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Radiation protection in Nuclear Medicine

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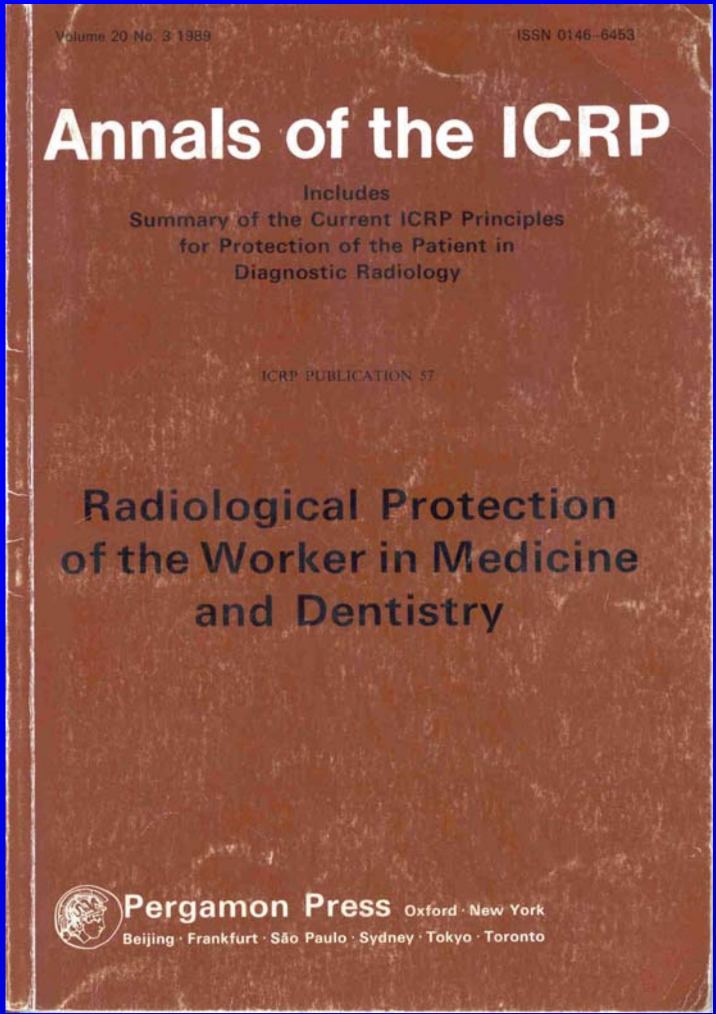
Summary

- **PET radiopharmaceuticals production**
  - Cyclotron site planning and shielding
  - Cyclotron components maintenance
  - Safe delivery of radioactive boluses
  - Gaseous emissions from synthesis modules
- **Radiopharmaceuticals manipulation and administration**
- **Multi modality scanners**
- **Classification of Nuclear Medicine departments**
  - Specification of ventilation system in Nuclear Medicine

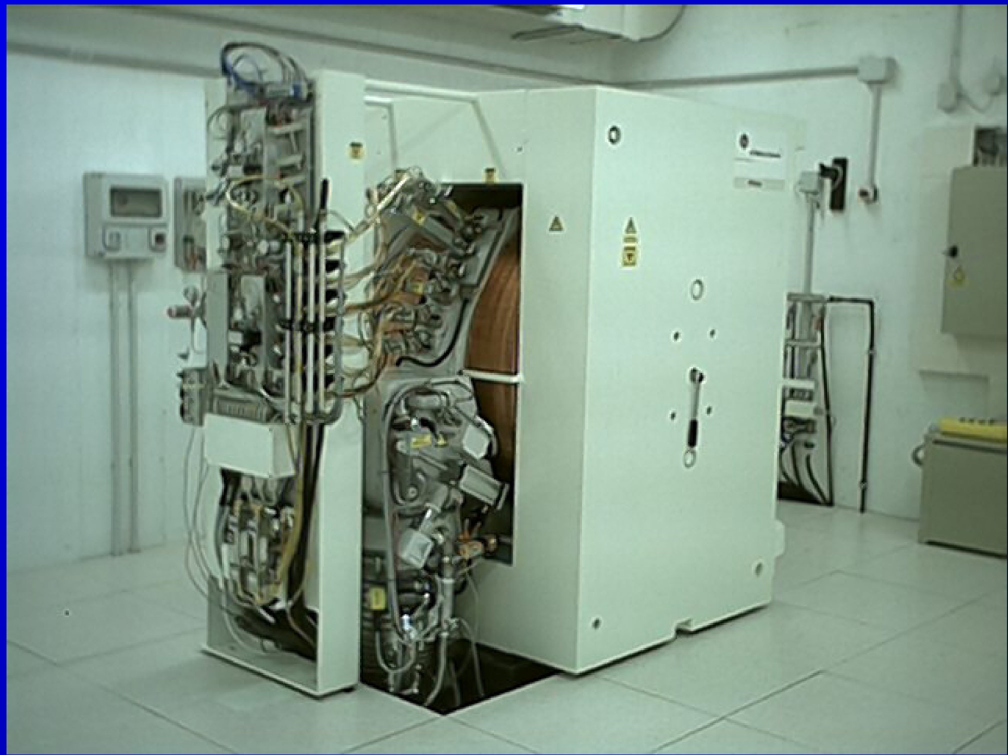
General reference: the ICRP 57



ICRP Publication 57 “Radiological protection of the worker in medicine and dentistry” , 1989

PET radiopharmaceuticals production

Cyclotron installations in the world



1998	206
2001	246
2005	261

Source: IAEA Directory of cyclotrons

Specific references per Cyclotron installations

In the ICRP57 only few sentences are dedicated to PET; in particular, cyclotrons are addressed only in para 234 and 471 – 481, less than 2 pages, mostly not dealing with specific issues, but with neutron therapy facilities.

Useful information is given in several reference documents:

- Technical Report No. 283 “Radiological safety aspects of the operation of proton accelerators”. IAEA, Vienna, 1988.
- NCRP Report No. 144 “Radiation Protection Design Guidelines for 0.1 - 100 MeV Particle Accelerator Facilities”. (Rev of **NCRP 51**). NCRP, Bethesda, 2004.
- Tecdoc 1211 “Charged particle cross section data base for medical radioisotope production: diagnostic radioisotopes and monitor reactions”. IAEA, Vienna, 2001)
- ICRP Publication 76 “Protection from Potential Exposures: Application to Selected Radiation Sources”. ICRP, Oxford, 1997.

However, a specific document supplying ready to use guidance on shielding and radiation protection of cyclotrons for biomedical use is still missing

Equations for shielding estimate with the TVL method

$$H_{expected} = H_{ref} \cdot \frac{U \cdot T}{d^2}$$

Basic equation for estimate of the expected dose at the target point; it is based on a reference dose value (at a certain angle and at a distance of 1 m); in general, *Href* will be different at 0° and 90°.

$$B_x = \frac{H_{limit}}{H_{expected}}$$

Required attenuation factor

$$n = \log_{10}\left[\frac{1}{B_x}\right]$$

Number of TVL required to obtain the requested attenuation

$$S_p = TVL_1 + (n-1) \cdot TVL_n$$

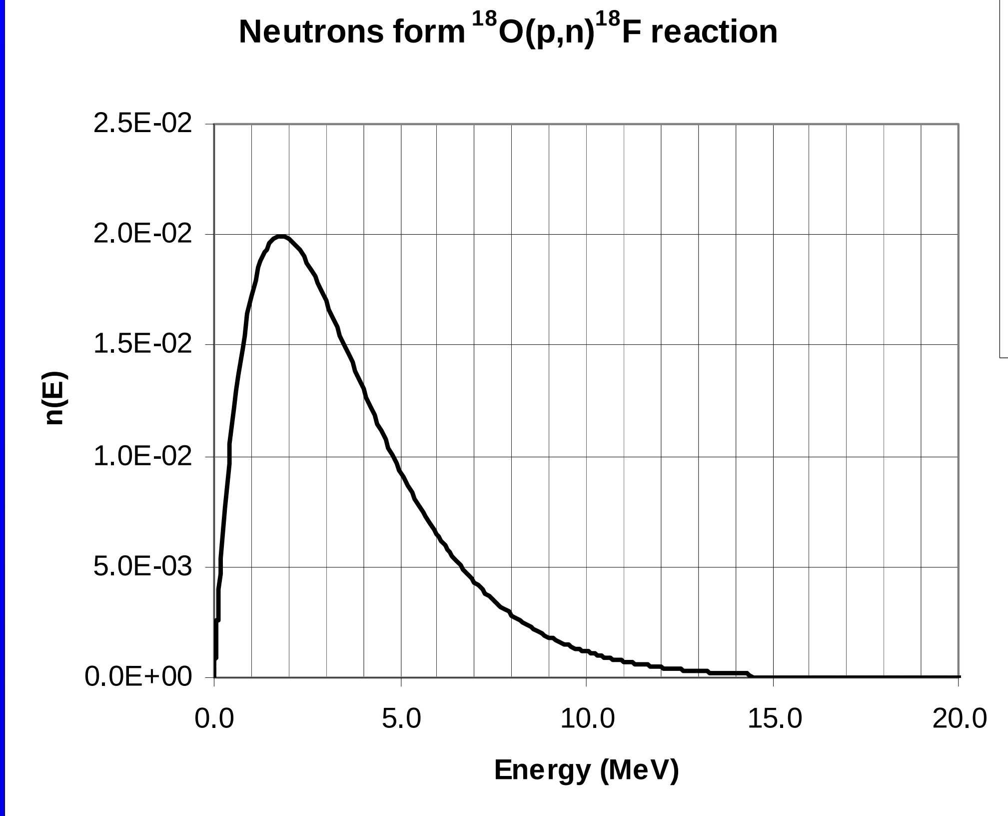
Shielding thickness calculated taking into account different values for the first and "equilibrium" TVL

$$S_{p,s} = S_p + HVL_n$$

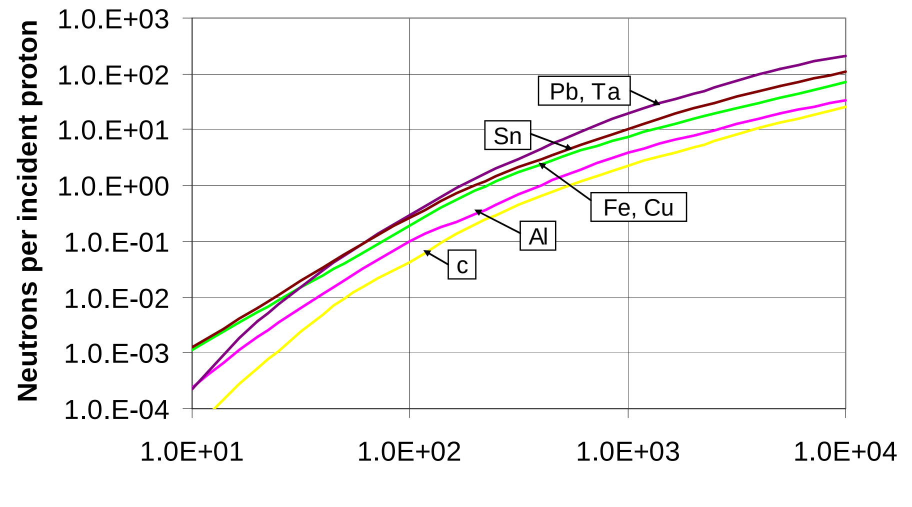
Final shielding thickness, with the addition of a "safety" HVL

See for comparison NCRP 151 on radiotheraphy LINACs

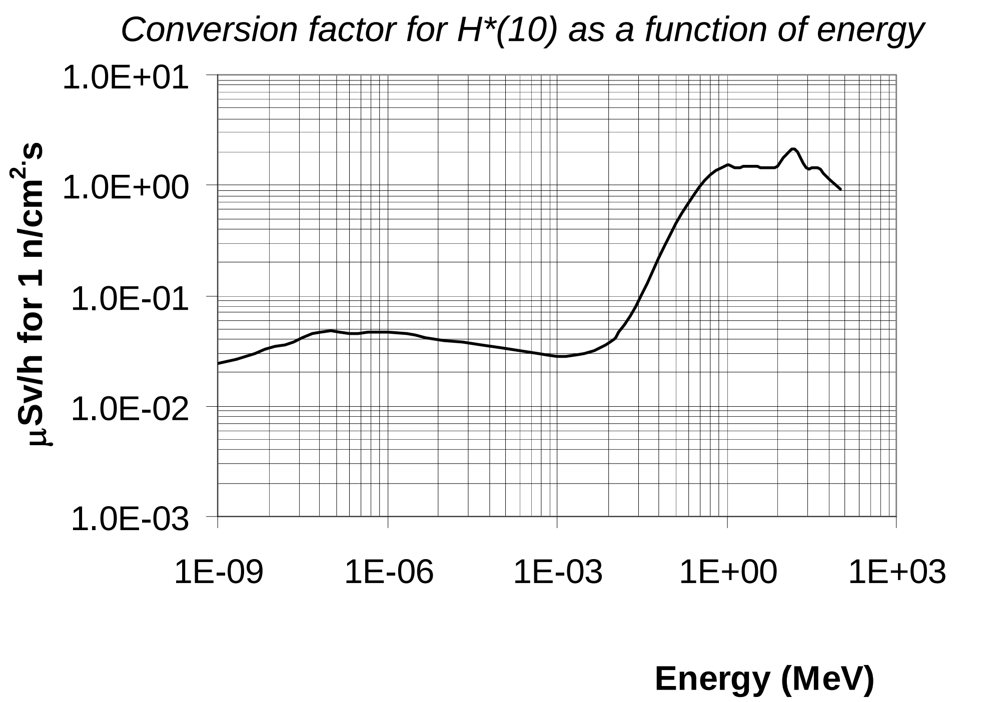
Basic data for cyclotron shielding



Vigliaturo et al., Eur J Nucl Med, 2008

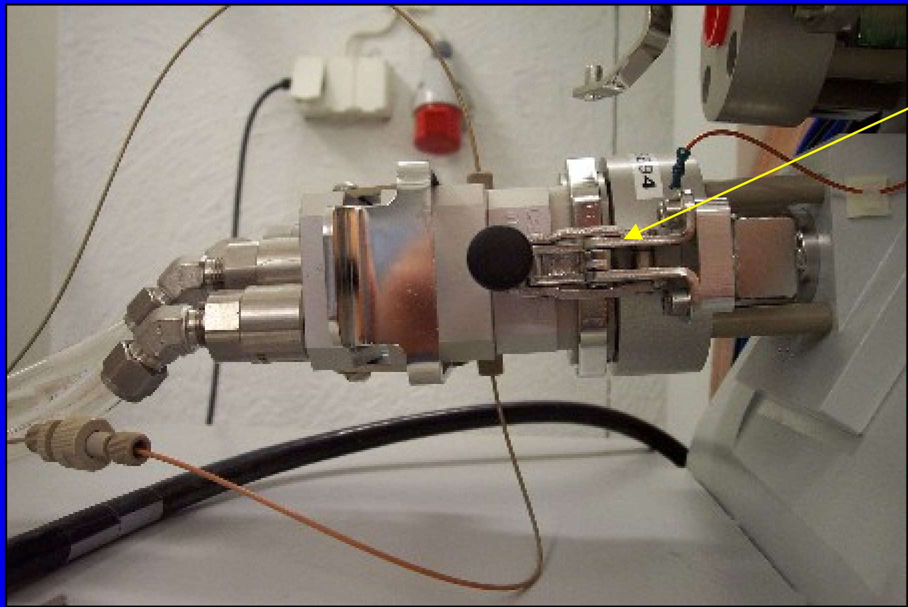


NCRP144 and IAEA TecRep283



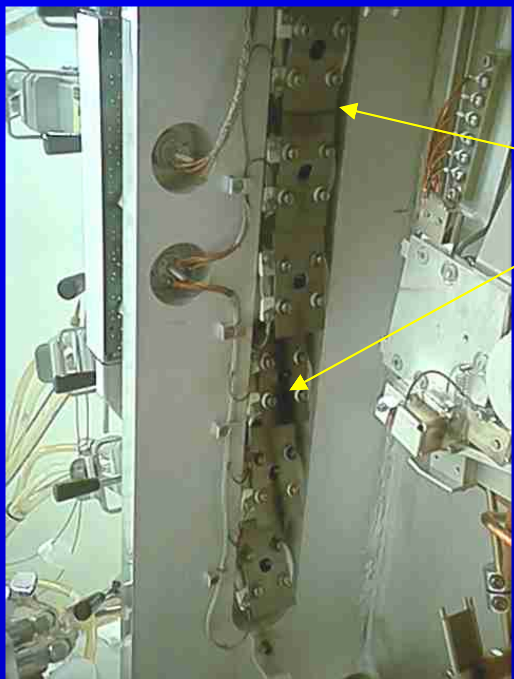
Annals of the ICRP Volume 26/3

Maintenance of cyclotron components



Target foils

Extraction



Collimators

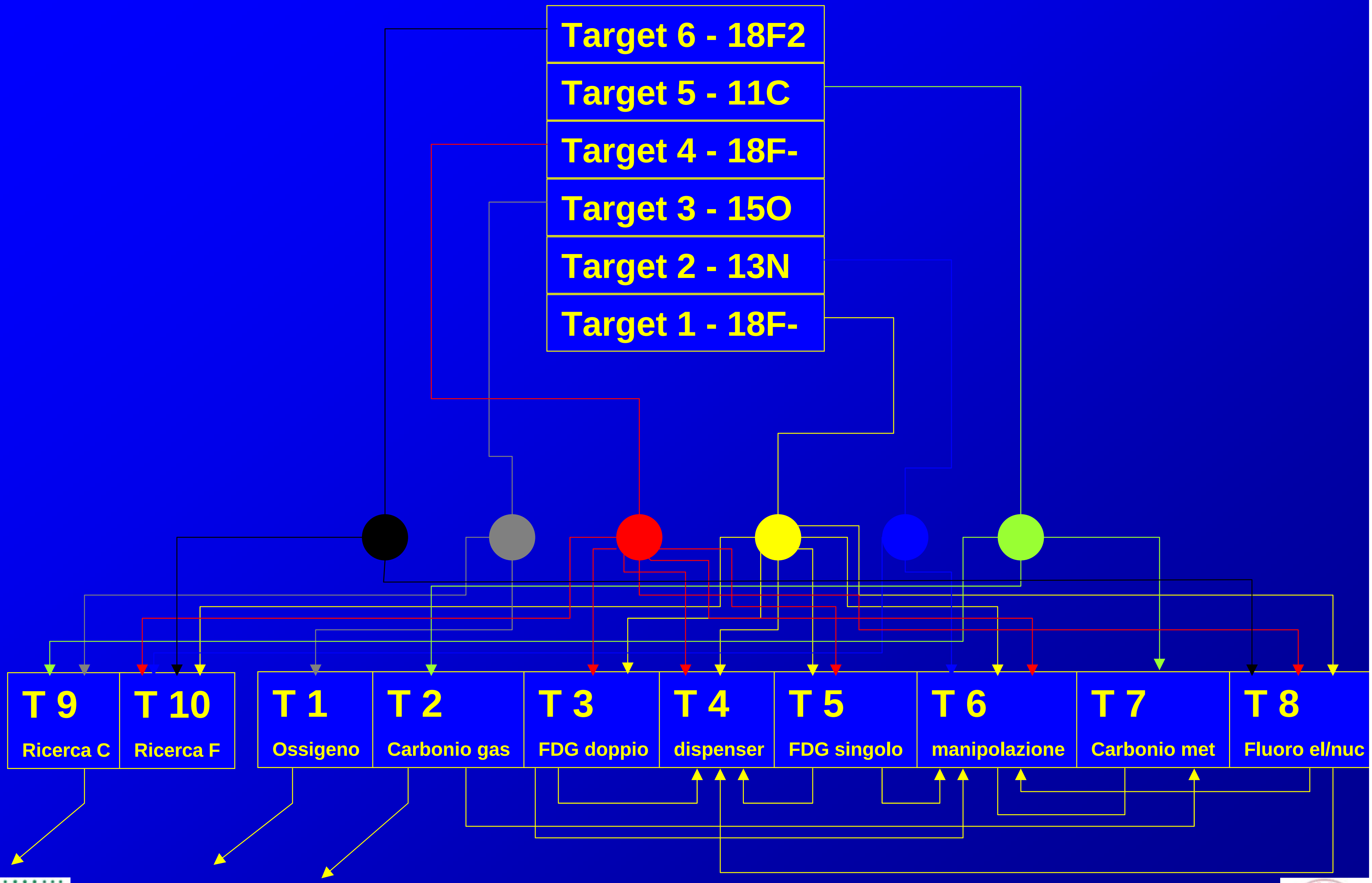
See also Mora, Bedogni, Esposito TS III 1.4 - 1095

Safety in the delivery of radioactive boluses

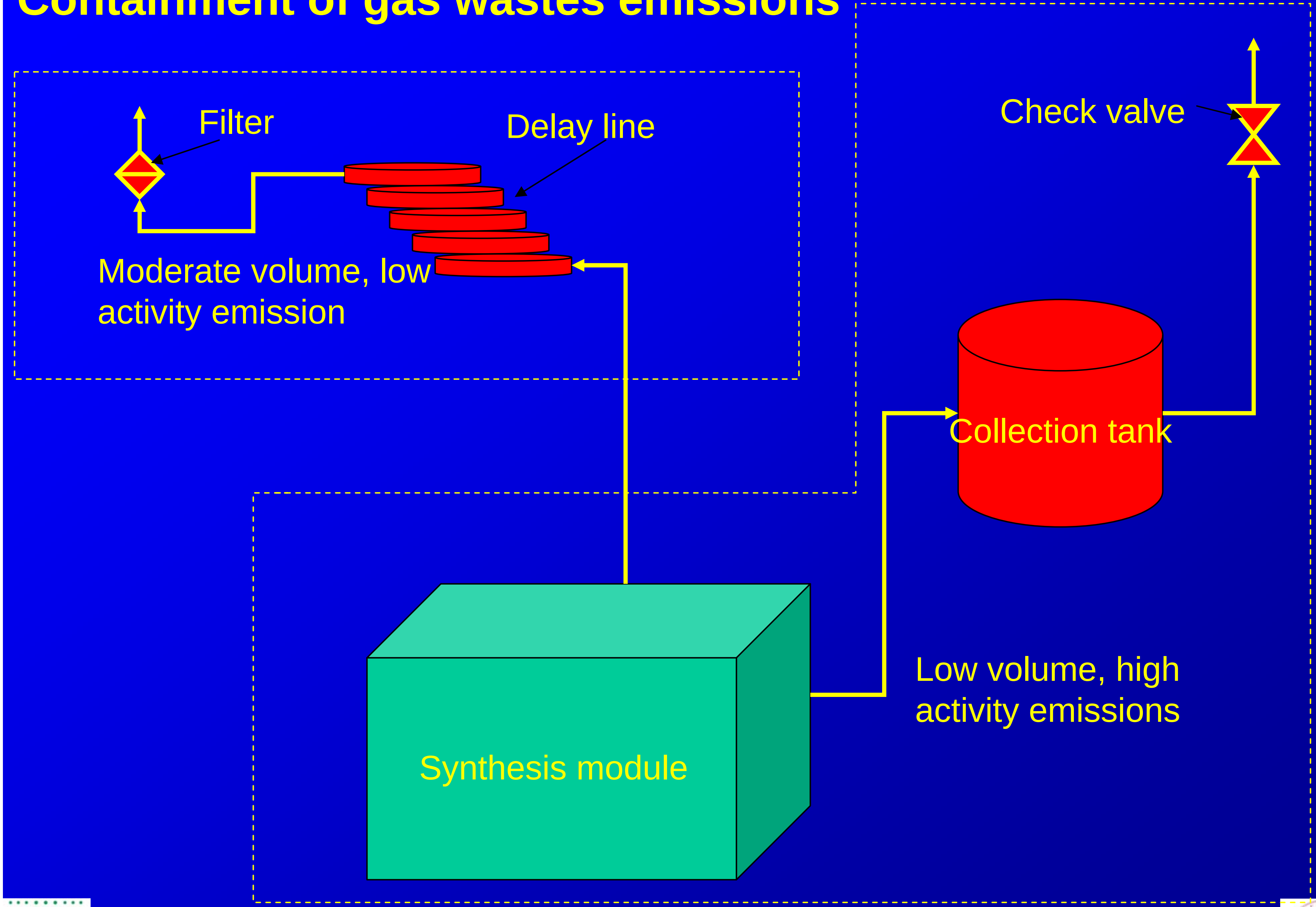
Safe delivery of relevant activities of liquid / gaseous radionuclides requires several conditions:

- the delivery line should be tighten;
- the receiving hot cell should be in a safe condition (doors closed, ventilation).

General scheme of targets – hot cells connection (Bologna)



Containment of gas wastes emissions



Radiopharmaceuticals manipulation and administration

Automatic administration of radiopharmaceuticals

Devices for safe injection of radiopharmaceuticals, based on automatically controlled peristaltic pump or syringe pump, are now available on the market by different producers. Their performance and efficacy is still to be demonstrated.

(see also Wallace TS III 3.3 - 2280)

Dosimetry of beta radiation in radiopharmaceutilacals preparation & administration

Use of beta emitting radiopharmaceuticals is continuously increasing. This includes PET radionuclides, since positron radiation has sufficient energy to escape from syringes and thin walled containers, and pure beta emitters, like ^{90}Y, or beta – gamma emitting radionuclides as ^{153}Sm or ^{177}Lu, and the always widely used ^{131}I.
This involves relevant changes in comparison to the consolidated experience with ^{99m}Tc

Dosimeters should be carefully selected; they need to have:

- very thin envelope (< 20 mg/cm^2), in order to avoid absorption of beta particles in the protective cover

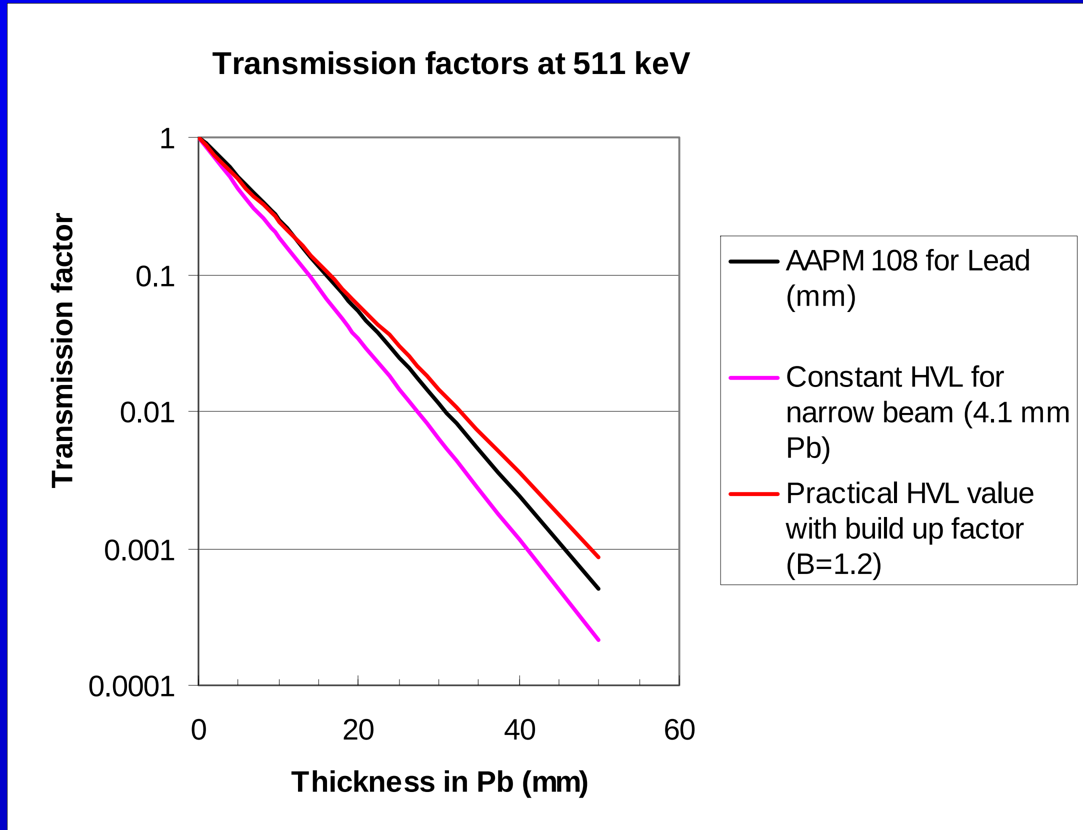
- proper calibration not only for gamma radiation, but also for beta particles (see www.eurados.org)

(see also Kop TS III 3.3 - 558)

Research work in modelling manipulation and administration in necessary to proper design dosimeters and optimize operation. See http://www.oramed-fp7.eu for an example of international cooperation in this field.

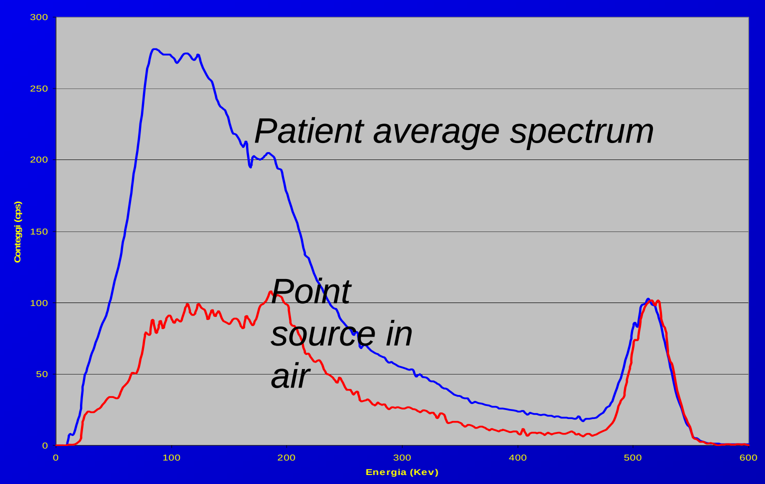
Multi modality scanners

Transmission and build up factors in “bad” geometry

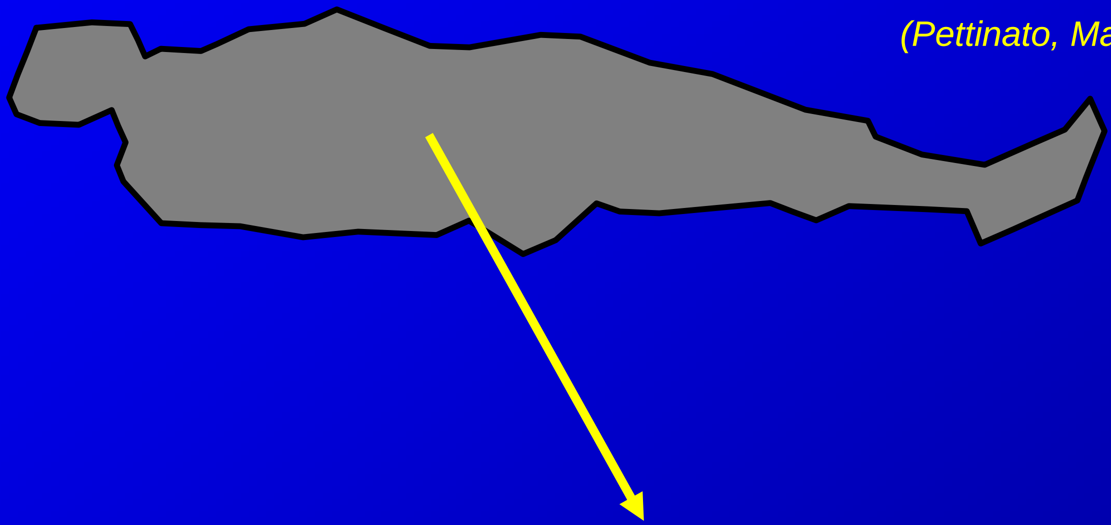


- the “old” analytical approach for the evaluation of build up factors may still be useful
- AAPM Report 108 gives build up factors for some shielding materials
- further research using MC techniques will improve shielding assessment

Irradiation from patients



(Pettinato, Marengo et al. Eur J Nucl Med 2006)



About 30 μSv/h at 100 cm
60 minutes after administration of 370 MBq of ^{18}F-FDG

See also Guimaraes et al. TS III 3.3 - 915

Classification of Nuclear Medicine departments

Classification in ICRP 57

Class	Radionuclide	Weghting factor
A	^{75}Se, ^{89}Sr, ^{125}I, ^{131}I	100
B	^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{51}Cr, ^{67}Ga, ^{99m}Tc, ^{111}In, ^{114m}In, ^{123}I, ^{201}Tl	1
C	^{3}H, ^{14}C, ^{81m}Kr, ^{127}Xe, ^{133}Xe	0.01

Type of operation or area	Weghting factor
Storage	0.01
Waste handling	0.1
Scintigraphic counting/imaging when administration is made elsewhere	
Patient waiting area	
Patient bed area (diagnostic)	
Local dispensing	1.0
Radionuclide administration	
Scintigraphic counting/imaging when administration is made in the same room	
Radiopharmaceutical preparation, simple	
Patient bed area (therapeutic)	
Radiopharmaceutical preparation, complex	10

Category of hazard	Floor	Surfaces	Fume cupboard	Room ventilation	Plumbing	First aid
Low	Cleanable	Cleanable	No	Normal facilities	Standard	Washing
Medium	Non-permeable, easily cleanable	Cleanable	Yes	Good	Standard	Washing & decontamination facilities
High	Continuous sheet welded to walls	Cleanable	Yes	Extractor fan	May require special plumbing	Washing & decontamination facilities

CEN model for ventilation in non-residential buildings

(not dealing with professional activities and specific sources of risk, i.e. radioactivity)

$$q_{tot} = n \cdot q_p + A \cdot q_b \qquad l \cdot s^{-1}$$

Term related to the number of occupants in a room

Term related to emission of pollutants form the building materials

•CEN/TC 156, Ventilation for non-residential buildings — Performance requirements for ventilation and room-conditioning systems. European Standard EN 13779.

•CEN/TC 156, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. European Standard EN 15251

A model for specification of ventilation in Nuclear Medicine

$$q_{tot} = n \cdot q_p + A \cdot q_b + A \cdot q_r$$

Term related to the number of occupants in a room

Term related to emission of pollutants form the building materials

Term related to risk factor

The risk related flow rate is selected according to the type of operation performed in the specific room, and is simply multiplied by the area

This gives an easy method to the expert in radiation protection to produce quantitative specification for the ventilation system in Nuclear Medicine department, that can be used unambiguously by the HVAC designer.

Data for specification of ventilation in Nuclear Medicine

Type of room	Typical range of occupancy (m^2/person)	Default value of occupancy (m^2/person)	Range of air flow rate q_p (l/sec.persona)	Default value of air flow rate q_p (l/sec.person)	Range of air flow for buiding emissions q_b (l/sec·m^2)	Default value of air flow for building emissions q_b (l/sec·m^2)	Range air flow rate for risk factor q_r (l/sec.m2)	Default air flow rate for risk factor q_r (l/sec.m2)
Diagnostic room	20 - 25	24	5 - 15	10	1.0 - 2.0	2.0	1.0 - 2.0	2.0
Control room	5 - 10	7	5 - 15	10	1.0 - 2.0	2.0	1.0 - 2.0	1.0
Laboratory	5 - 10	7	20 - 40	30	4.0 - 6.0	5.0	4.0 - 6.0	5.0
Wastes storage	20 - 25	24	5 - 15	10	1.0 - 2.0	2.0	1.0 - 2.0	2.0
"Hot" waiting room	1.5 - 2.5	2	10 - 15	12	4.0 - 6.0	5.0	0.0 - 1.0	0.0
Patient room	5 - 10	7	10 - 15	12	1.0 - 2.0	2.0	1.0 - 2.0	2.0

Conclusions

• Relevant progresses take place in Nuclear Medicine during the last few years.

• The number of installed cyclotron is greatly increased, and it is still growing all around the world, in order to fulfil the increasing demand of ^{18}F and other PET radionuclides.

• This process is determining the need of updating and improving safety and protection in PET centres, to allow for safe synthesis, dispensing and administration of radiopharmaceuticals.

• Progresses in this field will determine a positive feedback also for other applications, like targeted therapy

• Diagnostic procedures are now performed with multimodal PET-CT scanners, which require specific site planning and shielding. The experience grown in these years has then lead to the publication of detailed guidelines, that will be an example for similar needs as regards SPECT-CT scanners, that are now becoming more and more diffused.

• Classification and radiation protection design of Nuclear Medicine departments is still based on reference documents like ICRP Publication 57, that is now about 20 years old and needs review, in particular as regards quantitative specifications for the ventilation and other relevant aspects related to site planning of new equipment.

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