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DESIGN OF PET/CT FACILITIES

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IAEA Database of Cyclotrons used for Radionuclide Production

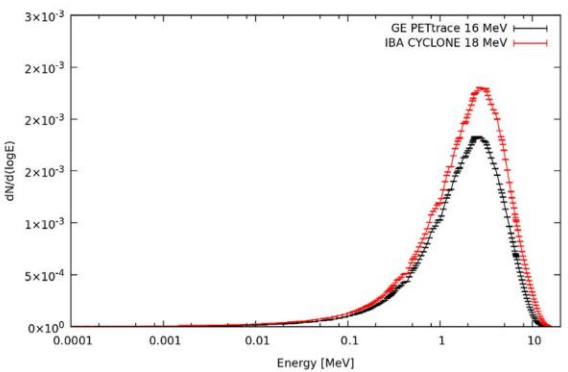
Company	August 2023
GE	411
IBA	268
Siemens + CTI	235
Sumitomo	183
ACSI	48
NIIEFA Efremov	39
Scanditronix	21
ABT	21
JSW	13
Kotron	8
Oxford+PMB	7
TCC	9
Other	4
Total	1267

In total, 1200+ cyclotrons sold (August 2023).

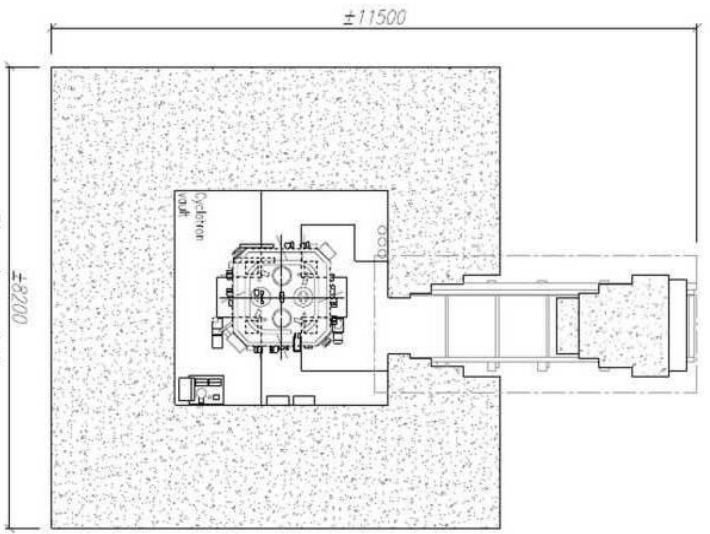
This is an approximate figure, several of these were decommissioned, or activity was discontinued.

PET cyclotrons

Cyclotron	Emax (MeV)	Particles	Imax (microA)	N.Max Target	Dual beam	Type of IS	Power tot. (kWh)	Self Shield
Advanced TR19	19 (variable)	H- (D- opt)	150 - 400	8	Y	Ext, filament	< 65	opt
GE MiniTrace	9.6	H-	60	6	Y (2° target fixed)	Int, PIG	< 35	Y
GE PetTrace	16.5	H- (D- opt)	80 - 150	6	Y	Int. PIG	< 75	opt
IBA Cyclone KIUBE	18 (selectable)	H-	100 - 300	8	Y	Int. PIG	< 65	opt
IBA Cyclone KEY	9.2	H-	100	3	N	Int. PIG	< 37	opt

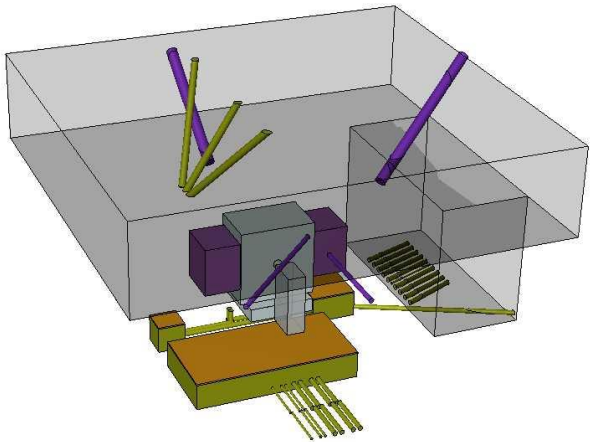


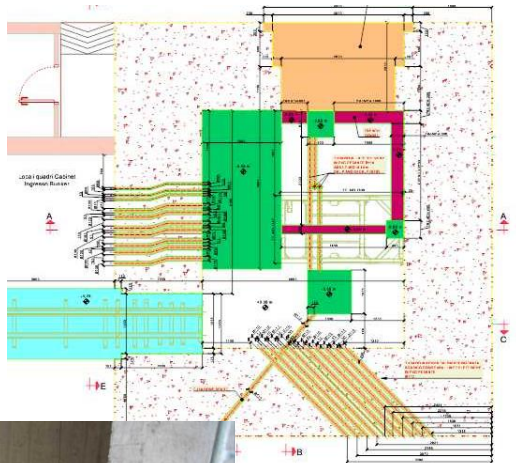
- Dose rates > 10 Sv/h @100 cm from target during irradiation
- Normal concrete (ρ=2.35 gr/cm^3) is the most favourable material
- Concrete composition and position of the reinforcing bars influence the activation
- Thicknesses 200 – 240 cm typical for non self-shielded cyclo



From Vichi, https://doi.org/10.1016/j.radphyschem.2020.108966

Ducts and penetrations in a vault



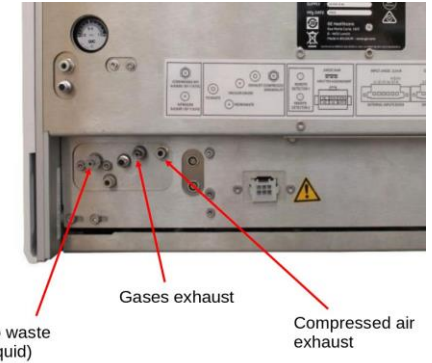


- A shield in general should be continuous
- In the case of PET cyclotrons it CANNOT be continuous
- Different penetrations and ducts, suitably shaped, are required
- Monte Carlo simulations are essential in duct design
- Radionuclides produced in liquid or gaseous form are transferred by pressure of an inert gas. Transfer lines must be tight.

Detail of the floating floor, the walls and the pipes containing the delivery lines, the RF cables, the control cables, etc.

From Infantino A. et al. Radiation Physics and Chemistry, Volume 116, p. 231-236. 2015

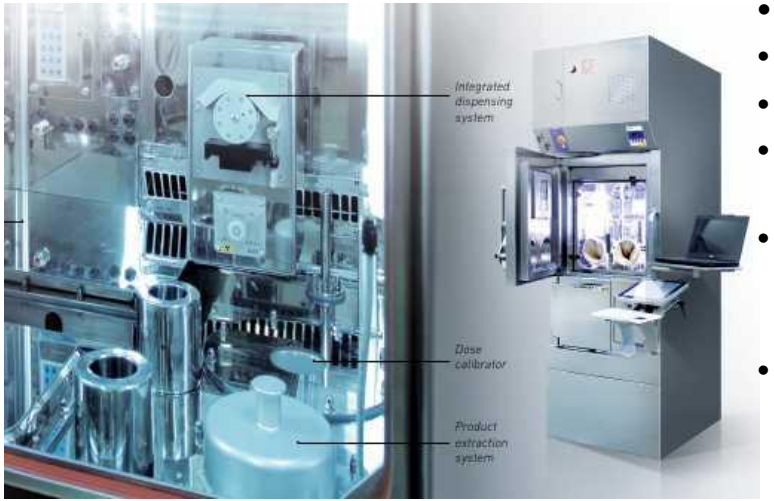
Need for automation. Synthesis modules.



- Nowadays, most manual operations on radiopharmaceuticals can be assisted, if not replaced, by automated operation.
- Appropriate devices are available to perform synthesis, filling vials and dispensing in syringes, with minimal or no need for manual intervention.

- Routine release of radioactive gases during synthesis of radiopharmaceuticals may occur in different phases, and strongly depends on the type of process
- In all cases, the exhaust point from the synthesis unit should be appropriately identified and connected to a suitable system (collection by means of plastic bags, connection of the exhausts to a gas delay line, connection to a sequence of chemical traps, e.g. Ascarite, NaOH, molecular sieves, activated charcoal, etc).

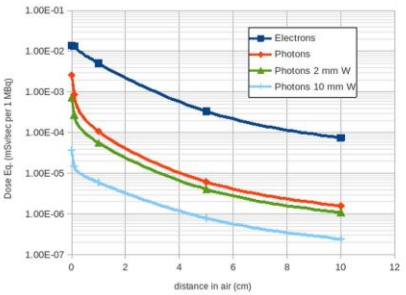
Need for automation. Evidence of high dose to hands.



- Activity produced in a cyclotron facility, per batch: 100 – 200 GBq
- ^{18}F-FDG activity received from an external radiopharmacy: 5 – 10 GBq
- Activity eluted by a ^{68}Ga generator : 1 – 2 GBq
- Specific hot cells, 3-10 cm thick lead shielding and finished in SS to facilitate cleanliness and sanitation, and operated at low pressure.
- Hot cells should have a monitoring system to control all operation conditions (temperature, pressure, air flow, radiation levels) inside the cell and in the exhausted air.
- The control system of the hot cell should include interlocks to ensure safe operation

Table 3. Comparison between EGSnrc simulation and dose rate measurements at 30 cm from an unshielded and shielded syringe.

	Deep dose rate (μGy/MBr.hr)			Skin dose rate (μGy/MBr.hr)		
	EGSnrc	Radeye G20-ER	% diff	EGSnrc	Radeye B20-ER	% diff
Unshielded syringe						
^{18}F	1.81 ± 0.01	1.80 ± 0.02	−0.6%	2.6 ± 0.1	2.4 ± 0.02	−8.3%
^{68}Ga	1.93 ± 0.02	2.11 ± 0.30	8.5%	24.8 ± 0.2	35.4 ± 0.84	29.9%
Shielded syringe						
^{18}F	0.49 ± 0.002	0.51 ± 0.01	3.9%	0.90 ± 0.01	0.61 ± 0.01	−47.5%
^{68}Ga	0.51 ± 0.01	0.54 ± 0.01	5.6%	2.27 ± 0.05	1.91 ± 0.21	−18.8%



This review shows that the exposure of the extremities—and particularly the skin of the fingers—is a topic in NM that deserves our ongoing attention. The ORAMED study, by now ten years old, was the last large scale initiative in which the extremity exposure during ^{99m}Tc, ^{18}F and ^{90}Y procedures was systematically investigated. This investigation increased the awareness of underestimating the finger dose using ring as well as wrist dosimeters. Based on the outcomes of this study, there was reason for concern with respect to the fingertip dose during the preparation and dispensing of ^{18}F for PET procedures.

Marengo M, Rubow S. , https://doi.org/10.1016/j.apradiso.2023.110705
McCann et al. https://doi.org/10.1088/1361-6498/ac0df5
Kollaard et al. https://doi.org/10.1088/1361-6498/ac31a2

It is not just matter of shielding

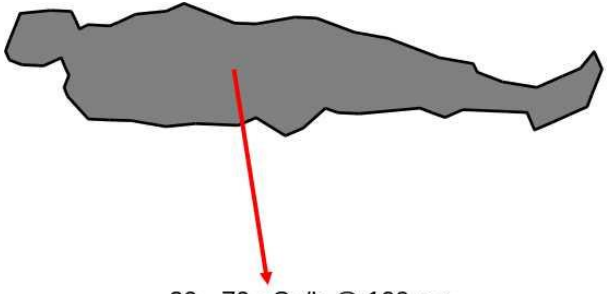
- As in many other applications, correct design is a key point in order to guarantee adequate radiation protection during operation.
- In Nuclear Medicine, and in particular in PET, it is not just a question of correctly designing the positioning and shielding of a piece of equipment.
- It is the entire process that must be properly planned and kept "under control" in order to ensure safe and effective operation.

A peculiar source term

Sequence of 18F-FDG patients

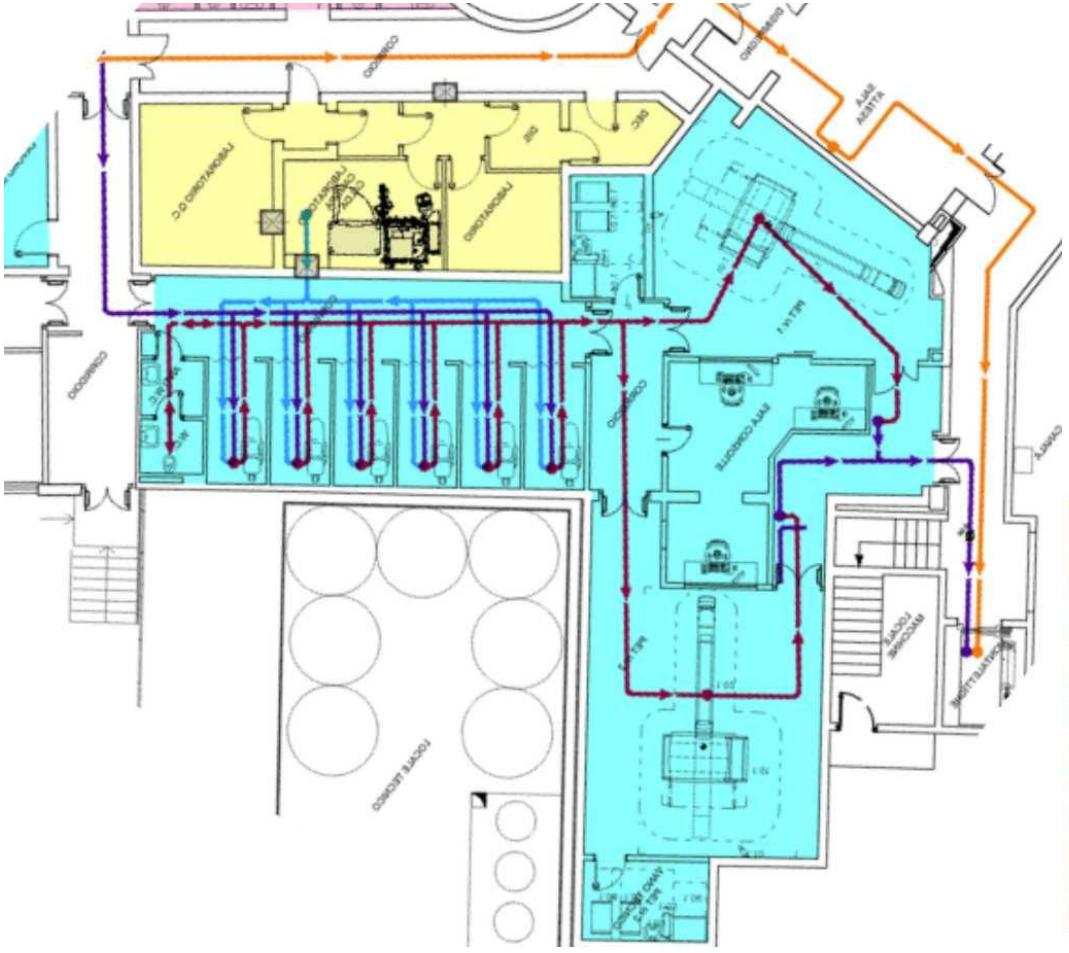
Task	09:00	09:15	09:30	09:45	10:00	10:15	10:30	10:45	11:00	11:15
Injection to 1st patient										
Uptake time 1st patient										
Scan 1st patient										
Injection to 2nd patient										
Uptake time 2nd patient										
Scan 2nd patient										
Injection to 3rd patient										
Uptake time 3rd patient										
Scan 3rd patient										
Injection to 4rt patient										
Uptake time 4rt patient										
Scan 4rt patient										
Injection to 5th patient										
Uptake time 5th patient										
Scan 5th patient										
Injection to 6th patient										
Uptake time 6th patient										
Scan 6th patient										

- ^{18}F has a half life of 110 min
- Once ^{18}F-FDG is administered to a patient, a time interval of 45 – 75 minutes is necessary to achieve proper bio-distribution (uptake phase)
- The scan itself will take about 15 – 20 minutes, including positioning etc.
- In order to achieve efficient use of the radiopharmaceutical, avoiding that it decays without being used, and the full occupation of the scanner, it is necessary to have careful timing of the sequence of injections to patients
- This allows you to have a patient ready to enter the scanner room and be examined as soon as the previous patient has finished
- As a consequence, about 4 injected patients per scanner are present at the same time

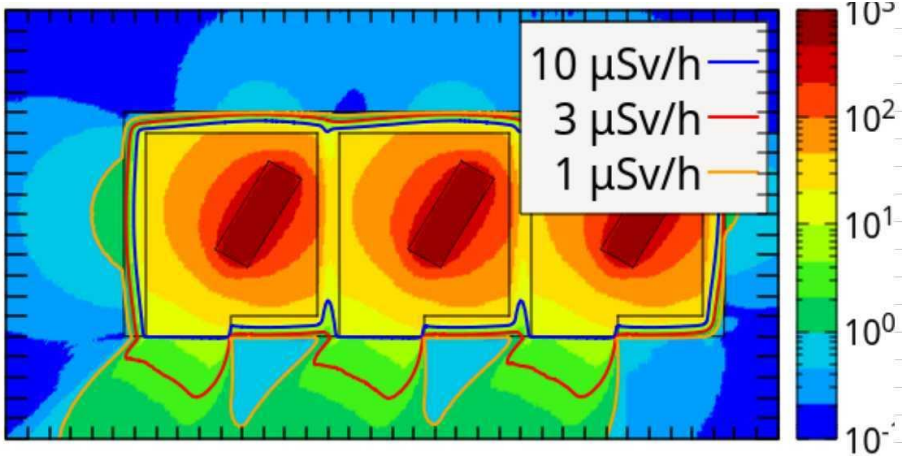


20 - 70 μSv/h @ 100 cm
after administration of typical activities of ^{18}F-FDG

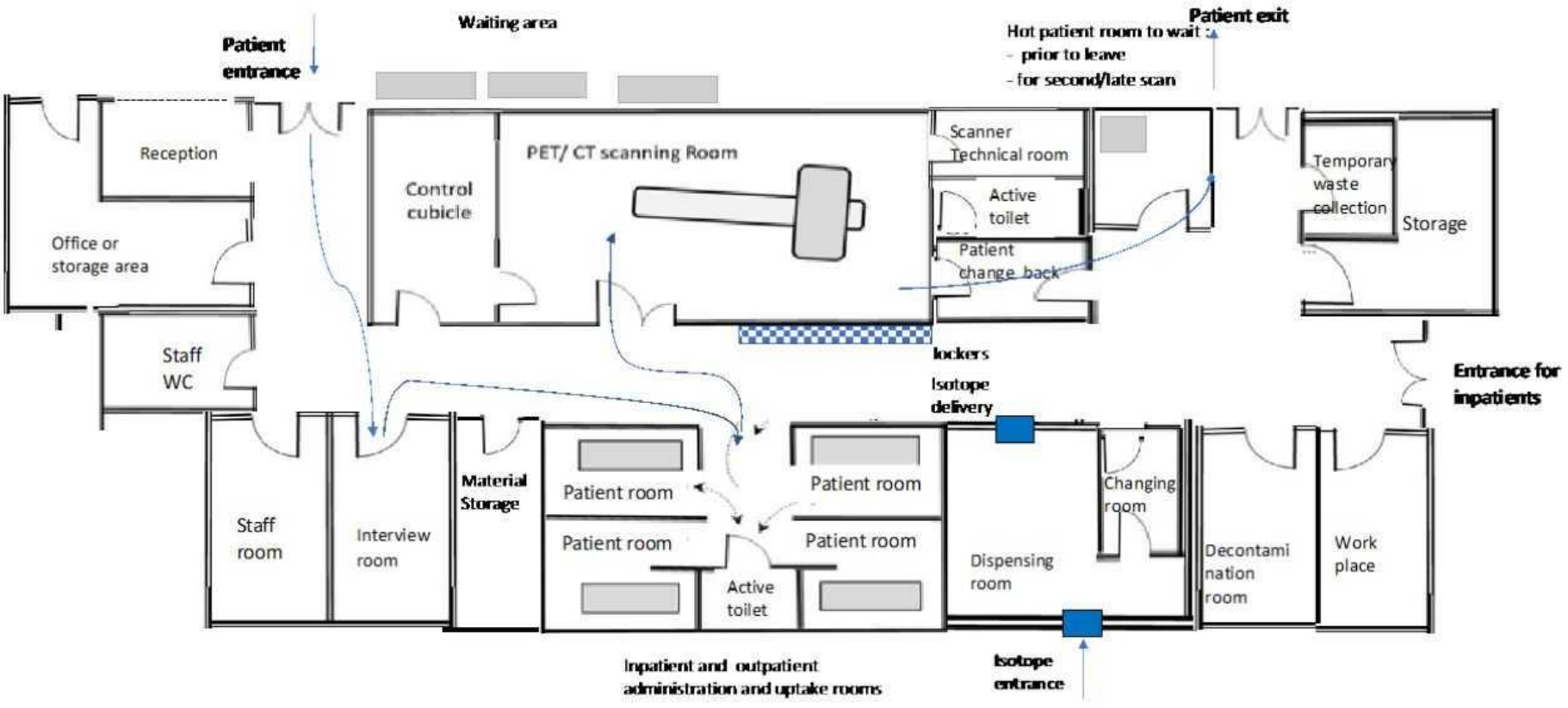
The administration/uptake areas are the sticking point



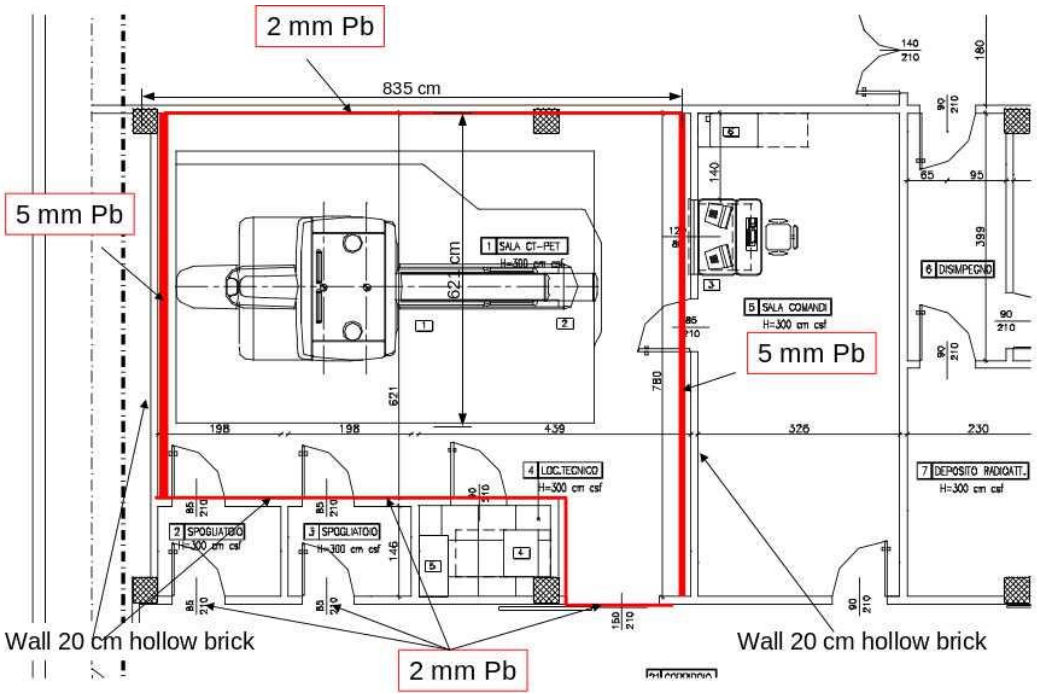
- The path of all sources (radiopharmaceuticals and especially patients) should be carefully planned
- The critical point is not the scanners, but the concentration of patients in some key points
- This is a great gym to practice optimization!



Careful planning of spaces and flows



It's not just a matter of shielding, but shielding is always important



- In multi-modality PET/CT scanners, the 511 keV emission has a much higher energy than the X-ray beam of the CT component.
- On the other hand, the 511 component has a relatively small but almost continuous dose rate, while the X-ray component is emitted only for a short time, but with a high dose rate.
- In general, the thickness of the barriers calculated to attenuate the 511 keV photons will also be sufficient to absorb X-radiation.
- Doors must be shielded, if possible avoiding motorized doors, which affect the pace of work.
- Viewing windows must be shielded @ 511 keV

Madsen, M.T. et al., 2006. PET and PET/CT shielding requirements. AAPM Task report 108, Med. Phys. 33, 4–15.

Key points

- Cyclotron vaults should be planned and constructed primarily to protect against secondary neutron radiation and concrete is the primary material normally used.
- Shielding requirements will depend on the incorporation of self-shielding.
- Radionuclide transfer systems within a cyclotron facility should be designed to minimise leakage and staff exposure, and pressures and airflow designed to limit spread of any airborne contamination.
    - Handling of PET radiopharmaceuticals during synthesis, filling vials and dispensing in shielded syringes should be automated as much as possible.
        - Patients remain in the PET facility for several hours including a rest period following 2-[^{18}F]FDG administration that may be 60 minutes. Planning movement of the patient through the department to minimise exposure of staff members is crucial.
        - The provision of shielded rooms for resting patients, the location of active toilets to minimise distances of any patient movement, and the siting of patient facilities adjacent to the scanning room are all important.
        - PET/CT facilities require shielding against almost continuous low dose rate exposure from 511 keV photon emissions and short higher dose rate CT x-ray exposures.
        - Protection of walls against 511 keV photons using concrete will dominate shielding requirements, but scattered CT x rays must be considered for the scanning room doors and windows.