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Exposure monitoring and DRLs in diagnostic nuclear medicine and hybrid imaging: quantities, procedures, methods. Italian experience with DRLs for nuclear medicine

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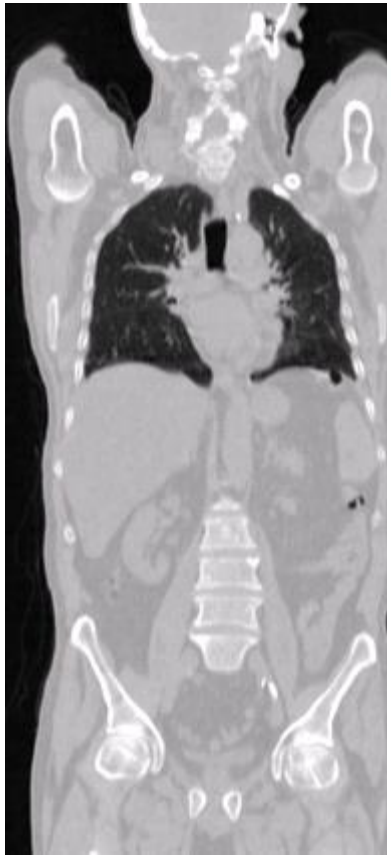
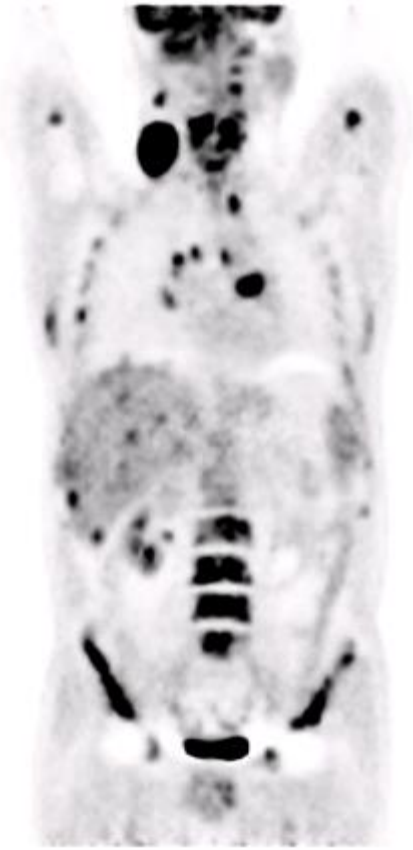
Anatomy versus function

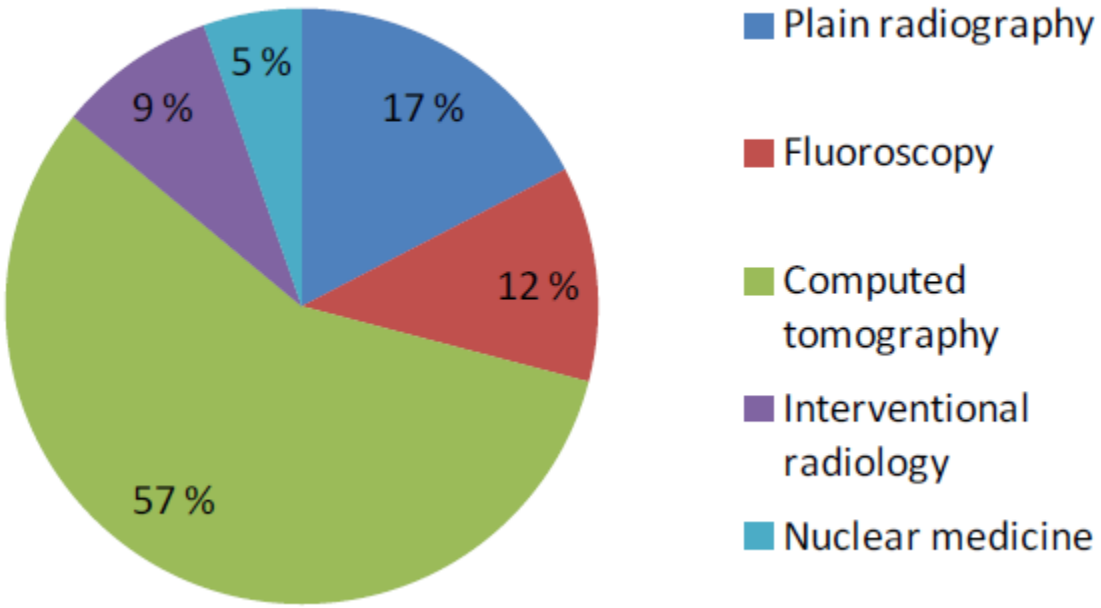




- Diagnostic imaging can be divided into two broad categories: those methods that define very precisely **anatomical details** and those that produce **functional or molecular** images.
- The first method (using CT and MRI) can provide exquisite details on organs and lesion location, size, morphology and structural changes to surrounding tissues, but only delivers limited information as to the organs and tumour's functioning.
- The second method (using PET and SPECT) can give insight into the physiology down to the molecular level, but cannot provide precise anatomical details.
- Combining these two methods enables the integration of anatomy and function in a single approach. The introduction of such "hybrid" imaging has allowed for the characterization of tumours in all stages.

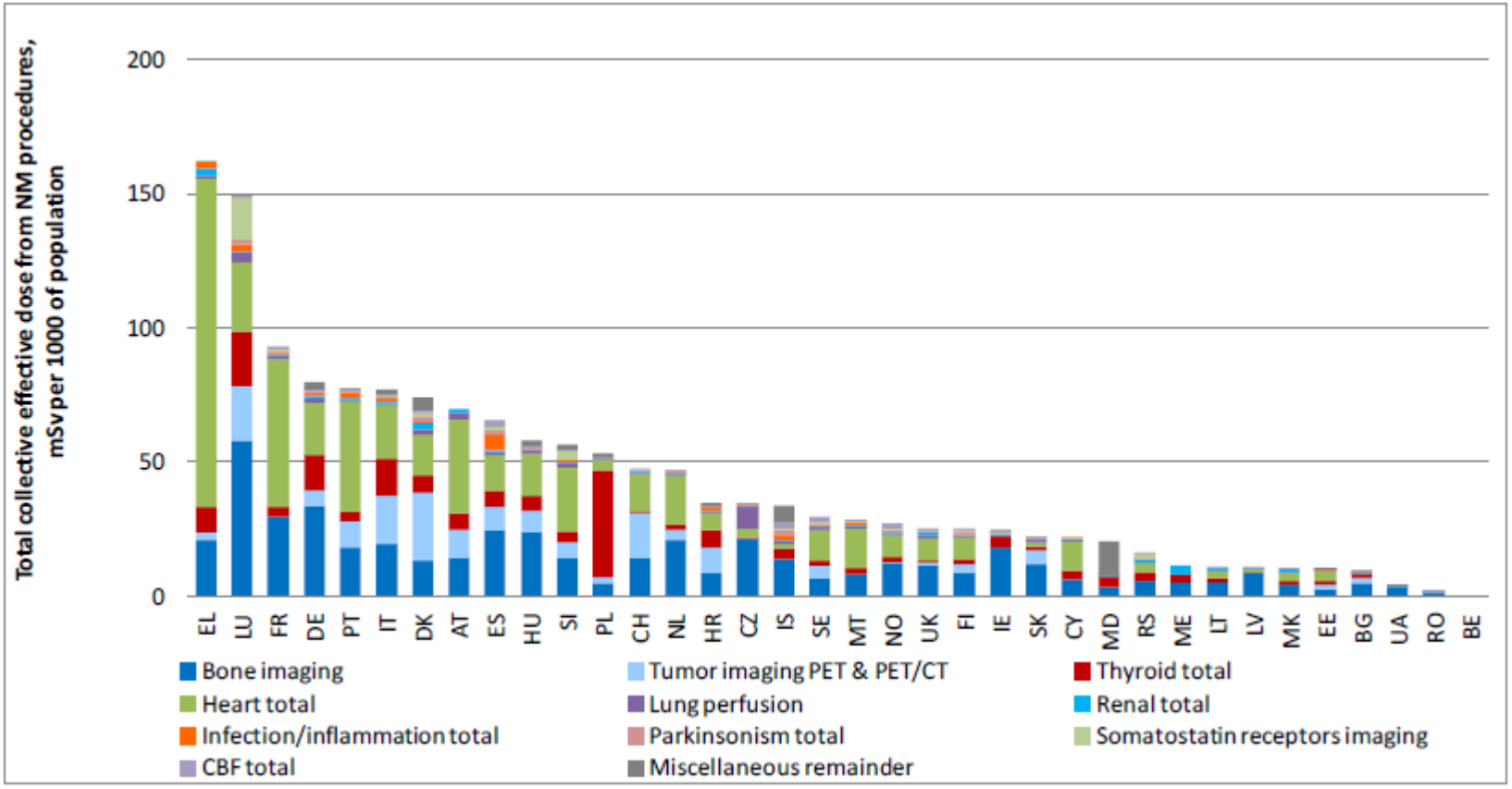
Medical Radiation Exposure of the European Population

National surveys carried out between 2007 and 2010 in Europe recorded the annual effective dose per caput in the participating European countries, which has been calculated to be about 1.1 mSv for all medical imaging. To put this value in perspective, it could be noted that it is about half the recent value of per caput medical radiation dose estimated in Australia and about one-third of the corresponding value in the USA.



Rif: RADIATION PROTECTION N° 180 (2014)

Medical Radiation Exposure of the European Population

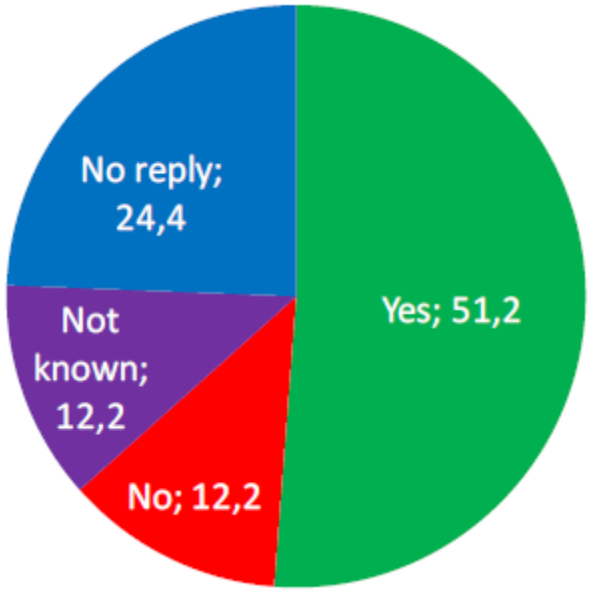


Total collective effective dose per 1000 of population, for the groups of NM examinations (one or more examinations of the same organ, the same target or closely similar objectives grouped together).

Rif: RADIATION PROTECTION N° 180 (2014)

Medical Radiation Exposure of the European Population

- PET-CT and SPECT-CT hybrid systems are not yet very common in several European countries, and in some countries, the first hybrid systems have just recently been introduced. For these systems, on the average 32 % of the CT scanners are used for diagnostic CT, while there are high variations from country to country: in France, all CT scanners of the hybrid systems are used only for attenuation correction, while in Italy all are also used for diagnostic purposes. More than half the countries reported that the use of PET-CT for oncological imaging has increased and is considered to be good practice in this application while some countries reported this to be only for certain indications.

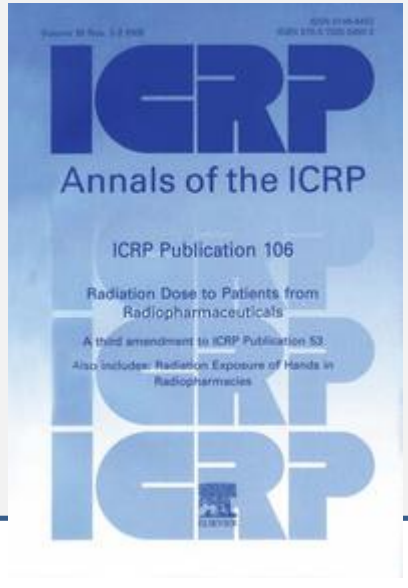


Rif: RADIATION PROTECTION N° 180 (2014)

Radiation dose to patients from radiopharmaceuticals

1971	ICRP Publication 17	Starting working on doses to patients from radiopharmaceuticals
1987 1991	ICRP Publication 53 ICRP Publication 62	Absobed doses per unit of activity administered from radiopharmaceuticals introduced into regular use sonce 1987
1998 2008	ICRP Publication 80 ICRP Pblication 106	Cover most radiopharmaceuticals in current use in diagnostic nuclear medicine

These reports support the nuclear physician and physicist in their responsability of optimising the use of nuclear medicine diagnostic techniques



Calculation of absorbed dose: biokinetic models

Target organs and tissues

Organs and tissues for which absorbed dose is calculated

Group 1:
- Adrenls
- Bone surfaces
- Breast
- Brain
- Gallbladder wall
- Gastrointestinal tract (Stomach wall – small intestine wall – large intestine wall)
- Heart wall
- Kidneys
- Liver
- Lungs
- Oesophagus
- Other tissues (mainly muscle tissue)
- Ovaries
- Pancreas
- Red bone marrow
- Skin
- Spleen
- Testes
- Thymus
- Thyroid
- Urinary bladder wall
- uterus

Source regions

Regions, different from target, in which radioactive decay accurs giving dose to target organs

Group 2:
- Brain
- Gallbladder wall
- Heart wall
- Salivary glands
- Spinal cord

Biokinetic models and data

Descriptive models

- Finding good biokinetic information from measurements on man is an hard work. In general published data are scarce, especially with regard to quantitative measurements.
- The clinician is often only interested in the initial distribution and metabolism of the test substance whereas for dosimetry calculation long-term retention is of prime importance.
- In addition to radioactive decay parameters, the particular information needed for dose calculation includes:
  - Fractional long-term retention of radionuclides and labelled compounds
  - Turnover of radiopharmaceuticals and its metabolites
  - Fractional GI absorption
  - Distribution of radionuclides within different organs
  - Radionuclides excretion pathways

Biokinetic models and data

Mathematical models

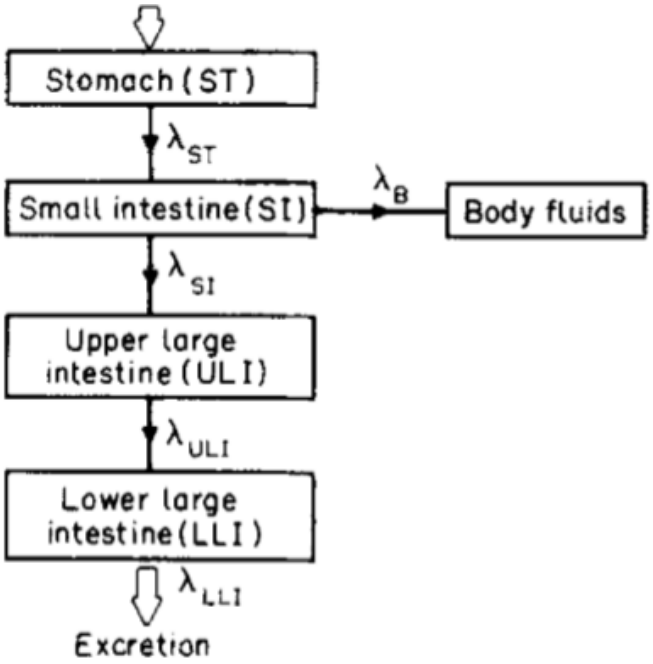
- The descriptive model based on the previous information allows the derivation of mathematical model consisting of differential and/or integral equations for the variation of the amount of radionuclide in different part of the body.

- The models available are mostly compartmental
- Compartment size, flow rates, and other physiological parameters allow numerical solution giving activity-time relationship for all the parts of the system which are then integrated to obtain cumulated activities needed for calculation of absorbed dose.

Rif: ICRP Publication 106 (2008)

Biokinetic models and data: an example the gastrointestinal tract

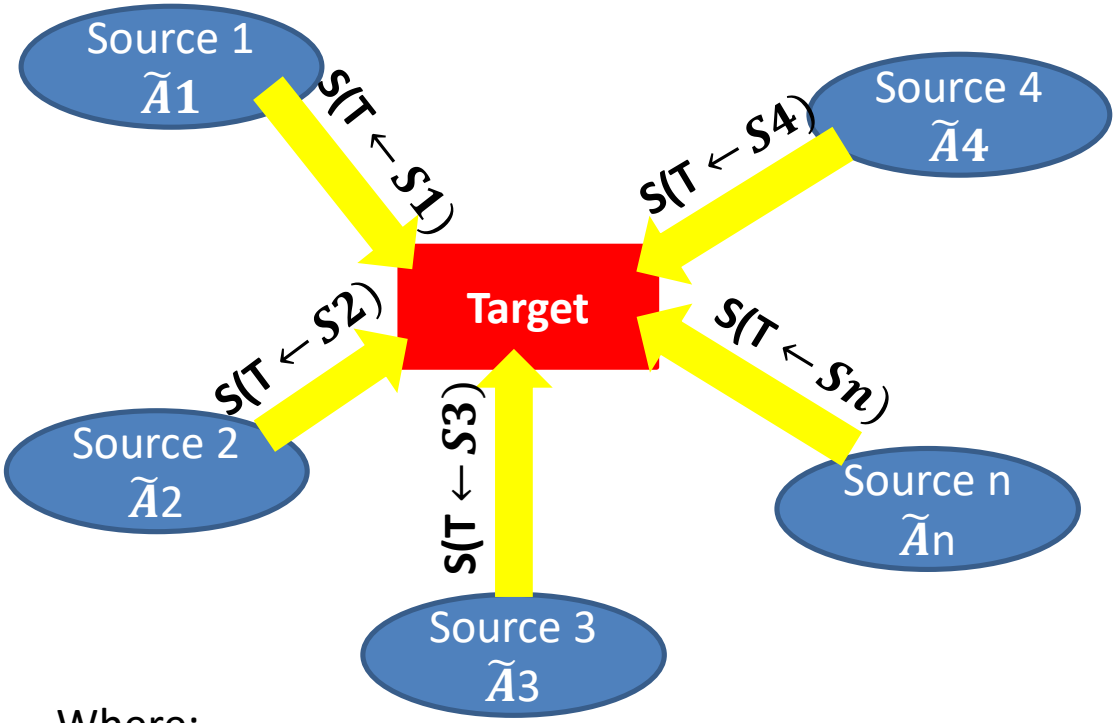
An example



Section of GI tract	Mass of walls* (g)	Mass of contents* (g)	Mean residence time (d)	λ (d^{-1})
Stomach (ST)	150	250	1/24	24
Small intestine (SI)	640	400	4/24	6
Upper large intestine (ULI)	210	220	13/24	1.8
Lower large intestine (LLI)	160	135	24/24	1

Rif: ICRP Publication 106 (2008)

Calculating absorbed dose



$$D_{\mathrm{T}} = \sum_{\mathrm{S}} D(\mathrm{T} \leftarrow \mathrm{S})$$

$$D(\mathrm{T} \leftarrow \mathrm{S}) = \widetilde{A}_{\mathrm{S}} \times \mathrm{S}(\mathrm{T} \leftarrow \mathrm{S})$$

Where:

$\widetilde{A_S}$ is the time integrated or cumulated activity equal to the total number of nuclear transformation in source organ S

S(T $\leftarrow S$) is the absorbed dose in T per unit cumulated activity in S (Snyder S-values)

Rif: ICRP Publication 106 (2008)

Calculating S-values

$$S(T \leftarrow S) = \frac{c}{M_T} \sum_i E_i Y_i \varphi_i$$

Where:

$\boldsymbol{M_T}$ is the mass of the target organ or tissue (tabulated)

$\boldsymbol{E_i}$ is the mean energy of radiation type i

$\boldsymbol{Y}$ is the yield of radiation type i per transformation

$\boldsymbol{\phi_i}$ is the absorbed fraction of energy of radiation type i

c is a constant depending on the units of the included quantities equal to 1 if E is in joule, M in kg and S in Gray

Rif: ICRP Publication 106 (2008)

Calculating the cumulated activity

$$\widetilde{A}_S(t) = \int_0^t A_S(u)du$$

$$\frac{dq_i}{dt} = -\lambda_{ii}q_i(t) - \lambda_p q_i(t) + \sum_{\substack{j=1 \\ j\neq i}}^{n} \lambda_{ij}q_j(t)$$

Where:
$\boldsymbol{q_i}$ is the amount of activity in compartment i

λ_{ii} is the fraction of activity in compartment i that is leaving in the unit of time

λ_{ij} is the fraction of activity flowing to compartment i from compartment j in the unit of time

λ_p is the radioactive decay constant

Rif: ICRP Publication 106 (2008)

Calculating the cumulated activity

$$A_S(t) = \sum_{i=1}^{n} k_i e^{-(\lambda_i + \lambda_p)t}$$

Where:

$\boldsymbol{q_i}$ is the amount of activity in compartment i

$\boldsymbol{k_i}$ is a constant

λ_i is the biological elimination constant of the exponential component i

λ_p is the radioactive decay constant

Rif: ICRP Publication 106 (2008)

Calculating the cumulated activity

$$\frac{\tilde{A}_S}{A_0} = F_S \sum_{j=n+1}^{n+m} a_j \sum_{i=1}^{n} \left\{ a_i \frac{T_i}{T_i - T_j} \left[\exp\left(\frac{-\ln(2)}{T_{i,eff}} t \right) - \exp\left(\frac{-\ln(2)}{T_{j,eff}} t \right) \right] \right\}$$

If we assume that the uptake in the organ Source is immediate, the result becomes:

$$\frac{\tilde{A}_S}{A_0} = F_S \sum_{i=1}^{n} a_i \frac{T_{i,eff}}{\ln(2)}$$

$\boldsymbol{F_S}$ that is the fraction of the administered sustance that would arrive in source organ or tissue S over all time if there were no radioactive decay

$\boldsymbol{a_i}$ that is the fraction of F_S that eliminated with a biological half time $\boldsymbol{T_i}$

n in the number of elimination components

$\boldsymbol{a_j}$ that is the fraction of F_S that is taken up with a biological half time $\boldsymbol{T_j}$

m is the number of uptake components

$\boldsymbol{T_{i,eff}}$ that is the elimination effective half life

$\boldsymbol{T_{j,eff}}$ that is the uptake effective half life

Rif: ICRP Publication 106 (2008)

Calculating the cumulated activity

$$\frac{\widetilde{A}_S}{A_0} = F_S \sum_{i=1}^{n} a_i \frac{T_{i,eff}}{\ln(2)}$$

$$\frac{1}{T_{i,eff}} = \frac{1}{T_i} + \frac{1}{T_p}$$

The cumulated activity in organ source only depends on:

$\boldsymbol{F_S}$ that is the fraction of the administered sustance that would arrive in source organ or tissue S over all time if there were no radioactive decay

$\boldsymbol{a_i}$ that is the fraction of F that is taken up with a biological half time $\boldsymbol{T_i}$

$\boldsymbol{T_{i,eff}}$ that is the elimination effective half life

Rif: ICRP Publication 106 (2008)

An example: 2-(18F)Fluoro-2-deoxy-2-D-glucose FDG ^{18}F

- FDG is a glucose analogue used in the characterization of glucose metabolism for staging or follow up of cancer diseases and for investigation of myocardial and cerebral glucose metabolism.
- It is used with intravenous administration
- After injection most is cleared rapidly from circulation with a biological half time lower than 1 minute
- Uptake of 4% from the heart wall
- Uptake 7%-10% from the brain
- Uptake of 5% from the liver
- Uptake 0.9% - 2.9% from the lungs
- All activity is excreted in urine

Rif: ICRP Publication 106 (2008)

An example: 2-(18F)Fluoro-2-deoxy-2-D-glucose FDG ^{18}F

- Based on these information the following biokinetic model is derived:
  - Initial uptake of 4% from the heart
  - Initial uptake of 8% from the brain
  - Initial uptake of 5% from the liver
  - Initial uptake of 3% from lungs
  - 80% uptake from other tissues

- A fraction of 30% of activity in other tissues is considered to be excreted in urine:
  - 25% is considered to be excreted in urine with biological half time of 12 minutes
  - 75% is considered to be excreted in urine with biological half time of 1.5 hours

Rif: ICRP Publication 106 (2008)

An example:
2-(18F)Fluoro-2-deoxy-2-D-glucose
FDG ^{18}F

Organ (S)	F_s	T (h)	a	$\widetilde{A}_s/A_0$(h)
Brain	0.08	∞	1.0	0.21
Heart wall	0.04	∞	1.0	0.11
Lungs	0.03	∞	1.0	0.079
Liver	0.05	∞	1.0	0.13
Other organs and tissues	0.80	0.20	0.075	1.7
		1.5	0.225	
		∞	0.70	
Urinary bladder contents	0.24			
Adult, 15 years, 10 years				0.26
5 years				0.23
1 year				0.16

Rif: ICRP Publication 106 (2008)

An example:
2-(18F)Fluoro-2-deoxy-2-D-glucose

Organ	Absorbed dose per unit activity administered (mGy/MBq)				
	Adult	15 years	10 years	5 years	1 year
Adrenals	1.2E-02	1.6E-02	2.4E-02	3.9E-02	7.1E-02
Bladder	1.3E-01	1.6E-01	2.5E-01	3.4E-01	4.7E-01
Bone surfaces	1.1E-02	1.4E-02	2.2E-02	3.4E-02	6.4E-02
Brain	3.8E-02	3.9E-02	4.1E-02	4.6E-02	6.3E-02
Breasts	8.8E-03	1.1E-02	1.8E-02	2.9E-02	5.6E-02
Gallbladder	1.3E-02	1.6E-02	2.4E-02	3.7E-02	7.0E-02
Gastrointestinal tract					
Stomach	1.1E-02	1.4E-02	2.2E-02	3.5E-02	6.7E-02
Small intestine	1.2E-02	1.6E-02	2.5E-02	4.0E-02	7.3E-02
Colon	1.3E-02	1.6E-02	2.5E-02	3.9E-02	7.0E-02
(Upper large intestine	1.2E-02	1.5E-02	2.4E-02	3.8E-02	7.0E-02)
(Lower large intestine	1.4E-02	1.7E-02	2.7E-02	4.1E-02	7.0E-02)
Heart	6.7E-02	8.7E-02	1.3E-01	2.1E-01	3.8E-01
Kidneys	1.7E-02	2.1E-02	2.9E-02	4.5E-02	7.8E-02
Liver	2.1E-02	2.8E-02	4.2E-02	6.3E-02	1.2E-01
Lungs	2.0E-02	2.9E-02	4.1E-02	6.2E-02	1.2E-01
Muscles	1.0E-02	1.3E-02	2.0E-02	3.3E-02	6.2E-02
Oesophagus	1.2E-02	1.5E-02	2.2E-02	3.5E-02	6.6E-02
Ovaries	1.4E-02	1.8E-02	2.7E-02	4.3E-02	7.6E-02
Pancreas	1.3E-02	1.6E-02	2.6E-02	4.0E-02	7.6E-02
Red marrow	1.1E-02	1.4E-02	2.1E-02	3.2E-02	5.9E-02
Skin	7.8E-03	9.6E-03	1.5E-02	2.6E-02	5.0E-02
Spleen	1.1E-02	1.4E-02	2.1E-02	3.5E-02	6.6E-02
Testes	1.1E-02	1.4E-02	2.4E-02	3.7E-02	6.6E-02
Thymus	1.2E-02	1.5E-02	2.2E-02	3.5E-02	6.6E-02
Thyroid	1.0E-02	1.3E-02	2.1E-02	3.4E-02	6.5E-02
Uterus	1.8E-02	2.2E-02	3.6E-02	5.4E-02	9.0E-02
Remaining organs	1.2E-02	1.5E-02	2.4E-02	3.8E-02	6.4E-02
Effective dose (mSv/MBq)	1.9E-02	2.4E-02	3.7E-02	5.6E-02	9.5E-02

ICRP Publication 106 (2008)

An example: Technetium-labelled MIBI 99mTc

- It is used for studies of myocardial perfusion and cardiac ventricular function.
- It is used with intravenous administration
- 99mTc MIBI is accumulated in viable myocardial tissue in proportion to regional blood
- the substance is rapidly cleared from the blood and taken up predominantly in muscular tissues (including heart), liver, and kidneys, with a smaller amount in salivary glands and thyroid.
- Other organs and tissues show a low uptake with a uniform distribution.

Rif: ICRP Publication 106 (2008)

An example: Technetium-labelled MIBI 99mTc

- When the substance is injected in conjunction with a stress test, there is a considerable increase of the uptake in heart and skeletal muscles, with a correspondingly lower uptake in all other organs and tissues.
- No redistribution takes place, and there is no evidence of any metabolism of the substance.
- The principal pathway for excretion is via the hepatobiliary system to the GI-tract, with some additional excretion via the kidneys.
- The major part of injected substance is excreted within 48 h.

Rif: ICRP Publication 106 (2008)

An example: Technetium-labelled MIBI 99mTc

Organ (S)	F_s	$T_{1/2}$	a	$\tilde{A}_s/A_o$
1) Resting subject				
Heart	0.015	4 h	0.67	4.18 min
		1 day	0.33	
Liver				40.5 min
Immediate uptake	0.18	1.3 h	0.85	
		1 day	0.15	
Delayed uptake	0.51			
Gall bladder	0.23			14.7 min
GI tract contents				
SI	0.69			29.7 min
ULI	0.69			38.7 min
LLI	0.69			18.9 min
Kidneys	0.14	7 h	1.00	39.4 min
Bladder contents	0.31			
Adult and 15 years				10.2 min
10 years				8.81 min
5 years and 1 year				5.93 min
Muscles	0.20	1 day	1.00	1.39 h
Salivary glands	0.015	1 day	1.00	6.25 min
Thyroid	0.003	2 h	1.00	23 s
Other organs and remaining tissues	0.45	1 day	1.00	3.12 h

Rif: ICRP Publication 106 (2008)

An example: Technetium-labelled MIBI 99mTc

Organ (S)	F_s	$T_{1/2}$	a	$\tilde{A}_s/A_o$
2) Exercise				
Heart	0.02	4 h	0.67	5.57 min
		1 day	0.33	
Liver				31.8 min
Immediate uptake	0.10	1.3 h	0.85	
		1 day	0.15	
Delayed uptake	0.60			
Gall bladder	0.23			12.2 min
GI tract contents				
SI	0.70			23.1 min
ULI	0.70			30.1 min
LLI	0.70			14.7 min
Kidneys	0.10	7 h	1.00	28.2 min
Bladder contents	0.30			
Adult and 15 years				8.93 min
10 years				7.70 min
5 years and 1 year				5.19 min
Muscles	0.40	1 day	1.00	2.78 h
Salivary glands	0.01	1 day	1.00	4.17 min
Thyroid	0.002	2 h	1.00	16 s
Other organs and remaining tissues	0.37	1 day	1.00	2.57 h

Rif: ICRP Publication 106 (2008)

An example:
Technetium-labelled MIBI 99mTc

Absorbed doses: Technetium-labelled MIBI (Resting subject)

^{99m}Tc 6.02 h

	Absorbed dose per unit activity administered (mGy/MBq)				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	7.5E−03	9.9E−03	1.5E−02	2.2E−02	3.8E−02
Bladder	1.1E−02	1.4E−02	1.9E−02	2.3E−02	4.1E−02
Bone surfaces	8.2E−03	1.0E−02	1.6E−02	2.1E−02	3.8E−02
Brain	5.2E−03	7.1E−03	1.1E−02	1.6E−02	2.7E−02
Breast	3.8E−03	5.3E−03	7.1E−03	1.1E−02	2.0E−02
Gall bladder	3.9E−02	4.5E−02	5.8E−02	1.0E−01	3.2E−01
GI-tract					
Stomach	6.5E−03	9.0E−03	1.5E−02	2.1E−02	3.5E−02
SI	1.5E−02	1.8E−02	2.9E−02	4.5E−02	8.0E−02
Colon	2.4E−02	3.1E−02	5.0E−02	7.9E−02	1.5E−02
(ULI	2.7E−02	3.5E−02	5.7E−02	8.9E−02	1.7E−01)
(LLI	1.9E−02	2.5E−02	4.1E−02	6.5E−02	1.2E−01)
Heart	6.3E−03	8.2E−03	1.2E−02	1.8E−02	3.0E−02
Kidneys	3.6E−02	4.3E−02	5.9E−02	8.5E−02	1.5E−01
Liver	1.1E−02	1.4E−02	2.1E−02	3.0E−02	5.2E−02
Lungs	4.6E−03	6.4E−03	9.7E−03	1.4E−02	2.5E−02
Muscles	2.9E−03	3.7E−03	5.4E−03	7.6E−03	1.4E−02
Oesophagus	4.1E−03	5.7E−03	8.6E−03	1.3E−02	2.3E−02
Ovaries	9.1E−03	1.2E−02	1.8E−02	2.5E−02	4.5E−02
Pancreas	7.7E−03	1.0E−02	1.6E−02	2.4E−02	3.9E−02
Red marrow	5.5E−03	7.1E−03	1.1E−02	3.0E−02	4.4E−02
Salivary glands	1.4E−02	1.7E−02	2.2E−02	1.5E−02	2.6E−02
Skin	3.1E−03	4.1E−03	6.4E−03	9.8E−03	1.9E−02
Spleen	6.5E−03	8.6E−03	1.4E−02	2.0E−02	3.4E−02
Testes	3.8E−03	5.0E−03	7.5E−03	1.1E−02	2.1E−02
Thymus	4.1E−03	5.7E−03	8.6E−03	1.3E−02	2.3E−02
Thyroid	5.3E−03	7.9E−03	1.2E−02	2.4E−02	4.5E−02
Uterus	7.8E−03	1.0E−02	1.5E−02	2.2E−02	3.8E−02
Remaining organs	3.1E−03	3.9E−03	6.0E−03	8.8E−03	1.6E−02
Effective dose (mSv/MBq)	**9.0E−03**	**1.2E−02**	**1.8E−02**	**2.8E−02**	**5.3E−02**

Absorbed doses: Technetium-labelled MIBI (Exercise)

^{99m}Tc 6.02 h

	Absorbed dose per unit activity administered (mGy/MBq)				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	6.6E−03	8.7E−03	1.3E−02	1.9E−02	3.3E−02
Bladder	9.8E−03	1.3E−02	1.7E−02	2.1E−02	3.8E−02
Bone surfaces	7.8E−03	9.7E−03	1.4E−02	2.0E−02	3.6E−02
Brain	4.4E−03	6.0E−03	9.3E−03	1.4E−02	2.3E−02
Breast	3.4E−03	4.7E−03	6.2E−03	9.7E−03	1.8E−02
Gall bladder	3.3E−02	3.8E−02	4.9E−02	8.6E−02	2.6E−01
GI-tract					
Stomach	5.9E−03	8.1E−03	1.3E−02	1.9E−02	3.2E−02
SI	1.2E−02	1.5E−02	2.4E−02	3.7E−02	6.6E−02
Colon	1.9E−02	2.5E−02	4.1E−02	6.4E−02	1.2E−01
(ULI	2.2E−02	2.8E−02	4.6E−02	7.2E−02	1.3E−01)
(LLI	1.6E−02	2.1E−02	3.4E−02	5.3E−02	9.9E−02)
Heart	7.2E−03	9.4E−03	1.0E−02	2.1E−02	3.5E−02
Kidneys	2.6E−02	3.2E−02	4.4E−02	6.3E−02	1.1E−01
Liver	9.2E−03	1.2E−02	1.8E−02	2.5E−02	4.4E−02
Lungs	4.4E−03	6.0E−03	8.7E−03	1.3E−02	2.3E−02
Muscles	3.2E−03	4.1E−03	6.0E−03	9.0E−03	1.7E−02
Oesophagus	4.0E−03	5.5E−03	8.0E−03	1.2E−02	2.3E−02
Ovaries	8.1E−03	1.1E−02	1.5E−02	2.3E−02	4.0E−02
Pancreas	6.9E−03	9.1E−03	1.4E−02	2.1E−02	3.5E−02
Red marrow	5.0E−03	6.4E−03	9.5E−03	1.3E−02	2.3E−02
Salivary glands	9.2E−03	1.1E−02	1.5E−03	2.0E−03	2.9E−03
Skin	2.9E−03	3.7E−03	5.8E−03	9.0E−03	1.7E−02
Spleen	5.8E−03	7.6E−03	1.2E−02	1.7E−02	3.0E−02
Testes	3.7E−03	4.8E−03	7.1E−03	1.1E−02	2.0E−02
Thymus	4.0E−03	5.5E−03	8.0E−03	1.2E−02	2.3E−02
Thyroid	4.4E−03	6.4E−03	9.9E−03	1.9E−02	3.5E−02
Uterus	7.2E−03	9.3E−03	1.4E−02	2.0E−02	3.5E−02
Remaining organs	3.3E−03	4.3E−03	6.4E−03	9.8E−03	1.8E−02
Effective dose (mSv/MBq)	**7.9E−03**	**1.0E−02**	**1.6E−02**	**2.3E−02**	**4.5E−02**

From **dose to patient** to **dose reference levels in nuclear medicine**

Why?

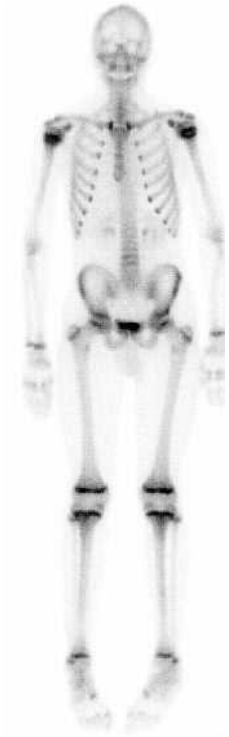
- The **optimization** of patient protection in diagnostic nuclear medicine procedures requires the application of examination-specific protocols tailored to patient age or size, region of imaging and clinical indication in order to ensure that patient doses are as low as reasonably achievable for the clinical purpose of the examination.

Which procedures?

- The examinations or procedures included should represent at least the **most frequent** examinations performed in the region for which dose assessment is practicable, with **priority** given to those that result in the highest patient radiation dose.

From **dose to patient** to **dose reference levels in nuclear medicine**

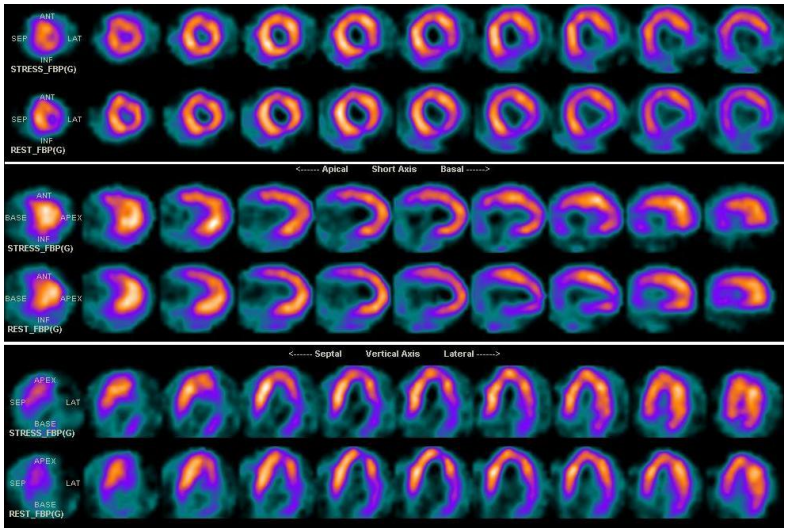
Planar acquisition



- Planar nuclear medicine imaging refers to two-dimensional imaging, utilising digital imaging detector systems, of patients who have had radiopharmaceuticals administered.

From **dose to patient** to **dose reference levels in nuclear medicine**

Single photon emission computed tomography

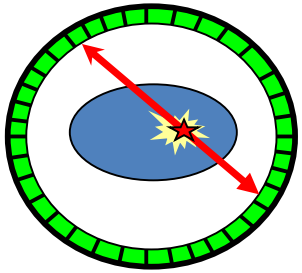


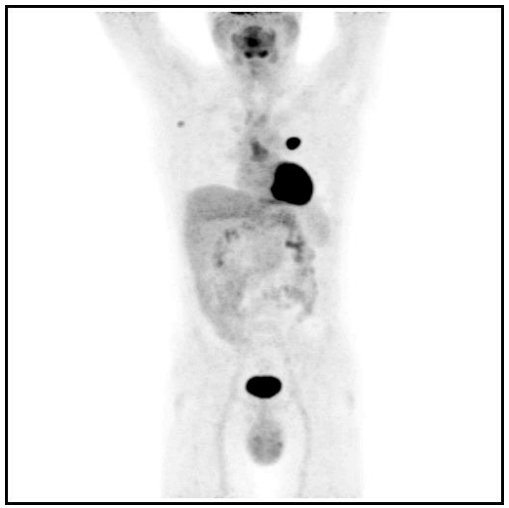
- SPECT is a nuclear medicine tomographic functional imaging technique that uses gamma rays produced from administered radiopharmaceuticals. It is similar to conventional nuclear medicine planar imaging, but uses one or more rotating gamma cameras and is able to provide three-dimensional information. This information is typically presented as cross-sectional images of the patient. These images can be freely reformatted and presented.

DRL values for SPECT studies are normally slightly higher than for the same radiopharmaceuticals used for planar imaging.

From **dose to patient** to **dose reference levels in nuclear medicine**

Positron emission tomography

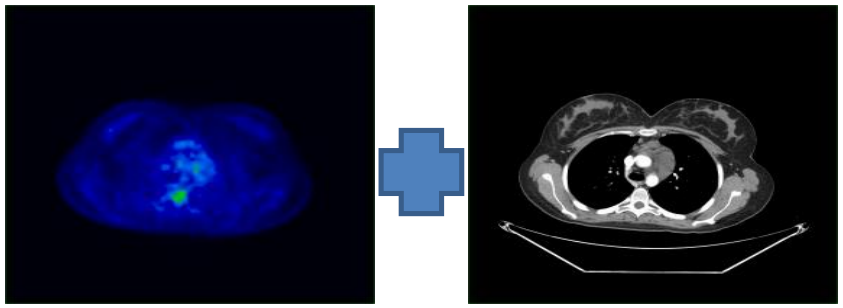


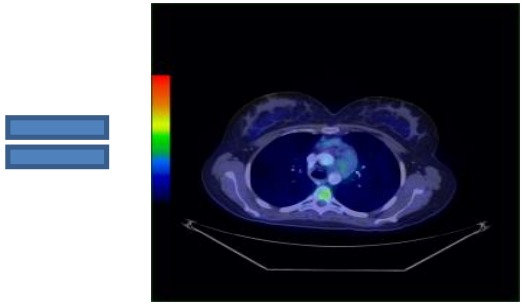


- PET is a nuclear medicine tomographic functional imaging technique that uses a positron-emitting administered radiopharmaceutical that produces, as a result of positron emission decay, pairs of 511-keV gamma photons emitted at almost 180^{o} to each other. These pairs of annihilation photons are detected in a stationary detector ring around the patient. Three-dimensional images of the activity concentration within the body are then constructed.

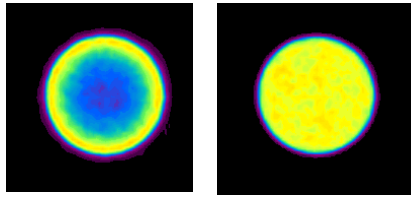
From **dose to patient** to **dose reference levels in nuclear medicine**

Hybrid technology





- PET and SPECT have been combined with CT (PET-CT and SPECT-CT), and PET has been combined with magnetic resonance imaging (MRI), because these combinations increase diagnostic accuracy by providing **both functional and anatomical images** of the body.
- The acquisition of accurately co-registered anatomical and functional images is a major strength of hybrid modality devices. A further important advantage in use of the CT images is the capability for **attenuation correction** of the PET and SPECT emission data.
- PET-CT has become one of the most rapidly growing medical imaging modalities.
- The patient dose from a PET-CT or SPECT-CT examination is the combination of the radiation exposures caused by the radiopharmaceutical and by the CT study.



From **dose to patient** to **dose reference levels in nuclear medicine**

Which dose quantities?

- For nuclear medicine, DRLs are set in activity administered to patient, and/or in administered activity per kg of body mass.

Which statistical indicator?

- For NM imaging typical levels of activity to be compared to DRL should be determined as the median values observed for representative samples of patients of a particular group (adults and children of defined sizes).

From **dose to patient** to **dose reference levels in nuclear medicine**

Reference

- The recommended administered activity are usually provided by authority or international association of nuclear medicine
  - RP 180 2014;
  - EANM, 2015;
  - SNMMI, 2015

- For an average adult patient may not be entirely representative of the real situation in practice.

Variability

- As the majority of hospitals and clinics use recommended administered activity levels or lower levels, there is less interdepartmental variation in patient dose than in diagnostic radiology.

From **dose to patient** to **dose reference levels in nuclear medicine**

Children

Obese patients

- Weight-based administered activities should be used for children, adolescents, and low-weight considered for other groups.
- Setting of a fixed maximum activity for very obese patients may also be considered.

From **dose to patient** to **dose reference levels in nuclear medicine**

Administered activity MBq

Administered activity per body weight MBq/kg

- For nuclear medicine imaging, DRLs are surveyed and have been set either by administered activity (MBq) or, preferably, by administered activity per body weight ($MBqkg^{-1}$).
- For some nuclear medicine investigations for which the radiopharmaceutical is concentrated predominantly in a single organ (e.g. thyroid, sentinel node imaging, pulmonary ventilation and perfusion studies), a standard activity could be administered for all adult patients.
- For other nuclear medicine examinations, the ideal would be for administered activities to be based on patient weight ($MBqkg^{-1}$).

From **dose to patient** to **dose reference levels in nuclear medicine**

Patient size

- Patient selection is an important aspect of establishing and using DRL values.
- In nuclear medicine, as in other imaging techniques, patient size plays an important role in the determination of required activity to achieve adequate image quality for a given procedure.
- Generally, surveys set a patient weight range.
- DRL values in adult nuclear medicine are normally based on the administered activities used for average-sized patients (e.g. 70±10kg), and then a DRL value for administered activity per body weight ($MBqkg^{-1}$) can be calculated.

From **dose to patient** to **dose reference levels in nuclear medicine**

Dosage Card (Version 5.7.2016)

Multiple of Baseline Activity

Weight kg	Class A	Class B	Class C	Weight kg	Class A	Class B	Class C
3	1	1	1	32	3.77	7.29	14.00
4	1.12	1.14	1.33	34	3.88	7.72	15.00
6	1.47	1.71	2.00	36	4.00	8.00	16.00
8	1.71	2.14	3.00	38	4.18	8.43	17.00
10	1.94	2.71	3.67	40	4.29	8.86	18.00
12	2.18	3.14	4.67	42	4.41	9.14	19.00
14	2.35	3.57	5.67	44	4.53	9.57	20.00
16	2.53	4.00	6.33	46	4.65	10.00	21.00
18	2.71	4.43	7.33	48	4.77	10.29	22.00
20	2.88	4.86	8.33	50	4.88	10.71	23.00
22	3.06	5.29	9.33	52-54	5.00	11.29	24.67
24	3.18	5.71	10.00	56-58	5.24	12.00	26.67
26	3.35	6.14	11.00	60-62	5.47	12.71	28.67
28	3.47	6.43	12.00	64-66	5.65	13.43	31.00
30	3.65	6.86	13.00	68	5.77	14.00	32.33

$$A[MBq]_{\text{Administered}} = BaselineActivity \times Multiple$$

- Radiopharmaceuticals are grouped into 3 classes
- A minimum recommended activity is also given

From **dose to patient** to **dose reference levels in nuclear medicine**

Actions

- Comparison of typical dose levels (median values) to DRLs is not sufficient, by itself, for optimisation of protection. Image quality or, more generally, the diagnostic information provided by the examination (including the effects of post-processing), must be evaluated as well
- If your values are below published DRL, this does not necessarily indicate satisfactory performance. Imaging techniques should always be reviewed for potential reduction in their levels of dose without compromising the clinical purpose of the examination;
- If your values are above DRL, there is a more urgent need to investigate whether simple changes can be made to the imaging settings selected for an examination in order to reduce values of radiation dose quantities whilst still providing the required clinical information;

From **dose to patient** to **dose reference levels in nuclear medicine**

Optimization!!!

- Individual practitioners are encouraged to use lower administered activities if their equipment or software permits, and the resultant image quality is adequate for diagnosis.

From **dose to patient** to **dose reference levels in nuclear medicine**

Optimization!!!

- In nuclear medicine, increasing the administered activity not only improves imaging quality but also reduces acquisition time.
- Reducing administered activity while maintaining image quality can be achieved by increasing acquisition time.
- However, prolonged acquisition times are not practical because patients cannot remain still and motion artefacts result in blurred images. On the other hand, it is not desirable, from a radiological protection point of view, to administer more activity to patients in order to achieve greater patient throughput.

From **dose to patient** to **dose reference levels in nuclear medicine**

- It is appropriate to set and present DRL values for each modality independently.

CT contribute

- Often a diagnostic-quality CT may not be needed for the nuclear medicine scan being performed, and a low-dose CT examination is adequate for attenuation correction and localisation.

- However, in some cases, the CT images from the PET-CT or SPECT-CT examination can be used to replace a diagnostic CT later, therefore reducing the exposure to the patient and providing additional information to aid in the interpretation of the nuclear medicine scan. This should be taken into account when setting DRLs.

DRL **in nuclear medicine: the italian experience**

Criteria

Procedures that:

- have a relatively high frequency of execution;
- have a unique name;
- allow DRL checks to be performed in a high percentage of radiological installations;
- are limited in number for each type of radiological installation

Setting DRL in practice

DRL in nuclear medicine: the italian experience

Procedure	Radiopharmaceutical	Guide line AIMN (MBq)	Guide line EANM (MBq)	European surveys (RP 180 – 2014) More frequent (MBq)	European surveys (RP 180 – 2014) Range (MBq)
Scintigrafia di Perfusione miocardica	Tl-201 cloruro	110-150	74-111	110	75-150
	Tc-99 tetrafosmina Tc-99m MIBI	740/esame (2 giorni) 370+1100 (singolo giorno)	350-700 per studio (2 giorni) 250-400 per il primo studio e tre volte tanto per il secondo (singolo giorno)	1200	300-1500
PET studio della vitalità miocardica	F-18 FDG	185-555	200-350		
PET studio di perfusione miocardica	N-13 ammonia	370-740	370-740		
	Rb-82	1110-2500 acq 2D 750-1550 acq 3D	1100-1500		
Angiocardio scintigrafia	Tc-99m eritrociti	555-1110 (10 MBq/kg a riposo – 15 MBq/kg durante test)	555-1110	750	600-1000
Scintigrafia tiroidea	Tc-99m pertecnetato	70-150	NA	80	75-222
	I-123 ioduro	7-20	8	20	10-37
Scintigrafia delle metastasi tiroidee*	I-131 iuduro	NA	75-185	400	90-400
Scintigrafia ossea	Tc-99m fosfati e fosfonati	300-740	300-740	600	500-1110
Scintigrafia renale sequenziale	Tc-99m DTPA	200 (3 MBq/kg)	37-185		150-540
	Tc-99m MAG3	160 (2 MBq/kg)	75	100	100-370
Scintigrafia renale	Tc-99m DMSA	40-160 (1 MBq/kg)	70		70-183
Scintigrafia di perfusione polmonare	Tc-99m MAA	120-160	40-120	150	100-296
Scintigrafia di ventilazione polmonare	Tc-99m technegas	40-140 (min attività nel crogiolo 400 MBq)	20-30		
	Tc-99m DTPA	40-160 (max attività nel	20-30		

DRL **in nuclear medicine: the italian experience**

Procedure	Radiopharmaceutical	Guide line AIMN (MBq)	Guide line EANM (MBq)	European surveys (RP 180 – 2014) More frequent (MBq)	Range (MBq)
Scintigrafia delle paratiroidi	Tc-99m MIBI	600-740	500-700		400-900
	Tc-99m pertecnetato		75-150		
Linfonodi sentinella	Tc-99m nanocolloidi	mammella: 5-30 (1 day) - 30-74 (2 days) melanoma: 16-40 (4-8/aloquota)(1 day) melanoma: 37-74 (2 days) arti: 74 (37/arto)	10-150		
	Tc-99m tilmanocept	mammella: 18.5 (1 day) - 37-74 (2 days) melanoma: 16-40 (4-8/aloquota)(1 day) melanoma: 37-74 (2 days) arti: 74 (37/arto)	NA		
Tomoscintigrafia cerebrale	Tc-99m exametazime	555-1110	740	500	500-1110
PET cerebrale	F-18 FDG	185	185-250		
PET cerebrale – aggregati di amiloide	F-18 fluorbetapir	370	370		
	F-18 flutemetamolo	185	185		
	F-18 fluorbetaben	260-360 (300)	300		
Scintigrafia delle infezioni/infiammazioni	Tc-99m globuli bianchi	185-370			110-370
	In-111 Ossina	20	10-18.5		
Scintigrafia – tumori neuroendocrini	In-111 pentetreotide	200	220		

DRL **in nuclear medicine: the italian experience**

Procedure	Radiopharmaceutical	Guide line AIMN (MBq)	Guide line EANM (MBq)	European surveys (RP 180 – 2014)	
				More frequent (MBq)	Range (MBq)
Scintigrafia del reflusso esofageo – dello svuotamento gastrico – del transito esofago/gastro/duodenale	Tc-99m DTPA	80	18.5–37		
PET per infezioni/infiammazioni	F18-FDG	4-5 MBq/kg	2.5-5.0 MBq/kg ; 175-350		
PET oncologico	F-18 FDG	2-5.4 MBq/kg	14 MBq (min/lettino)/kg		200-400
	F-18 colina	3-4 MBq/kg	50-400		
	Ga-68 DOTA	100-300	100-200		