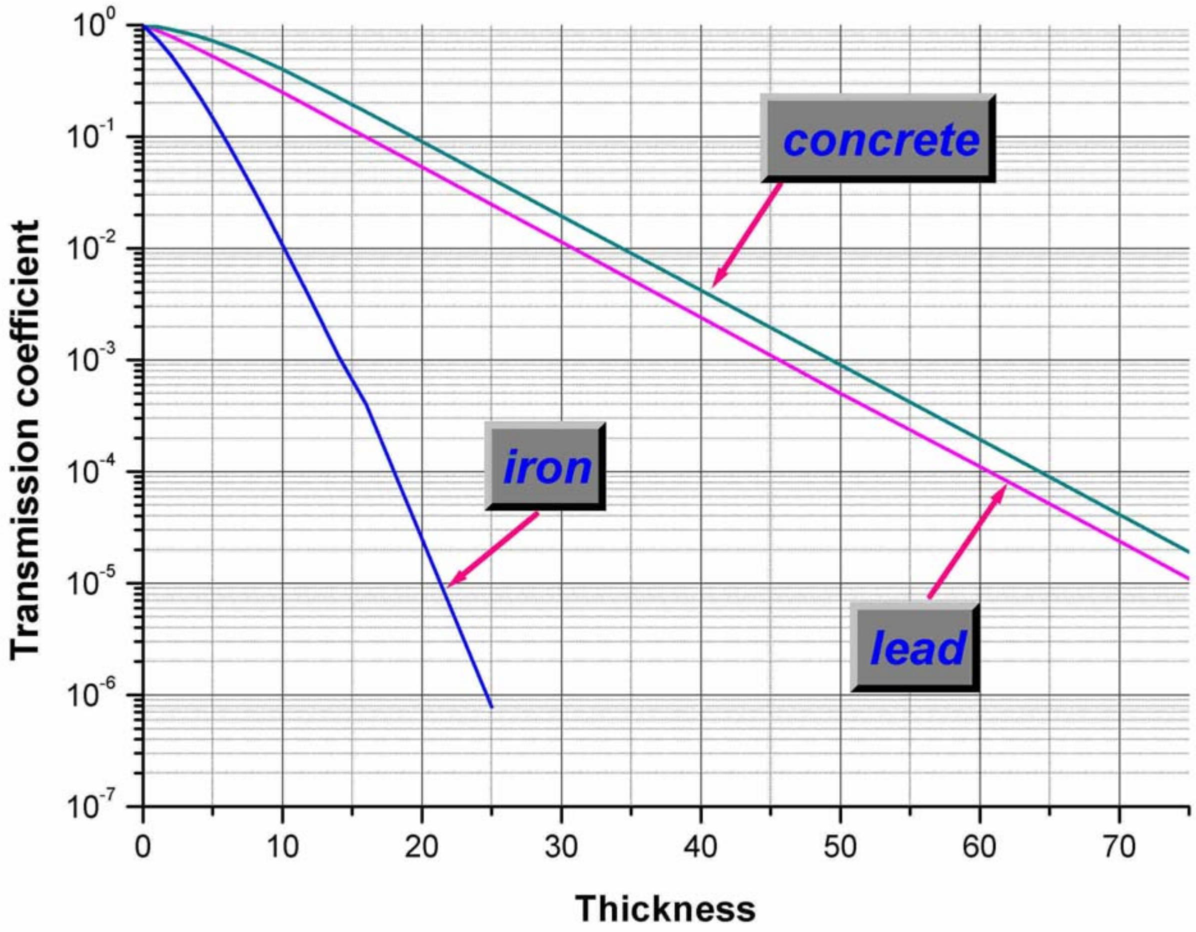
effective dose considering shielding

effective dose considering no shielding

Materials used in PET shielding

- *Lead ($\delta = 11.35\ g / cm^3$)*
- *Steel ($\delta = 7.86\ g / cm^3$)*
- *Ordinary concrete ($\delta \approx 2.35\ g / cm^3$)*
- *Masonry (mix of brick and mortar, $\delta \approx 1.6\ g / cm^3$)*
- *patient ($\delta \approx 1\ g / cm^3$)*

Materials used in PET shielding



Materials used in PET shielding

but, what about k values for masonry ?

we can use k for ordinary concrete, but using

$$X_{brick} = \frac{\delta_{brick}}{\delta_{concr}} X_{concr}$$

taking into account that $\delta \approx 1.6$ g/cm^3

$$X_{brick} = \frac{1.6 \quad g/cm^3}{2.35 \, g/cm^3} X_{concr} = 0.68 \; X_{concr} \cong 2/3 \; X_{concr}$$

and what about the patient ?

studies suggest an effective body absorption factor of 0.36

so, for radiation protection patient may be considered as a **point source** with a transmission factor of **k=0.64**

Dose Reduction Factor

$$D(t) = \int_0^t \dot{D}_0 \, e^{-\lambda t} \, dt \quad \Rightarrow \quad D(t) = \dot{D}_0 \frac{1}{\lambda}\left(1 - e^{-\lambda t}\right)$$

$$\Downarrow$$

$$D(t) = \dot{D}_0 \, t \, \frac{1}{\lambda t}\left(1 - e^{-\lambda t}\right)$$

$$R_t = \frac{1}{\lambda \cdot t} \cdot \left(1 - e^{-\lambda t}\right) \quad \Rightarrow \quad D(t) = \dot{D}_0 \cdot t \, R_t$$

Dose Reduction Factor

Typical values for the dose reduction factor

t	R_t
30 min.	0.911
45 min	0.871
60 min.	0.832
90 min.	0.762
120 min	0.701
8 hours	0.314

Occupancy factor, T

the average fraction of the effective irradiation time that a maximally exposed individual remains in the area or point of interest

i.e the person who spends the most time there

Occupancy factor, T

controlled areas

Suggested occupancy factors (for use as a guide in planning shielding when other sources of occupancy data are not available)

Location	Occupancy Factor T
Full occupancy areas, administrative offices, treatment planning areas, treatment control rooms, nurse stations, attended waiting rooms, occupied space in nearby building	1
Adjacent treatment room, patient examination room adjacent to shielded vault.	1/2
Corridors, employee lounges, staff rest rooms.	1/5
Treatment vault door.	1/8
Public toilets, unattended vending rooms, storage areas, outdoor areas with seating, unattended waiting rooms, patient holding areas, attics, janitors´ closets.	1/20
Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas (unattended), stairways, unattended elevators.	1/40

Calculation model

point source model is used

- *is a simple model*
- *is conservative for radiation protection purposes*

Calculation model

$$D = \Gamma \frac{A \; t_{op} \; N}{d^2} \; k \; R_t \; T$$

- D: effective annual dose produced during operation
- Γ: effective dose rate constant
- A: activity when operation begins
- t_{op}: time duration of operation
- N: number of annual operations
- d: distance from source to calculation point
- k: transmission factor
- R_t: dose reduction factor
- T: occupancy factor

Radiation sources

- *sources stored in hot lab*
- *patient in uptake room*
- *patient in PET/CT scanner*

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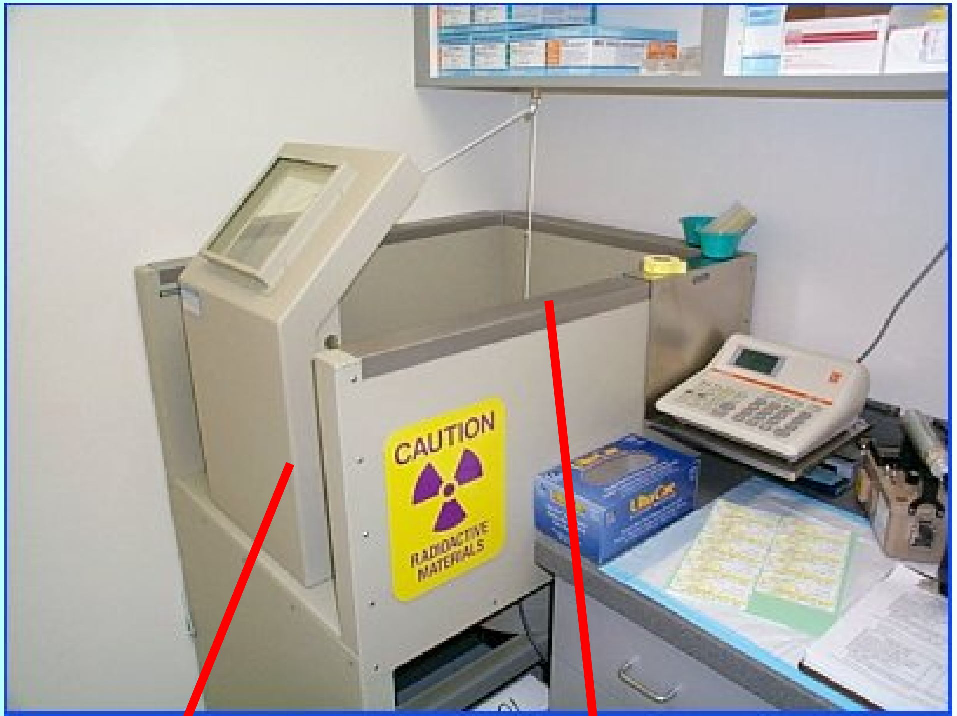
The hot lab



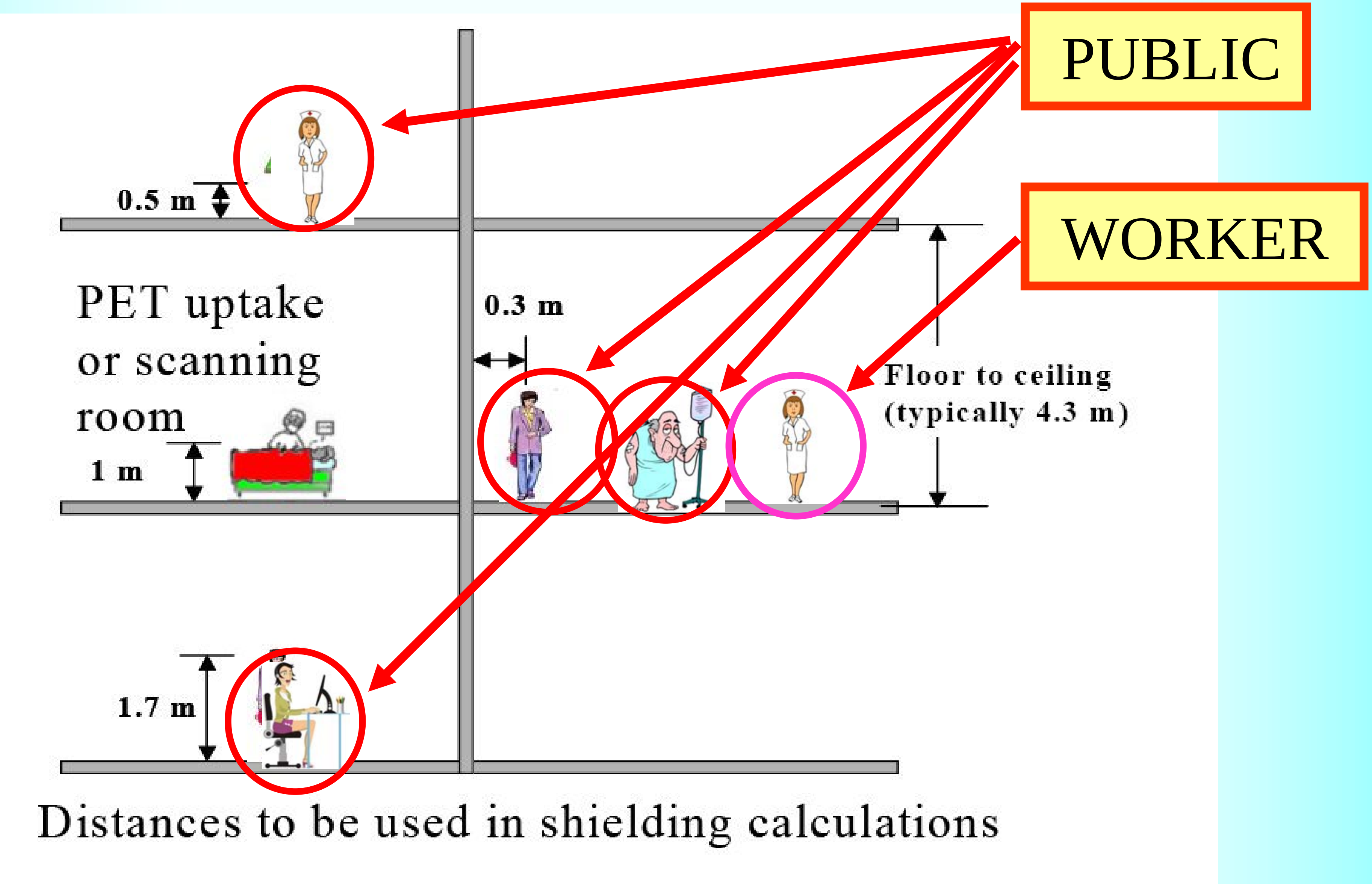
lead container

typically 5 cm-thick $\Longrightarrow$ $k \approx 5\ 10^{-4}$

Radiation sources

- ~~*sources stored in hot lab*~~
- *patient in uptake room*
- *patient in PET/CT scanner*

Calculation model



Typical dose assessment

let's suppose a typical PET study

- *administered activity : 555 MBq (15 mCi)*
- *uptake time : 60 minutes*
- *acquisition time : 45 minutes*
- *40 patients per week*

Typical dose assessment

dose constrains from Nuclear Regulatory Authority of Argentina will be supposed

- *occupational exposure : 5 mSv per year*
- *members of public : 100 μSv per year*

Radiation protection considerations

radiation safety must be guaranteed by the facility design itself and not by particular procedures

usually, surrounding uncontrolled areas in the vicinity of the PET facility have an occupancy factor of 1

Radiation protection considerations

- Prior to injection to the patient, the radioactive aliquot has to be transferred from the vial to the syringe.
- This operation is carried out interposing a lead shield between the vial and the operator.
- In order to allow visual shadowing of the operation, lead glass has to be used.
- This operation may last only a few seconds

Radiation protection considerations

lead glass

Radiation protection considerations

- after the syringe was loaded with the radioactive solution, it has to be translated to the uptake room, where the patient is injected.

lead

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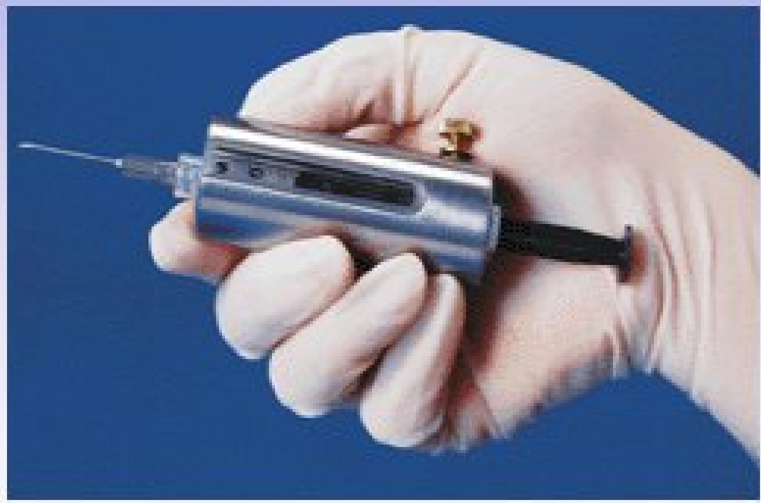
Radiation protection considerations

- Once in the uptake room, radioactive aliquot is injected to the patient.
- Because of the high effective dose constant associated, hand doses for individuals drawing up and administering PET radiopharmaceuticals can be substantial.
- For the typical case described, the dose rate at 5 cm from an unshielded syringe is 30.86 mSv/h
- This operation may last between up to 1 min,
- In this case the annual dose to a technician should be about 1070 mSv

Radiation protection considerations

Tungsten syringe shields can reduce the hand dose, but the additional weight can make injections difficult.



Syringe Shields (Tungsten and Lead Glass)

Radiation protection considerations

- The injection may be administered to the patient using a catheter, with the syringe located within the mentioned lead shielding.

Radiation protection considerations

- Other ways to reduce hand dose
  - Use automatic dispensing systems
  - Divide the injection responsibilities among the staff.

Radiation protection considerations

- If a single member of the staff would remain at 1 m from the patient during uptake time, then the annual dose to this technician should be 85 mSv

- Consequently, the staff should develop procedures to minimise the time spent near the radioactive patient.

In other words, the practice should be "optimised".

Radiation protection considerations

- Information collection, explanations, blood collection or other tests should be performed as much as possible before radioactivity has been administered.
- Remote monitoring of the patients using video cameras could also be used.

Radiation protection considerations

- Portable lead shields can be used effectively to shield patients in uptake rooms, where they are required to remain stationary.

Radiation protection considerations

- The gantry of the PET tomograph can provide a substantial reduction of the dose rate.
- This depends on the actual geometry and placement of the tomograph in the room as well as the type of scanning procedures.
- If information on the tomograph shielding characteristics is available from the vendor, it can be incorporated into the calculation.

but normally the most conservative approach is taken, i.e. no shielding from the tomograph is assumed.

Radiation protection considerations

- During image acquisition, at least one technologist is located at the PET system console where both, the patient and the progress of the imaging study, can be monitored.

- Ideally, the console area should be located more than 2 m away from the scanner to reduce the operator dose below ALARA levels.

- In this case, the annual dose results to be 11.4 mSv

- which correspond to about 7 mm of lead or equivalent

walls
lead + masonry

viewing window
glass lead

CONTROL CONSOLE

Radiation protection considerations

- New facilities can efficiently use concrete to achieve required shielding factors, while in existing facilities lead is often the best resort.
- Uncontrolled areas with high occupancy should be located as far as possible from the uptake and imaging rooms.

Radiation protection considerations

• Portable lead shields may be used effectively to shield patients in uptake rooms, where they are required to remain stationary.

Radiation protection considerations

- The placement of the door must be carefully considered to avoid the expense with installing one with substantial lead shielding.

- It is a good idea to have the hot bathroom, reserved for PET patients, within the immediate imaging area, so that they do not alter the background counts of other detection devices as they pass through the clinic.

Radiation protection considerations

- If uncontrolled areas are located above and below the uptake and tomograph rooms, the spacing between floors may need to be greater than normal.

- If that is not feasible, the floors need to be able to bear the weight associated with additional shielding.

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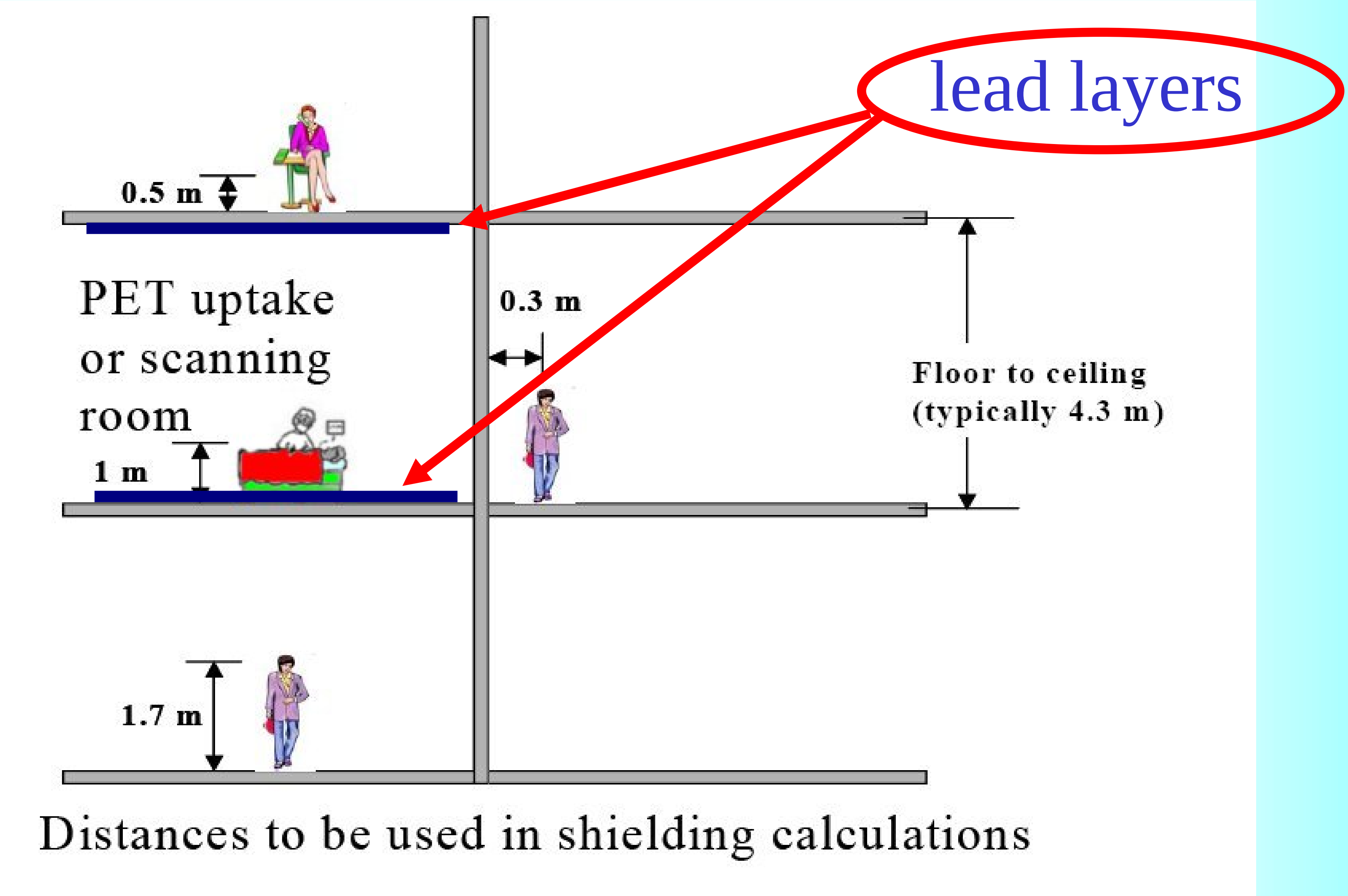
Radiation protection considerations



Thanks for your attention…