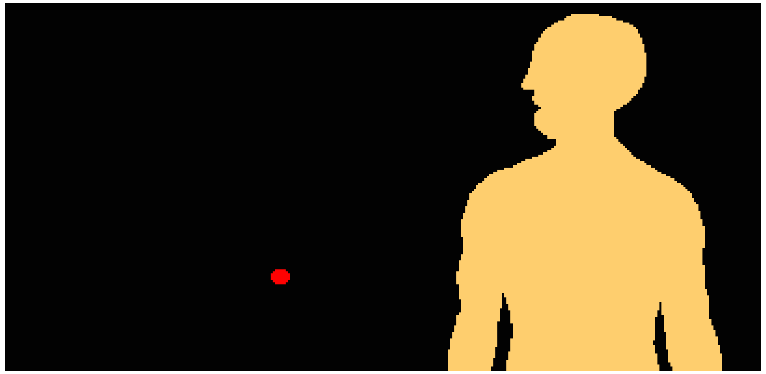


Prof **François Bochud**
Institute of Radiation physics (IRA)
UNIL - CHUV

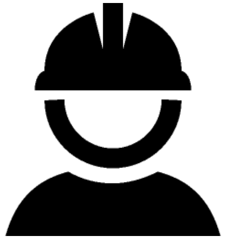
Introduction to Medical Physics

Patient dose and radiation protection

Learning objectives

- Describe the **general method** used to estimate the **patient dose** in radiodiagnostic and in nuclear medicine
- Describe the **dosimetric quantities** and the methodology used in **radiodiagnostic** to estimate the dose
- Explain the **main difference** between **external irradiation** and **internal contamination**
- Explain the basic of the computation of dose with **compartmental models**

Radiation protection principles
(occupational *versus* patients)



1. Justification

of the activity

generic
&
individual

2. Optimization

ALARA
*(as **low** as reasonably achievable)*

ARARA
*(as **right** as reasonably achievable)*

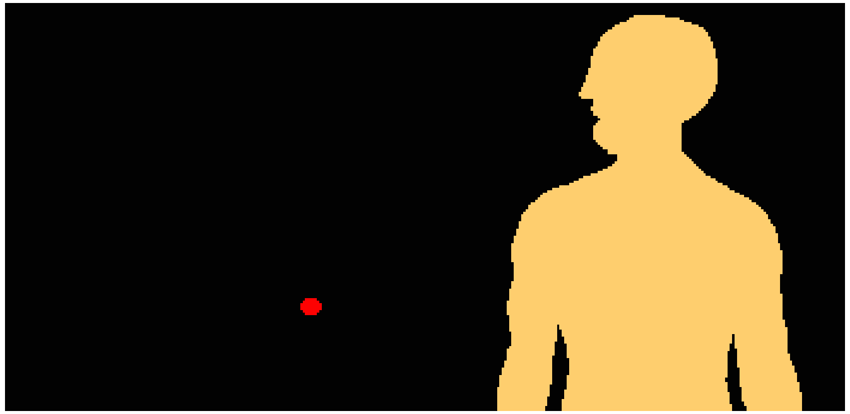
3. Limitation

dose limits
dose constraints

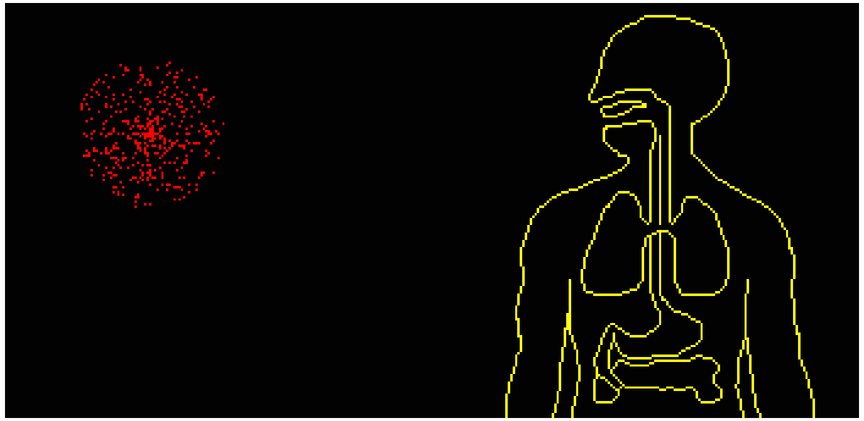
diagnostic reference level (DRL)
(value to be compared with the practice)

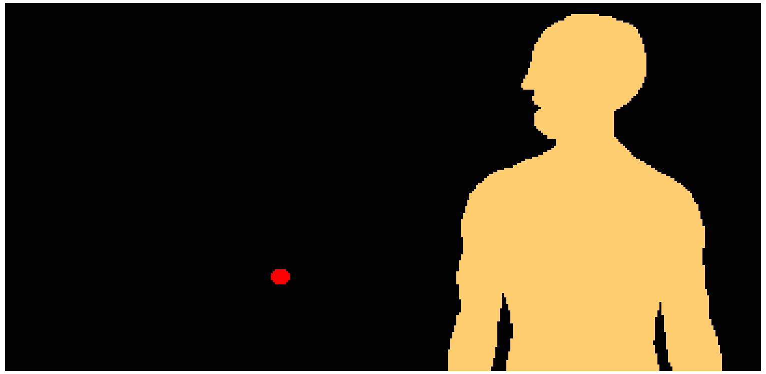
Two irradiation situations

- **External** irradiation
  - Radiation generators
  - Sealed radioactive source



- **Internal** contamination
  - Open radioactive source



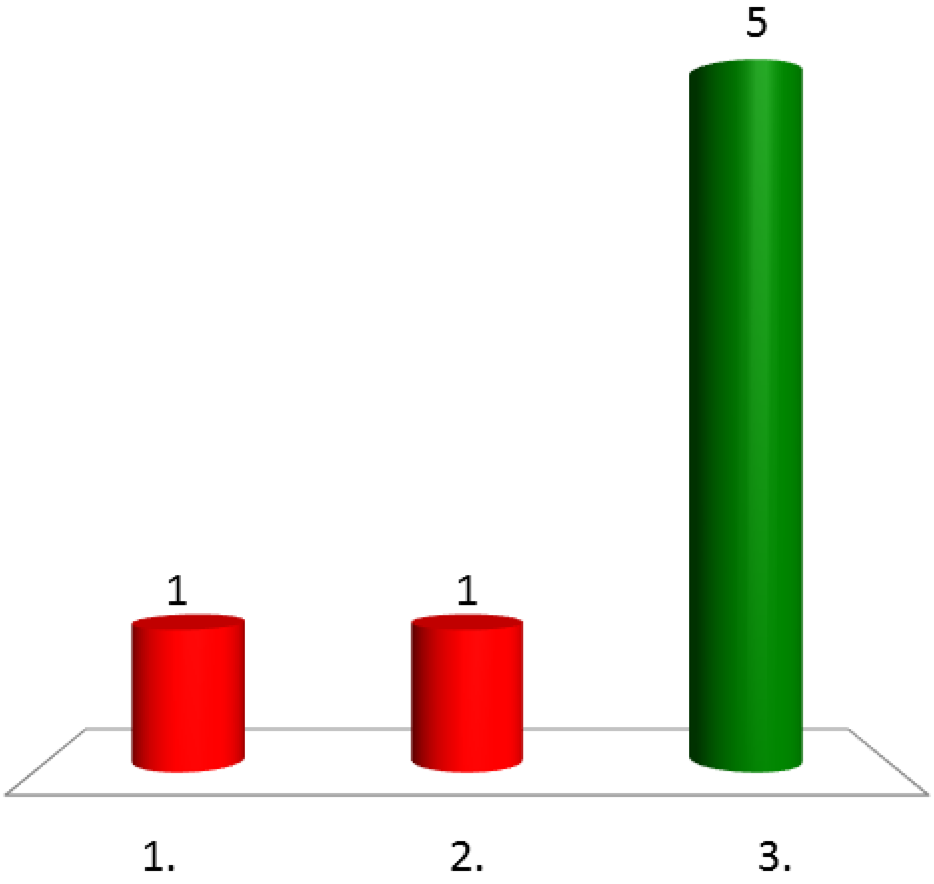


Patient dose and radiation protection

1.
Diagnostic radiology

What is the highest contribution of dose to the population in medical imaging?

1. Conventional radiography
2. Dental radiography
3. Computed Tomography



7 sur 7

Number of examinations/1000 caput

(European countries)

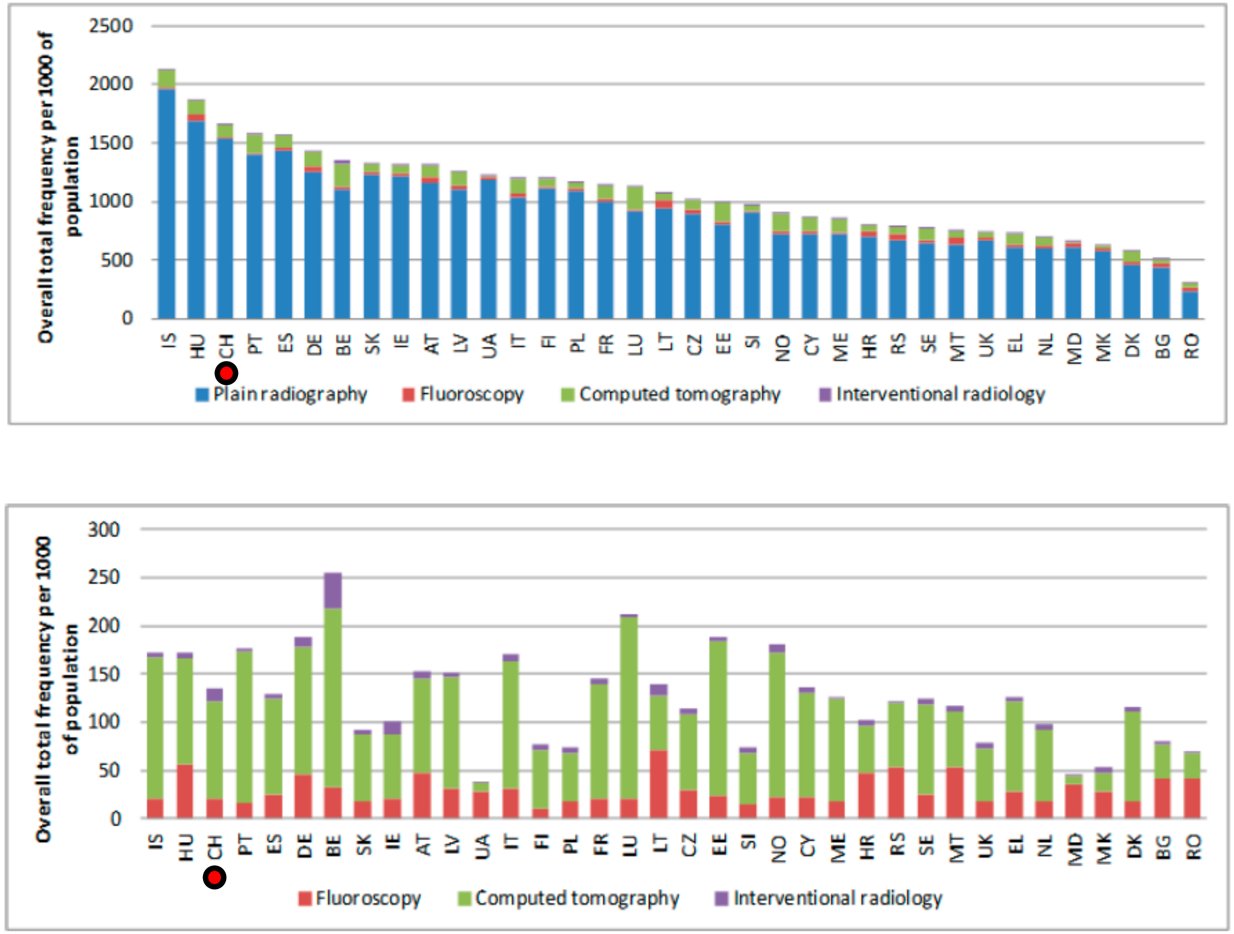
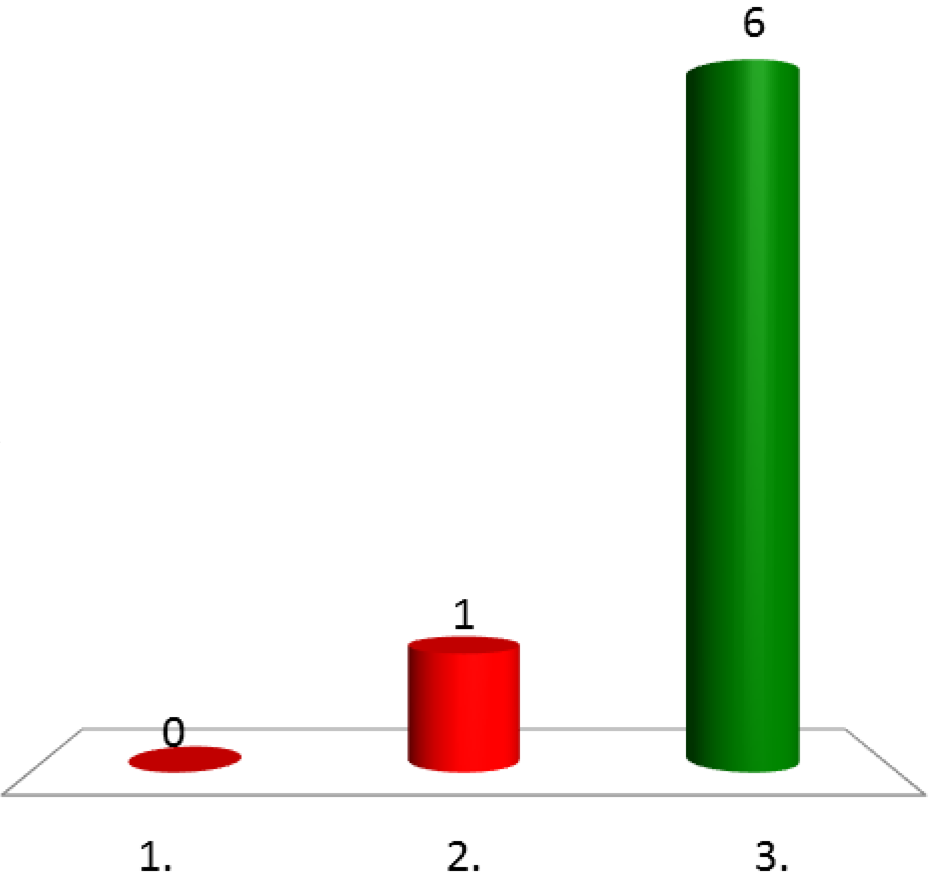


Figure 1: **Total frequencies of diagnostic and interventional radiology procedures per 1000 of population for different countries, including plain radiography (including dental), fluoroscopy, CT and interventional radiology (upper). Without plain radiography (lower) (2).**

RADIATION INDUCED LONG-TERM HEALTH EFFECTS AFTER MEDICAL EXPOSURE, European Commission (2015)

What is the **effective dose** ?

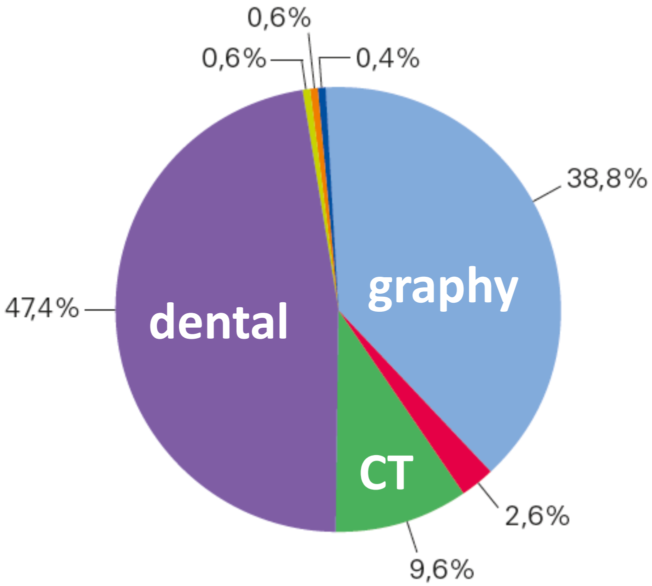
1. Energy deposited per unit of mass
2. Absorbed dose weighted by the radiation quality factors w_R
3. Equivalent dose weighted by the tissue quality factors w_T



7 sur 7

Radiological examinations
(Switzerland)

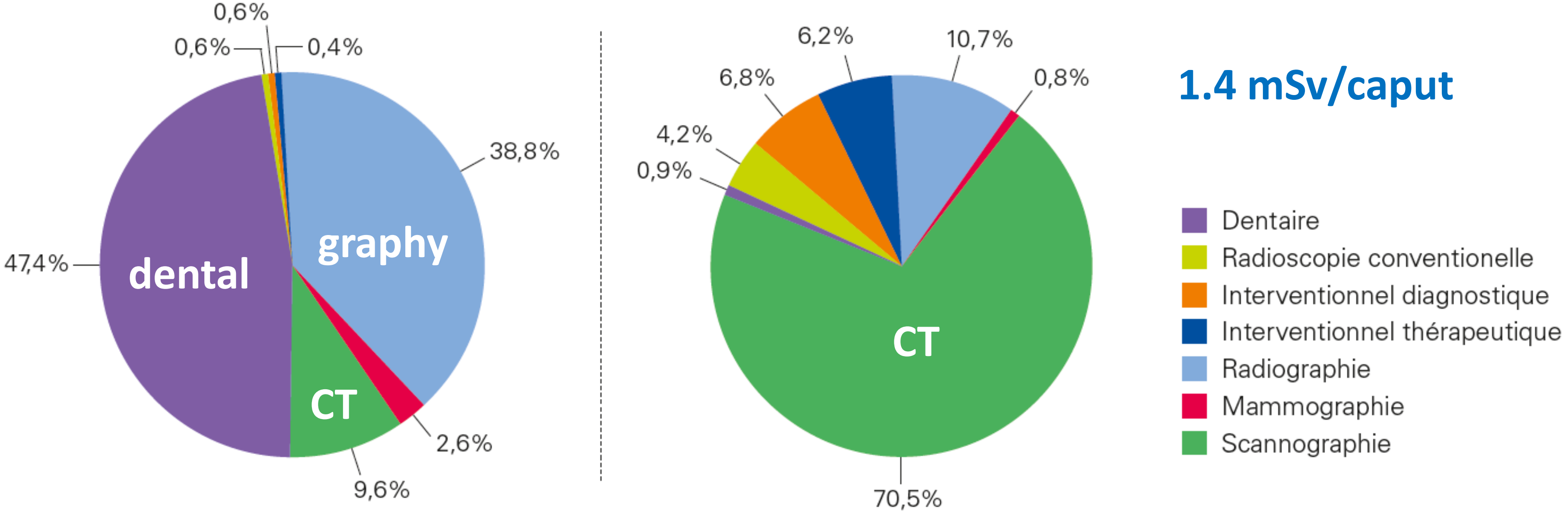
number of examinations



FOPH, Radiation protection, Annual report 2015

Radiological examinations

(Switzerland)



number of examinations

effective dose

1.4 mSv/caput

Fig. 4: Répartition de la fréquence et contribution aux doses de rayonnement des différents examens radiologiques, IRA 2015

FOPH, Radiation protection, Annual report 2015

Time evolution of radiological dose

(Switzerland)

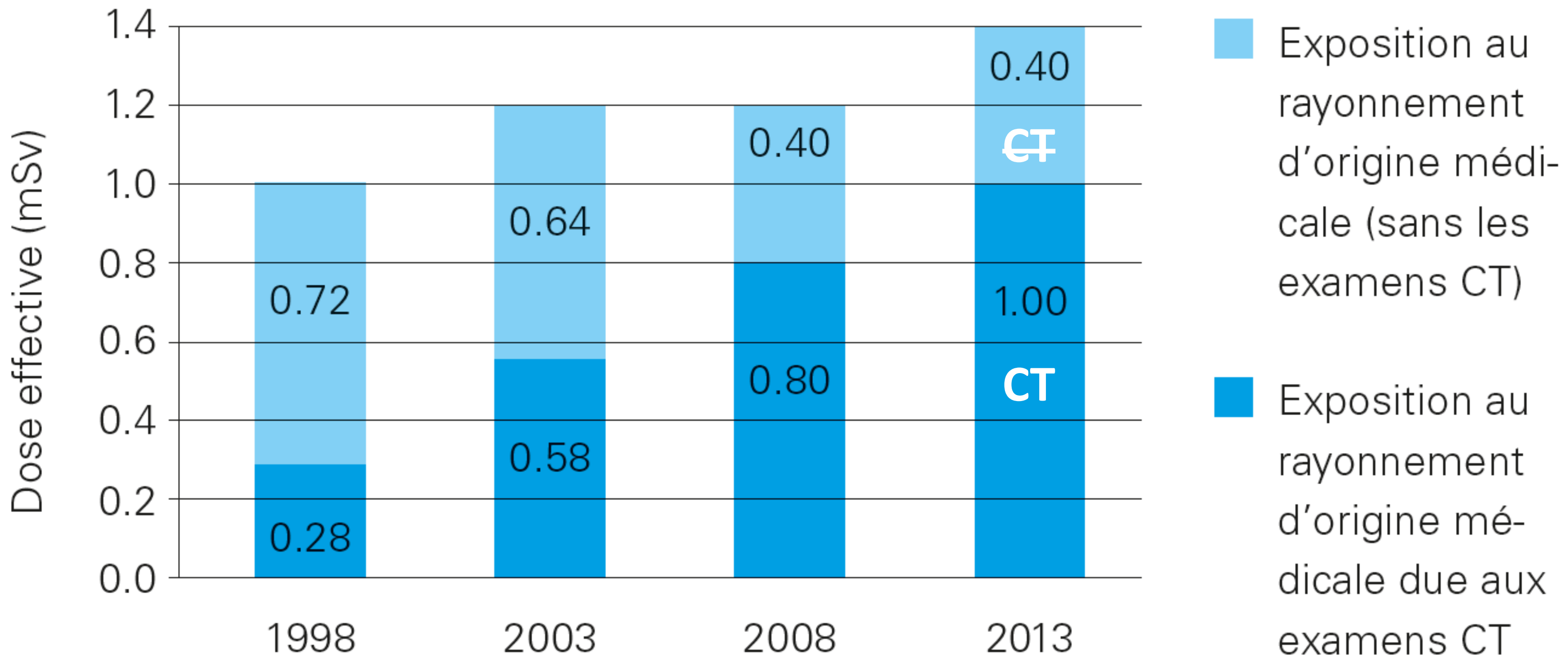


Fig. 3 : L'exposition au rayonnement d'origine médicale augmente du fait des examens CT ; en ce qui concerne les autres applications, la tendance est à la baisse.

FOPH, Radiation protection, Annual report 2015

Methodological scheme

Effective dose

risk indicator *(ICRP, UNSCEAR)*

$$E = DQ \times e_{DQ}$$

Dosimetric quantity

specific to the patient

specific to the installation

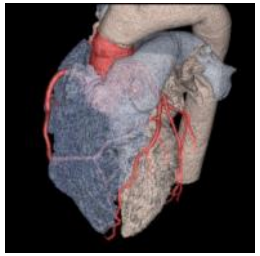
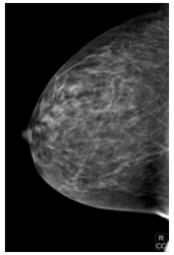
(this quantity is ***measured***

or ***calculated*** *in practice)*

Conversion factor

generic

adult / pediatric

Imaging modality	Dosimetric quantity (DQ)
Radiography 	**ESAK** [mGy] Entrance Skin Air Kerma
	D_e [mGy] Entrance dose in air
Radioscopy 	**KAP** [$mGy\ cm^2$] Kerma Area Product
	IRP [mGy] Interventional Reference Point
Computed tomography (CT) 	**CTDI** [mGy] CT Dose Index
	DLP [mGy cm] Dose Length Product
Mammography 	**ESAK** [mGy] Entrance Skin Air Kerma
	MGD [mGy] Mean Glandular Dose

Patient dose and radiation protection

1.1

Diagnostic radiology

Radiography

ESAK in radiography

(entrance skin air kerma)

ESAK can be **measured**

ESAK can be **calculated**

$$ESAK = C \times \left(\frac{U[kV]}{100} \right)^2 \times Q[mAs] \times \frac{1}{d^2}$$

C = 0.10 mGy m^2/mAs

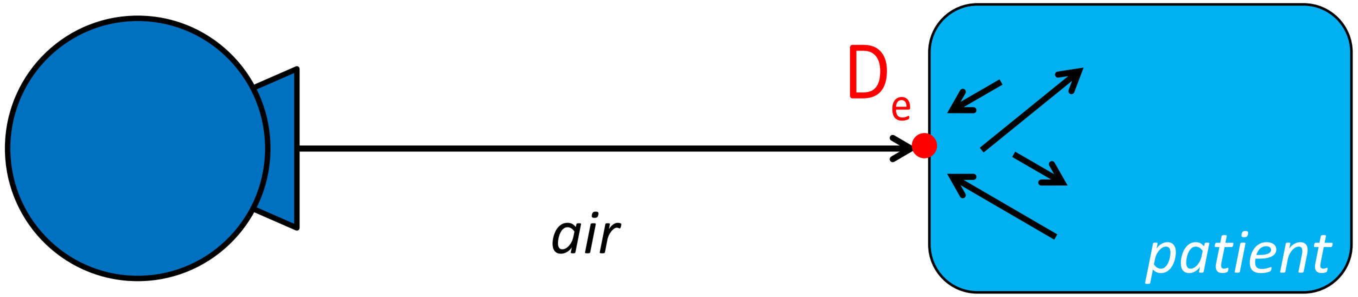
(air kerma constant at d=1m, U=100kV,
total filtration=3mm Al)
varies from one installation to another (±50%)

D_e in radiography

$$D_e = ESAK \times BSF \times F_{K \to D}$$

Backscatter Factor
(1.2 < BFS < 1.5)

Kerma-Dose factor $F_{K \to D} = \dfrac{\left.\dfrac{\mu_{en}}{\rho}\right)_{air}}{\left.\dfrac{\mu_{tr}}{\rho}\right)_{air}} \approx 1$



Exercise

What is the entrance dose in air for a radiography of the abdomen with the following parameters?

U = 80 kV
Q = 40 mAs
d = 80 cm

5 sur 7

1. Press "1" when you are finished

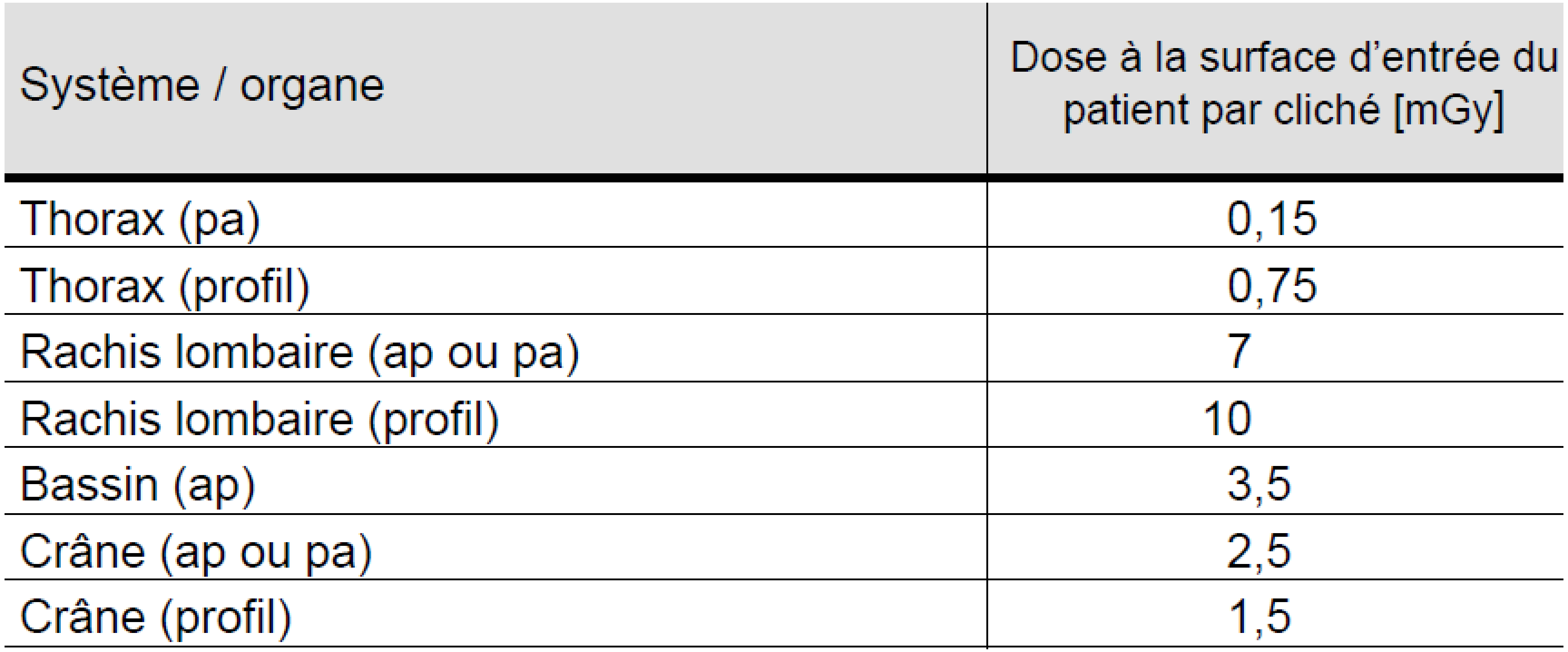
Exercise: D_e in radiography

$$D_e = \underbrace{\overset{0.1\text{ mGy m}^2\text{/mAs}}{C} \times \overset{80\text{ kV}}{\left(\frac{U}{100}\right)^2} \times \overset{40\text{ mAs}}{Q} \times \frac{1}{\underset{0.8\text{ m}}{d^2}}}_{=\text{ESAK}} \times \overset{1.3}{\text{BSF}} \times \overset{1.0}{F_{K\to D}}$$

$$= 5.2\ \text{mGy}$$

Example of Swiss **Diagnostic Reference Level** (DRL) for radiography

D_e



Système / organe	Dose à la surface d'entrée du patient par cliché [mGy]
Thorax (pa)	0,15
Thorax (profil)	0,75
Rachis lombaire (ap ou pa)	7
Rachis lombaire (profil)	10
Bassin (ap)	3,5
Crâne (ap ou pa)	2,5
Crâne (profil)	1,5

Computation of E in radiography

(Example of a chest x-ray PA (postero-anterior))

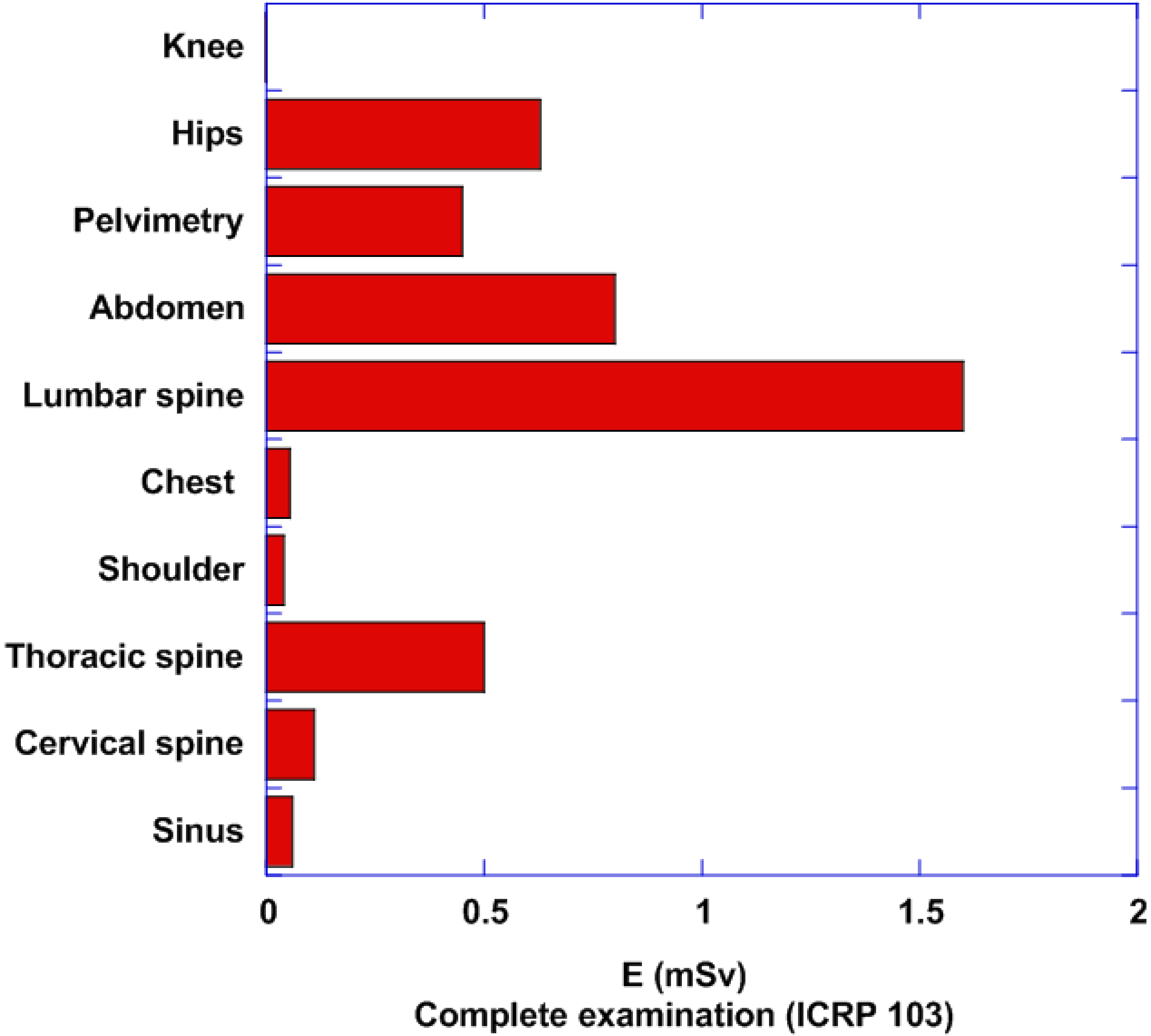
Effective dose: $E = e_{D_E} \times D_e$

Organ	Concerned fraction	Dose relative to D_e	w_T	Contribution to e_{De} [mSv/mGy]
Gonads	0%	0%	0.20	0.000
Red bone marrow	20%	100%	0.12	0.024
Colon	10%	100%	0.12	0.012
Lungs	100%	50%	0.12	0.060
Stomac	100%	30%	0.12	0.036
Bladder	0%	0%	0.05	0.000
Breasts	100%	10%	0.05	0.005
Liver	100%	30%	0.05	0.015
Esophagus	80%	50%	0.05	0.020
Thyroid gland	50%	50%	0.05	0.012
Skin	7%	100%	0.01	0.001
Bone surface	2%	100%	0.01	0.002
Rest	0%	0%	0.05	0.000
Total				**~0.20**

Conversion factors e_{De} for the main radiographic exams

Exam	Incidence	field size (cm^2)	e_{De} [mSv/mGy]
Skull	PA	20x25	0.02
Chest	PA	33x37	0.20
Shoulder	AP	18x25	0.02
Cervical spine	AP	15x20	0.07
Dorsal spine	AP	16x35	0.17
Lombar spine	AP	16x35	0.21
Abdomen	AP	30x40	0.31
Abdomen	PA	30x40	0.15
Hip	AP	18x30	0.17
Knee	AP	15x18	0.005

Typical magnitude of the **effective dose** E in **radiography**



Patient dose and radiation protection

1.2

Diagnostic radiology

Fluoroscopy

Fluoroscopy

(Slightly more complex than radiography)

Tissue (deterministic) effects

should not be
a surprise

IRP
Interventional
Reference Point

representative of the
peak skin dose

Stochastic effects

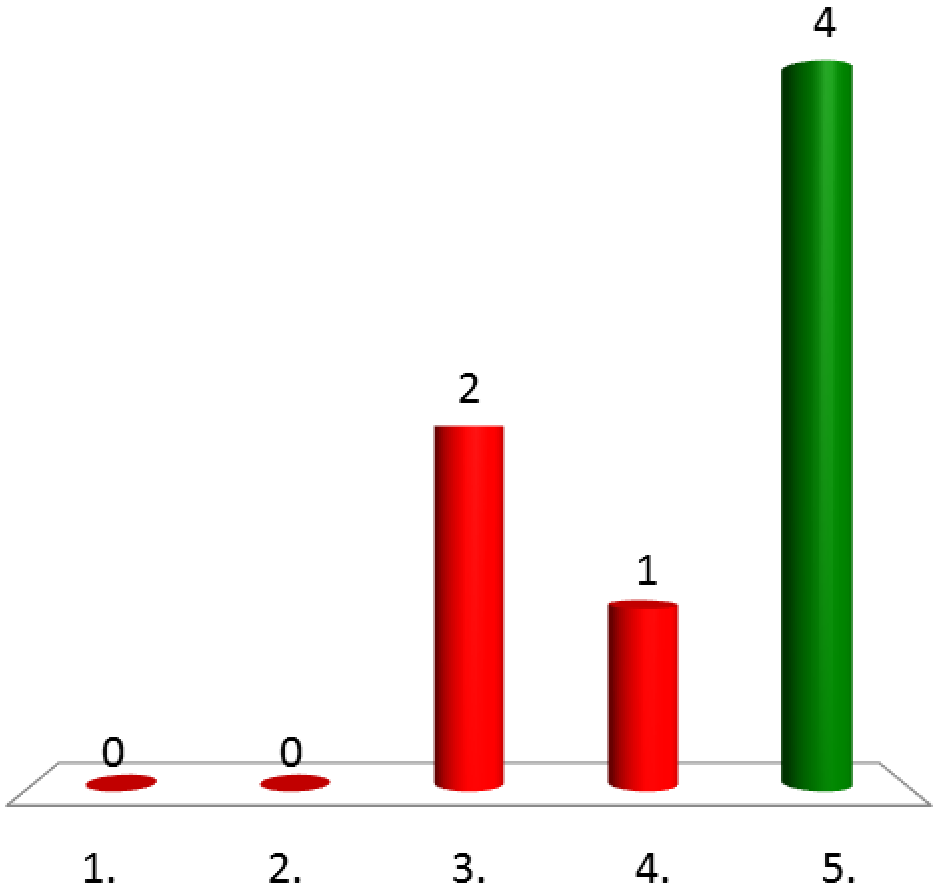
must be
optimized

KAP
Kerma Area
Product

representative of the
effective dose

You measured an **air kerma** of **120 mGy** at a distance of **5 cm** from the focal spot. What would be the magnitude of the air kerma at a **distance of 1 m**?

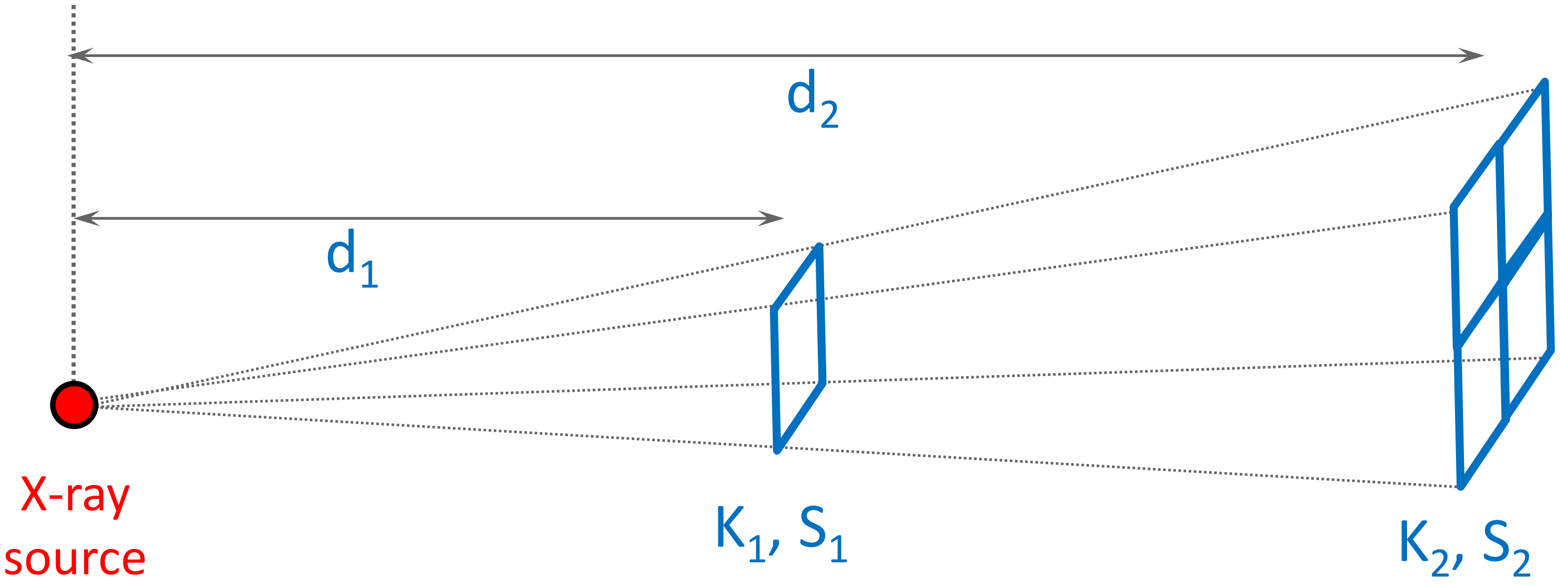
1. 120 mGy
2. 24 mGy
3. 6 mGy
4. 3 mGy
5. 0.3 mGy



7 sur 7

Fluoroscopy: **KAP** does not depend on distance

(KAP: kerma area product)



kerma $K \propto \frac{1}{d^2}$

area $S \propto d^2$

$$K_1 \times S_1 = K_2 \times S_2$$

Fluoroscopy: KAP

Direct measurement

Ionization chamber
at the tube exit

Calculation

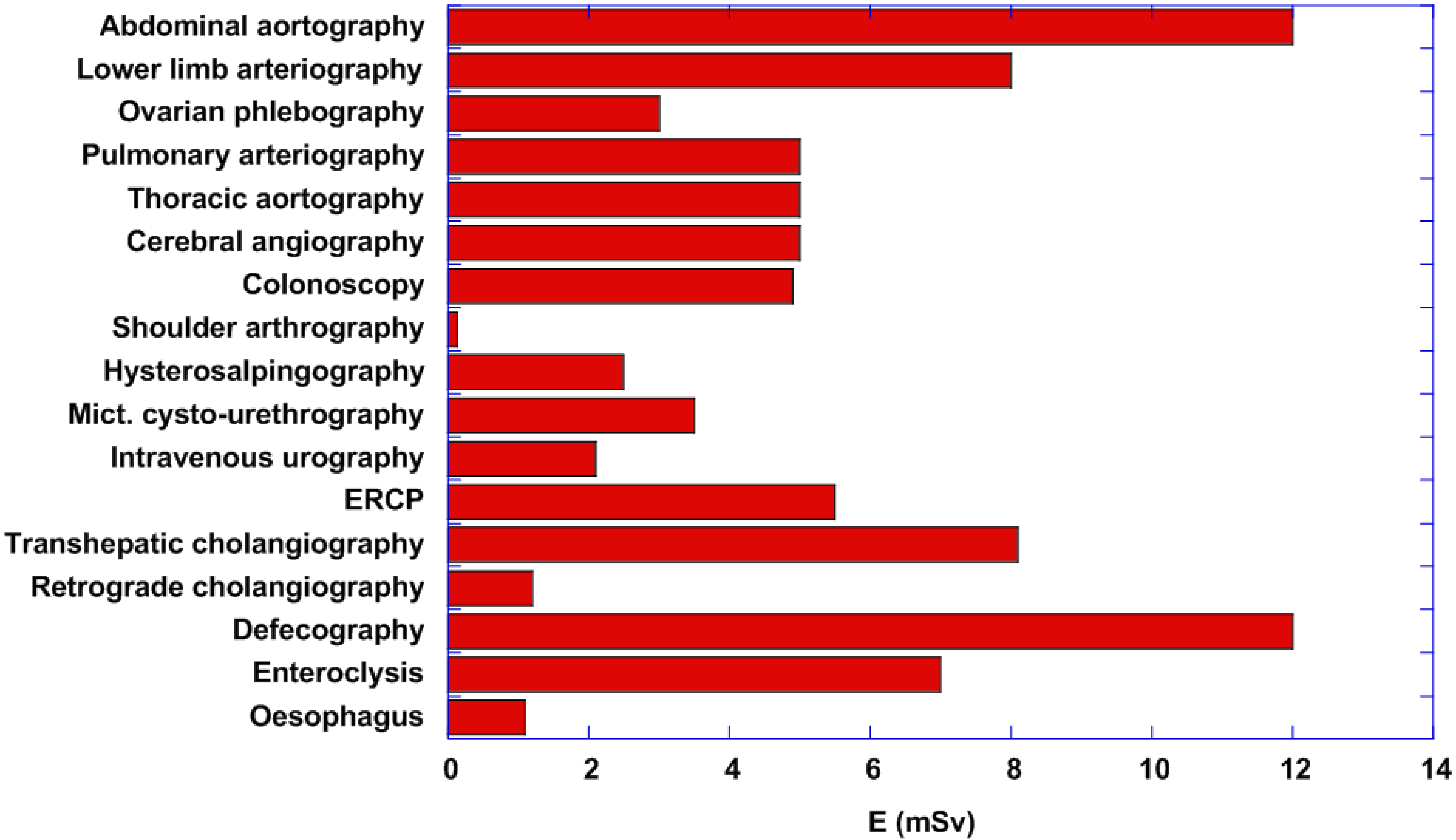
From the exposition parameters
(kV, mAs, axis dose rate, field size)

Computation of the **effective dose** E in **fluoroscopy**

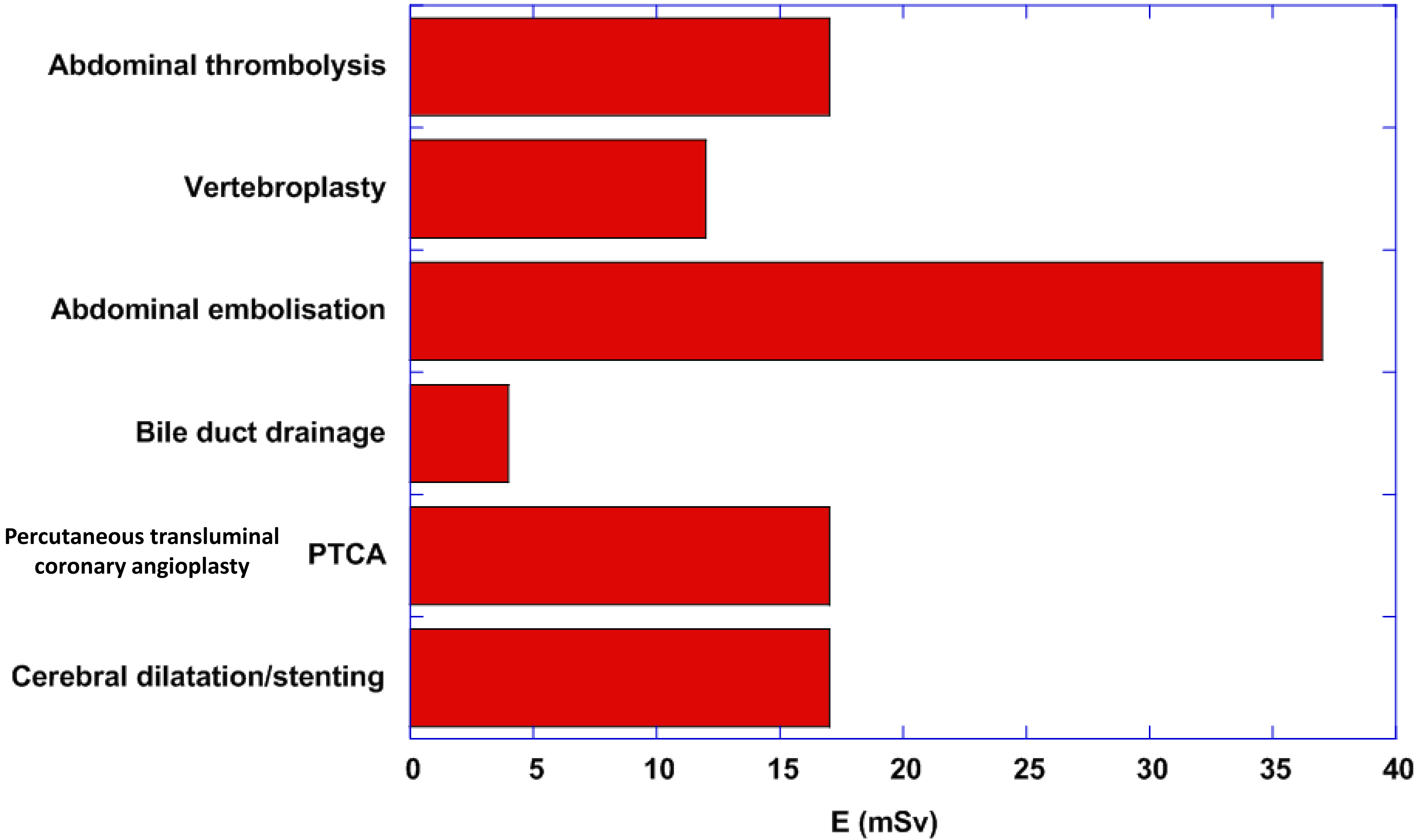
$$E = e_{KAP} \cdot KAP$$

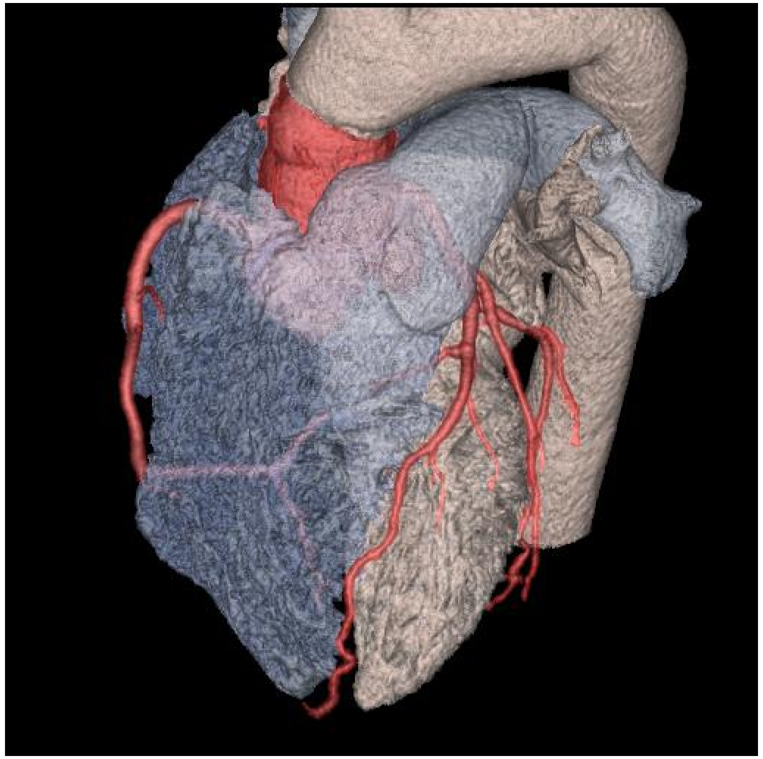
Exam	**e_{KAP} [mSv /Gy / cm^2]**
Skull AP	0.04
Chest PA	0.1
Abdomen AP	0.2
Lumbar spine LAT	0.1

Typical magnitude of the **effective dose E** in **diagnostic fluoroscopy**



Typical magnitude of the **effective dose E** of **therapeutic fluoroscopy**





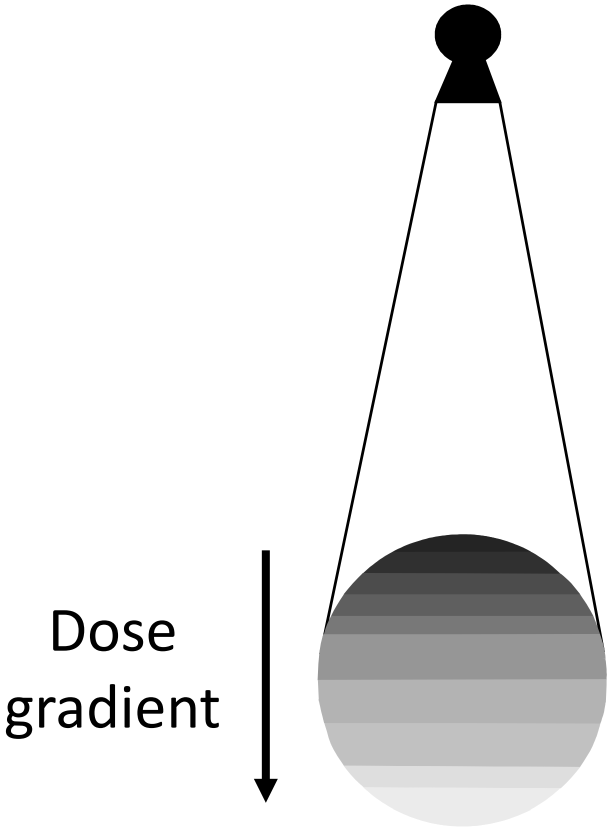
Patient dose and radiation protection

1.3

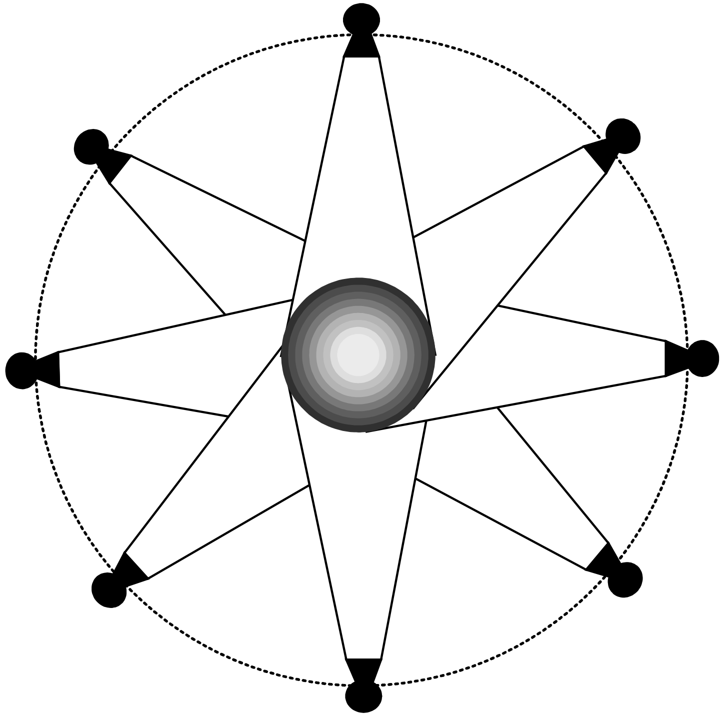
Diagnostic radiology

CT: Computed Tomography

Dose distribution in CT



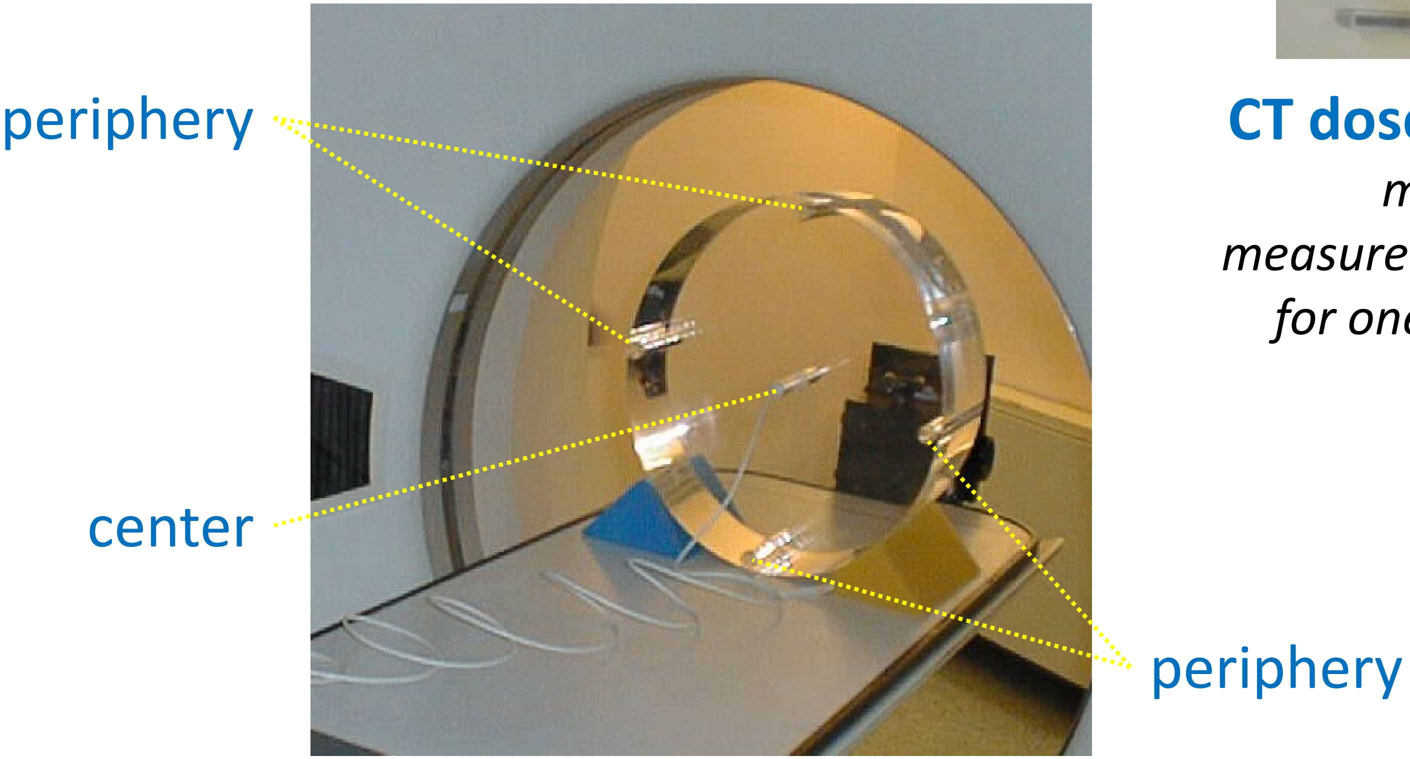
Contrary to radiography, the explored volume receives a relative **homogenous dose**



Dose distribution with circular symmetry

Weighted CTDI ($CTDI_w$)

$$CTDI_w = \frac{1}{3} CTDI_{center} + \frac{2}{3} CTDI_{periphery} \quad [mGy/mAs]$$



CT dose index (CTDI)

mean dose
measured in the phantom
for one tube rotation

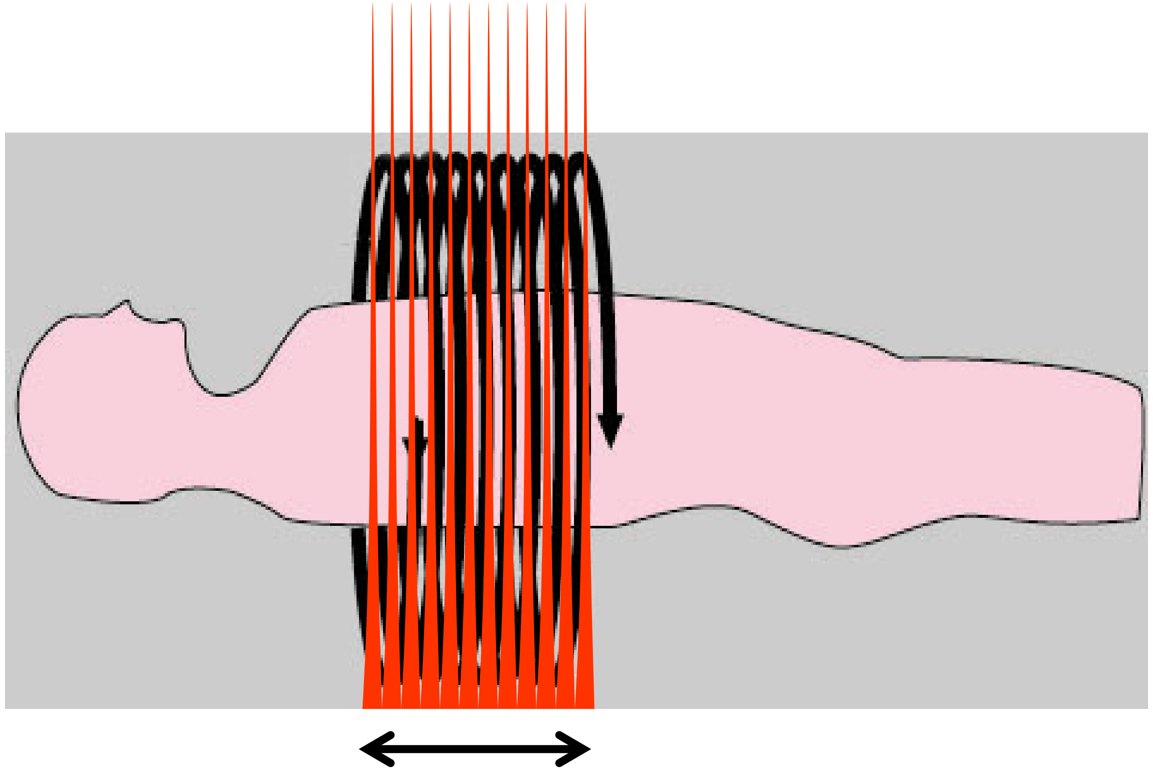
$\mathrm{CTDI_{vol}}$: mean dose in the slice

$$\mathrm{CTDI_{vol}} = \mathrm{CTDI_w} \times \frac{Q}{\text{pitch}} \quad [\mathrm{mGy}]$$

$$\text{pitch} = \frac{\text{table translation for 1 tube rotation [mm]}}{\text{nominal x-ray collimation thickness [mm]}}$$

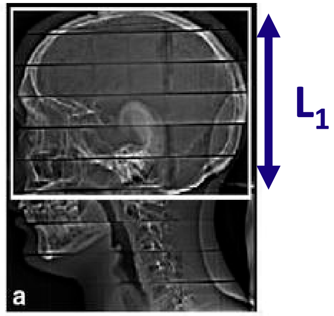
Dose Length Product (DLP)

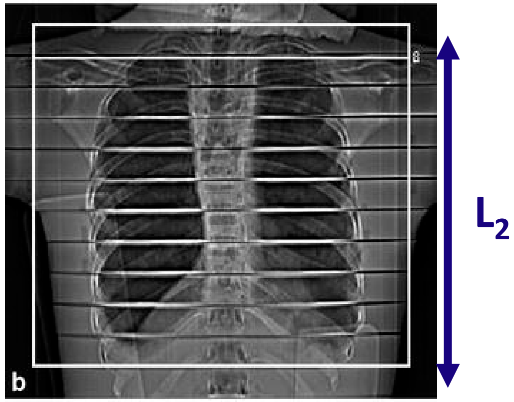
$$DLP = CTDI_{vol} \times L \quad [\text{mGy cm}]$$

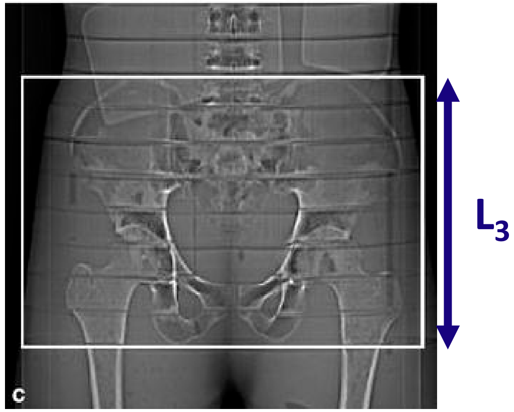


scanned length L

Computation of the **effective dose E** in CT







$CTDI_{vol} \times L_i$	$\times$	$e_{DLP;i}$	$=$	E_i
$DLP_1 = CTDI_{vol} \times L_1$		0.0023		E_1
		(0.0054)		
$DLP_2 = CTDI_{vol} \times L_2$		0.017		E_2
		(0.015)		
$DLP_3 = CTDI_{vol} \times L_3$		0.019		E_3

$$\boxed{E = \sum_i E_i}$$

Exercise

What is the **effective dose** of a **chest CT** exam with the following parameters?

U = 120 kV
Q = 160 mAs
Rotation time = 0.6 s
Collimation = 16 x 1.25 mm
Reconstructed slice thickness = 2.5 mm
Pitch = 1.2
Examined length = 30 cm
$\mathrm{CTDI_w}$ = 0.1 mGy/mAs
e_{DLP} = 0.015 mSv/(mGy cm)

4 sur 7

1. Press "1" when you are finished

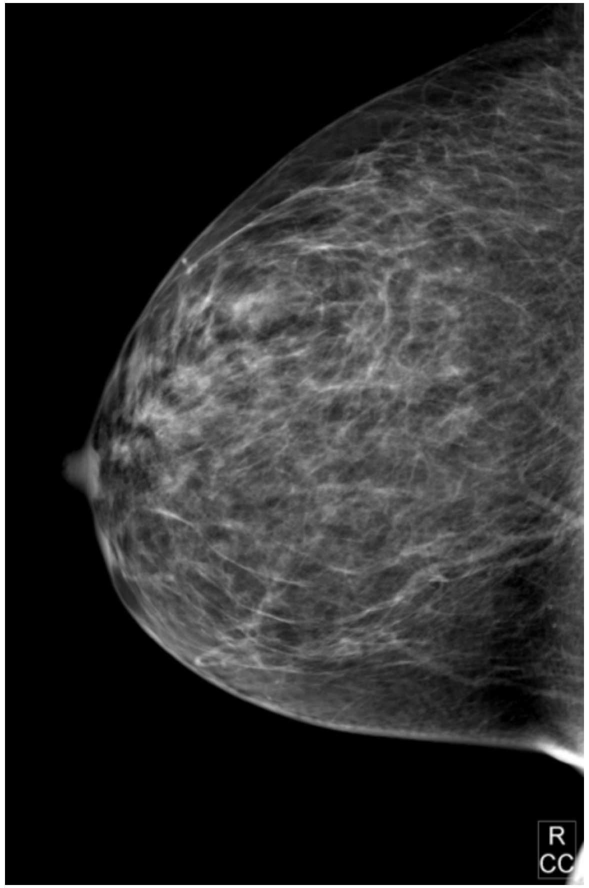
Exercise *(solution)*

U = 120 kV
Q = 160 mAs
Rotation time = 0.6 s
Collimation = 16 x 1.25 mm
Reconstructed slice thickness = 2.5 mm
Pitch = 1.2
Examined length = 30 cm
$CTDI_w$ = 0.1 mGy/mAs
e_{DLP} = 0.015 mSv/(mGy cm)

$$E = CTDI_w \times \frac{Q}{\text{pitch}} \times L \times e_{DLP} =$$

$$= 0.1 \times \frac{160}{1.2} \times 30 \times 0.015 =$$

$$= 6 \ \text{mSv}$$



Patient dose and radiation protection

1.4

Diagnostic radiology

Mammography

ESAK in mammography

(ESAK: entrance skin air kerma)

charge [mAs]

$$\mathrm{ESAK} = \Gamma_K \frac{Q}{d^2}$$

kerma constant
[mGy m^2/mAs]

focus-skin distance [m]

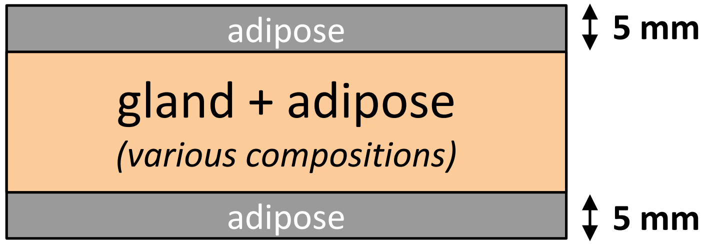
depends on the anode/filtration
and voltage
Mo/Mo 28 kV: $\Gamma_K = 0.05$ mGy m^2/mAs

ESAK in mammography

- ESAK (or D_e) **not** really **representative of risk**
- The effective dose E is even worse
  - w_T considers an android human (50% male / 50% female)
  - only **one organ** irradiated

- The **Mean Glandular Dose** (MGD) is a good risk estimator

$$MGD = ESAK \times mgd_{ESAK} \quad [mGy]$$

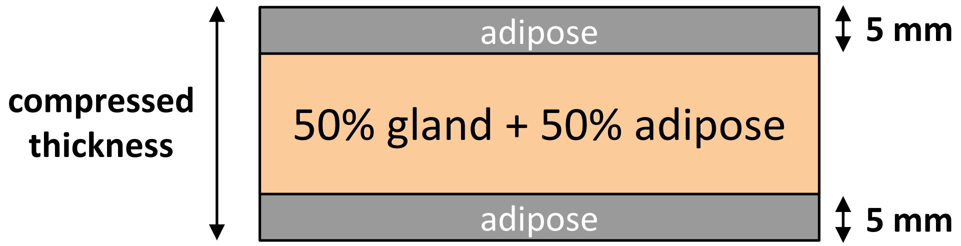


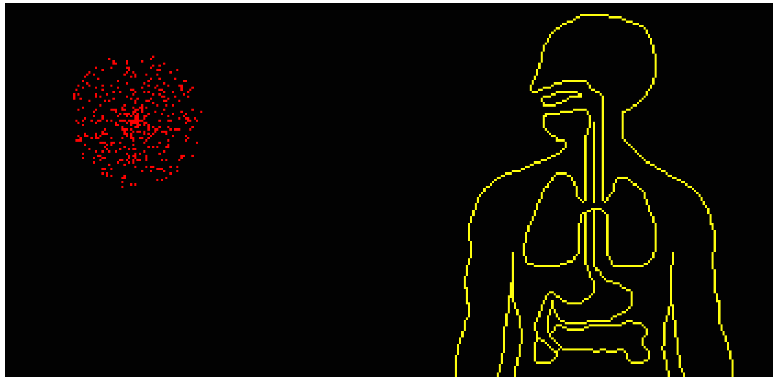
mgd$_{ESAK}$ for a 50/50 composition

(50 % glandular / 50 % adipose tissues)

Half **V**alue **L**ayer
of the x-ray beam

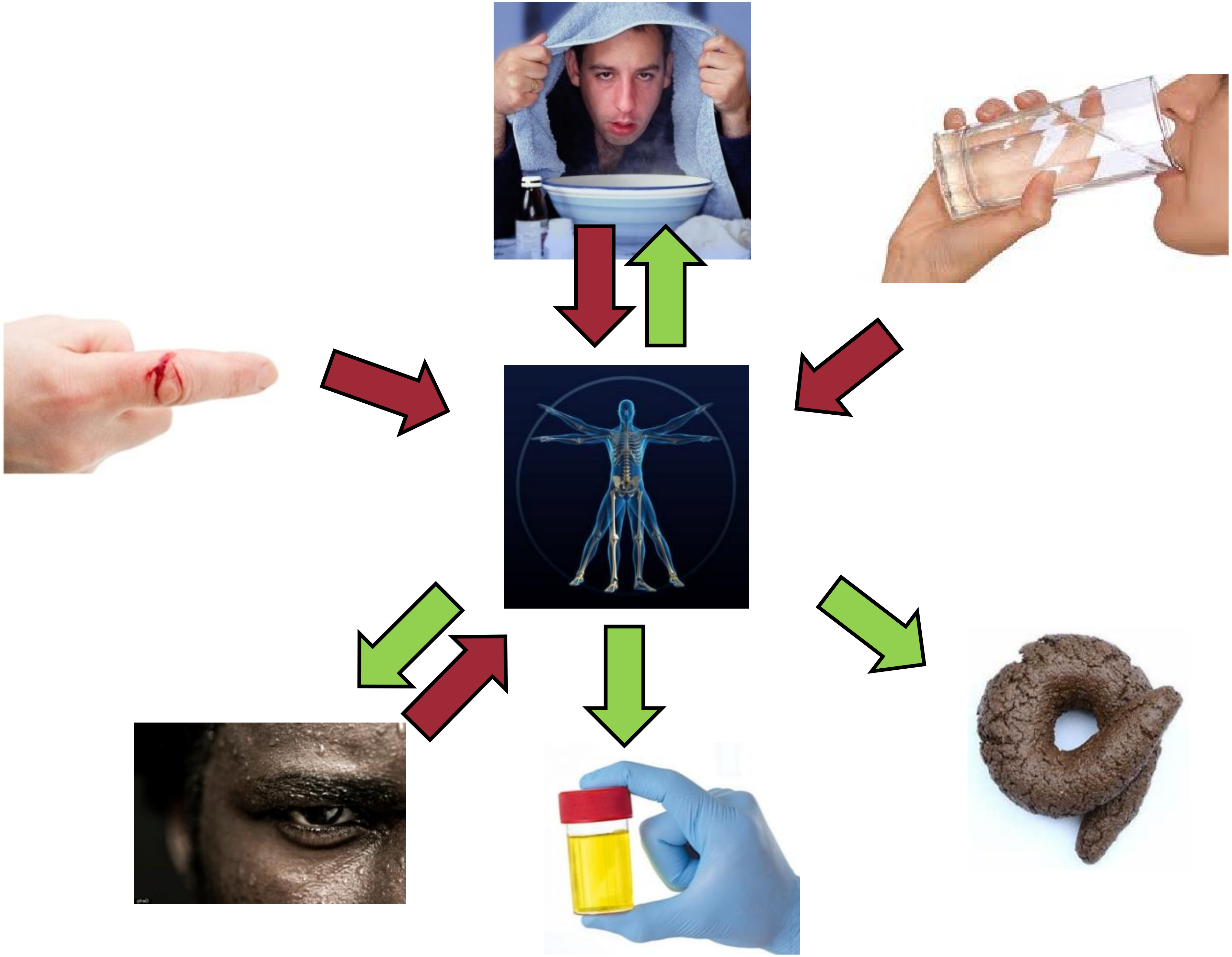
HVL	Compressed breast thickness [mm]		
[mm Al]	30	50	70
0.25	0.23	0.14	0.094
0.30	0.27	0.16	0.11
0.35	0.31	0.19	0.13
0.40	0.34	0.21	0.15





Patient dose and radiation protection

2.
Nuclear medicine



A **target region** r_T can be irradiated
from **other source regions** r_S
or from **the region itself**

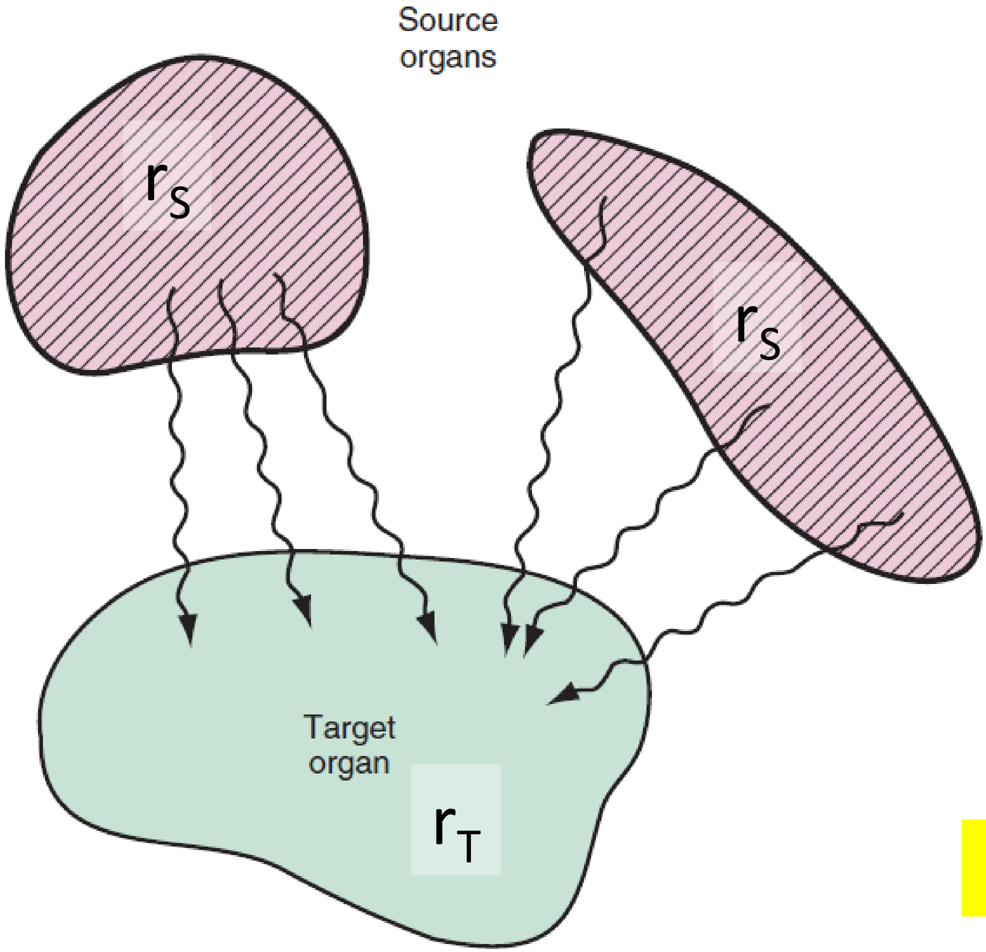


FIGURE 22-1 Absorbed dose delivered to a target organ from one or more source organs containing radioactivity is calculated by the absorbed fraction dosimetry method.

blackboard

Cherry, Sorenson, Phelps, Physics in Nuclear Medicine, Sauders Elsevir, 2012

Equivalent dose in target region r_T

Intake
(activity incorporated)

$$H_T = I$$

Equivalent dose in target region r_T

Number of nuclear transformations in source region r_S per unit of intake during time τ

Intake *(activity incorporated)*

$$H_T = I \sum_S \tilde{a}(r_S, \tau)$$

Number of nuclear transformations

$$\tilde{A}(r_S, \tau) = I \times \tilde{a}(r_S, \tau)$$

Equivalent dose in target region r_T

Number of nuclear transformations in source region r_S per unit of intake during time τ

Physiology
Biokinetic

Intake
(activity incorporated)

$$H_T = I \sum_{S} \tilde{a}(r_S, \tau) S_w(r_T \leftarrow r_S)$$

radiation weighted S *(S-factor)*
equivalent dose to target region r_T per nuclear transformation of a given radionuclide in source region r_S

Physics
Radiophysics & geometry

Patient dose and radiation protection

2.1

Nuclear medicine

Computation of the S factor

Transport of energy from r_S to r_T is computed by **Monte Carlo simulation**

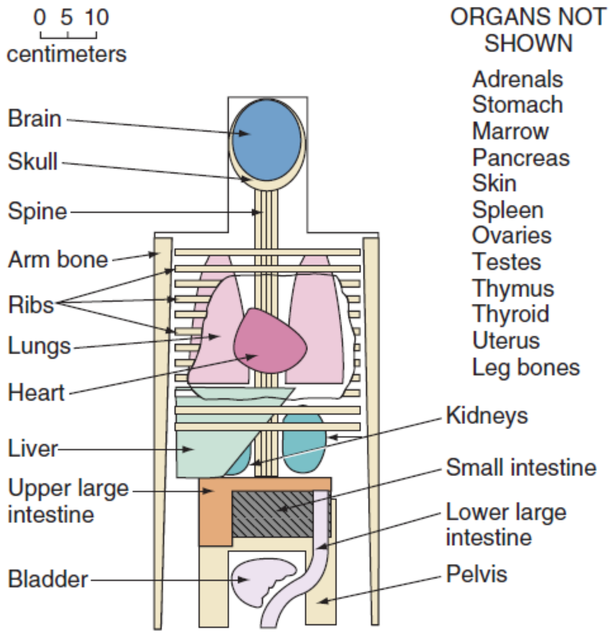
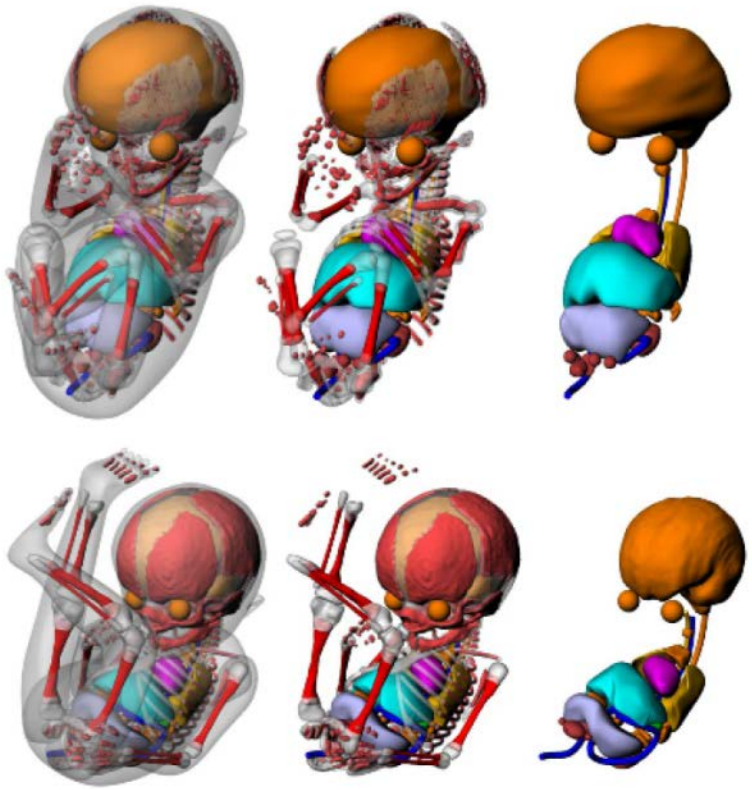


FIGURE 22-5 Representation of an "average man" used for MIRD dose calculations and tables. (*Adapted with permission from Snyder WS, Fisher HL Jr, Ford MR, Warner GG: Estimates of absorbed fractions for monoenergetic photon sources uniformly distributed in various organs of a heterogenous phantom.* J Nucl Med Suppl *3:9, 1969.*)

MIRD phantom

ICRP-110 voxel phantoms

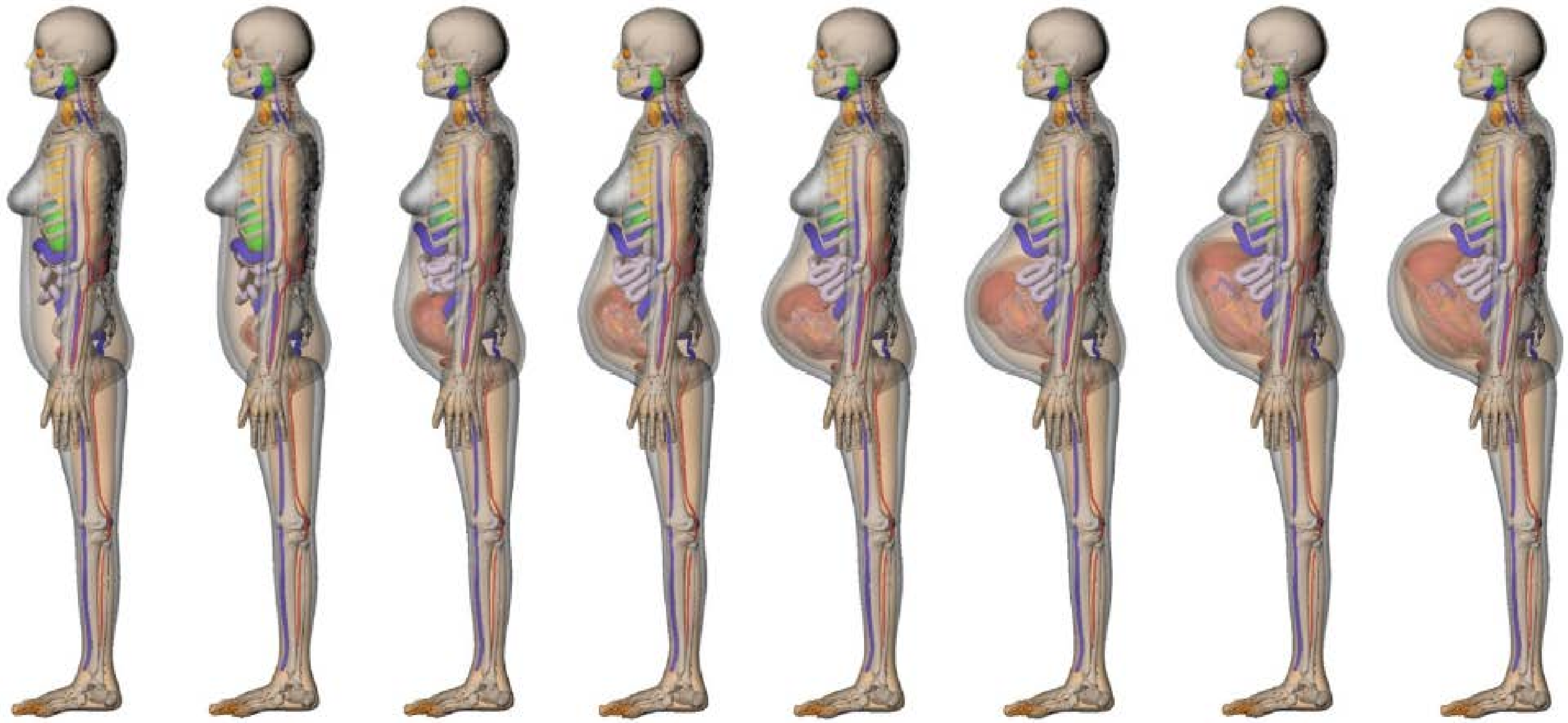
Other ICRP phantoms



Fetal phantoms

To be realized by ICRP TG 96 with support of U.S. Environmental Protection Agency

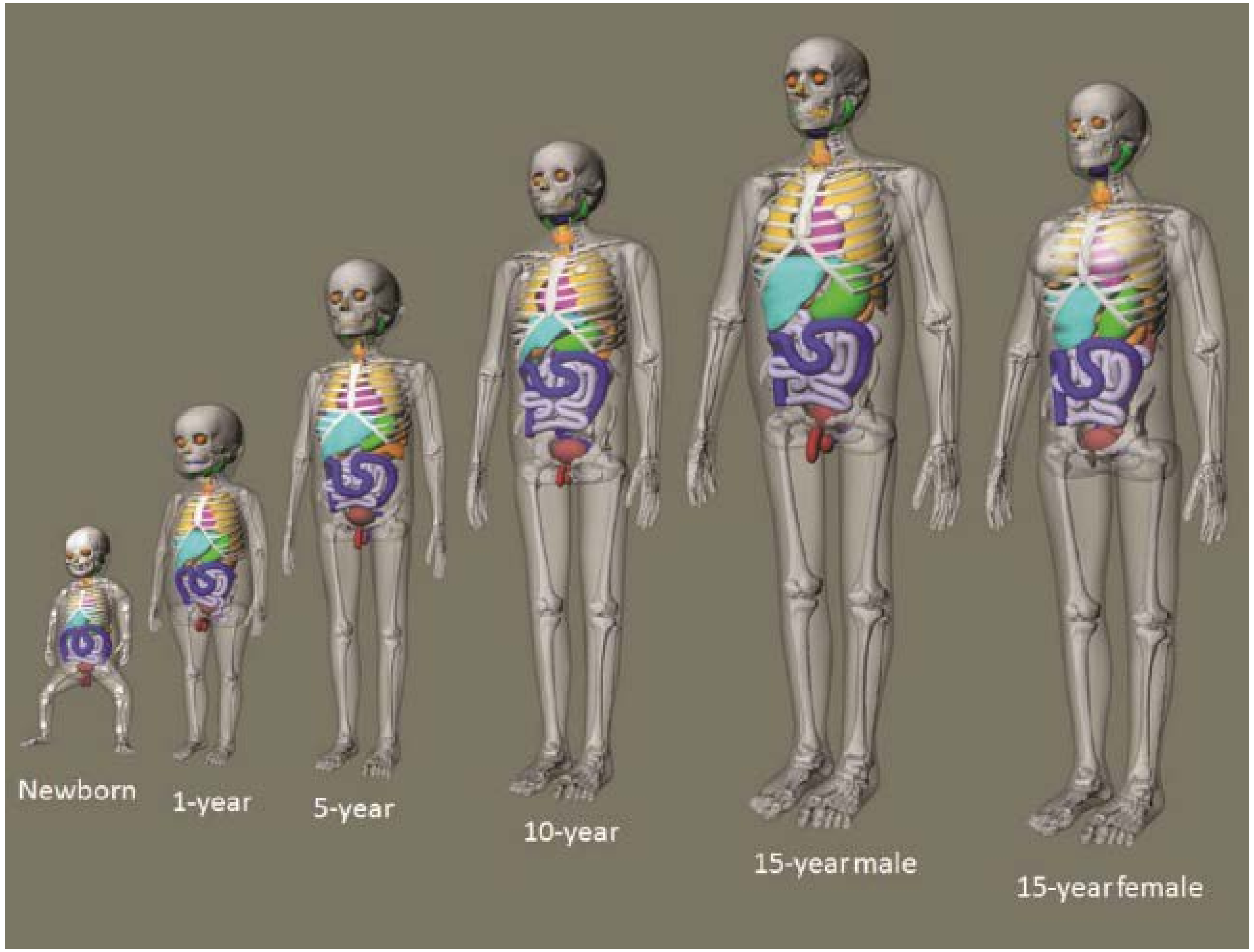
Other ICRP phantoms



pregnant women (8 weeks to 38 weeks post-conceptions)

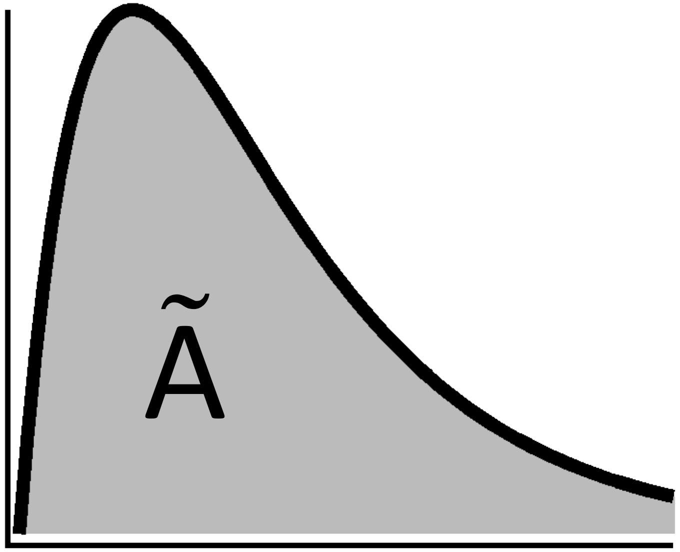
To be realized by ICRP TG 96 with support of U.S. Environmental Protection Agency

Other ICRP phantoms



pediatric reference phantoms

To be realized by ICRP TG 96 with support of U.S. Environmental Protection Agency



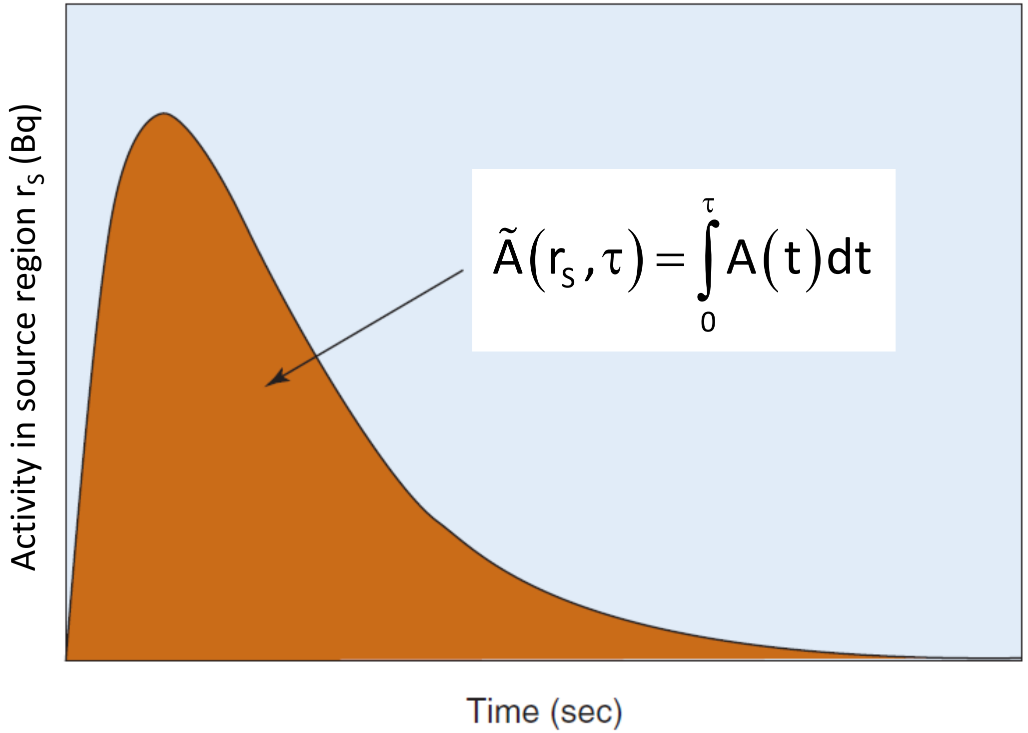
Dose to the patient

2.3

Nuclear medicine

Direct measurement of the number of nuclear transformations

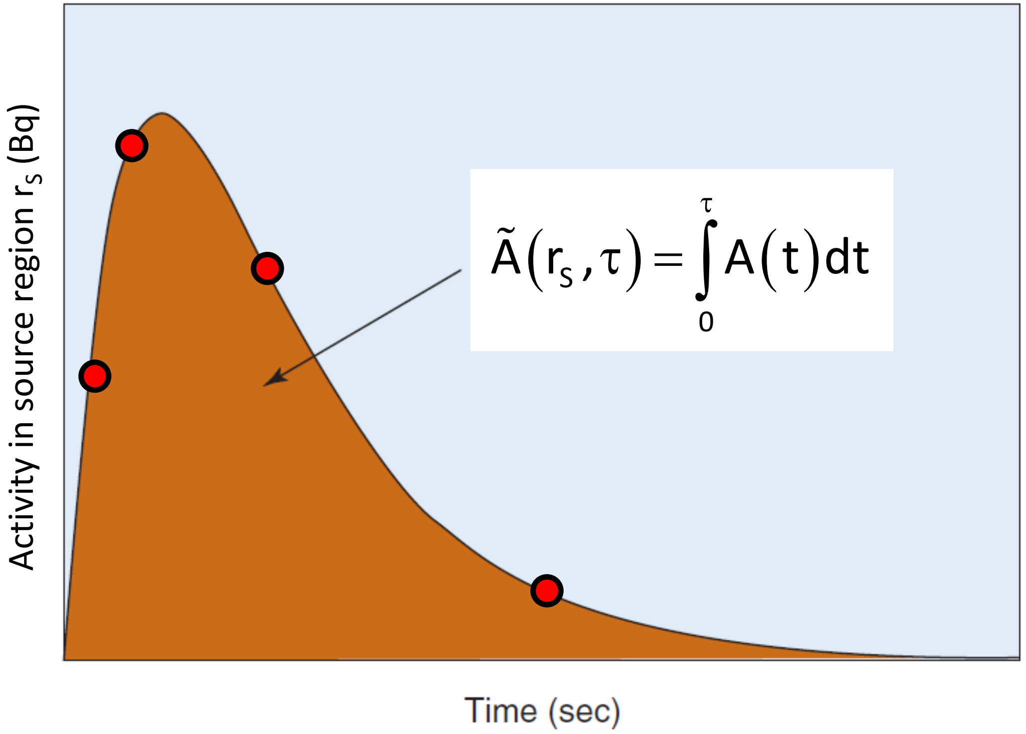
Number of nuclear transformations within **source region r_S**



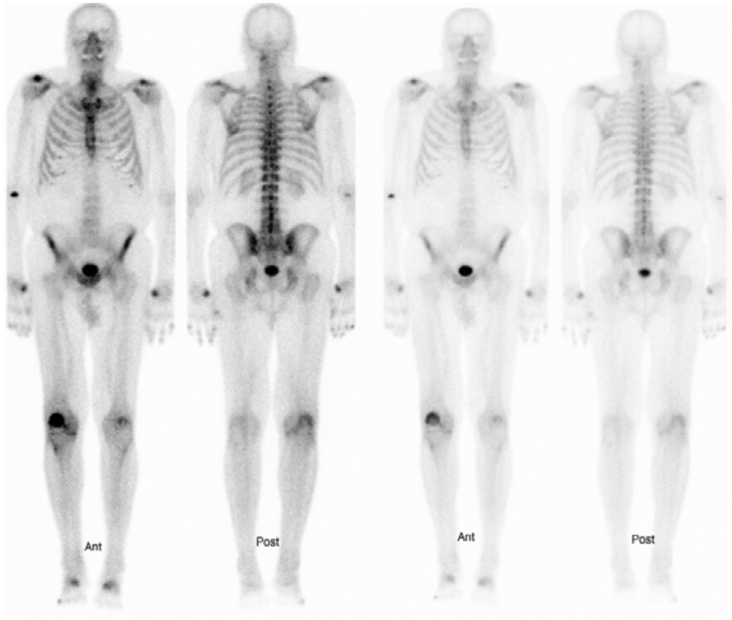
$$\tilde{A}(r_S,\tau)=\int_0^{\tau} A(t)\,dt$$

Cherry, Sorenson, Phelps, Physics in Nuclear Medicine, Sauders Elsevir, 2012

$\tilde{A}(r_S, \tau)$ can be **measured** in **nuclear medicine**

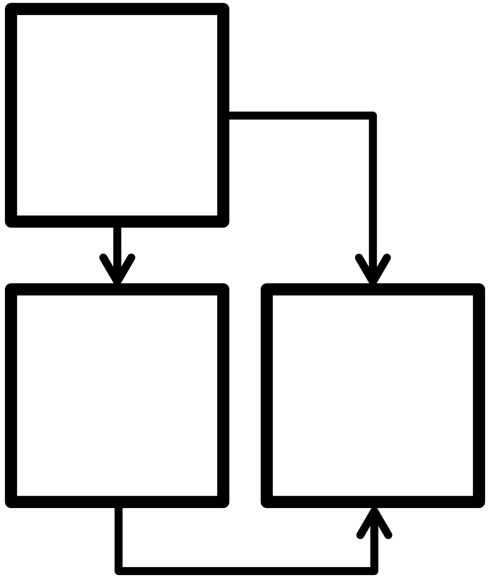


$$\tilde{A}(r_S, \tau) = \int_0^{\tau} A(t)\,dt$$



quantitative SPECT
imaging performed
at different times allows us
to estimate $\tilde{A}(r_S, \tau)$

Cherry, Sorenson, Phelps, Physics in Nuclear Medicine, Sauders Elsevir, 2012



Dose to the patient

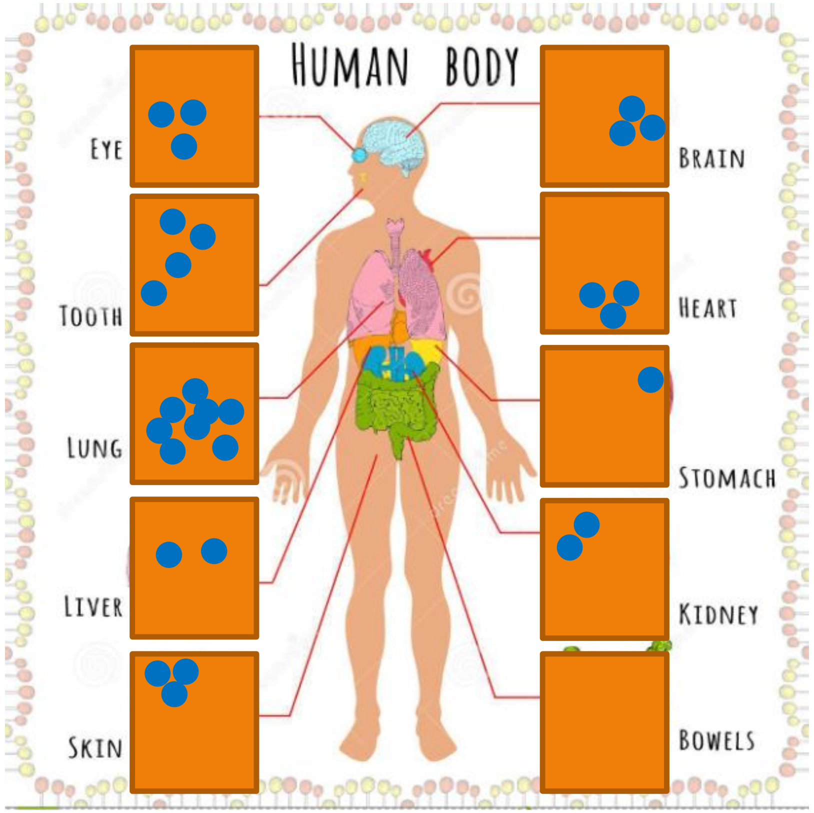
2.4

Nuclear medicine

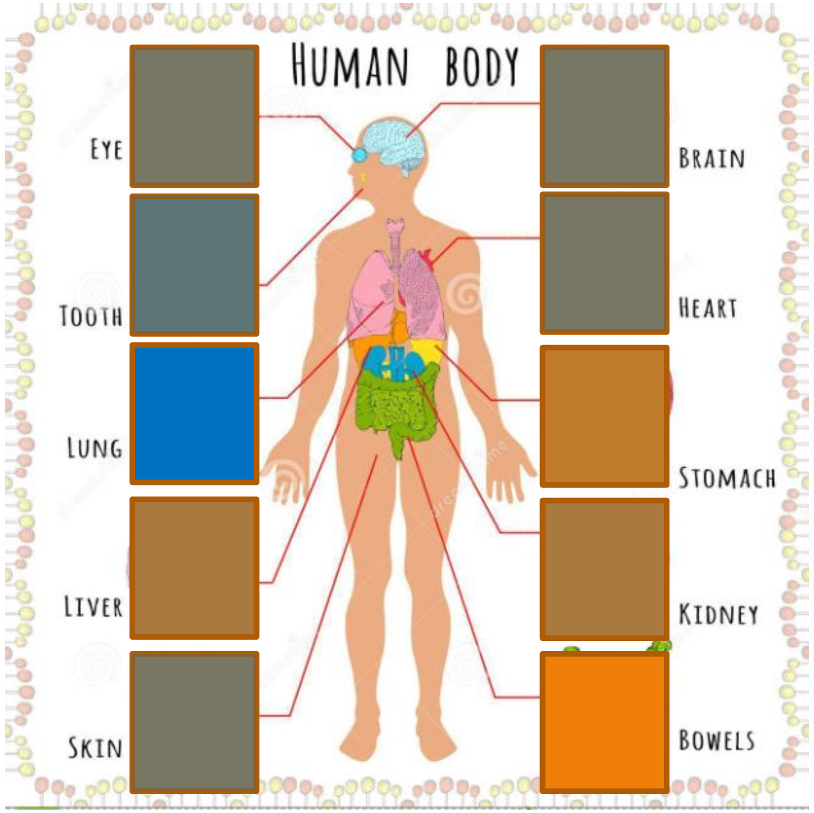
Compartment models

$\tilde{A}(r_S,\tau)$ can be **computed** with **compartmental biokinetic models**

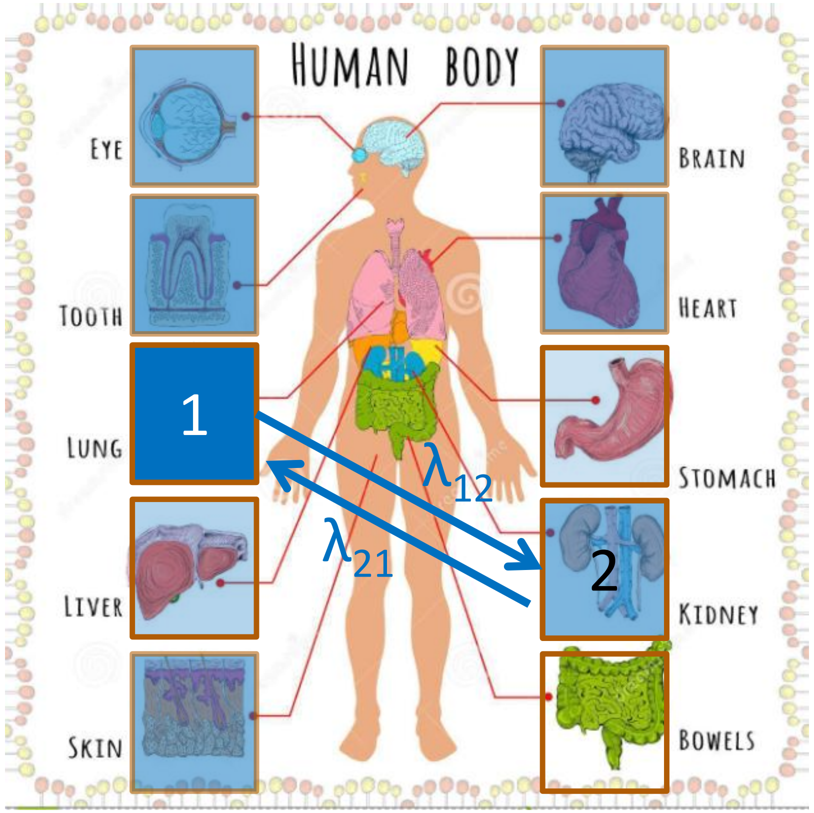
Organism divided
in sub-systems:
Compartments



The compartments are considered as **instantaneously homogenous**



Continuous transfer
between the
compartments

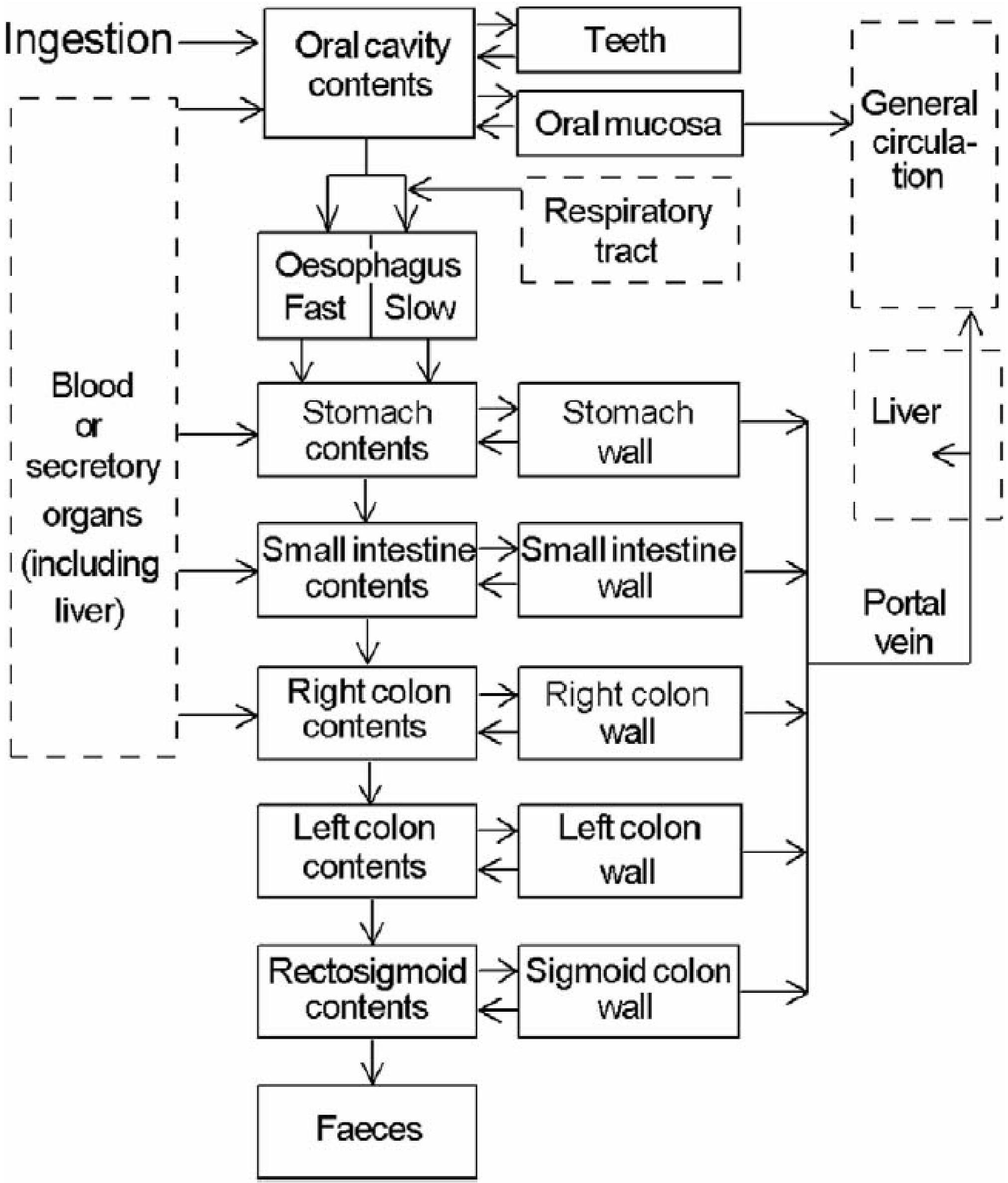


Flux from one compartment to another

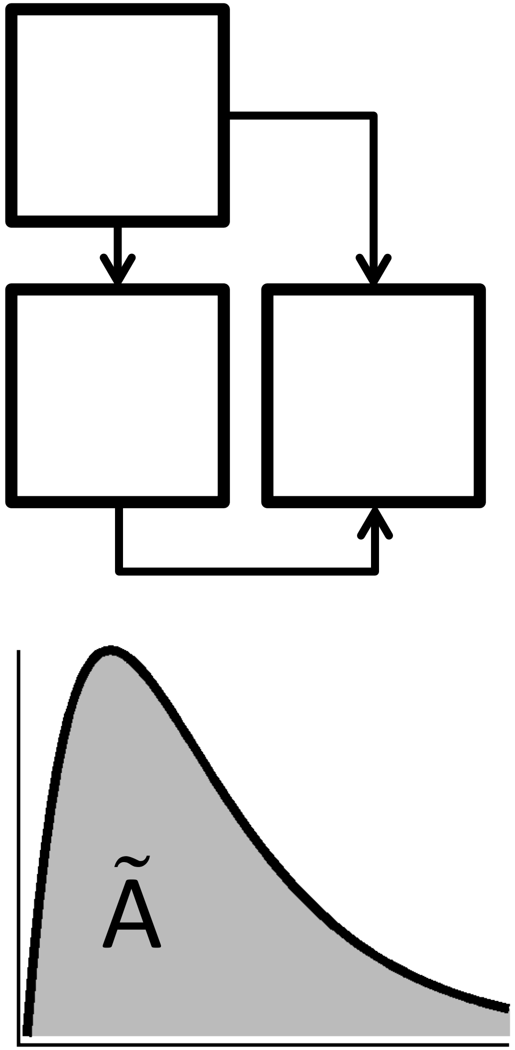
Proportional
to A in the source

λ: **fractional transfer rate**
probability of transfer from one compartment to another
per unit of time

HATM *(human alimentary tract model)*



ICRP-100



Dose to the patient

2.5

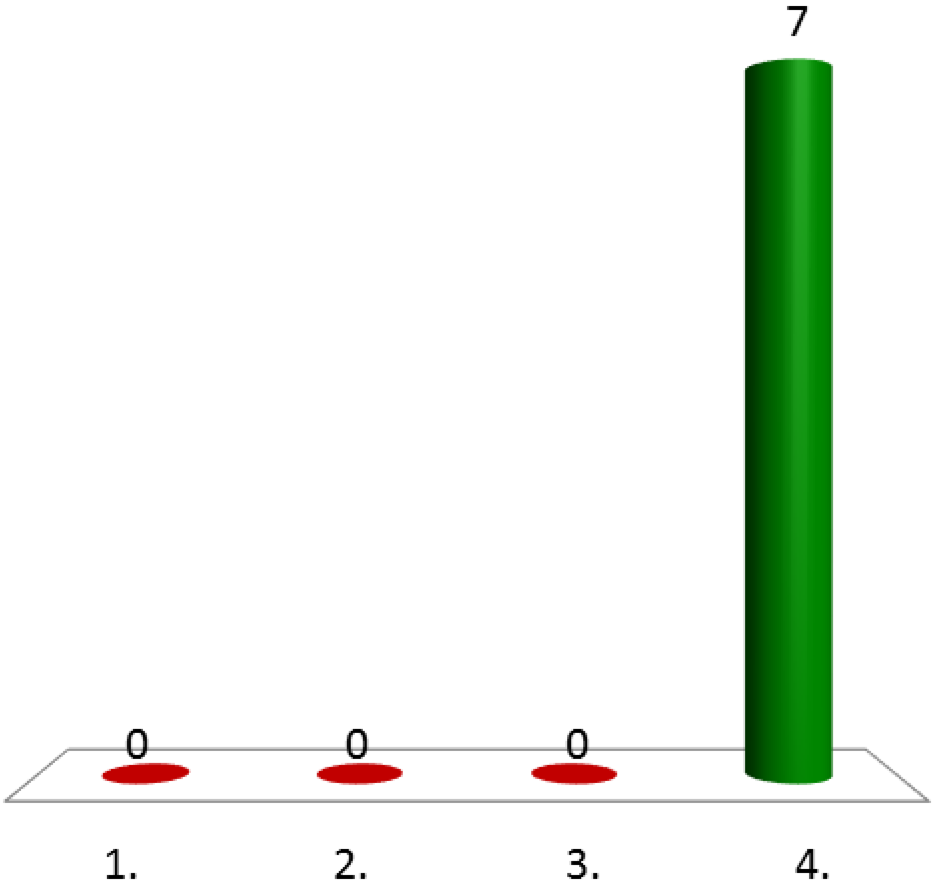
Nuclear medicine

Computation of the number of nuclear transformations with compartmental models

What is the solution to this differential equation?

$$f(x) = -\frac{df(x)}{dx}$$

1. $f(x) = -x + b$
2. $f(x) = -x^2 + bx + c$
3. $f(x) = -a/x$
4. $f(x) = a\exp(-x)$

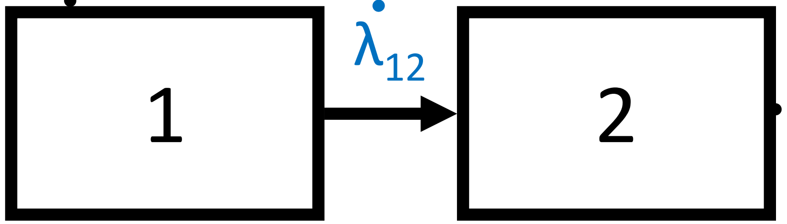


7 sur 7

Simple case with ***two compartments*** *and* ***one flux***

$$\frac{\partial A_1}{\partial t} = -\lambda_{12} A_1$$

Probability of transfer from compartment 1 to 2



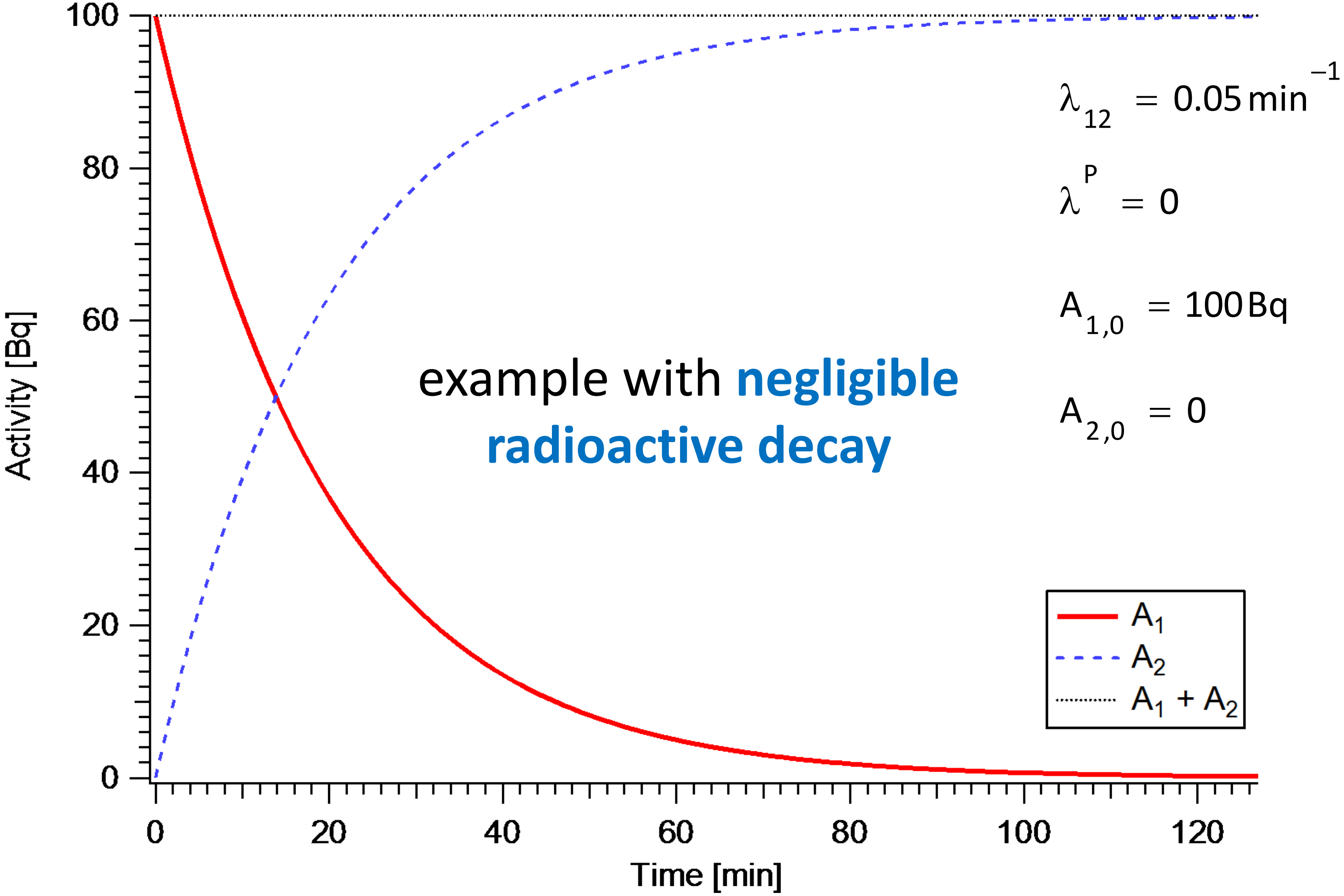
$$\frac{\partial A_2}{\partial t} = \lambda_{12} A_1$$

Flux proportional to the source content

(time series)

$$A_1(t) = A_{1,0} e^{-\lambda_{12} t}$$

$$A_2(t) = A_{2,0} + A_{1,0}\left[1 - e^{-\lambda_{12} t}\right]$$



example with **negligible radioactive decay**

$\lambda_{12} = 0.05\,\mathrm{min}^{-1}$

$\lambda^{P} = 0$

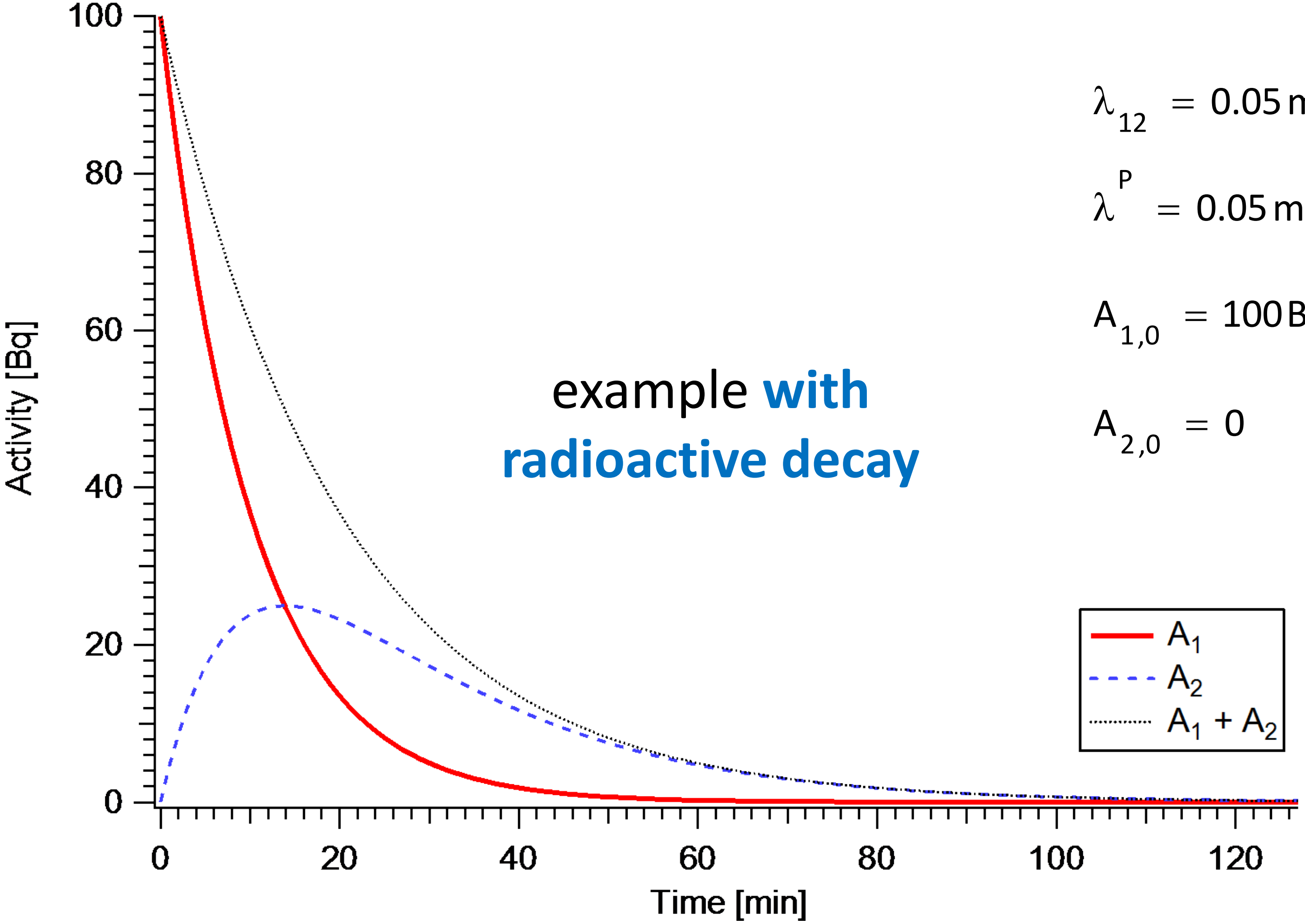
$A_{1,0} = 100\,\mathrm{Bq}$

$A_{2,0} = 0$

(time series)

$$A_1(t) = A_{1,0} e^{-\lambda_{12} t}$$

$$A_2(t) = A_{2,0} + A_{1,0}\left[1 - e^{-\lambda_{12} t}\right]$$



example **with radioactive decay**

$\lambda_{12} = 0.05\,\text{min}^{-1}$

$\lambda^{P} = 0.05\,\text{min}^{-1}$

$A_{1,0} = 100\,\text{Bq}$

$A_{2,0} = 0$

(time series)

$$A_1(t) = A_{1,0}e^{-\lambda_{12}t}$$

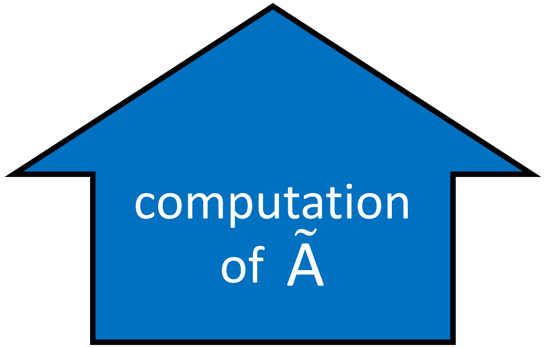
$$A_2(t) = A_{2,0} + A_{1,0}\left[1 - e^{-\lambda_{12}t}\right]$$

solution

(integration
of the time series)

$$\tilde{A}\left(r_{S1},\tau\right)=\int A_1\left(t\right)dt=A_{1,0}\frac{1}{\lambda_{12}}=A_{1,0}\frac{T_{bio,12}}{\ln 2}$$

$$\tilde{A}\left(r_{S2},\tau\right)=\int A_2\left(t\right)dt=A_{2,0}+\left(1-A_{1,0}\frac{T_{bio,12}}{\ln 2}\right)$$



computation
of $\tilde{A}$

(time series)

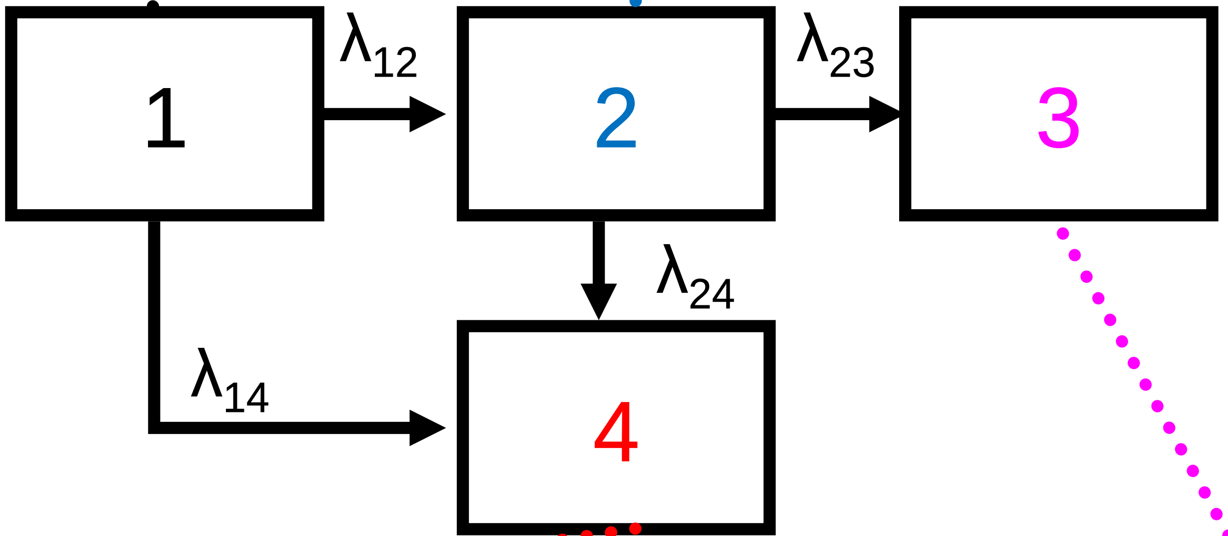
$$A_1\left(t\right)=A_{1,0}e^{-\lambda_{12}t}$$

$$A_2\left(t\right)=A_{2,0}+A_{1,0}\left[1-e^{-\lambda_{12}t}\right]$$

Simple case with **four compartments** and **four fluxes**

$$\frac{\partial A_1}{\partial t} = -\lambda_{12} A_1 - \lambda_{14} A_1$$

$$\frac{\partial A_2}{\partial t} = \lambda_{12} A_1 - \lambda_{23} A_2 - \lambda_{24} A_2$$



$$\frac{\partial A_4}{\partial t} = \lambda_{14} A_1 + \lambda_{24} A_2$$

$$\frac{\partial A_3}{\partial t} = \lambda_{23} A_2$$

Matrix formalism

$$\frac{\partial A_1}{\partial t} = -\lambda_{12} A_1 - \lambda_{14} A_1$$

$$\frac{\partial A_2}{\partial t} = \lambda_{12} A_1 - \lambda_{23} A_2 - \lambda_{24} A_2$$

$$\frac{\partial}{\partial t}\begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{pmatrix} = \begin{pmatrix} -\lambda_{12} - \lambda_{14} & 0 & 0 & 0 \\ \lambda_{12} & -\lambda_{23} - \lambda_{24} & 0 & 0 \\ 0 & \lambda_{23} & 0 & 0 \\ \lambda_{14} & \lambda_{24} & 0 & 0 \end{pmatrix}\begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{pmatrix}$$

$$\frac{\partial A_4}{\partial t} = \lambda_{14} A_1 + \lambda_{24} A_2$$

$$\frac{\partial A_3}{\partial t} = \lambda_{23} A_2$$

Diagonal terms: **outputs**

The **radioactive decay** effect can be taken into account by adding the decay constant λ_{nuc} in each diagonal term of **Λ**

$$\frac{\partial}{\partial t}\begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{pmatrix} = \begin{pmatrix} -\lambda_{12}-\lambda_{14} & 0 & 0 & 0 \\ \lambda_{12} & -\lambda_{23}-\lambda_{24} & 0 & 0 \\ 0 & \lambda_{23} & 0 & 0 \\ \lambda_{14} & \lambda_{24} & 0 & 0 \end{pmatrix}\begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{pmatrix}$$

$$\boxed{\Lambda_{ii} = \sum_{j\neq i} -\lambda_{ij}}$$

Off-diagonal terms: **inputs**

$$\frac{\partial}{\partial t}\begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{pmatrix} = \begin{pmatrix} -\lambda_{12}-\lambda_{14} & 0 & 0 & 0 \\ \lambda_{12} & -\lambda_{23}-\lambda_{24} & 0 & 0 \\ 0 & \lambda_{23} & 0 & 0 \\ \lambda_{14} & \lambda_{24} & 0 & 0 \end{pmatrix}\begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{pmatrix}$$

$$\boxed{\Lambda_{ij} = \lambda_{ji}}$$

Solution of the problem

Condensed notation

$$\frac{\partial \mathbf{A}}{\partial t} = \mathbf{\Lambda A}$$

Solution

$$\mathbf{A}(t) = \mathbf{A}_0 e^{\Lambda t}$$

$$\frac{\partial}{\partial t}\begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{pmatrix} = \begin{pmatrix} -\lambda_{12}-\lambda_{14} & 0 & 0 & 0 \\ \lambda_{12} & -\lambda_{23}-\lambda_{24} & 0 & 0 \\ 0 & \lambda_{23} & 0 & 0 \\ \lambda_{14} & \lambda_{24} & 0 & 0 \end{pmatrix}\begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{pmatrix}$$

Knowing the **time evolution** of the **activity A** in each compartment allows us to compute the **number of nuclear transformations** $\tilde{\mathbf{A}}(\tau)$

$$\frac{\partial \mathbf{A}}{\partial t} = \mathbf{\Lambda A} \qquad \mathbf{A}(t) = \mathbf{A}_0 e^{\Lambda t}$$

$$\tilde{\mathbf{A}}(\tau) = \int_0^\tau \mathbf{A}_0 e^{\Lambda t} dt$$

*(integration of **A**(t) between times 0 and τ)*

Equivalent dose to each organ

$$H_T = I \sum_S \tilde{a}(r_S, \tau) S_w(r_T \leftarrow r_S)$$

Direct measurement through imaging
or
compartmental model **calculation**

Monte Carlo
radiation transport
calculation

Effective dose

$$E = \sum_T w_T H_T$$

for a known individual

$$E = \frac{\sum_T w_T H_T\left(\text{female}\right) + \sum_T w_T H_T\left(\text{male}\right)}{2}$$

for a generic person

Patient dose and radiation protection

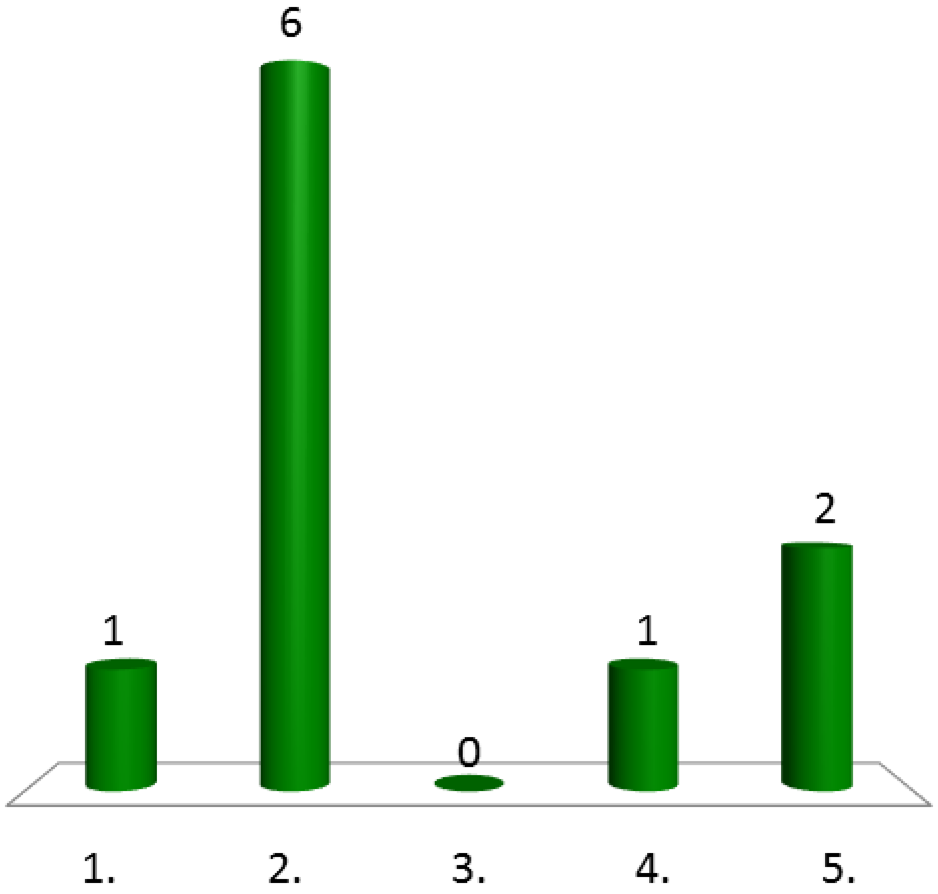
3.

Summary of the dosimetric quantities

Which affirmation concerning the **effective dose** is correct?

(multiple responses possible)

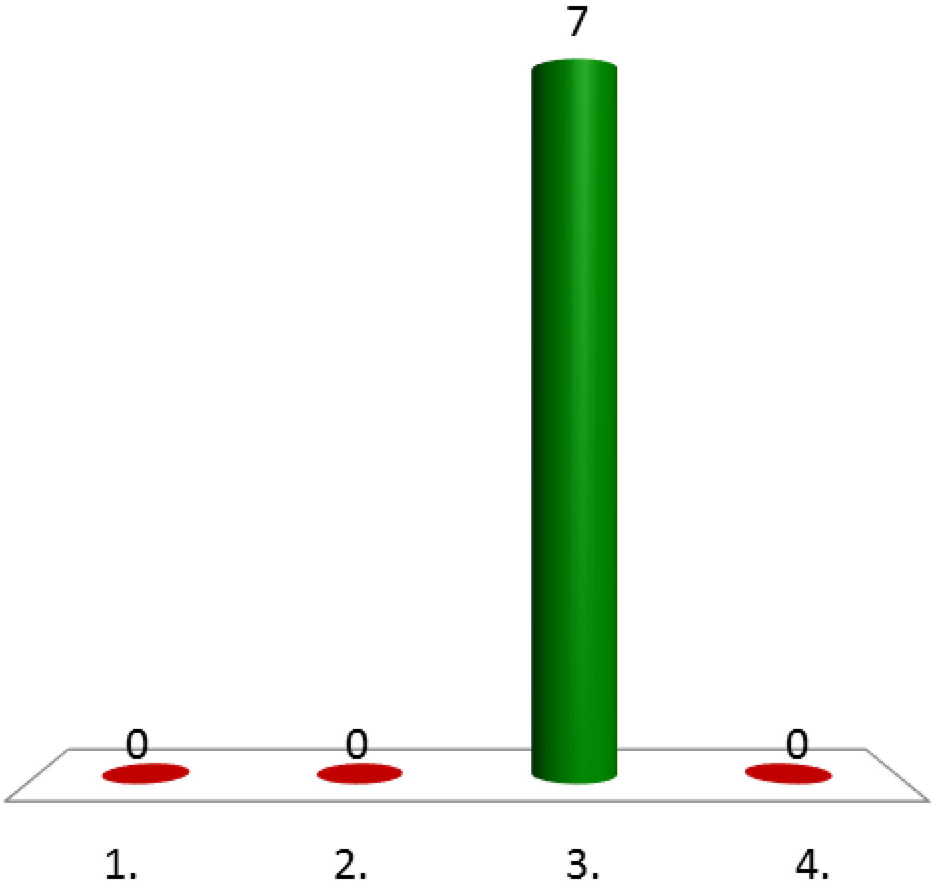
1. It estimates the global risk for a population
2. It estimates the global risk for an individual
3. It is related to an androgyn reference person
4. It is useful to compare different irradiation conditions
5. It is linked to the risk observed on the Hiroshima & Nagasaki survivors



7 sur 7

For which imaging modality, is the effective dose not relevant to estimate the risk?

1. Chest x-ray
2. Abdomen x-ray
3. Mammography
4. Full body CT scan



7 sur 7

Radiology

The **most relevant risk** is estimated by the **effective dose**, E

$$E = DQ \times e_{DQ}$$

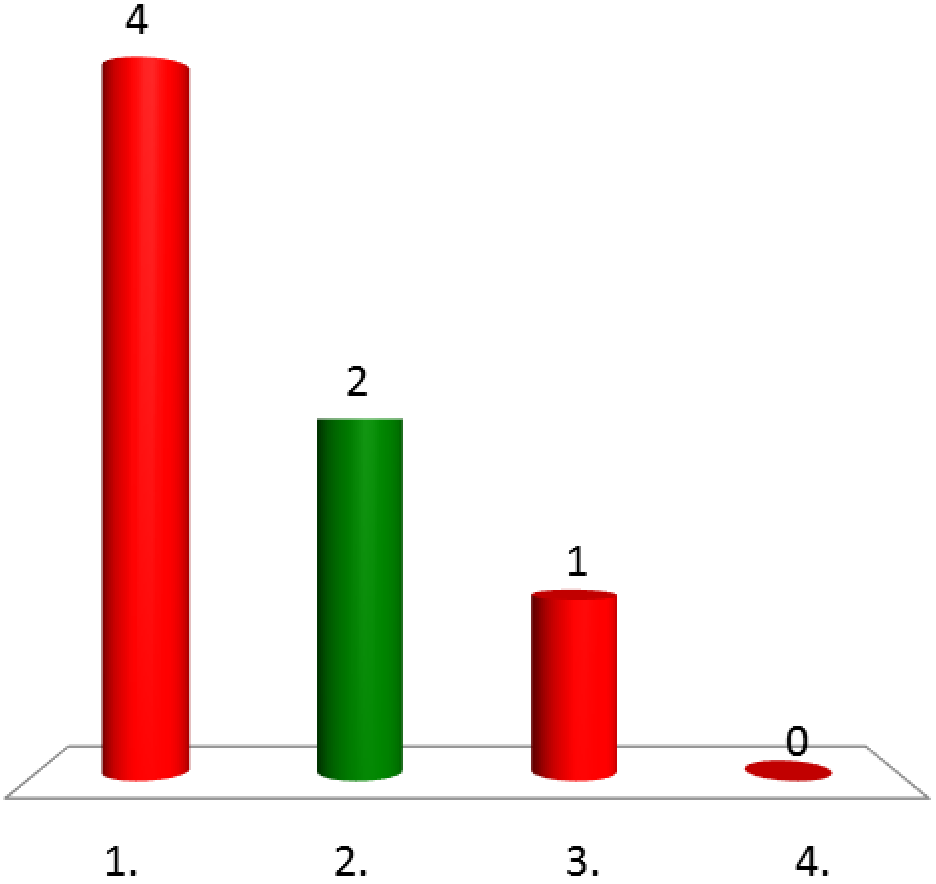
Exceptions:

fluoroscopy, where the skin is the most at risk (**IRP**);
mammography, where only one organ is exposed (**MGD**)

Imaging modality	**Dosimetric quantity (DQ)**
Radiography	**ESAK** [mGy] Entrance Skin Air Kerma
	D_e [mGy] Entrance dose in air
Radioscopy	**KAP** [mGy cm^2] Kerma Area Product
	IRP [mGy] Interventional Reference Point
Computed tomography (CT)	**CTDI** [mGy] CT Dose Index
	DLP [mGy cm] Dose Length Product
Mammography	**ESAK** [mGy] Entrance Skin Air Kerma
	MGD [mGy] Mean Glandular Dose

How do we restrict the dose delivered to the patient?

1. Dose limits are applied with specific values for each type of exam *(**limitation** principle)*
2. Dose reference levels are proposed for each type of exam *(**optimization** principle)*
3. There are no legal restriction
4. No idea



7 sur 7

Radiology and dose reference levels (**DRL**)

Comparisons with **dose reference levels** (DRL) is performed through the **dosimetric quantities** (DQ)

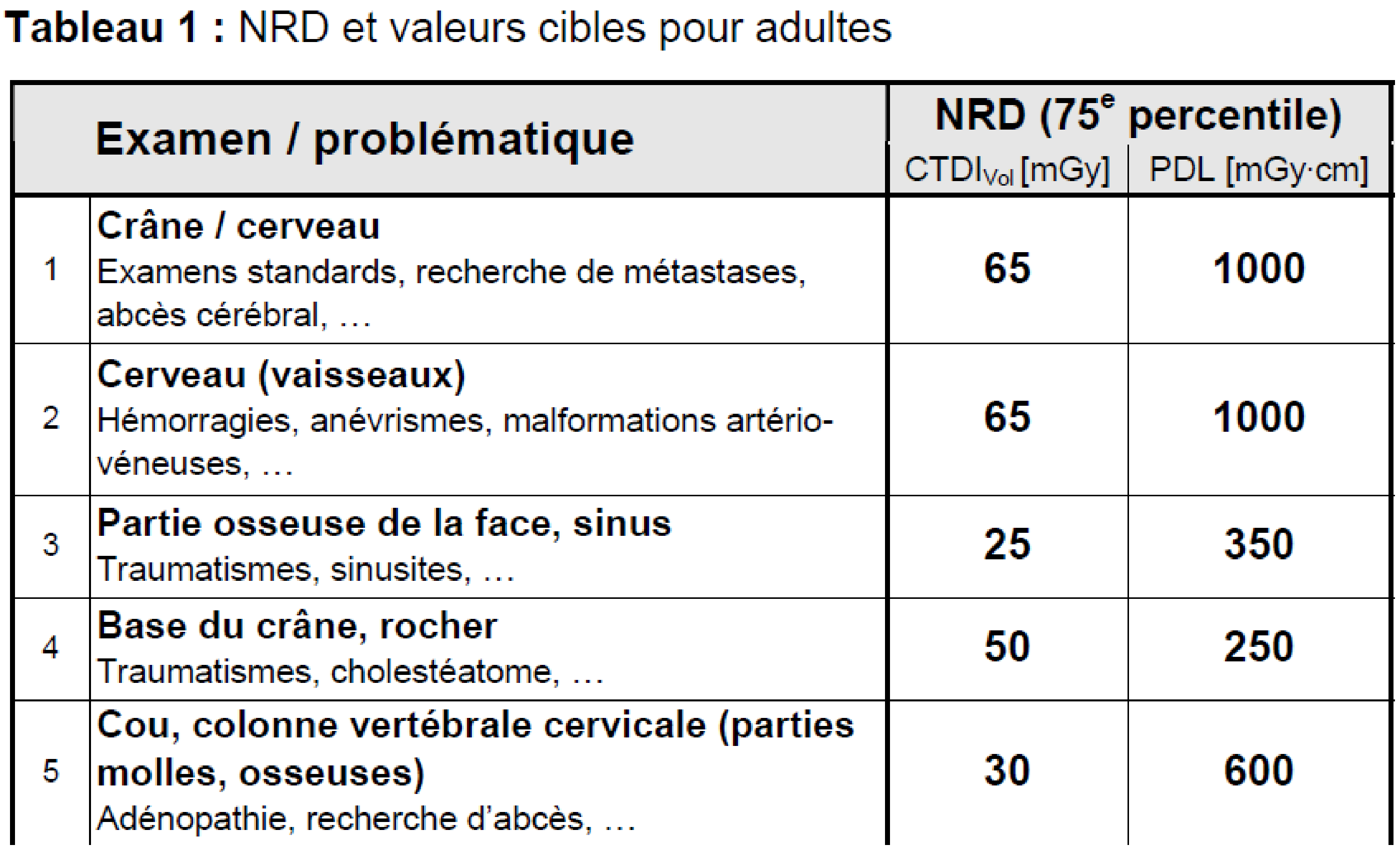


Tableau 1 : NRD et valeurs cibles pour adultes

	Examen / problématique	**NRD (75^{e} percentile)**	
		CTDI$_{Vol}$ [mGy]	PDL [mGy·cm]
1	**Crâne / cerveau** Examens standards, recherche de métastases, abcès cérébral, …	**65**	**1000**
2	**Cerveau (vaisseaux)** Hémorragies, anévrismes, malformations artério-véneuses, …	**65**	**1000**
3	**Partie osseuse de la face, sinus** Traumatismes, sinusites, …	**25**	**350**
4	**Base du crâne, rocher** Traumatismes, cholestéatome, …	**50**	**250**
5	**Cou, colonne vertébrale cervicale (parties molles, osseuses)** Adénopathie, recherche d'abcès, …	**30**	**600**

Notice OFSP R-06-06; Niveaux de référence diagnostiques en tomodensitométrie