Questions spéciales de radioprotection: dosimétrie et CQ en radiologie

RPR 3010

S. Vynckier

Module 1 :
Evaluation des doses au patient

Chap. 1 : Les expositions médicales
Chap. 2 : Grandeurs utilisées en dosimétrie patient
Chap. 3 : Mesures et calcul des doses au patient
Chap. 4 : Evaluation des doses au patient
- Tomodensitométrie
- Lavement baryté
- Thorax
- Interventionnel

Module 2 :
Optimisation de la dose au patient

Chap. 1 : Niveaux de référence
Chap. 2 : Facteurs d 'optimisation
Chap. 3 : Optimisation de la dose et qualité de l 'image

Module 3 :
Contrôle de qualité

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Chap. 2 : Aspect légal du contrôle de qualité
Chap. 3 : Contrôle de qualité en mammographie
Chap. 4 : Critères de qualité d 'image
Chap. 5 : Critères d 'acceptabilité des installations

Module 1

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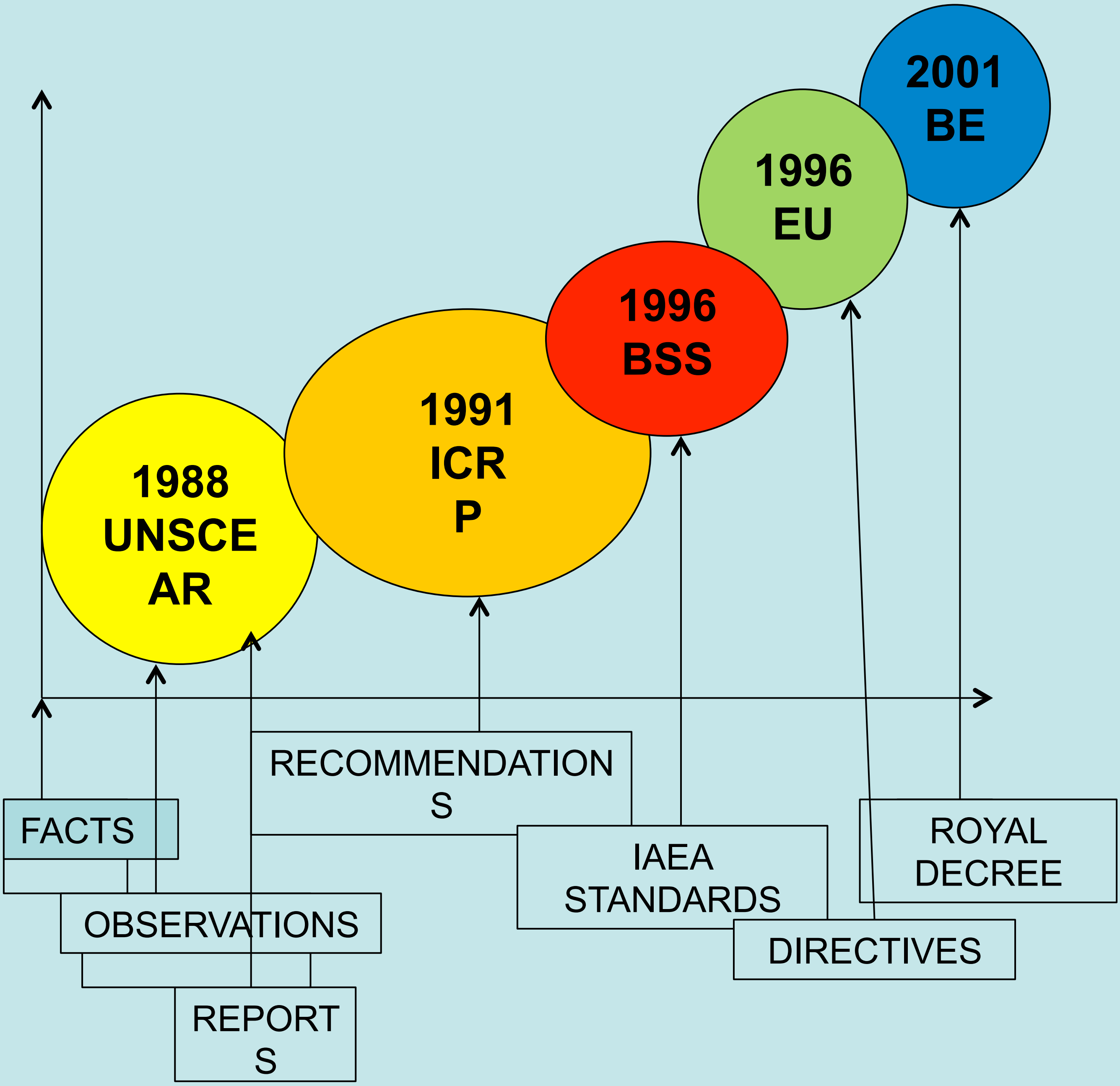
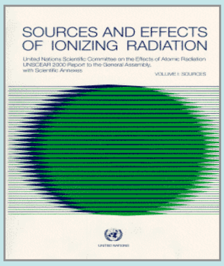
The making of RP regulations

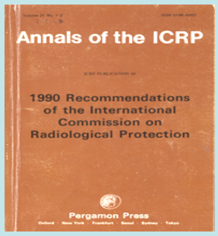


Foundation of regulation on radiation protection



- UNSCEAR
  - United Nations Scientific Committee on the effects of Atomic Radiation
  - Most important international institution :
    - Overview and evolution of the exposure of the world population to all sources of ionising radiation (nuclear industry, medical exposure, natural sources, …)
    - Synthesis of scientific knowledge about the health effects of ionising radiation (clinical effects, cancer risk, hereditary effects, …)
  - 1988
    - Health effects of exposure to ionising radiation >
    - Source of information: epidemiologic study of the Hiroshima and Nagasaki survivors

Foundation of regulation on radiation protection



- ICRP
  - International Commission on Radiological Protection
  - Recommendations
    - 1928 (workers and acute effects)
    - 1977 (basic principals of radiation protection)
      - Justification
      - ALARA
      - Individual dose limits
    - 1991 (ICRP-60)
      - Lowering of the dose limits
        - » 50 mSv/y to 20 mSv/y (workers)
        - » 5 mSv/y to 1 mSv/y (population)

Foundation of regulation on radiation protection

- IAEA
  - International Atomic Energy Agency
  - Scientific reports and conferences (Tsjernobyl, biological effects of low doses, …)
  - Publication (1996)
    - International Basic Safety Standards for protection against ionizing radiation and for the safety of radiation sources

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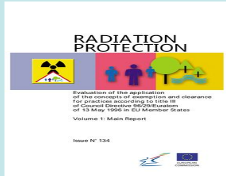
    - Council Directive 96/29/Euratom laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation

Foundation of regulation on radiation protection



- EU
  - Council Directive 96/29/Euratom
    laying down basic safety standards
  - Council Directive 97/43/Euratom
    on health protection of individuals against the dangers of
    ionizing radiation in relation to **medical exposure**
  - Binding: implementation in national legislation
    - » **Royal Decree of July 2001 laying down the General Regulation for the protection of the public, workers and the environment against the hazards of ionizing radiation**
  - Minimal: national legislation can be more severe

Foundation of regulation on radiation protection

- New developments:
  - UNSCEAR 2006 + 2008
  - ICRP 103
  - Revised Basic Safety Standards Directive (Council Directive 2013/59/Euratom)
    - Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with the new BSS Directive by **6/02/2018**

Natural Sources: cosmic radiation

Average in USA is 0.26 mSv (26 mrem) at sea level, approximately doubling with every 2000-m increase in altitude In Denver, for example, it is about 0.5 mSv At sea level, about:

- 63% mesons
- 15% electrons
- 21% neutrons

Average annual effective dose equivalent to a person in the USA is 0.27 mSv

Average annual effective dose equivalent due to air travel is about 0.1 mSv

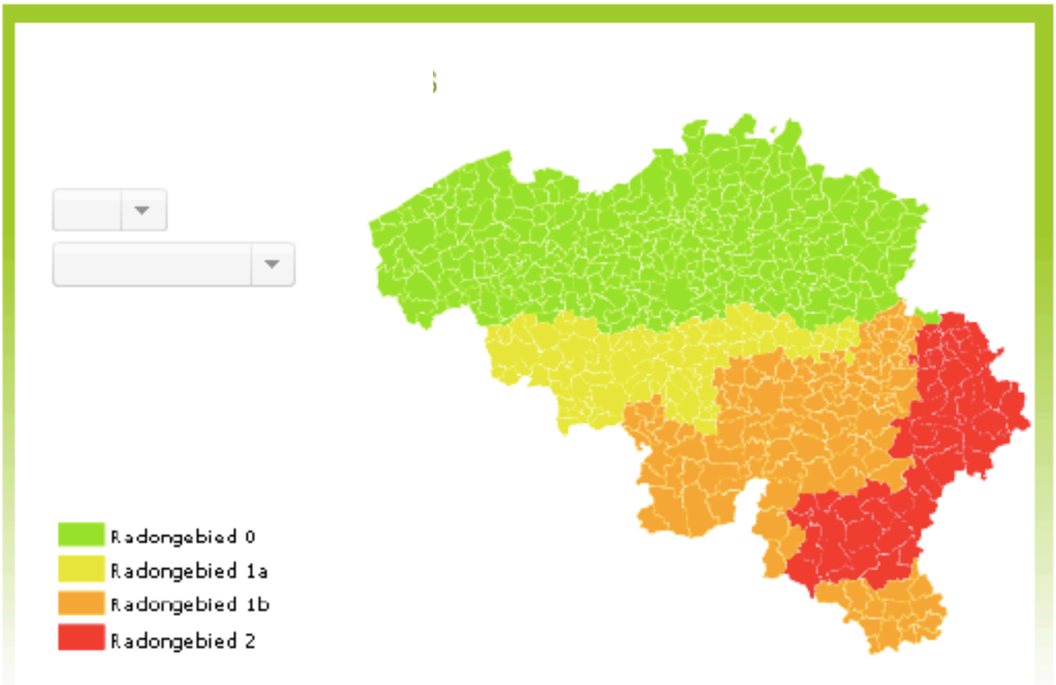
Natural Sources: radionuclides in the body

- Mainly K-40 and Po-210
- Average annual individual effective dose equivalent about 0.39 mSv
  - K-40 about 0.18 mSv/year
  - Po-210 about 0.14 mSv/year

Natural Sources: inhaled radionuclides

- Mainly Rn-222
- Average individual annual dose equivalent:
  - to whole lung: 0.2 mSv
  - to bronchial epithelium: 24 mSv
- Average individual annual effective dose equivalent about 2 mSv

Radon levels



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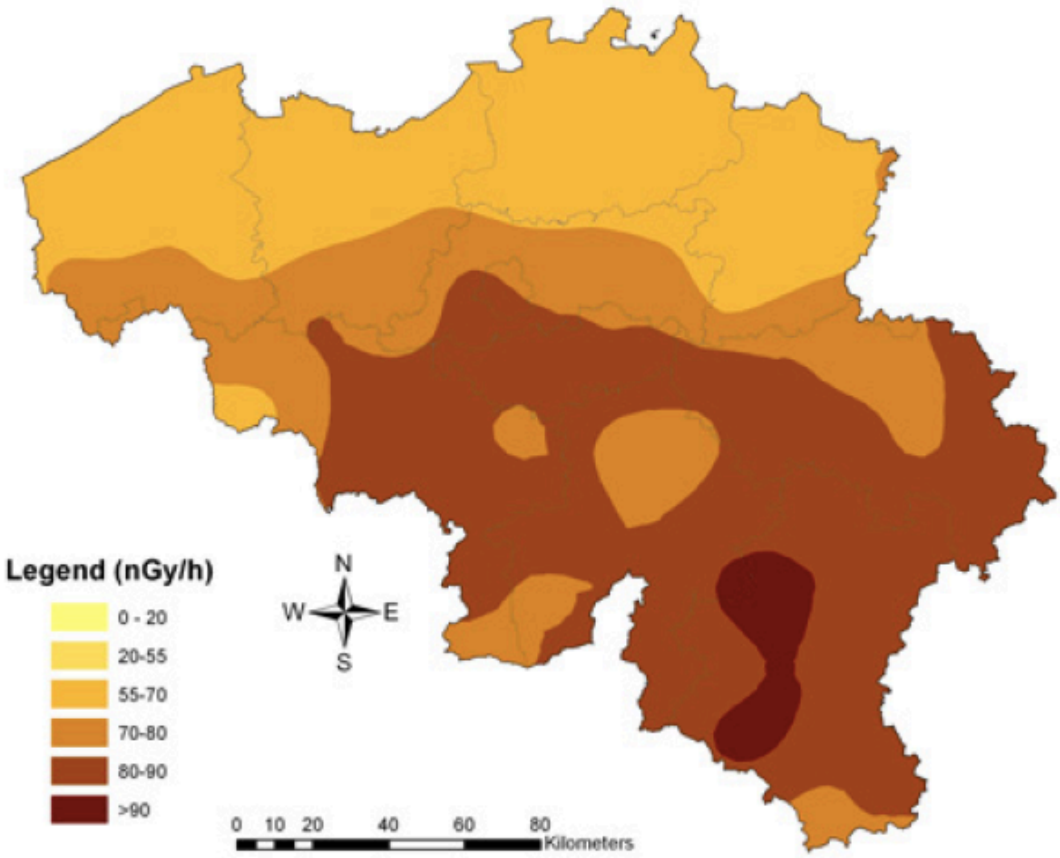
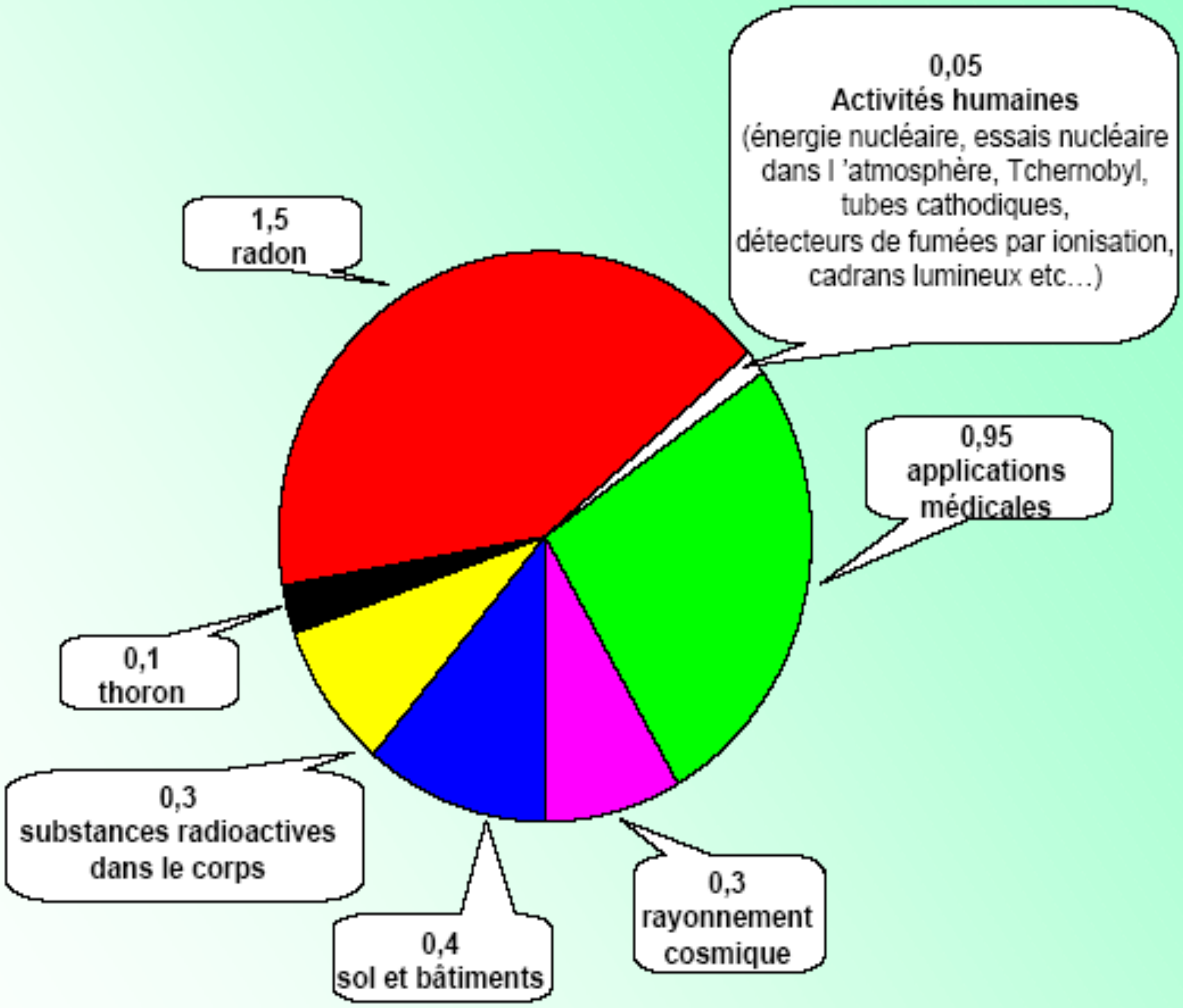
Terrestrial levels





Synthèse	mSv/an/habitant
Dose d 'origine médicale : Radioactivité naturelle :	0,95 (1/3) 2,00 (2/3)

Human-made Sources: occupational exposures

- Average annual effective dose equivalent to radiation workers about 2.2 mSv:
  - medicine: 1.5 mSv
  - industry: 2.4 mSv
  - nuclear fuel cycle: 6.0 mSv
  - government: 1.2 mSv
  - other workers: 1.7 mSv

Human-made Sources: medical exposures

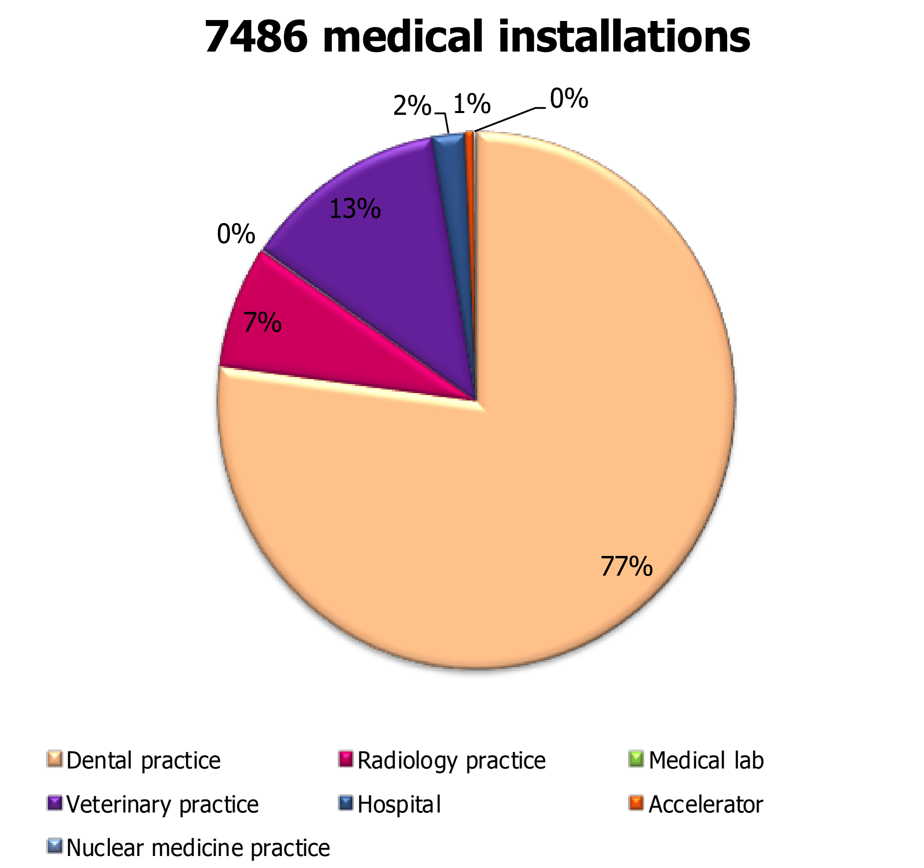
- Average annual individual effective dose equivalent in the USA is about 0.54 mSv
  - diagnostic X rays: 0.39 mSv
  - nuclear medicine: 0.14 mSv
  - radiation therapy: probably $<$0.01 mSv

What’s the challenge?

Medical installations in Belgium

Dental practice	5769
Radiology practice (private)	550
Medical lab	10
Veterinary practice	954
Hospital	155
Accelerator	39
Nuclear medicine practice (private)	9

(dd 19/01/2016)

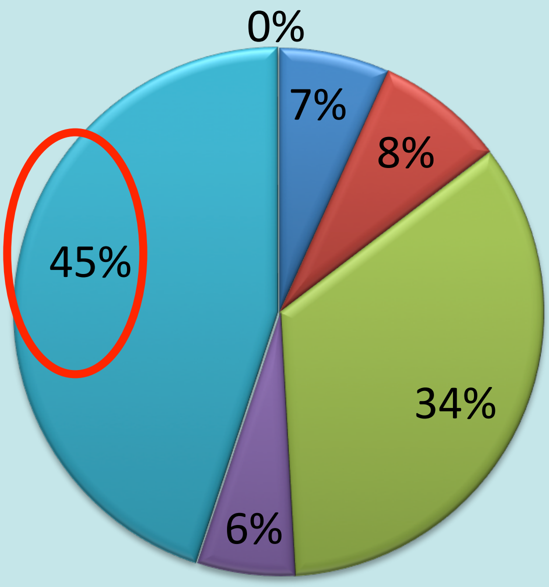


What's the challenge?

Exposure of the Belgian population to ionizing radiation

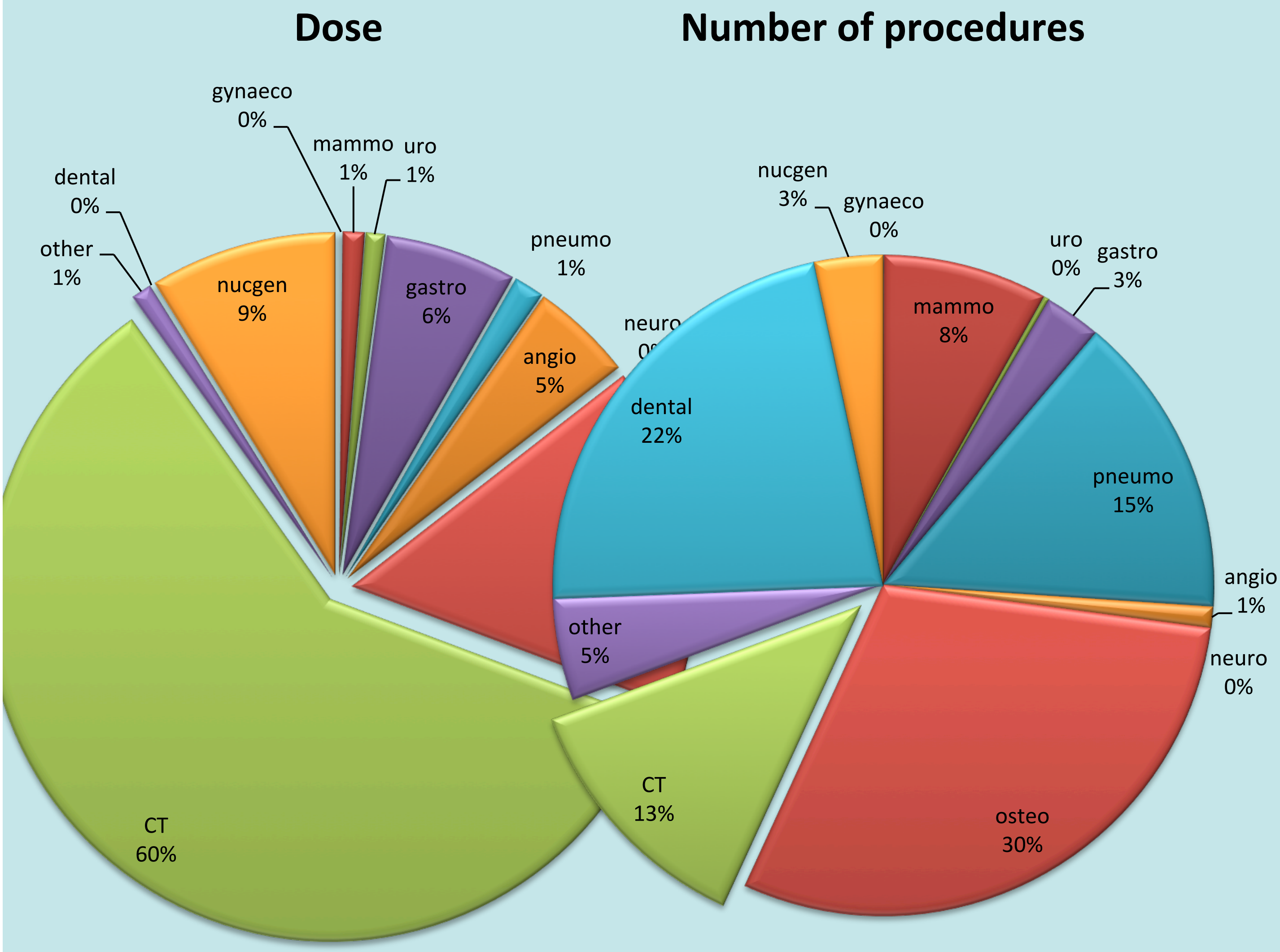
Total average exposure per caput : **5,1 mSv / year**

- **Cosmic rays** 0,3 mSv/year
- **Natural IR on earth** : 0,4 mSv/year
- **Internal exposure by inhalation of natural radionuclides**: 1,8 mSv/year
- **Internal exposure by ingestion of natural radionuclides**: 0,3 mSv/year
- **Medical applications**: 2,3 mSv/year



What's the challenge?

Largest source of medical exposure: **CT**



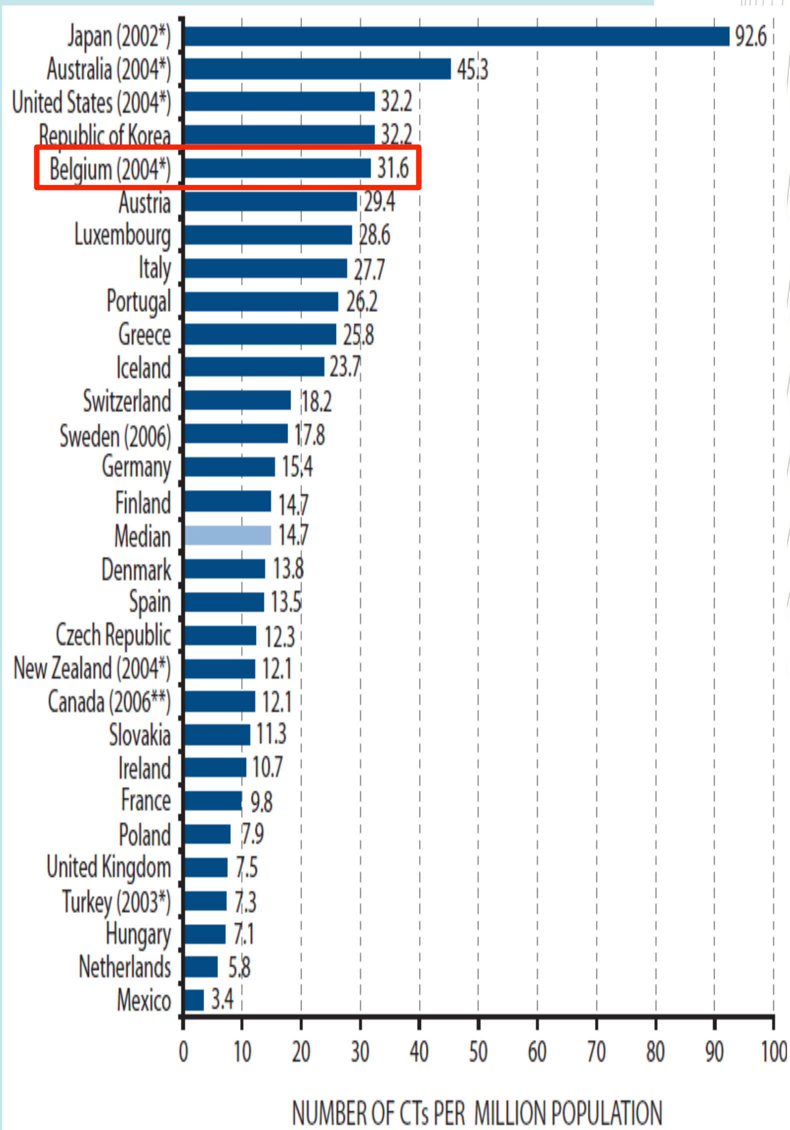
What's the challenge?

International comparison of the number of radiological examinations per 1000 inhabitants

(UNSCEAR 2008)

Japan	1862
Belgium	**1445**
Russian Fed.	1076
Germany	1055
Luxemburg	879
Spain	863
France	761
Norway	727
Sweden	566
Netherlands	537
UK	487

Number of CT scanners per 1M inhabitants



UNSCEAR 2008

FANC AFCN

Radiological imaging

1985-1990, N° exams/1000 inhabitants, /y, in health care level I countries (UNSCEAR 1993)

UK	480
Sweden	520
Netherlands	530
Spain	570
Norway	640
USA	800
Luxembourg	810
France	990
USSR/Russ.Fed.	990
W.-Germany	1030
Japan	1160
Belgium	1290

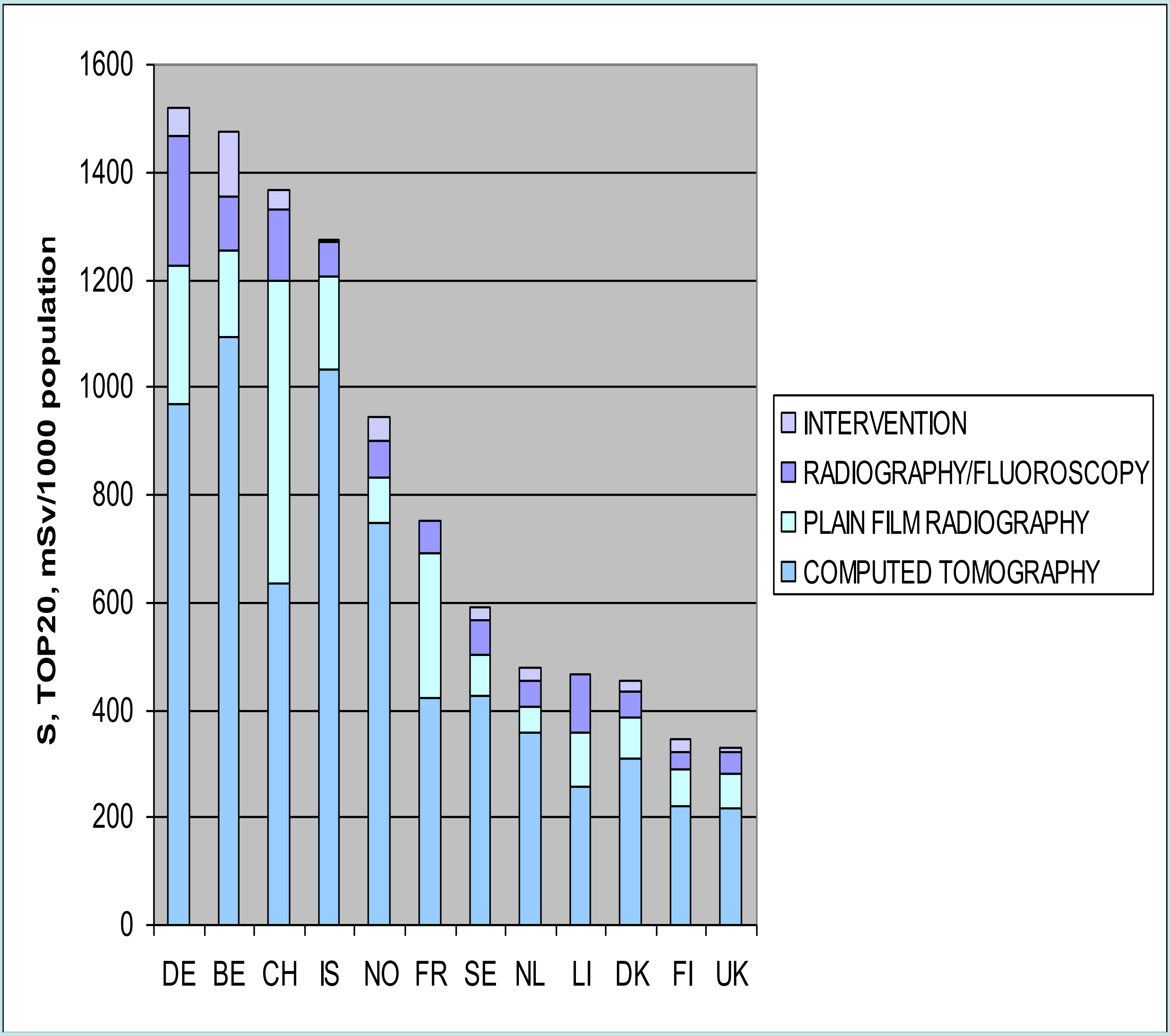
Radiological imaging

Period 1997-2007, N° exams per 1000 inhabitants, /y

health care level I countries (UNSCEAR, Aug 2010)

UK	488
Netherlands	537
Sweden	566
Norway	727
France	762
Luxembourg	878
Germany	1055
Russian Federation	1076
Belgium	1445
Japan	862

“Top 20” exams in Eu, 2008



Age-gender dependance

E J Hall and D J Brenner

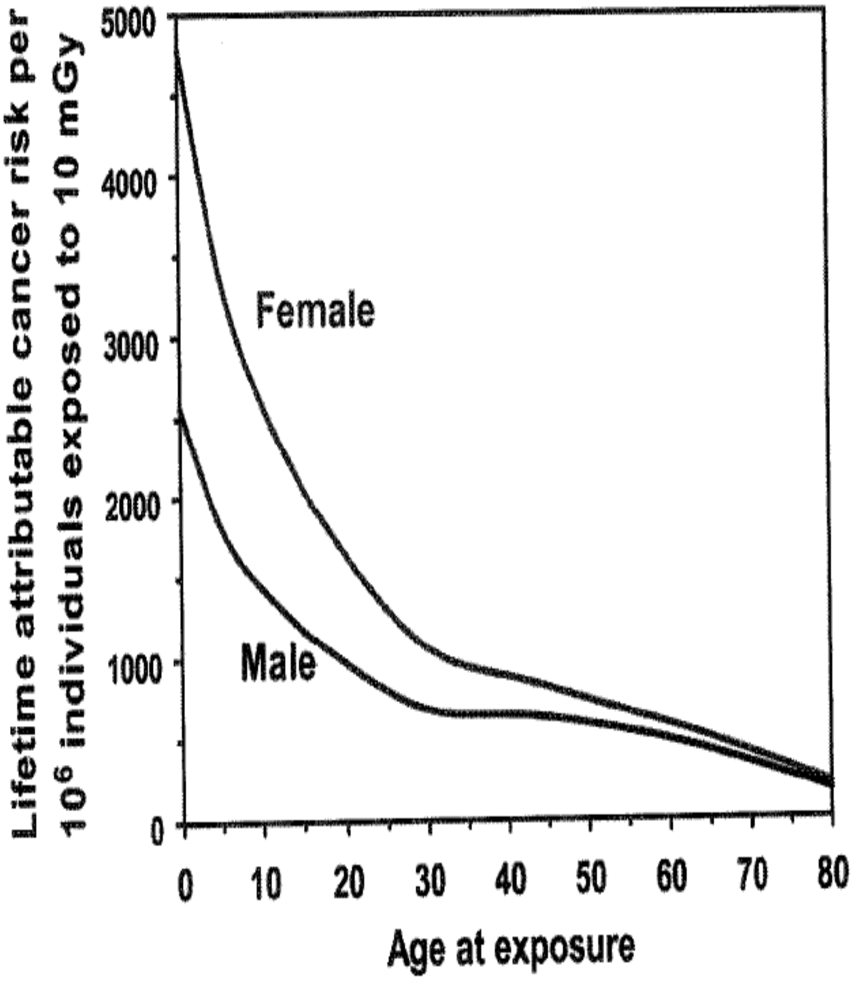
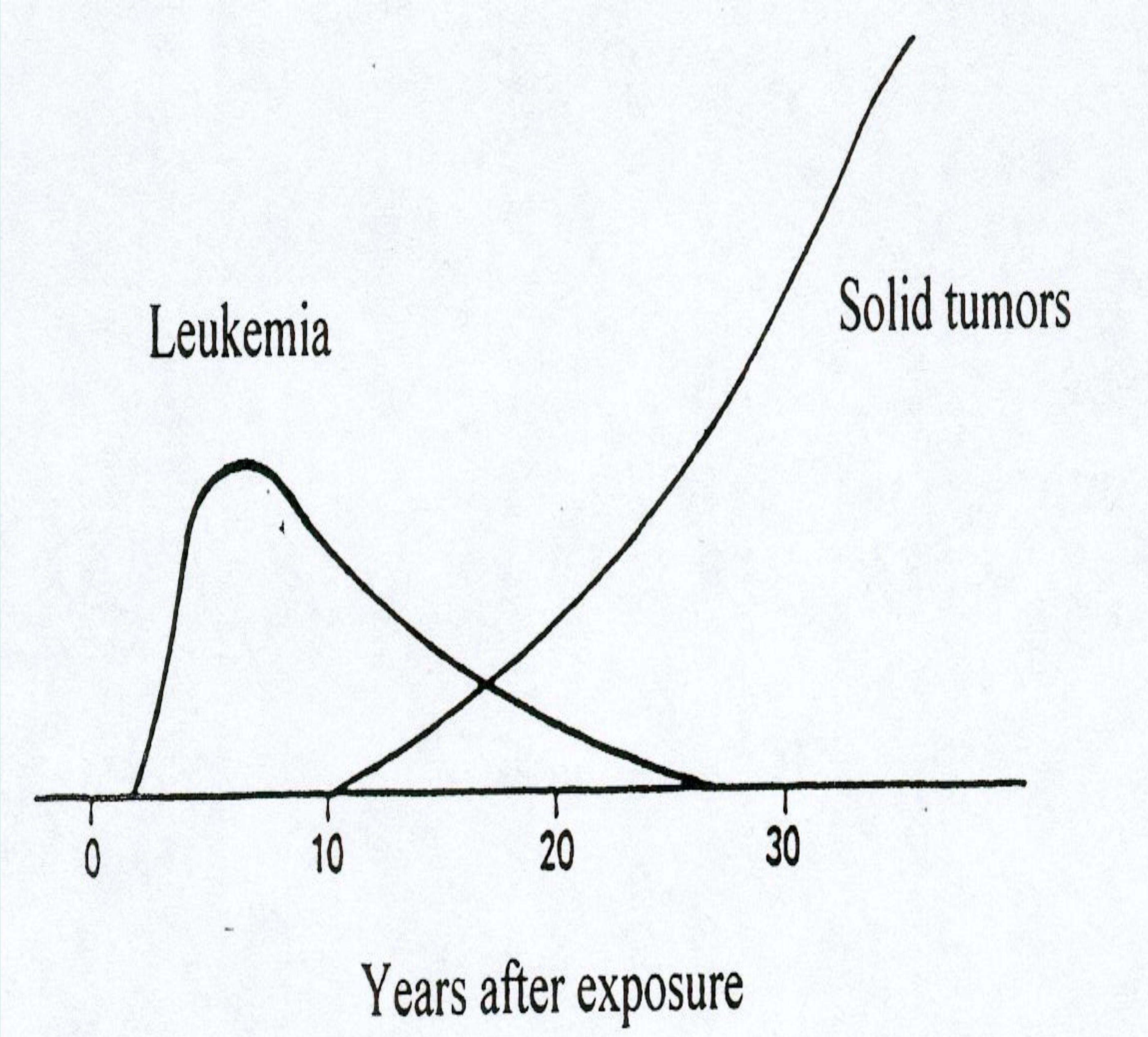


Figure 6. Estimated attributable lifetime risk from a single small dose of radiation as a function of age at exposure [74]. Note the dramatic decrease in radiosensitivity with age. The higher risk for the younger age groups is not expressed until late in life.

Cancer risk from diagnostic radiology
Hall & Brenner, BJR 81, 2008

Latency time for radiation-induced cancers



Global strategy in the medical sector?

First: understand the medical sector

- Primary goal= to cure
- Personality profiles (MD vs engineer)
- Insurance claims, image

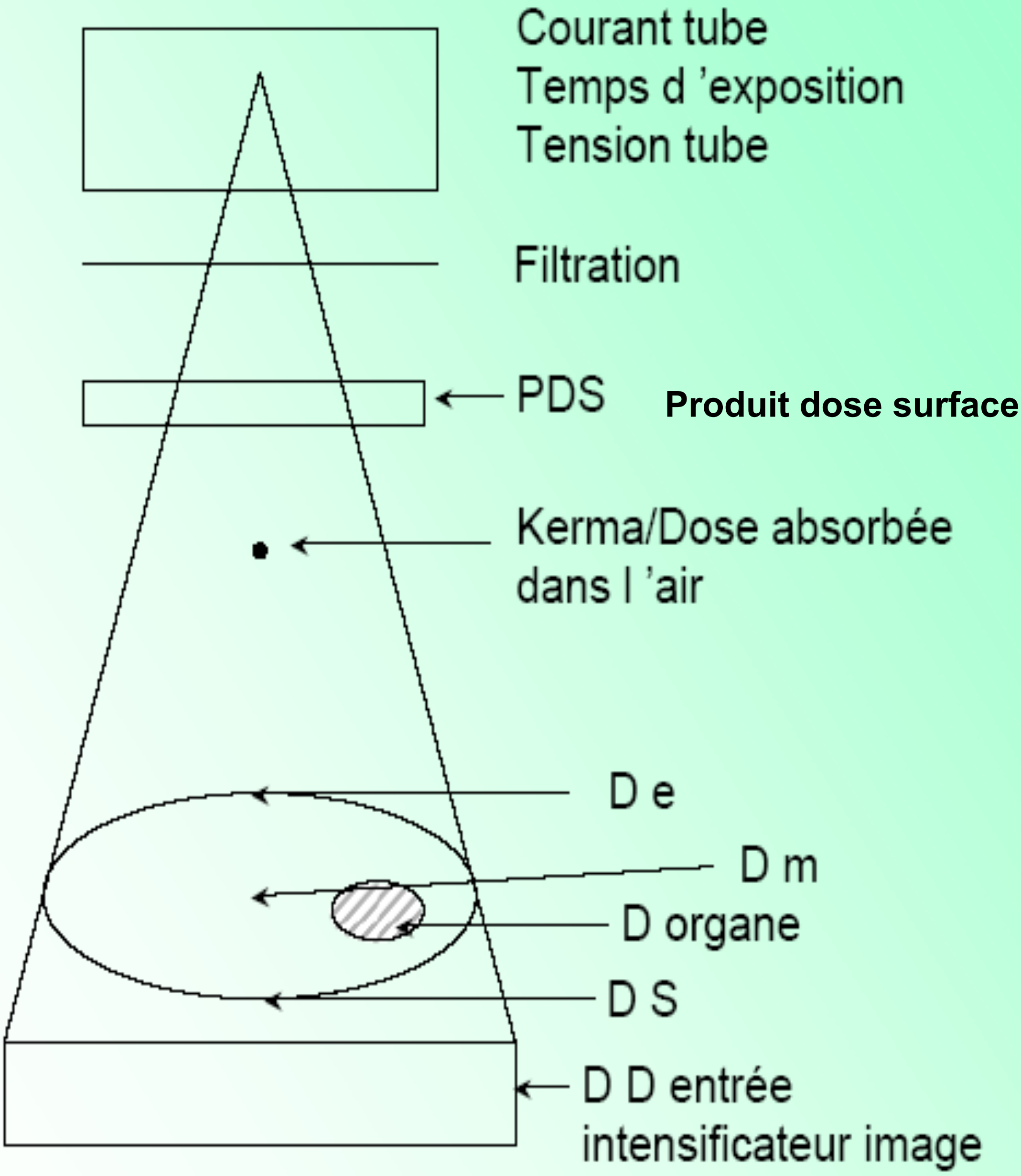
Collective increase of:

- Awareness of the risks
- Safety culture (facilities)
- ALARA culture for the patient (minimal dose for the required goal)

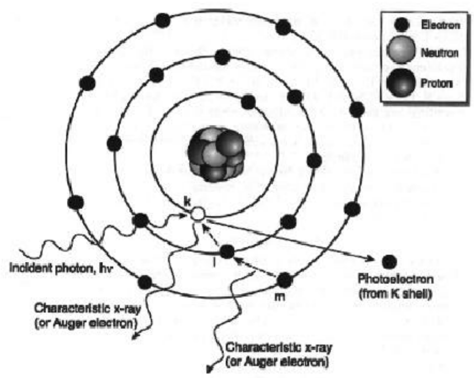
Arsenal:

- Authorisations : facility, users
- Recognitions : HPE, MPE and radiopharmacists
- Control + inspection
- Incident management
- Regulation
- Communication
- Research and development

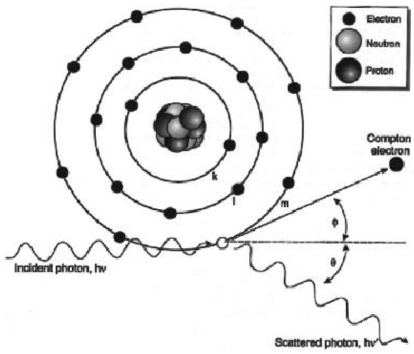
Module 1 : Evaluation des doses patient
Chap. 2 : Grandeurs utilisées en dosimétrie patient
Sujet : Description schématique



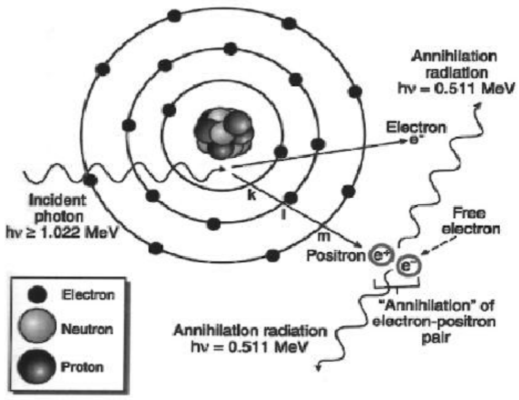
Absorption of X-rays
Photoelectric process



Absorption of X-rays
Compton process



Absorption of X-rays
Pair production

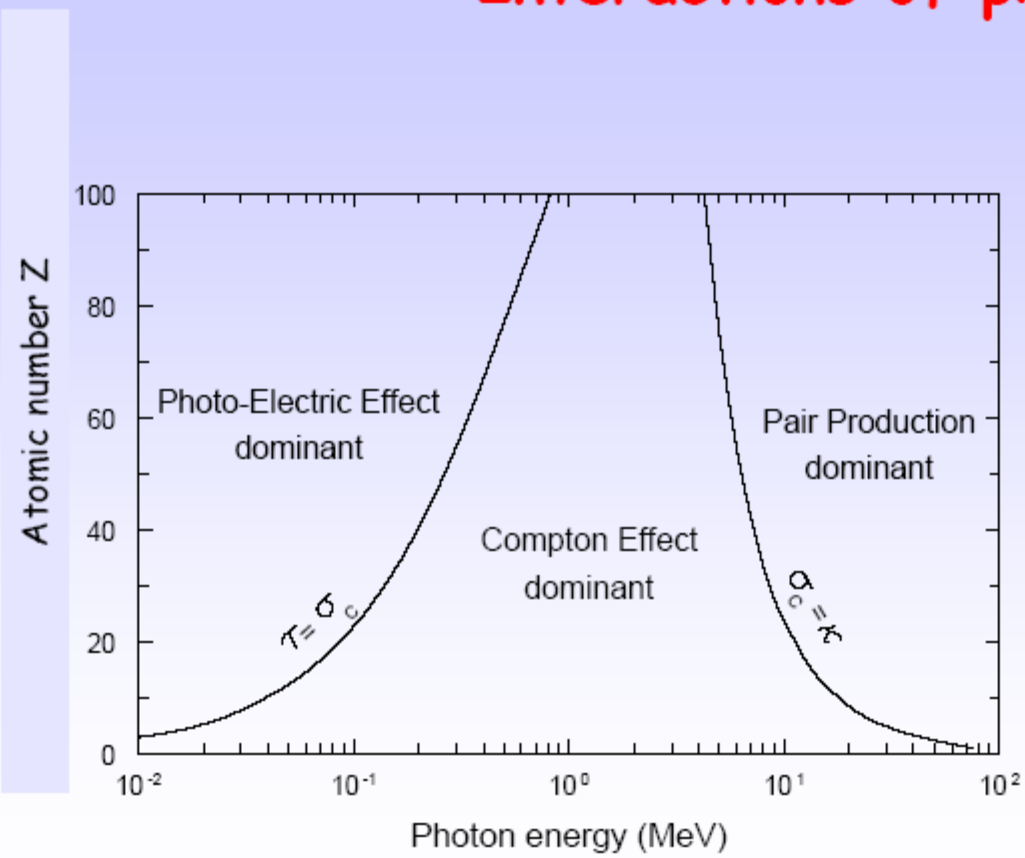


KERMA **(Photons)**

(Kinetic Energy Released per Unit Mass)

$$K\ air = \frac{dE_{tr}}{dm}$$

Interactions of photons



Dose absorbée (Point volume dV)

kerma (symbol K)

Kinetic Energy Released per unit MAss

Broad description: energy transferred per unit mass

Unit:	gray (Gy)	1 Gy = 1 J kg^{-1}
Old unit:	rad	1 Gy = 100 rad

Accurate description:

$$K = \frac{dE_{tr}}{dm}$$

with:

E_{tr} = energy transferred

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Synthèse : A l 'équilibre, en radiodiagnostic

K air = D air

Dose équivalente

$H = D \,.\, W_R$ Facteur de pondration lié à la nature du rayonnement

unité : $J \,.\, kg^{-1}$ nom : Sievert (Sv)

Dose efficace

$E = \Sigma \,.\, H_i \,.\, W_T$ Facteur de pondration tissulaire

unité : $J \,.\, kg^{-1}$ nom : Sievert (Sv)

Dose collective

$S = W_i \; H_i \; P_i$

P_i : nombre de membres
nom : Sievert.Homme

Dose reçue par une population, définie comme le produit du nombre d'individus par la dose moyenne équivalente ou efficace reçue par cette population.

Valeurs de W_r

photons X et γ : 1
électron : 1
proton : 5
neutron : de 5 à 20
rayonnement α : 20

Les rayonnements α sont donc les plus dangereux pour les tissus.

Ainsi, les gonades (W_t = 0.20) et la moelle osseuse (W_t = 0.12) sont particulièrement sensibles par rapport à l'os et à la peau (W_t = 0.01).

remarque: la somme des W_t de tous les organes sensibles est de 1.

DOSE ABSORBEE x W_r = DOSE EQUIVALENTE

La dose équivalente est donc la dose absorbée par le tissu en tenant compte de la nature du rayonnement.

DOSE EQUIVALENTE x W_t = DOSE EFFICACE

Dose à la surface d 'entrée du patient

D_e = D air . FRD   **Facteur rétrodiffussion**

unité : J . kg^{-1} nom : gray (Gy)

Dose organe

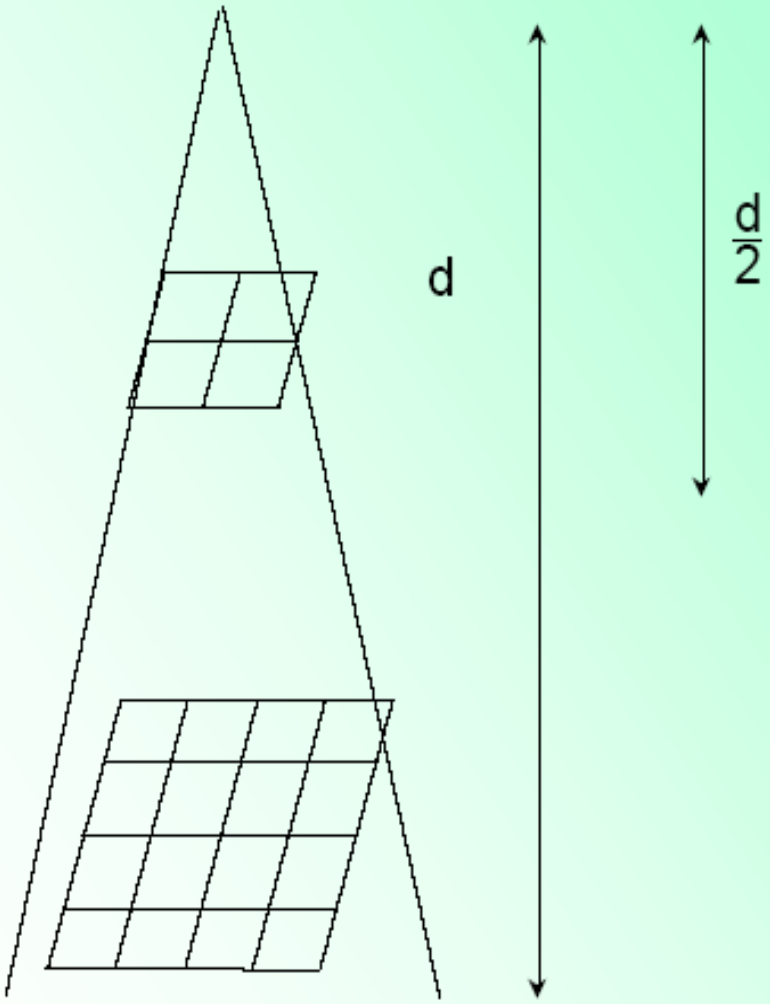
$$D_T = \frac{dE_T}{dm_T}$$

unité : J . kg^{-1} nom : gray (Gy)

Module 1 : Evaluation des doses patient
Chap. 2 : Grandeurs utilisées en dosimétrie patient
Sujet : Grandeurs dose patient

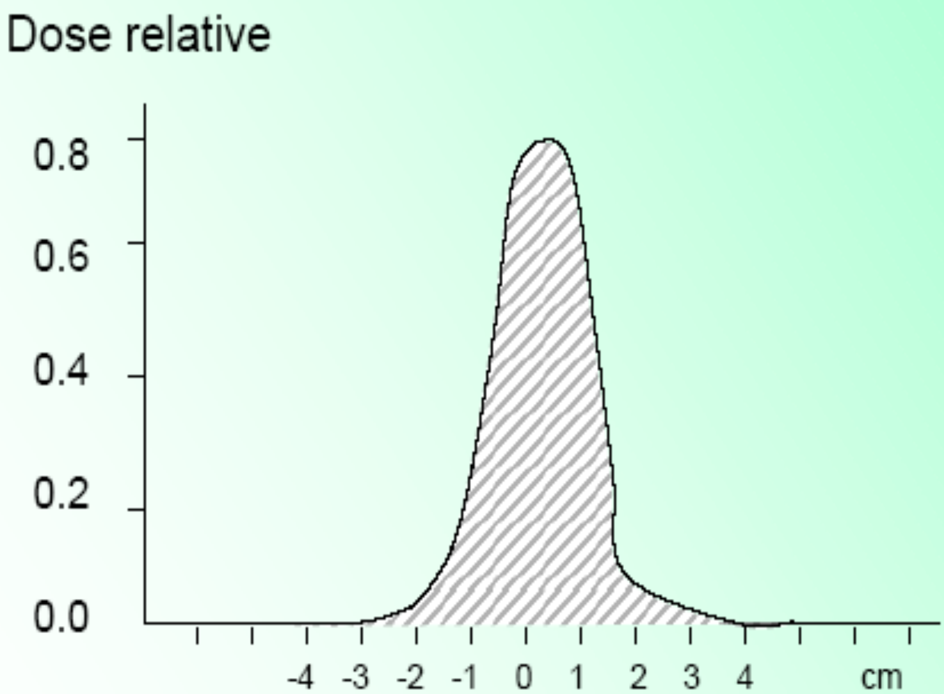
Produit dose surface (DAP)

$$PDS = \int_A D_{air\,(A)} \cdot dA$$



Module 1 : Evaluation des doses patient
Chap. 2 : Grandeurs utilisées en dosimétrie patient
Sujet : Grandeurs dosimétriques en tomodensitométrie

$$\underline{\text{CTDi}}_{\text{air}} = \frac{1}{T}\int_{-\infty}^{+\infty} D_{(z)}\, dz$$

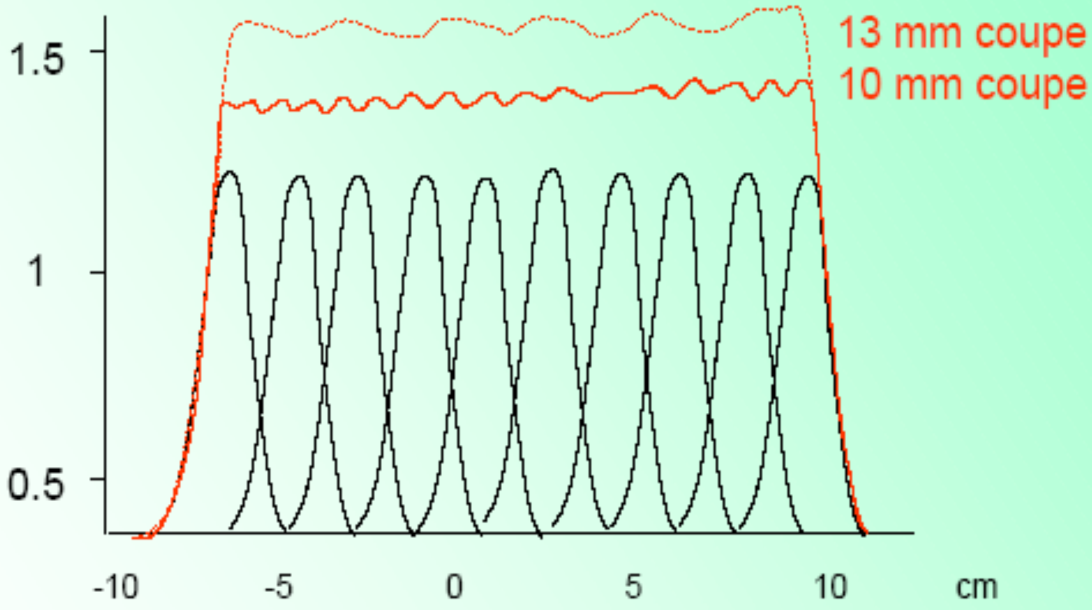


Module 1 : Evaluation des doses patient
Chap. 2 : Grandeurs utilisées en dosimétrie patient
Sujet : Grandeurs dosimétriques en tomodensitométrie

- $CTDI_{100}$

$$CTDI_{100} = 1/nT * \int_{-50}^{50} D(z)dz$$

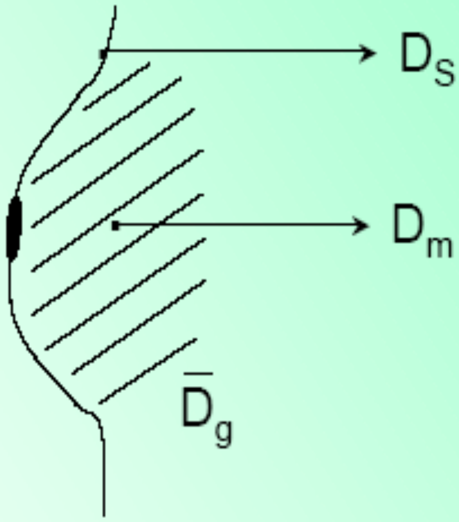
- Weighted CTDI: $CTDI_W = 1/3 * CTDI_{100}(\text{center}) + 2/3 * CTDI_{100}(\text{perifery})$



$DLP = \Sigma\ CTDi\ .\ T\ .\ N$ **Dose length product**

T : épaisseur de coupe
N : nombre de coupes

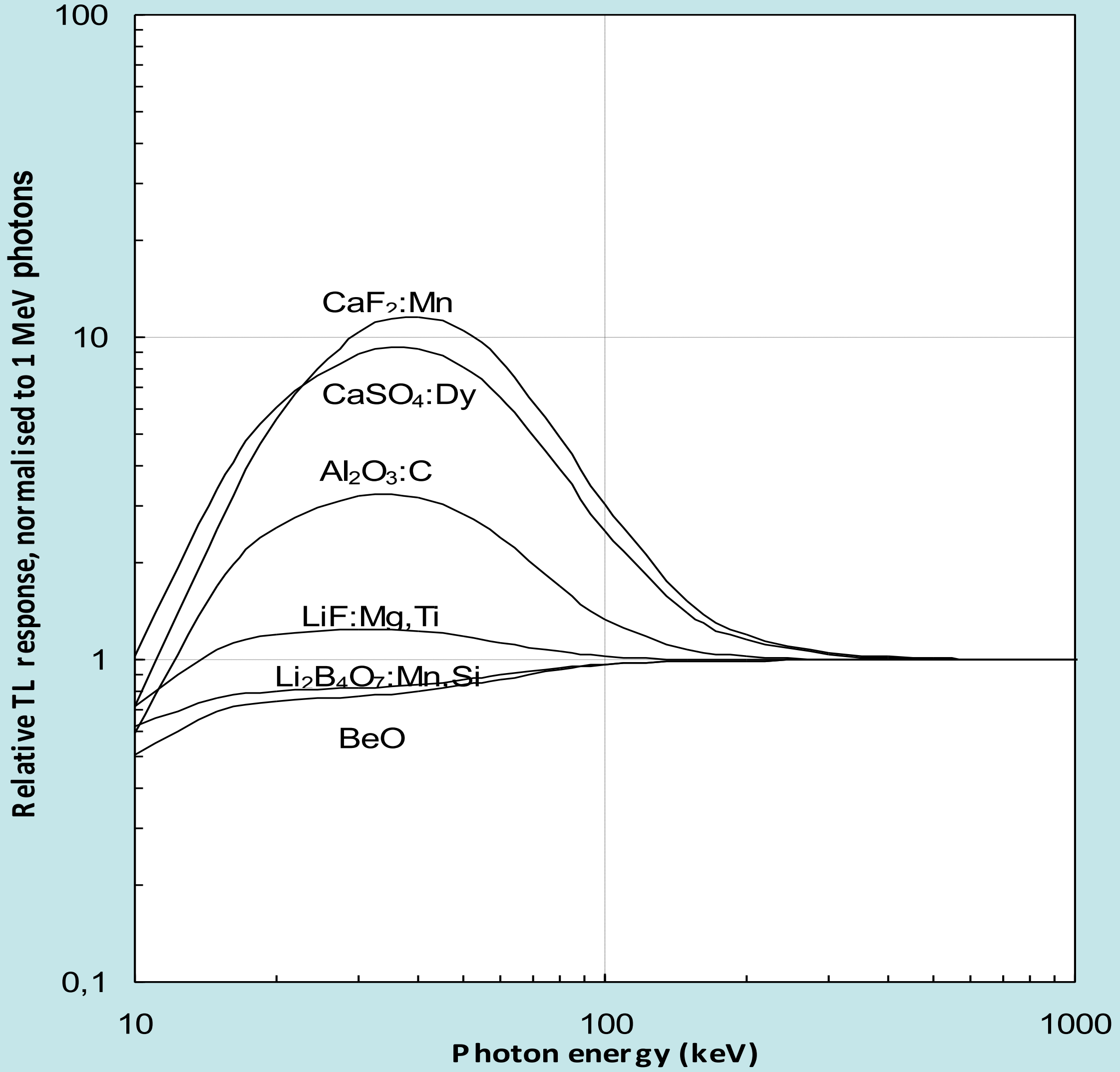
Module 1 : Evaluation des doses patient
Chap. 2 : Grandeurs utilisées en dosimétrie patient
Sujet : Grandeurs dosimétriques en mammographie



$$\overline{D}_g = K_{air} \cdot g$$

HVL (mm Al)	Facteur g de conversion (mGy/mGy)
0,30	0,177
0,35	0,202
0,40	0,223

Module 1 : Evaluation des doses patient
Chap. 3 : Mesures et calcul des doses au patient
Sujet : Dosimètres thermoluminescents



Synthèse : $Li_2B_4O_7$, LiF — TLD les plus utilisés

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Paramètres techniques fixés pour le calcul

- Type de générateur
- Tension appliquée au tube RX
- Filtration du faisceau
- Distance foyer-film (DFF)
- Distance foyer-peau (DFP)
- Nombre de mA.s
- Dimension du champ d 'irradiation
- Epaisseur du patient

Module 1 : Evaluation des doses patient
Chap. 3 : Mesures et calcul des doses au patient
Sujet : Calcul des doses

Dose-air à 1m

Valeurs calculées D_a mGy . mAs^{-1} . m^2 (30 x 30 cm²)			
kV	Filtration (mm Al)		
	2,0	2,5	3
50	0,046	0,039	0,034
60	0,064	0,053	0,046
70	0,083	0,070	0,061
80	0,105	0,088	0,077
90	0,129	0,105	0,094
100	0,155	0,130	0,113
110	0,183	0,153	0,133
120	0,213	0,176	0,155
130	0,245	0,205	0,178
140	0,279	0,233	0,203
150	0,314	0,263	0,229

$$D_a\ (20 \times 20\ cm^2) = D_a\ (30 \times 30\ cm^2) \times 0{,}98$$

$$D_a\ (10 \times 10\ cm^2) = D_a\ (30 \times 30\ cm^2) \times 0{,}92$$

Dose entrée

$$D_e = D_a \left(\frac{100}{DFE} \right)^2 .FRD.mAs$$

Distance foyer-entrée

Facteurs rétrodiffusion

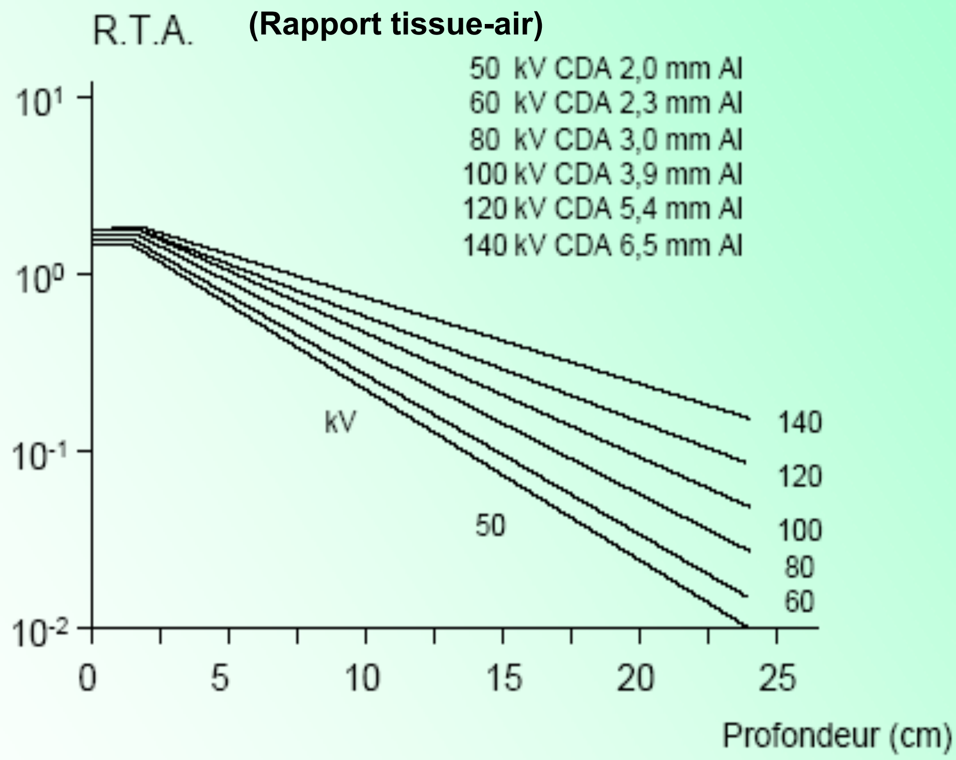
U (kV)	FRD
50	1,25
60	1,32
70	1,35
80	1,40
90	1,42
100	1,46
110	1,48
120	1,50
130	1,52
140	1,52

Dose en profondeur z

$$D_z = D_a \left(\frac{100}{DFZ} \right)^2 .RTA.mAs$$

Distance foyer-prof.z

(Rapport tissue-air)



R.TA. Pour différentes qualités de faisceau
(champ 30 cm x 30 cm - Filtration totale : 3 mm Al)

Scanner	Slice thickness (mm)	$_nCTDI_{air}$ (mGy mAs^{-1})	$_nCTDIW_{head}$ (mGy mAs^{-1})	$_nCTDIW_{body}$ (mGy mAs^{-1})
Toshiba Xvision EX	10	0.236	0.145	0.059
Philips Tomoscan AV	10	0.201	0.15	0.074
Siemens DRH	8	0.153	0.111	0.093
Siemens DRH	8	0.156	0.126	0.094
Siemens AR.Star	10	0.385	0.262	0.093
Siemens AR.Star	10	0.381	0.284	0.84

Hospital	Head	Abdomen	Chest	C. spine	IAM
A	51.6 (51.6-51.6)	29.1 (29.1-29.1)	16.6 (15.8-19.7)	59.1 (49.5-69.3)	40.6 (36.9-46.3)
B	56.6 (56.6-56.6)	37.6 (32.4-38.1)	21.1 (16.6-37.7)	69.3 (69.3-69.3)	69.3 (69.3-69.3)
C	21.5 (20.7-21.6)	16.0 (14.8-22.2)	26.0 (4.2-31.5)	29.9 (17.8-35.3)	22.3 (14.2-25.2)
D	65.0 (65.0-65.0)	13.0 (11.8-23.6)	8.9 (8.9-8.9)	40.5 (40.5-40.5)	23.4 (22.0-24.0)
E	50.8 (28.8-64.1)	8.5 (5.9-11.6)	11.6 (5.9-17.9)	12.2 (5.8-22.3)	28.9 (13.7-44.3)
F	70.9 (55.2-78.8)	10.0 (7.3-13.3)			
Third quartile	64	29	20	62	37
Reference dose	60	35	30		

Référence : Radiation doses from CT in the sultanate of oman

C. GODDARD

B.J.R. 1999

Module 2

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Module 2 : Optimisation de la dose au patient
Chap. 1 : Niveaux de référence
Sujet : Niveaux de référence CEE

Niveaux de référence diagnostiques exprimés en dose à la surface d'entrée par radio

Radiographie		Dose à la surface d'entrée par radio (mGy)	
		R-U[4] et Europe[5]	Scandinavie[6]
Rachis lombaire	AP	10	6
	Lat	30	
	ALS*	40	
Abdomen	AP	10	
Bassin	AP	10	5
Thorax	PA	0.3	0.2
	Lat	1.5	0.5
Crâne	AP	5	
	PA	5	
	Lat	3	

* Articulation lombo-sacrée

Niveau de référence diagnostiques exprimés en produits dose-surface par examen

Examen	Produit doses-surface par examen (Gycm²)	
	R-U[4]	Scandinavie[6]
Rachis lombaire	15	10
Lavement baryté	60	50
Ingestion baryté	25	25
Urographie intraveineuse	40	20
Abdomen	8	
Bassin	5	4

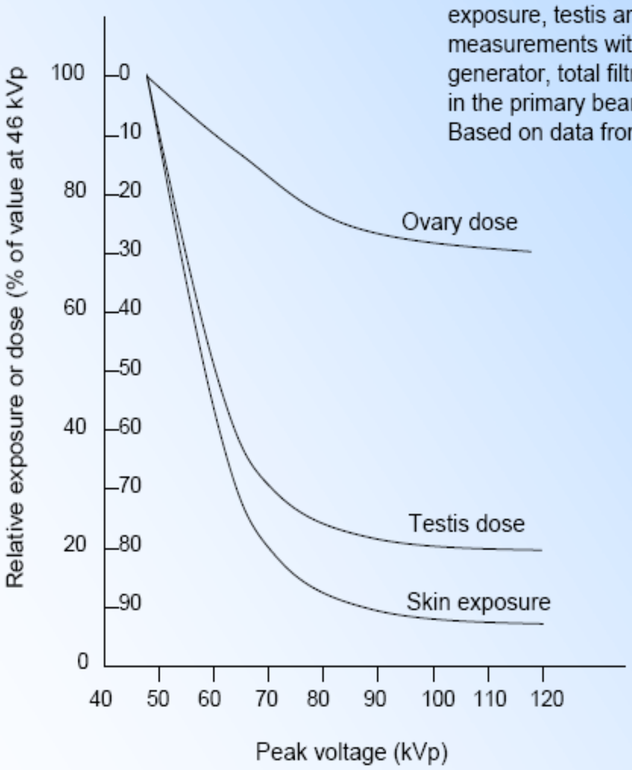
Niveaux de référence diagnostiques recommandés pour les examens de tomodensitométrie [3]

Examen	Indice de dose pondéré de tomodensitométrie par tranche (mGy)	Produit dose-longueur par examen (mGy cm)
Tête (courant)	58	1050
Thorax (courant)	27	650
Abdomen (courant	33	70
Bassin (courant)	33	570

Module 2 : Optimisation de la dose au patient
Chap. 2 : Facteurs d 'optimisation
Sujet : Tension appliquée au tube RX

Tension (kV)	22	25	27	30
Dose cutanée (mGy)	30	20	16	10
Dose à mi-épaisseur (mGy)	1.8	1.4	1.28	1.05

The effect of kV variation. Typical curves for skin exposure, testis and ovary doses, based on phantom measurements with a field size 30 x 40 cm, a 4-value -ray generator, total filtration of 1 mm Al-equivalent, gonads in the primary beam and a *constant exist exposure*. Based on data from Z. M. Beekman (50)

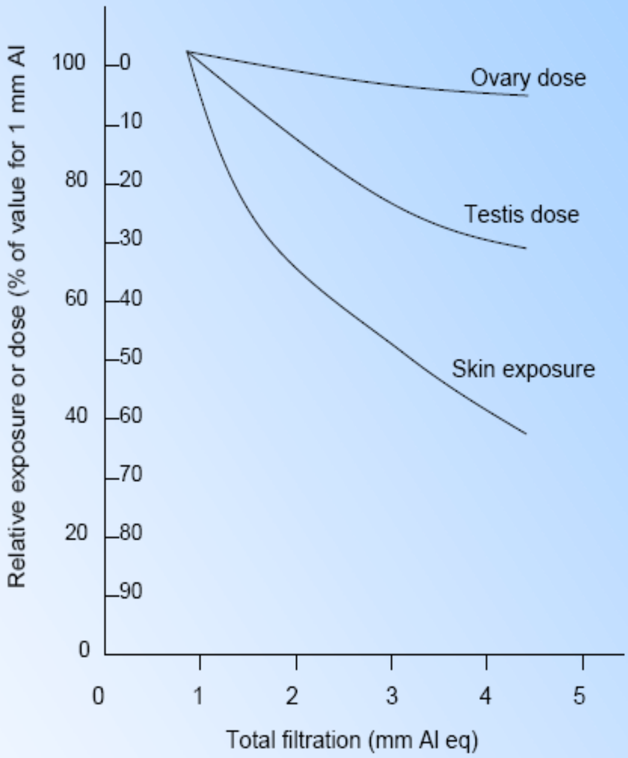


Synthèse : 80 kV → 100 kV
réduction dose cutanée : 35 %
mi-épaisseur : 15 %

Module 2 : Optimisation de la dose au patient

Chap. 2 : Facteurs d 'optimisation

Sujet : Filtration du faisceau X

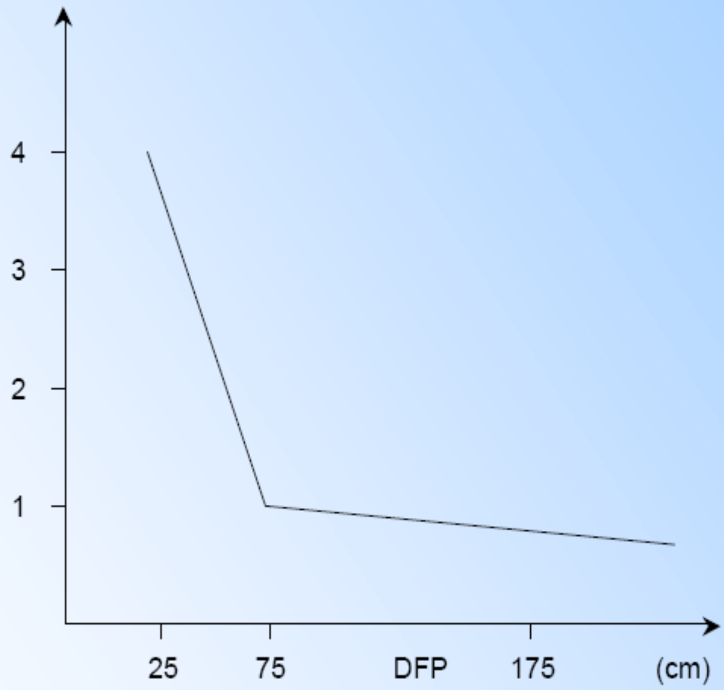


The effect of filtration on patients dose. Typical curves for skin exposure, testis and ovary doses, based on man-sized phantom measurements with a abdominal field size 30 x 40 cm, a 4-value generator, 80 kVp, gonads in the primary beam and a *constant exist exposure*. Based on data from Z. M. Beekman (50)

<u>Synthèse</u> : 80 kV : 2,5 mm Al → 3 mm Al
réduction dose cutanée 10 %

Module 2 : Optimisation de la dose au patient
Chap. 2 : Facteurs d 'optimisation
Sujet : Taille du champ, DFP, matériaux

Distance focus-peau



Synthèse : 80 kV : 110 cm → 80 cm
augmentation de la dose cutanée de 35 %

Module 2 : Optimisation de la dose
au patient
Chap. 2 : Facteurs d 'optimisation
Sujet : Facteurs d 'optimisation en
tomodensitométrie

1. Facteurs « Machine »

- Génération et type de scan
- Géométrie du faisceau
- Détecteurs
- Qualité du rayonnement

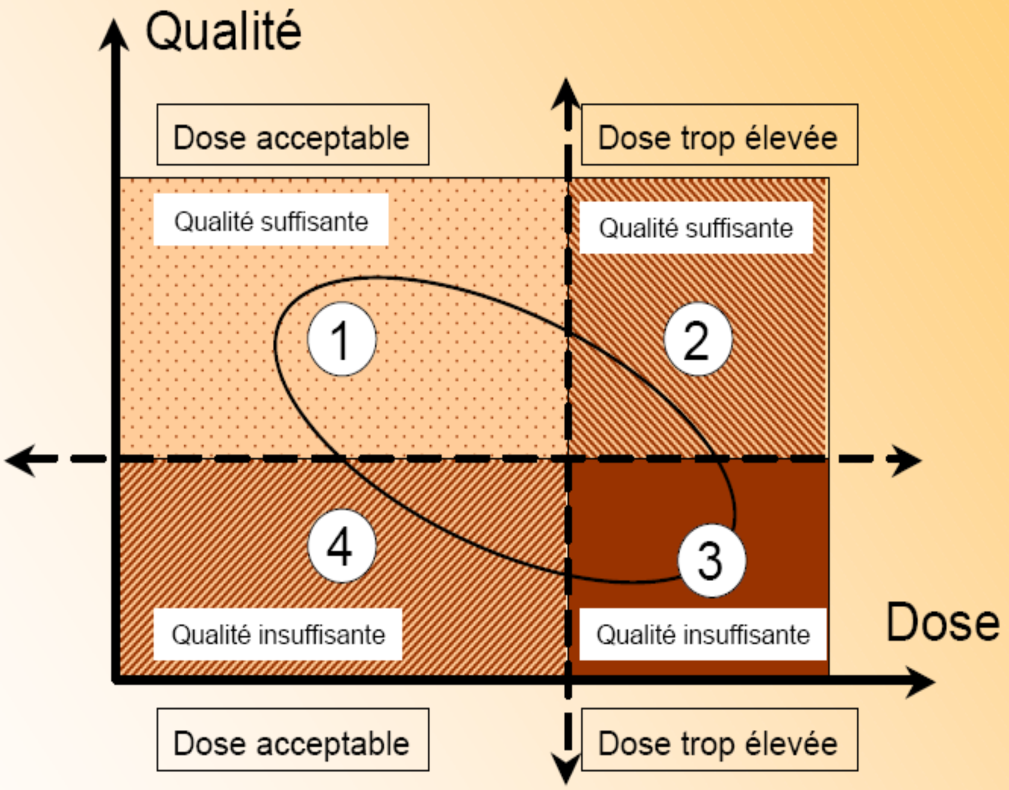
2. Facteurs « Opérateur »

- kV; mAs
- Angle de rotation
  overscan - halfscan
- Epaisseur de coupe
- Espace intercoupe
- Nombre de coupes
- Taille pixel

Module 3

RPR3010
S. Vynckier

Module 3 : Contrôle de qualité
Chap. 1 : L 'assurance qualité
Sujet : Rapport qualité/dose



Module 3 : Contrôle de qualité
Chap. 2 : Aspect légal
Sujet : A.R. 02 octobre 1997

Article 51.1. Appareils
51.1.1. Marquage CEE

Article 51.3. Assistance d 'experts agréés en radiophysique
51.3.1.
- dosimétrie appareillage
- dosimétrie patient
- cahier de charge
- protocoles CQ
- optimisation doses patient
- CQ appareillage

Article 53. Utilisateurs
docteur médecine, vétérinaire, LSD
autorisés par l 'Agence
attestation compétence
(45 heures théorie)
(30 heures pratique)

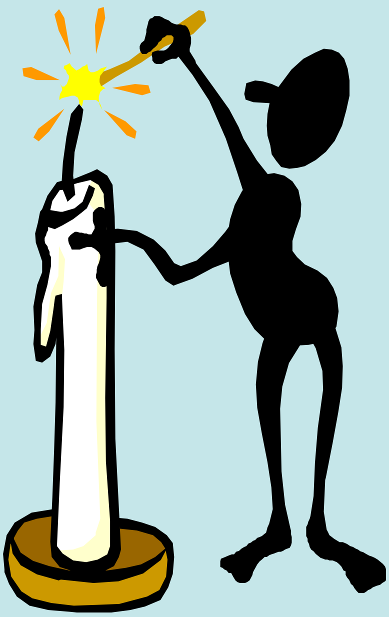
RADIOTHERAPY

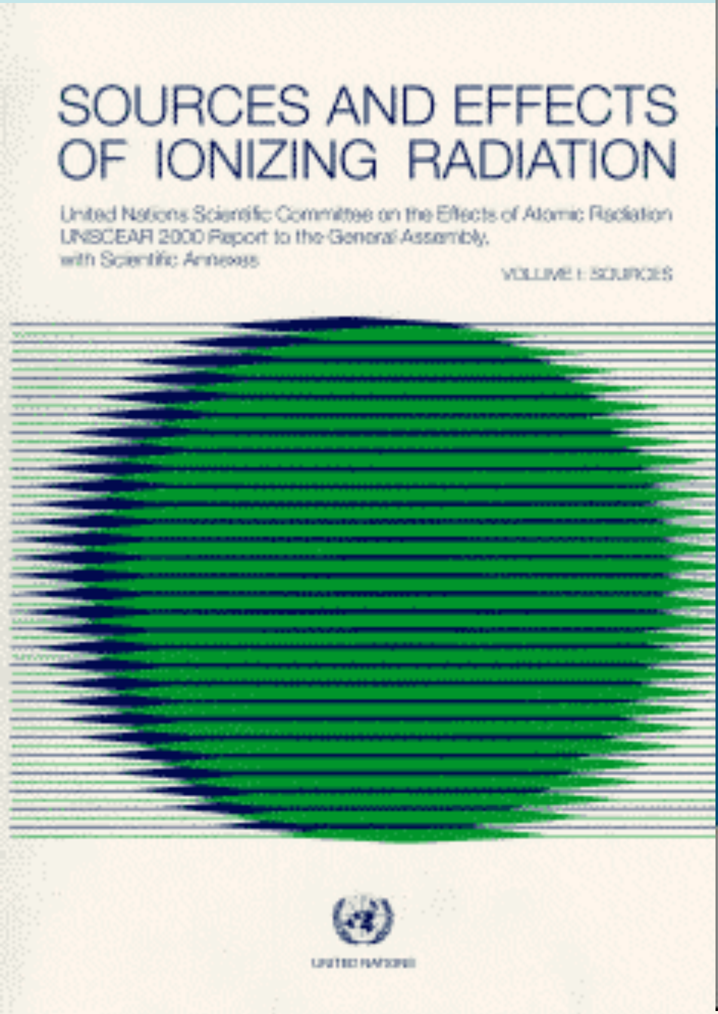
Regulatory aspects

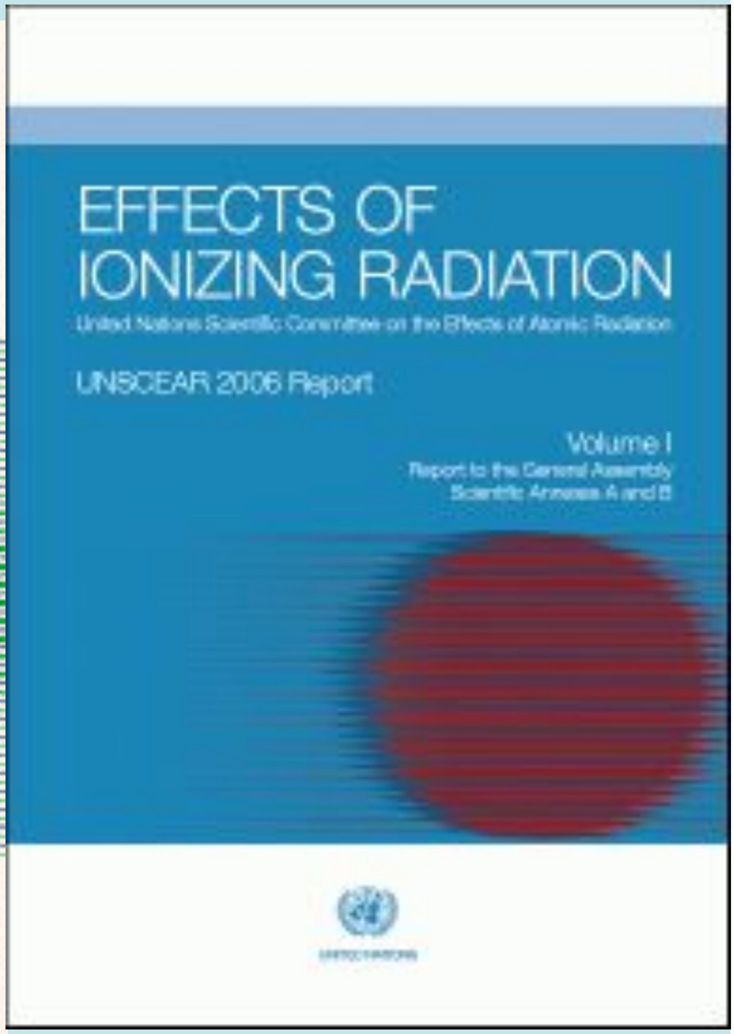
1. **International context**

2. **Belgian legislation**

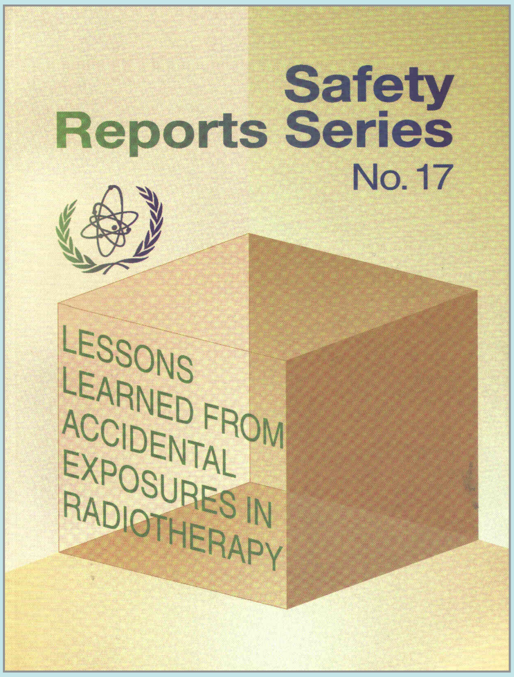
3. **Incidents/accidents**







United Nations Scientific Committee on the Effects of Atomic Radiation

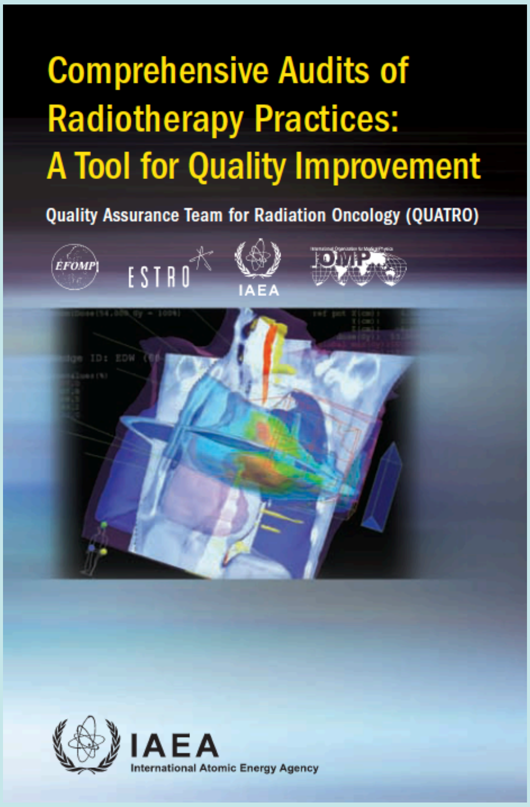


International Atomic Energy Agency (IAEA)

"LESSONS LEARNED FROM ACCIDENTAL EXPOSURES IN RADIOTHERAPY"

Report No. 17

Vienna, 2000



International Atomic Energy Agency (IAEA)

Audits: QUATRO

Quality Assurance team for Radiation Oncology

Vienna, 2007

Belgian legislation

•**Directive 93/42/EEC** :
'Medical devices'

•**Directive 96/29/Euratom**:
•'Basic safety standards'

•**Directive 97/43/Euratom** :
'Medical exposures'

⇒**Royal Decree 20/07/01**

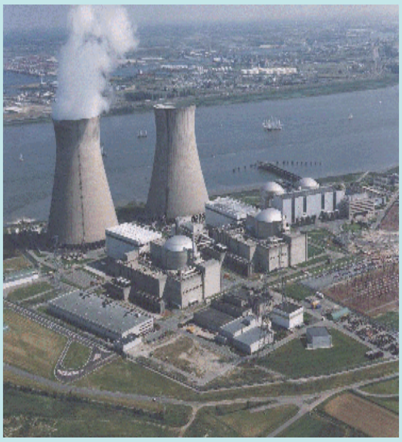
+ modifications

www.fanc.fgov.be

Licensing for installations RD art. 3-18

1. Classification as f^ion^

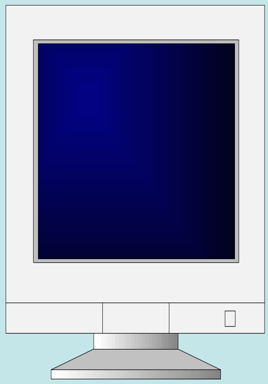
(risk)



Class I

Class II

Class III



Class IV

Apparatus, “medical device”

- Directive 93/42/EEC, CE-mark
- Competence of Federal Agency for Pharmaceutical products (FAGG-AFMPS)
- Safety/security sufficiently guaranteed?

People at work in radiotherapy

- Radiotherapist as licensed “user”
- Physicist as “Qualified expert in radiation physics”, or MPE
- Nursing staff, technologists as “Helpers” (“Auxiliaires”)

Licensed "user"

- **MD, radiotherapist (or NM for metabolic th)**
- Specific **education & training in RPR** of
  - At least **200h for radiotherapy**
  - advice of "**medical jury**" with regard to the fulfilment of this requirement
  - **Continuous education** required
- **License** for 10y max, rather general to very restrictive (institutions, applications…)
- Recognition as specialist in radiotherapy **does not** imply you are automatically licensed as user (yet)

MPE, QE in medical radiation physics

- Certification : conditioned by diploma + education & training 600h, apprenticeship (1y at least) positive advice “medical jury”

- Fields of competence: RT, NM, RL

- What? RPR patient :

  dosimetry, calibration, QC, protocols, projects for optimization…

“Helper”
“Auxiliaire”

- ➢ Acts under responsibility, surveillance and instructions of licensed “user”
- ➢ Mandatory education and training in both applied techniques and RPR
- ➢ RPR at least 60h for RT
- ➢ Continuous education required

Incidents and accidents

- prevention by QA: QC, procedures, audits…: a legal (and deontological) obligation

- incident recording and reporting

  - mandatory: e.g. source loss, serious equipment failure

  - voluntary

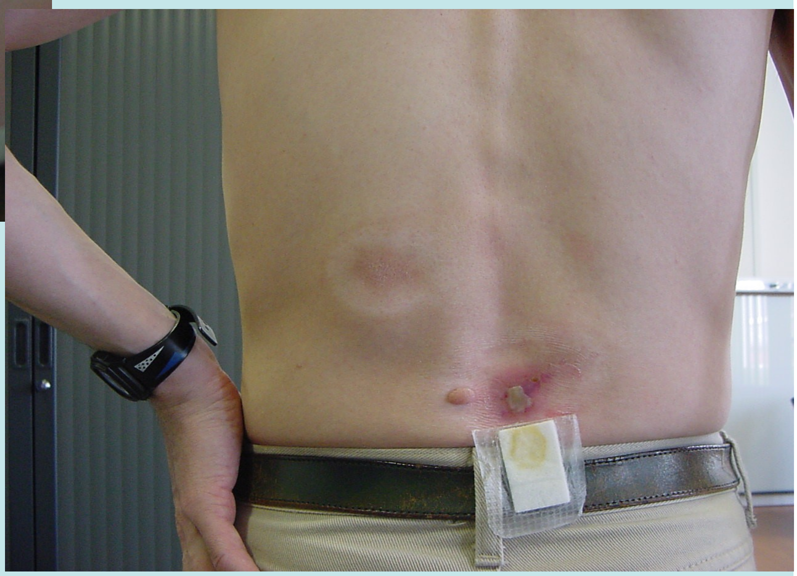
Mad River Community Hospital California 2009

Jacoby Roth, 23 months of age, several hours after receiving ***151 CT scans*** *in a 68-minute period.*

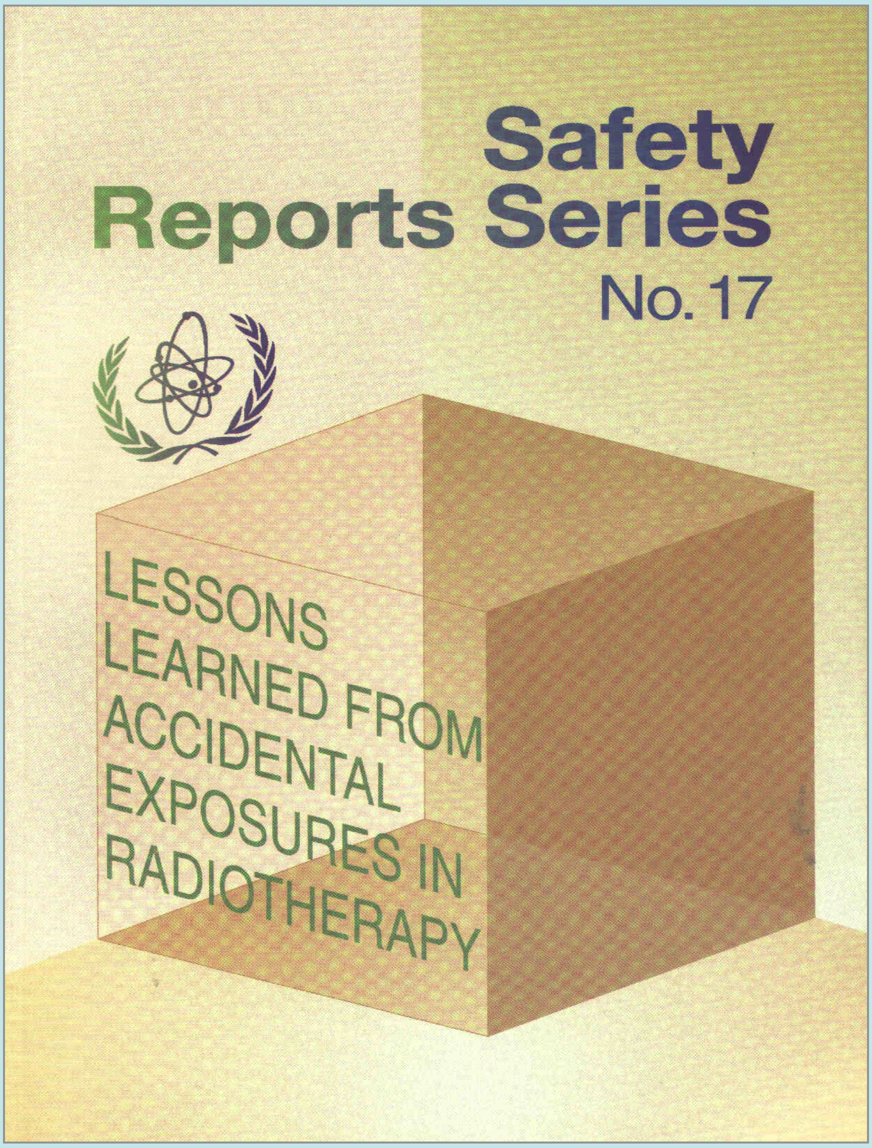
Photo courtesy of Roth family attorney Don Stockett.

A 23-month old boy received a radiation overexposed during multiple CT scans at Mad River Community Hospital. The boy was brought to the hospital ER for a possible neck injury. The CT technologist made a total of 151 CT scans of the boy's face and neck area over a period of 65 minutes, until the boy's father objected to the process. The technologist stated she thought the machine was broken and pushed the scan button four times in order to register a complete image. A second technologist made 25 successful CT scan images about 90 minutes later in a one minute period. The second technician was "horrified" when she saw the records of the earlier scans and reported the imaging department manager. The boy developed radiation burns on the cheeks and around the head and neck in a plane from under the eyes through the ears and neck. A subsequent investigation concluded that the first technician had to have pushed the scan button 151 times, and estimated the boy received a localized dose of 280 rad or up to 1100 rad "using a factor of four for paediatric size and makeup," also estimating an additional lifetime risk of fatal cancer of 39%.

Belgium 2003



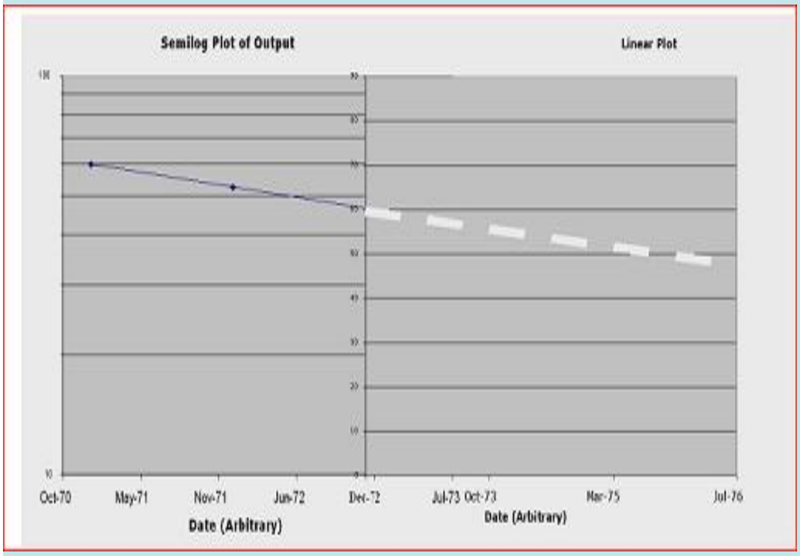
Accidents in Radiotherapy



RPR3010
S. Vynckier

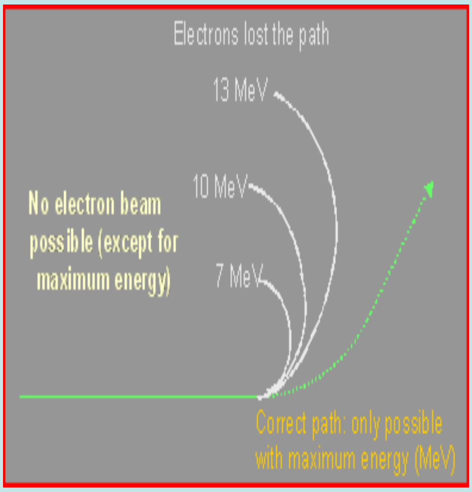
Case 1: Use of an incorrect decay curve for ^{60}Co (USA, 1974-76)

- Initial calibration of a ^{60}Co beam was correct, but ..
- A decay curve for ^{60}Co was drawn: by mistake, the linear Y-axis did not correspond to the original log Y-axis, so straight line extrapolation resulted in ever-more incorrect output values; and (2) the linear X-axis did not correspond to the original calendar axis, so extrapolation led to incorrect date values.
- Treatment times based on it were longer than appropriate, thus leading to overdoses, which increased with time reaching up to 50% when the error was discovered



- **There were no beam measurements in 22 months** and a total of 426 patients affected
- Of the 183 patients who survived one year 34% had severe complications

Case 2: Incorrect accelerator repair & communication problems (Spain, 1990)



- Accelerator fault followed by an attempt to repair it
- Electron beam was restored but electron energy was misadjusted
- Accelerator delivered 36 MeV electrons, regardless of energy selected

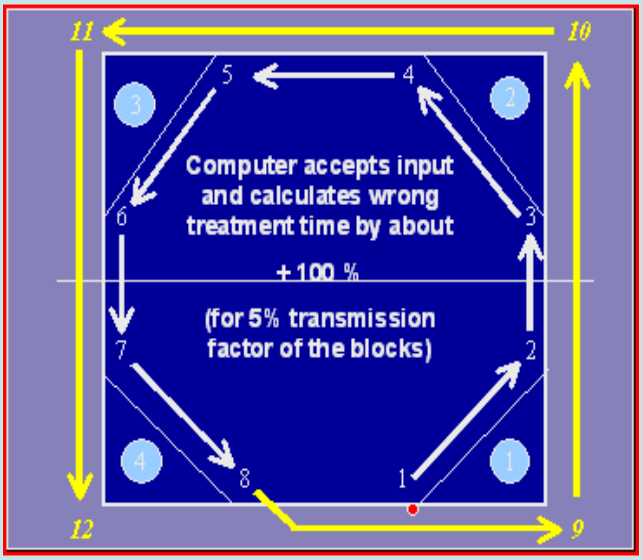
- The design of this accelerator meant that a homogenous field was achieved through scanning of the electron beam, where the current of the scanning magnet had to match the selected electron energy. As the electron energy was at the maximum, the deflection in the scanning magnets was too small and the field thus became concentrated in the centre.

- Treatments resumed without notifying physicists for beam checks

Cont’d: nr 2 : Incorrect accelerator repair & communication problems (Spain, 1990)

- There was a discrepancy between energy displayed and energy selected, which was attributed to a faulty indicator, instead of investigating the reason for the discrepancy
- A total of 27 patients were affected with massive overdoses and by distorted dose distribution due to wrong electron energy
- At least 15 of these patients died from the accidental overexposure and two more died with overexposure as major contributor

Case 3: Untested change of procedure for data entry into TPS (Panama, 2000)



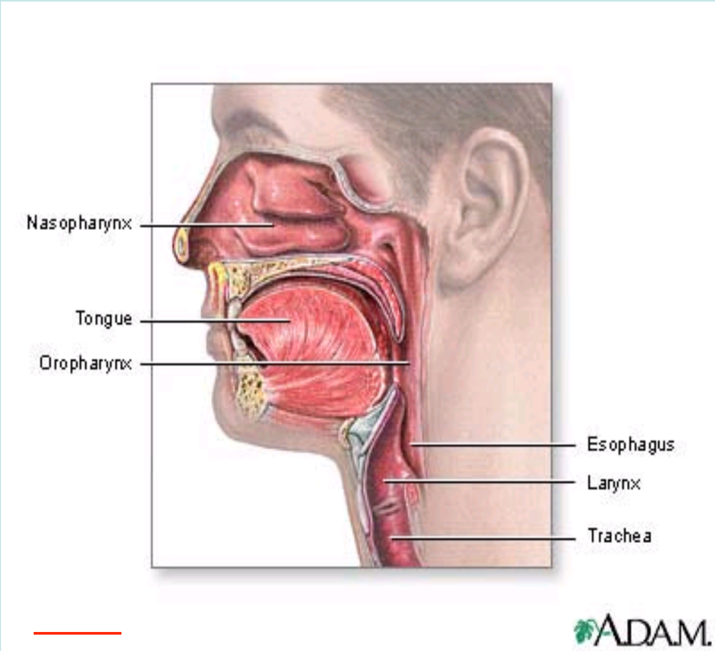
- A TPS allowed entry of four shielding blocks for isodose calculations, one block at a time
- Need for five shielding blocks led to deviation from standard procedure for block data entry: several blocks were entered in one step
- Instructions for users had some ambiguity with respect to shielding block data entry
- TPS computer calculated treatment time, which was double the normal one (leading to 100% overdose)

Cont'd nr 3: Untested change of procedure for data entry into TPS (Panama, 2000)

- There was no written procedure for the use of TPS, and therefore, a change of procedure was neither written nor tested for validity
- Computer output was not checked for treatment time with manual calculations
- The error affected 28 patients;
- One year after the event, at least five had died from the overexposure

Incorrect IMRT planning (USA)

- March 2005, USA
  - A patient is due to be treated with IMRT for head and neck cancer (oropharynx)

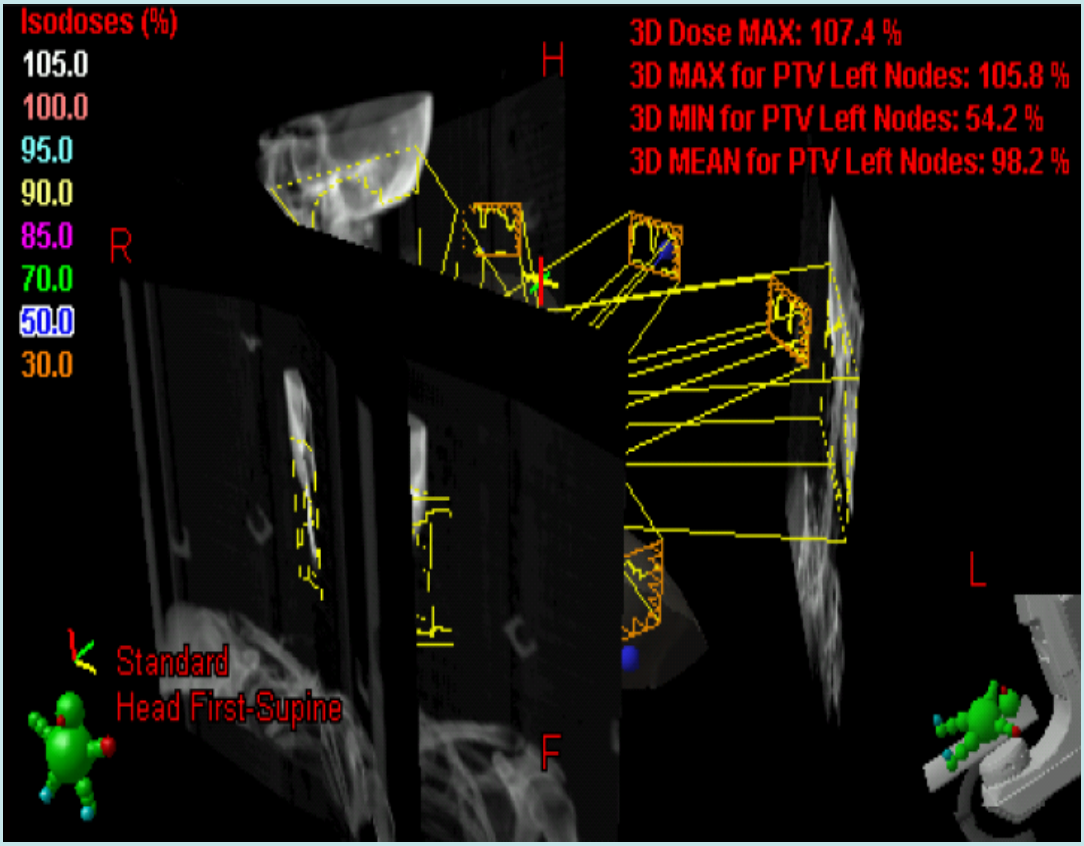


What happened?

- March 4 – 7, 2005
  - An IMRT plan is prepared: "1 Oropharyn". A verification plan is created in the TPS and measurements by Portal Dosimetry (with EPID) confirms correctness.

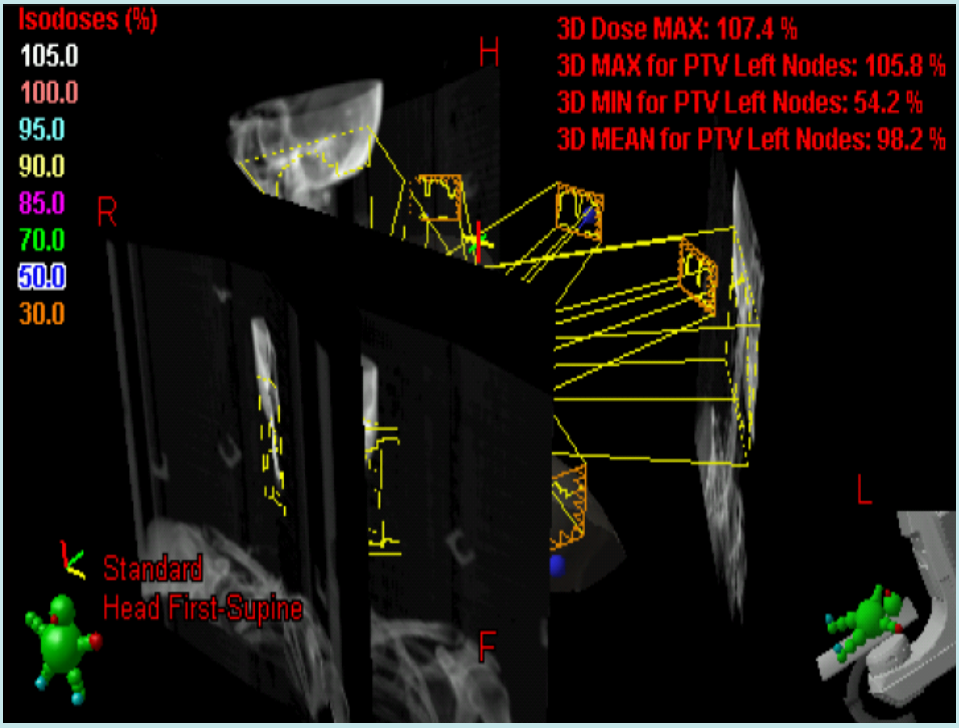
Example of an EPID (Electronic Portal Imaging Device)
(Picture: P.Munro)

- March 8, 2005
  - The patient begins treatment with the plan “1 Oropharyn”. This treatment is delivered correctly.



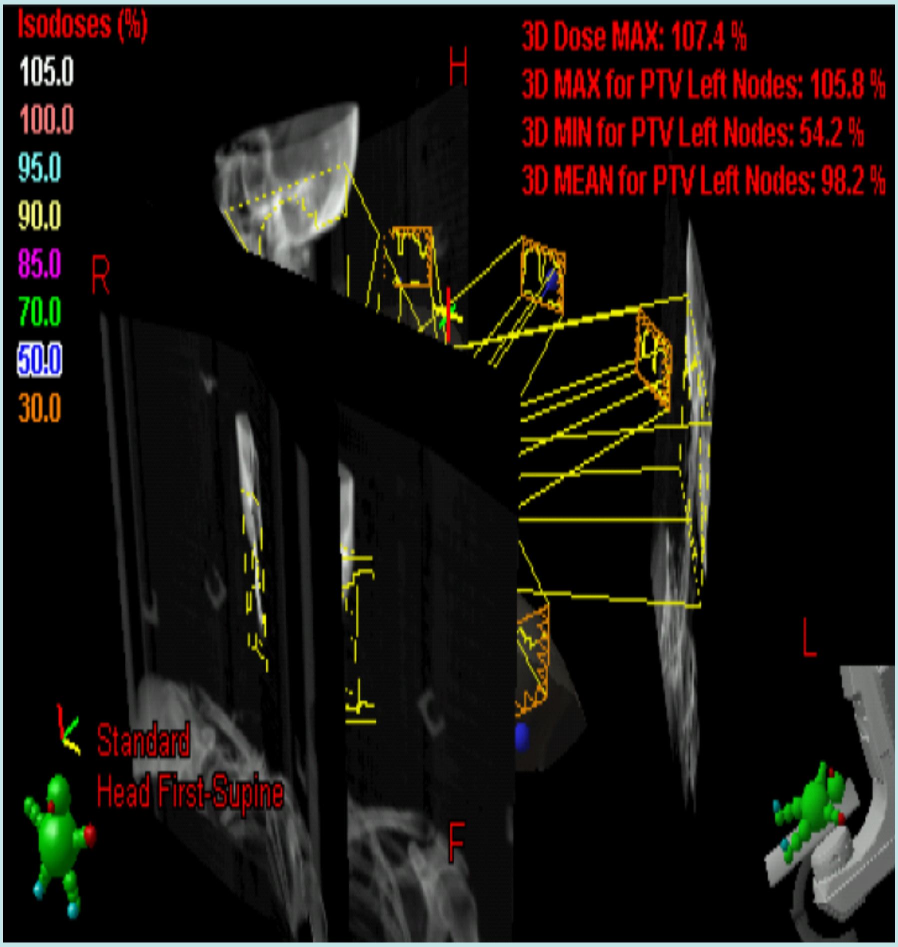
“Model view” of treatment plan (Picture: VMS)

- March 9-11, 2005
  - Fractions #2, 3 and 4 are also delivered correctly. Verification images for the kV imaging system are created and added to the plan, now called “1A Oropharyn”.



“Model view” of treatment plan (Picture: VMS)

- March 11, 2005
  - The physician reviews the case and wants a modified dose distribution (reducing dose to teeth) “1A Oropharyn” is copied and saved to the DB as “1B Oropharyn””.

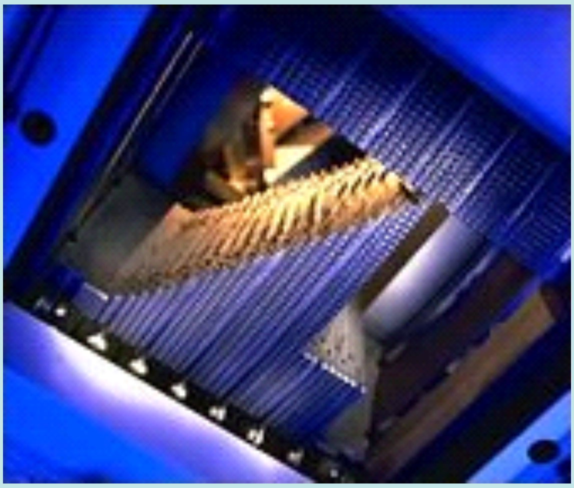


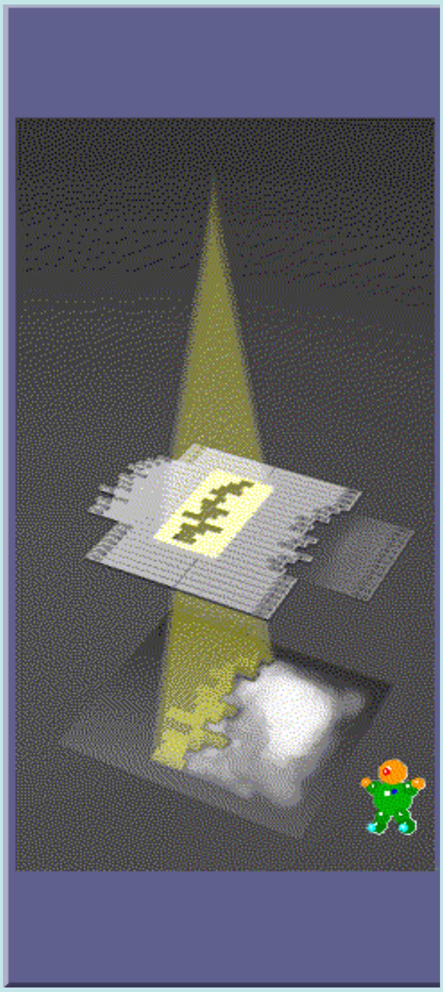
“Model view” of treatment plan (Picture: VMS)

- March 14, 2005
  - Re-optimization work (new constraints) on "1B Oropharyn" starts on workstation 2 (WS2).
  - Fractionation is changed. Existing fluences are deleted and re-optimized. New optimal fluences are saved to DB.

Optimal and Actual Fluences ?

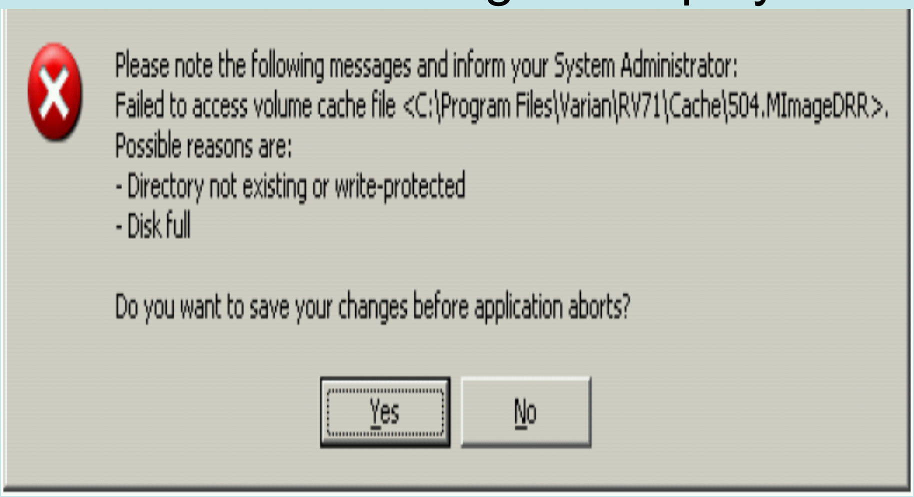
- March 14, 2005
  - Final calculations are started, where MLC motion control points for IMRT are generated. Normal completion.





- March 14, 2005, 11 a.m.
  - “Save all” is started. All new and modified data should be saved to the DB.
  - In this process, data is sent to a holding area on the server, and not saved permanently until ALL data elements have been received.
  - In this case, data to be saved included:
  - (1) actual fluence data,
  - (2) a DRR
  - (3) the MLC control points

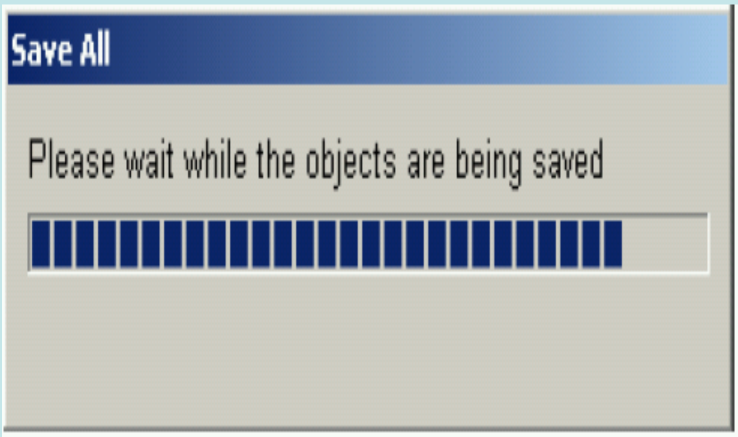
- March 14, 2005, 11 a.m.
- The actual fluence data is saved normally.
  - Next in line is the DRR. The “Save all” process continues with this, but is not completed.
  - Saving of MLC control point data would be after the DRR, but will not start because of the above.
  - An error message is displayed



Operator choice : Yes → New saving of the data

MLC control points data moved to holding area

- The DRR is, however, still locked into the faulty first attempt to save.
- This means the second save won't be able to complete.
- The software would have appeared to be frozen.



FROOZEN

Ctrl-Alt-Del

The DB performs a « roll-back » to return the data in the holding area to its last knows valid state.

The treatment plan now contains :

1) Actual Fluence Data
2) Not a complete DRR
3) No MLC control points data

- Within 12 s, another workstation, WS1, is used to open the patients plan.

- Valid fluences were already saved. Calculation of dose distribution is now done by the planner and saved.

- MLC control point data is not required for calculation of dose distribution.

- No control point included in the plan

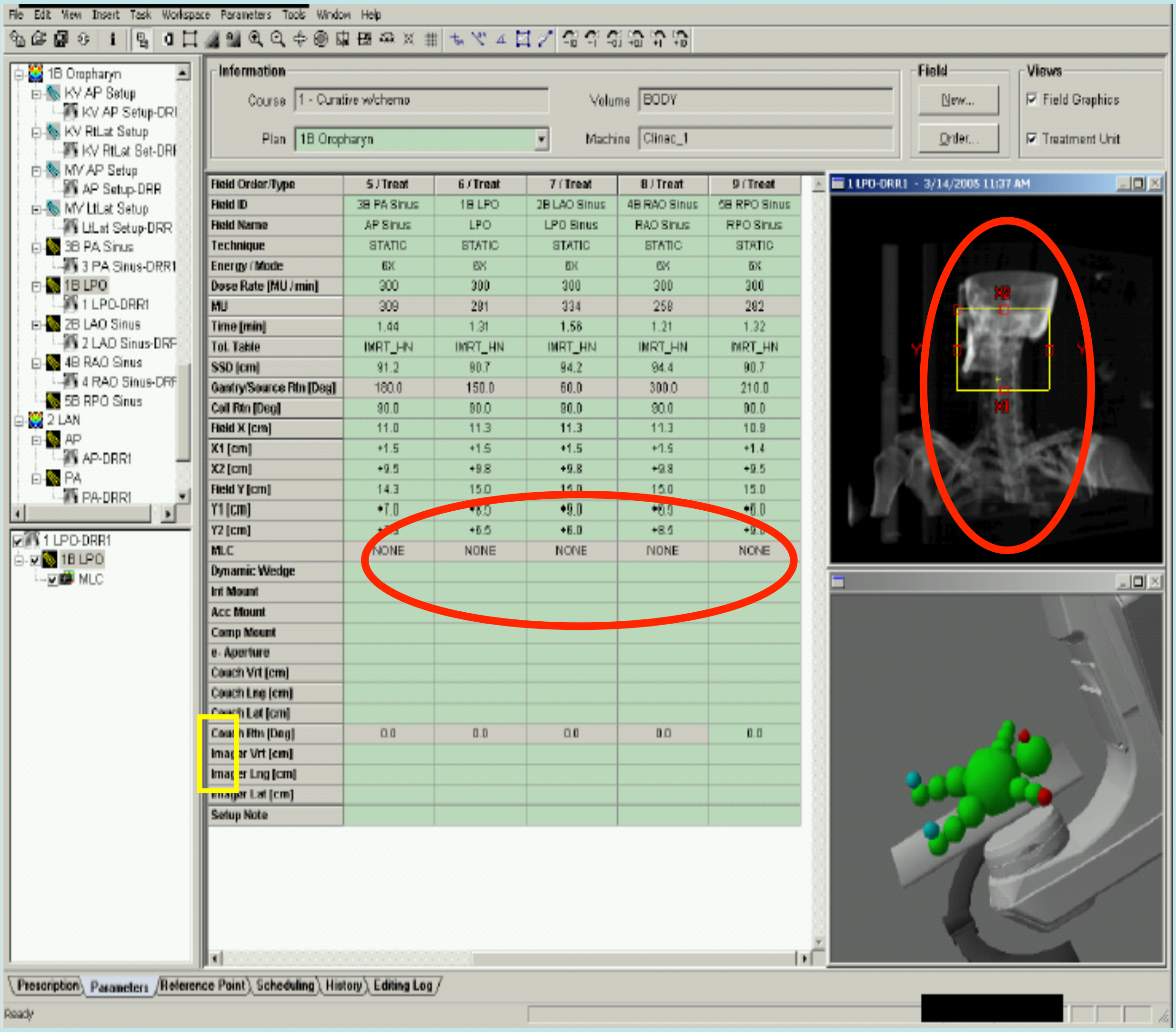
- No verification plan is generated or used for checking purposes, prior to treatment (should be done according to clinics QA program)

- The plan is subsequently prepared for treatment (treatment scheduling, image scheduling, etc) – after several computer crashes.

- It is also approved by a physician

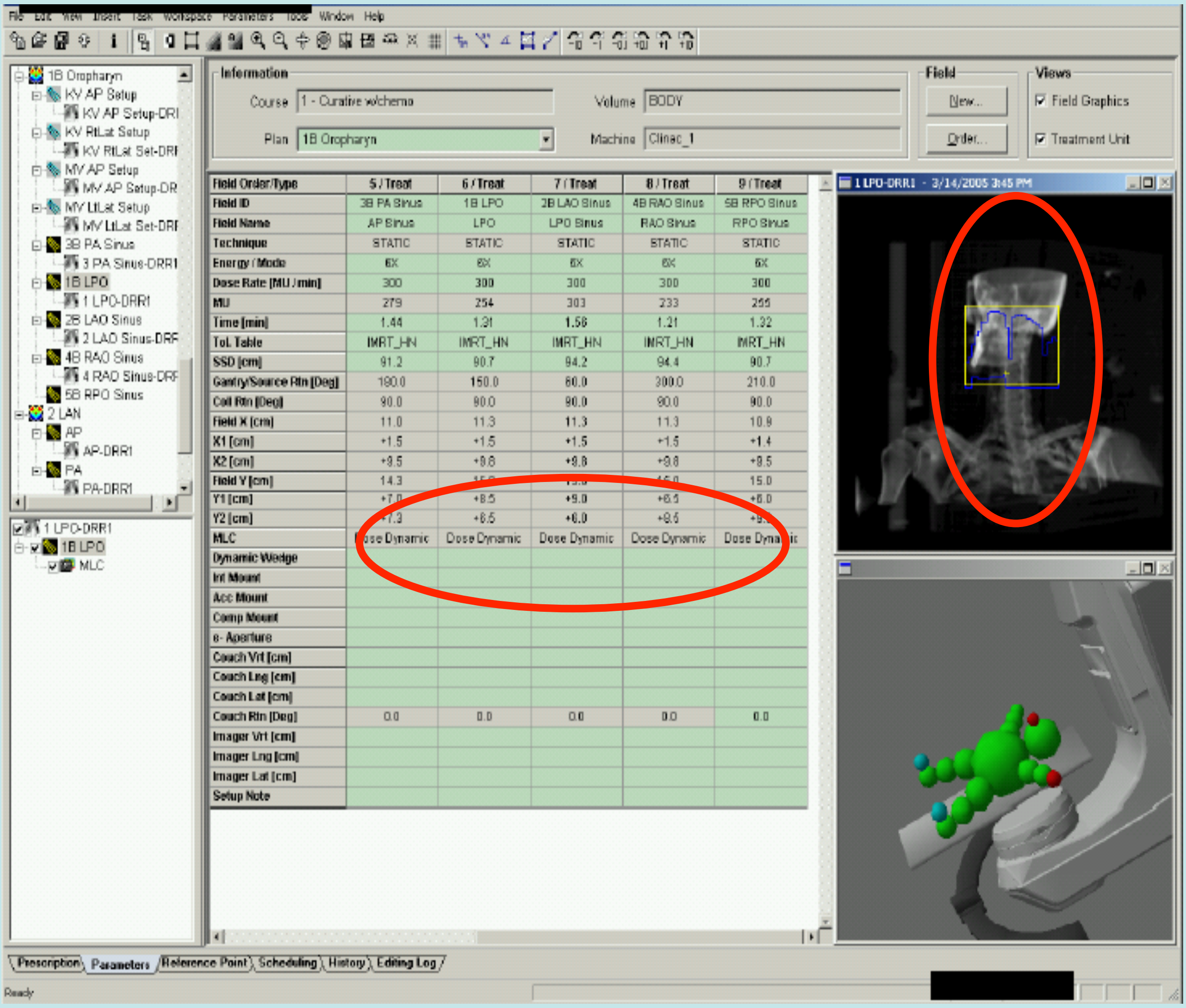
- According to QA program, a <u>second physicist</u> should then have reviewed the plan, including an overview of the irradiated area outline, and the MLC shape used.

Would have been seen on verification:



Field Order/Type	5 / Treat	6 / Treat	7 / Treat	8 / Treat	9 / Treat
Field ID	3B PA Sinus	1B LPO	2B LAO Sinus	4B RAO Sinus	5B RPO Sinus
Field Name	AP Sinus	LPO	LPO Sinus	RAO Sinus	RPO Sinus
Technique	STATIC	STATIC	STATIC	STATIC	STATIC
Energy / Mode	6X	6X	6X	6X	6X
Dose Rate [MU / min]	300	300	300	300	300
MU	309	281	334	258	282
Time [min]	1.44	1.31	1.56	1.21	1.32
Tol. Table	IMRT_HN	IMRT_HN	IMRT_HN	IMRT_HN	IMRT_HN
SSD [cm]	91.2	90.7	94.2	94.4	90.7
Gantry/Source Rtn [Deg]	180.0	150.0	60.0	300.0	210.0
Coll Rtn [Deg]	90.0	90.0	90.0	90.0	90.0
Field X [cm]	11.0	11.3	11.3	11.3	10.9
X1 [cm]	+1.5	+1.5	+1.5	+1.5	+1.4
X2 [cm]	+9.5	+9.8	+9.8	+9.8	+9.5
Field Y [cm]	14.3	15.0	[illegible]	15.0	15.0
Y1 [cm]	+7.0	+8.5	+9.0	+6.5	+6.0
Y2 [cm]	[illegible]	+6.5	+6.0	+8.5	[illegible]
MLC	NONE	NONE	NONE	NONE	NONE
Dynamic Wedge					
Int Mount					
Acc Mount					
Comp Mount					
e- Aperture					
Couch Vrt [cm]					
Couch Lng [cm]					
Couch Lat [cm]					
Couch Rtn [Deg]	0.0	0.0	0.0	0.0	0.0
Imager Vrt [cm]					
Imager Lng [cm]					
Imager Lat [cm]					
Setup Note					

■ <u>Should</u> have been seen on verification:



Discovery of accident

- March 15-16, 2005
  - The patient is treated without MLCs for three fractions
  - On March 16, a verification plan is created and run on the treatment machine. The operator notices the absence of MLCs.
  - A second verification plan is created and run with the same result.
  - The patient plan is loaded and run, with the same result.

Impact of accident

- The patient received 13 Gy per fraction for three fractions, i.e. 39 Gy in 3 fractions

Lessons to learn

1. Include in the Quality Assurance program
   - In-vivo dosimetry
   - Provide independent check of exposure times/MU
2. Develop procedures for indicating clearly software that is commissioned for clinical use, and software that has been removed from clinical service
3. There should be procedures to perform complete commissioning of treatment planning equipment before first use
4. There should be formal procedures for calibrating a treatment unit on a regular schedule
5. Formal procedures for reporting incidents, returning medical equipment after maintenance or when the repair might have affected beam parameters
6. Ensure that staff is properly trained in the operation of the equipment and understands the operating procedures

Radioactive corpses

Art.69:

- **limiting radiation risks, particularly for post-mortem examinations, embalming, cremation**

- **case by case approach**

Module 3 : Contrôle de qualité
Chap. 5 : Critères d 'acceptabilité des installations de radidologie
Sujet :

Commission européenne

Radioprotection 91

Critères d 'acceptabilité des installations de radiologie (y compris de radiothérapie) et de médecine nucléaire

1997

Direction générale
« Environnement, sécurité nucléaire et protection civile »