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Diagnostic reference levels in medical practice

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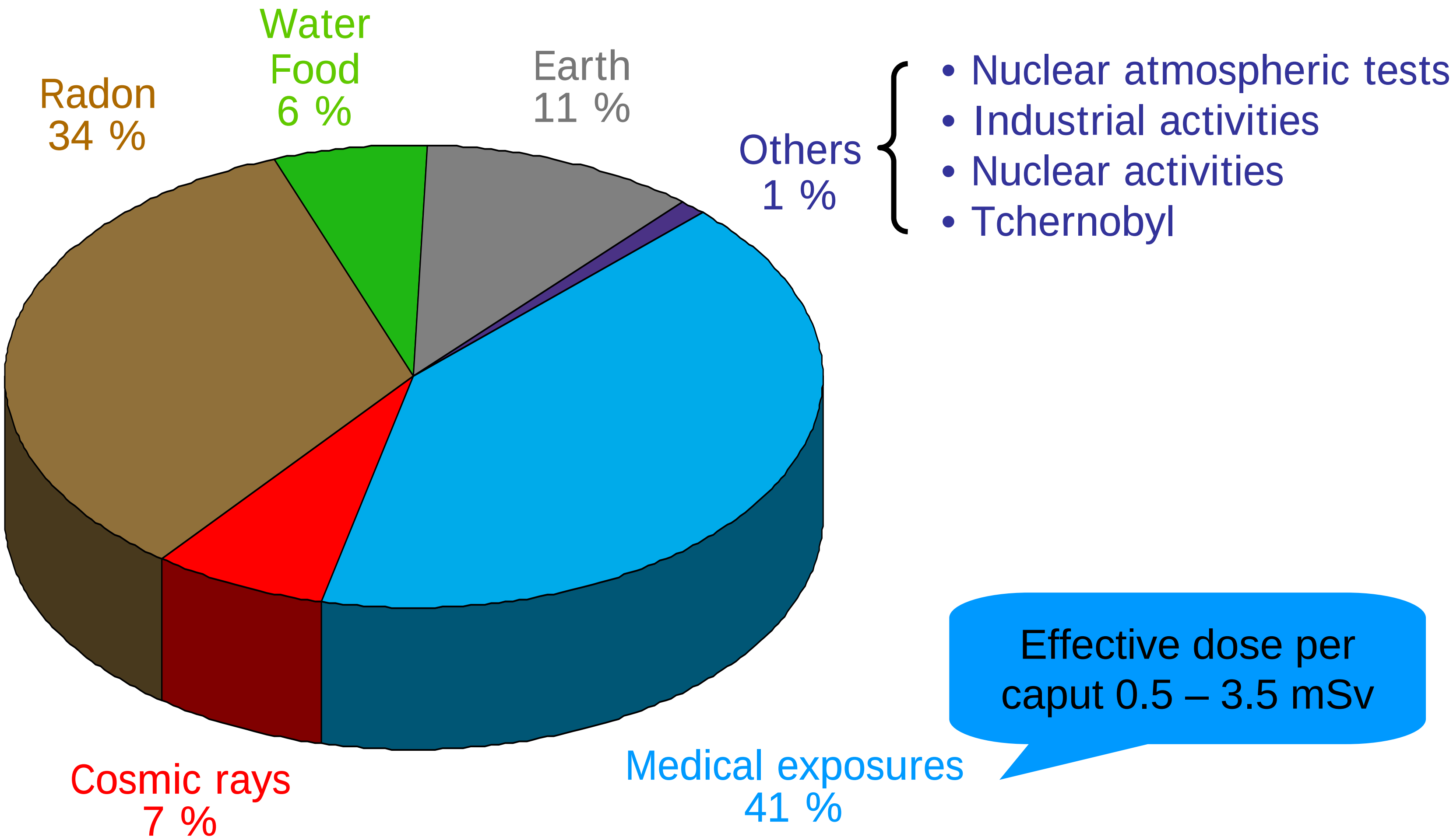
- ✓ A DRL strategy

Rationale for RP in medicine (1)



Effective dose per caput 0.5 – 3.5 mSv

Rationale for RP in medicine (2)

- Medical exposures = largest source of exposition of artificial origin
- Medical exposures are increasing with medical imaging growth : diagnosis, therapeutic strategy, therapy
- Domain of low doses ? except in therapy, repeated CT and interventional radiology
- High collective dose : the total population is concerned although most examinations in old patients, but children are more sensitive

Rationale for RP in medicine (3)
The principles of radiation protection

- Justification : Yes
- Optimisation : Yes
- Limitation of dose : No

  - a good quality image is necessary in order not to compromise the clinical value associated with the exposure, i.e., the diagnosis or the therapeutic strategy,
  - the highest possible dose must be delivered to cure a tumor

Rationale for RP in medicine (4)
Justification principle

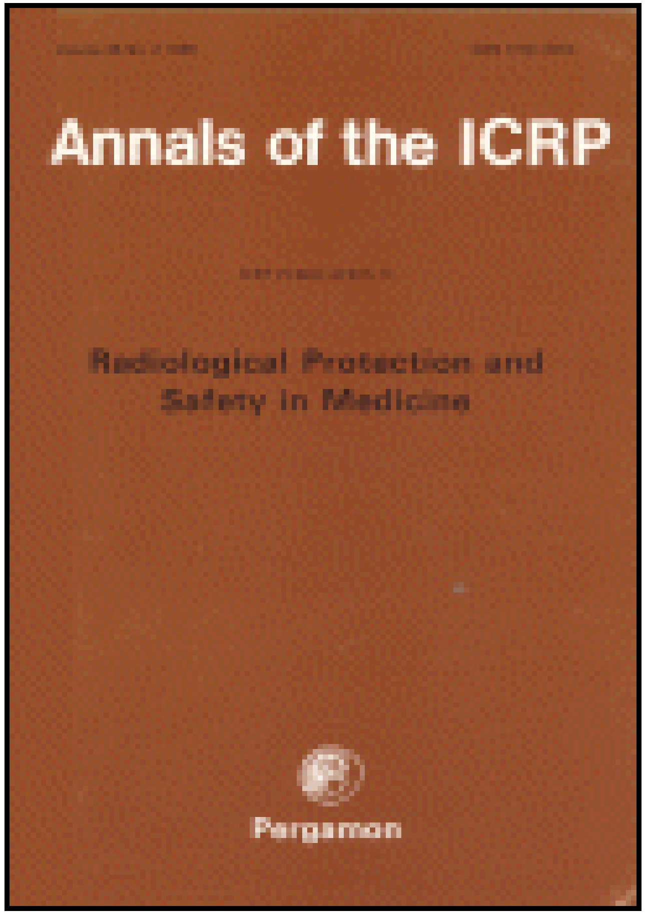
- The clinical benefit outweighs the risk associated with the exposure: the benefit is immediate and the risk of low doses ot IR, if it exists, is small at a long term !
- Goal : to perform only useful exposure, i.e., examinations which result being positive or negative is expected to comfort the diagnosis or to change patient management
- Referral criteria for imaging guide to help fulfill the justification principle

Rationale for RP in medicine (5)
Optimisation principle

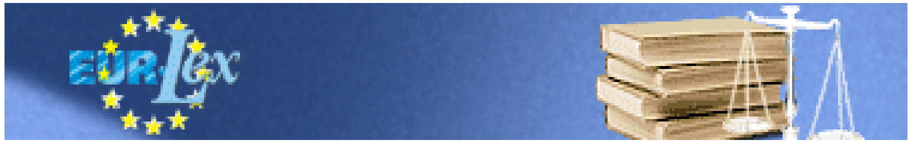
- Once an examination has been decided, the corresponding procedure must be optimized : ALARA
- Procedure guide to help fulfill the optimisation principle
- Attention to be paid to the most frequent examinations and those delivering the highest doses
- Attention to be paid to children, young adults, pregnant women

Rationale for RP in medicine (6)
Diagnostic reference levels

A tool for optimisation



Recommendation 73, 1996



Council directive 97/43/Euratom of 30 juin 1997 on health protection of individuals against the dangers of ionizing radiation in relation to medical exposure and repealing directive 94/466/Euratom.

Art 4 : Member States promote the establishment and the use of diagnostic reference levels for radiodiagnostic examinations

DRLs are defined in the Council Directive 97/43 Euratom as

"dose levels in medical radiodiagnostic practices or, in the case of radiopharmaceuticals, levels of activity, for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment. These levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied".

Thus DRLs apply only to diagnostic procedures in radiology or nuclear medicine and do not apply to radiation therapy.

Diagnostic reference levels (1)
Needs

- Need for the evaluation that procedures are optimized and remained optimized
- Need for quantitative indicators of the doses delivered
- Indicators must provide an evaluation of the performance of the examination
- Indicators to be used to continuously improve the procedures

Diagnostic reference levels (2)

Strategy : to perform a longitudinal monitoring of Indicators

- in each department
- for each medical device
- for comparison between institutions at a national and international level
- as a mean to know the necessity for further optimisation of exposures

Diagnostic reference levels (3)

Which criteria for the indicators ?

They must

- be clearly defined
- easy to measure or to calculate
- give directly an indication of the importance of the dose delivered
- allow easy correlations with the technical parameters of the examination
- be adapted to all type of equipements

Diagnostic reference levels (4)

are not

- dose limits or constraints
- optimal values
- separated from the image quality
- applicable to individual exposures
- indicators of radiological risk
- a line of separation between good and poor practice

Diagnostic reference levels (5)

are

- established for the most frequent and irradiating routine examinations
- for groups of standard size patients (70 ± 3 kg and 20cm antero-posterior trunk thickness)
- or for standard phantoms
- obtained for specific groups of children (age, size, weigth)
- guides for optimisation

Diagnostic reference levels (6)

- DRLs should not be exceeded in routine when examinations are performed in accordance with the procedures (good and normal practice)
- The goal is not to deliver doses constantly lower than DRLs because images of “poor quality” would not provide the diagnostic information (large patients)

Diagnostic reference levels (7)
The use of DRLs for optimisation

- DRL parameters are measured in each institution
- DRLs are established nationaly
- Local reviews of DRL parameters are undertaken routinely
- Comparison is made with national values
- Actions are taken if DRLs are exceeded consistently

The necessity to establish DRLs

- Large dispersion of doses
- Limitation of dose dispersion
- Necessity to harmonize good practices
- Suppression of useless doses

Dispersion of doses

Variability of mean entrance dose (mGy) to patients in different countries for the same examination

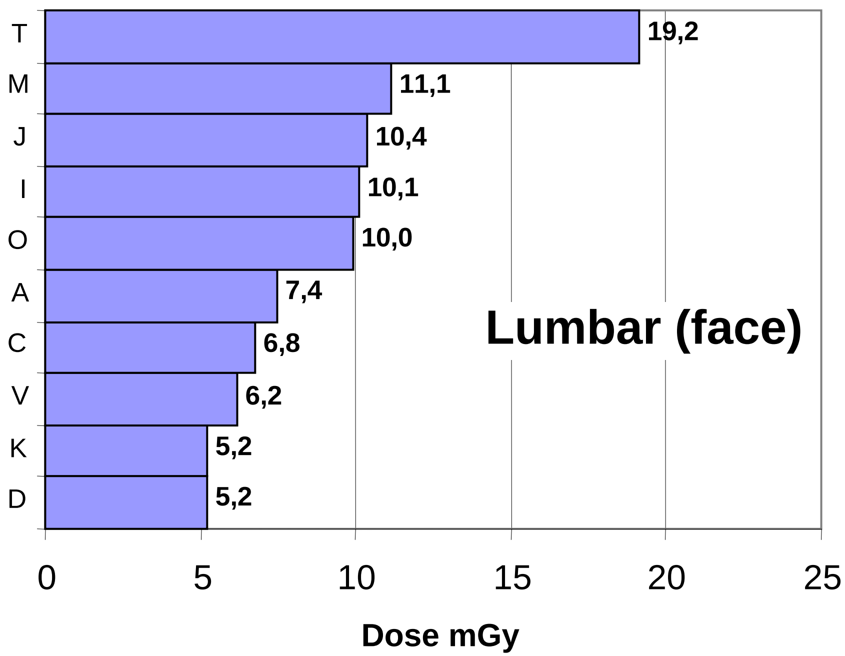
(European Commission Trial 1991)

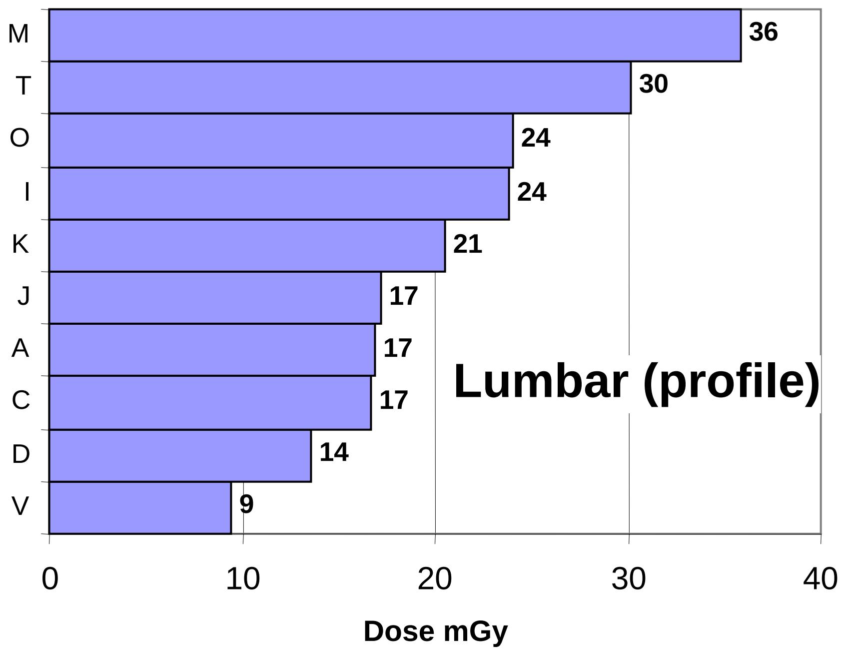
Country	Lumbar spine (face)	Lumbar spine (profile)
Espagne	46,2	56,8
Irlande	17,1	50,1
Allemagne	30,6	46,7
Norvège	14,6	45,4
France	23,1	36,5
UK	14,9	35,3
Italie	26,1	30,3
Belgique	11,5	27,4
Pays-Bas	8,4	27,1
Danemark	9,9	19,9

Diagnostic reference levels in medical practice

Dispersion of doses

French study (2001-2002)
Variation of mean entrance dose
in different French institutions for lumbar spine X ray





Dispersion of doses

Variability of mean entrance dose in different French institutions (2001-2002)

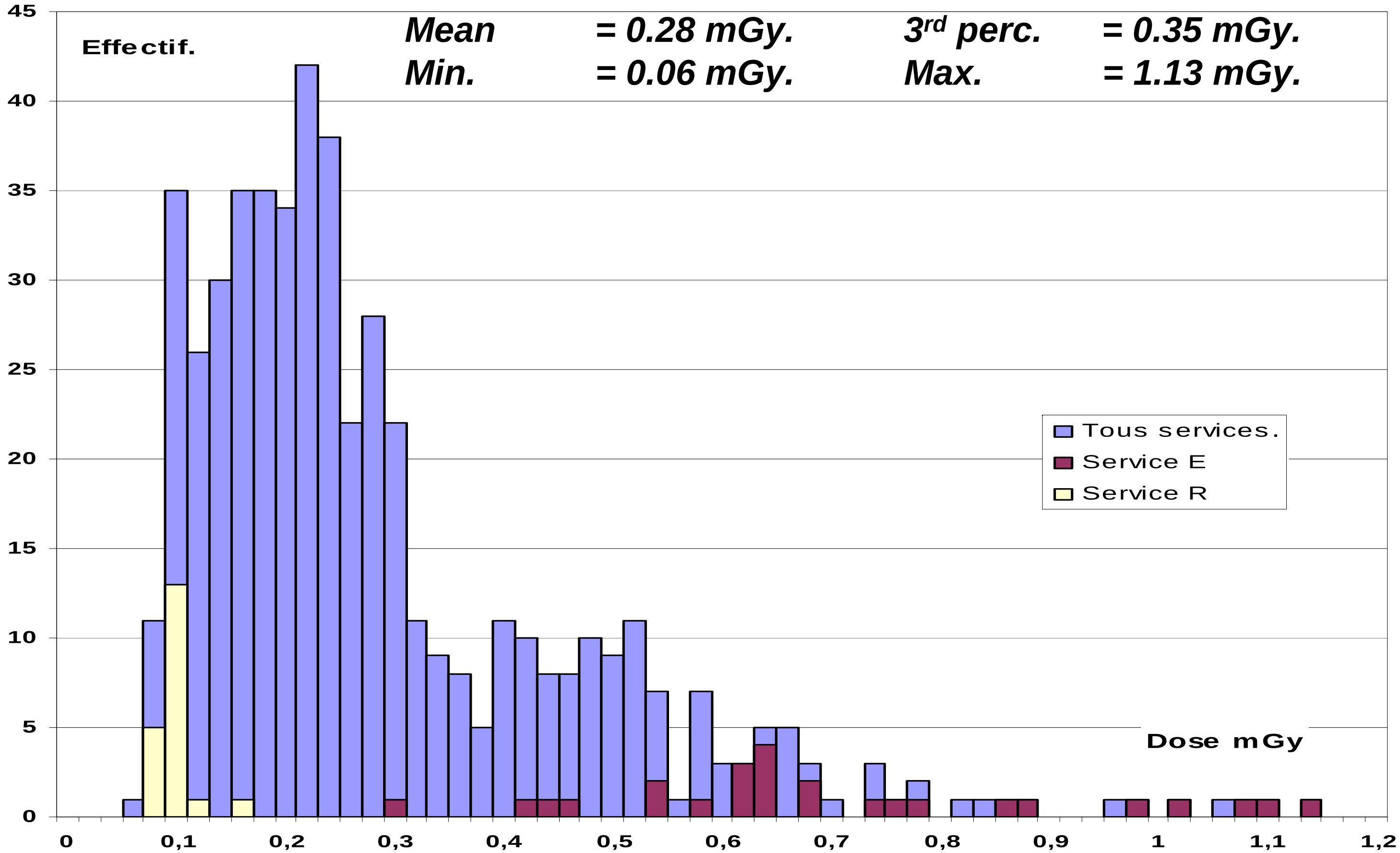
Examination	Chest Post-Anterior	Abdomen	Lumbar spine Face	Lumbar spine Profile
Nomber of institutions	24	21	11	11
Mean De (mGy)	**0,28**	**5,2**	**8,2**	**19,5**
Mean De (Maximale*)	0,70	10,4	19,2	36
Mean De (Minimale*)	0,09	2,4	5,2	9,5
Max/Min between institution	**7,8**	**4,3**	**3,7**	**3,8**

*per institution

Diagnostic reference levels in medical practice

Dispersion of doses

French study (2001-2002)



Chest X ray postero-anterior.

Diagnostic reference levels in medical practice

Dispersion of doses

French study (2001-2002)
Variability of mean DLP
for different CT examinations for different institutions

Examination	Chest standard	Chest high resolution	Abdomen standard	Brain standard
Number of institutions	15	12	15	13
Mean DLP (mGy.cm)	**316**	**81**	**384**	**735**
Absorbed Dose*	14 mGy	4 mGy	15 mGy	50 mGy
Effective Dose*	4,5 mSv	1,1 mSv	6 mSv	1,5 mSv
DLP max (mGy.cm)	**675**	**241**	**921**	**2117**
DLP min (mGy.cm)	**156**	**27**	**186**	**267**
Ratio max/min	**4,3**	**8,9**	**4,9**	**7,9**

* rough evaluation

Which DRL parameters ?

They must be

- clearly defined
- easy to measure or to calculate
- directly correlated with the parameters of the procedure
- easily accessible
- adapted to all type of equipements

➢ in nuclear medicine : injected activities

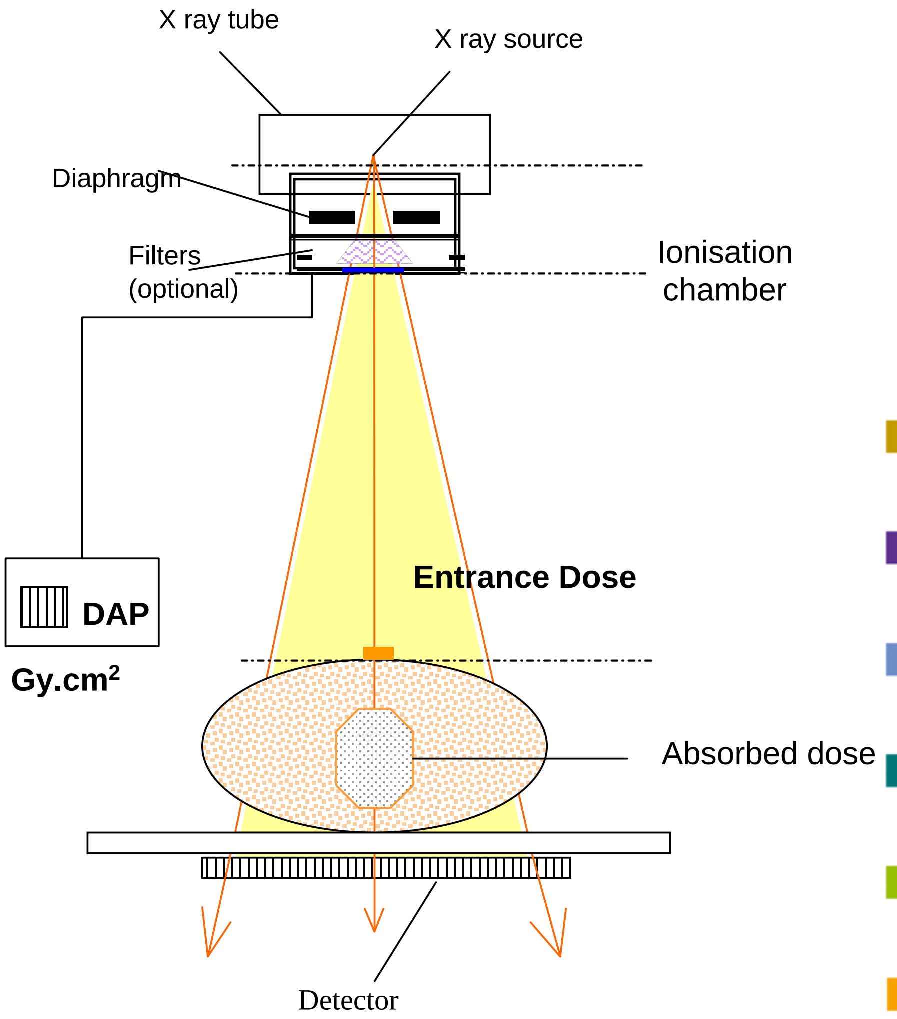
➢ in radiology : doses

The choice of DRL parameter in classical radiology (1)

Which dose ?

- dose rate in air mGy/s
- entrance dose mGy,
- absorbed dose mGy
- product (dose x area),

  DAP Gy.cm²
- effective dose mSv.



The choice of DRL parameter in classical radiology (2)

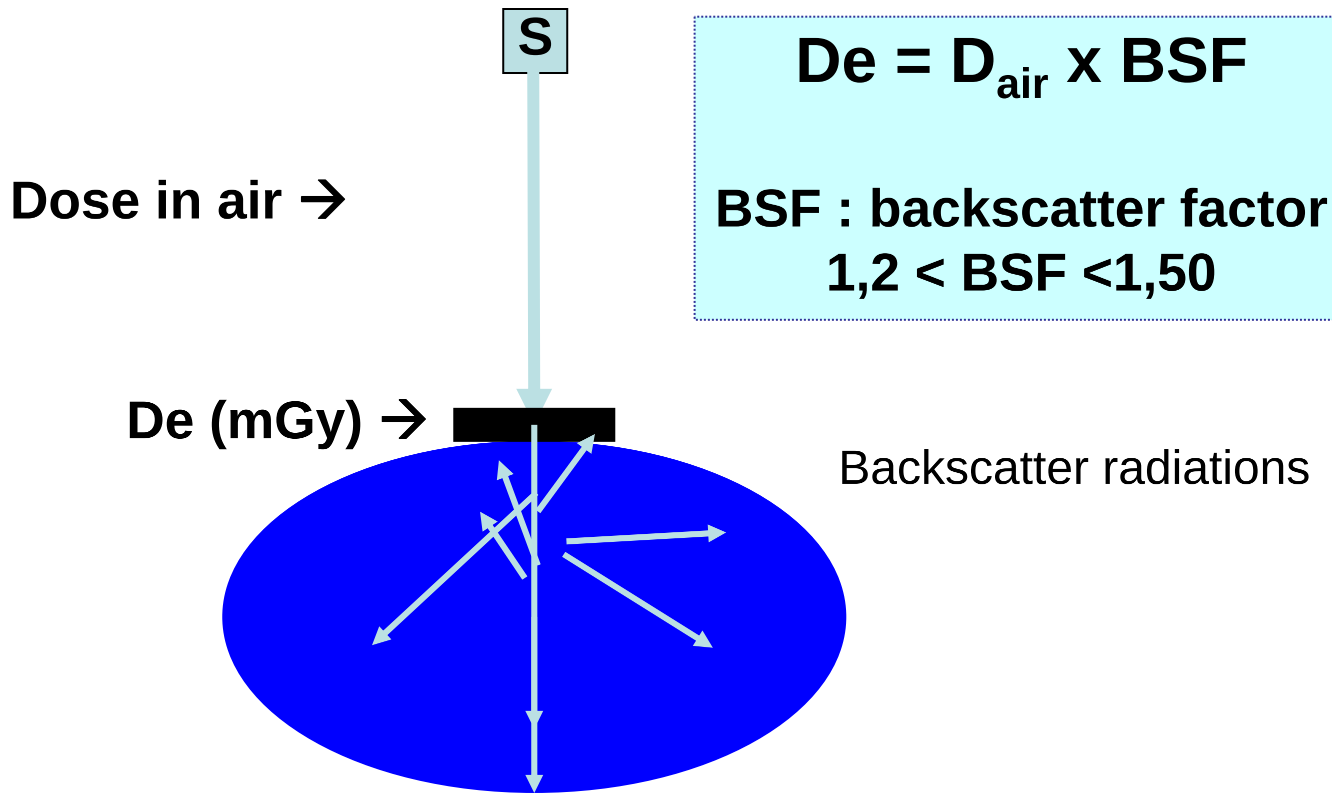
(mGy or mSv : one example)

3 « doses » for one single view !!!

Examination	**Entrance Dose De**	**Mean absorbed Dose**	**Effective Dose E**
Doses …*	**Milligrays (mGy)**		**Millisieverts (mSv)**
		uterus	
Abdomen	**10**	**1,5**	**1**

The choice of DRL parameter in classical radiology (3)

Entrance dose : De



$De = D_{air} \times BSF$

BSF : backscatter factor

$1,2 < BSF < 1,50$

The choice of DRL parameter in classical radiology (4)

Entrance dose $De = K_0 \times BSF \times (U/100)^2 \times Q \times (1/DSS)^2$

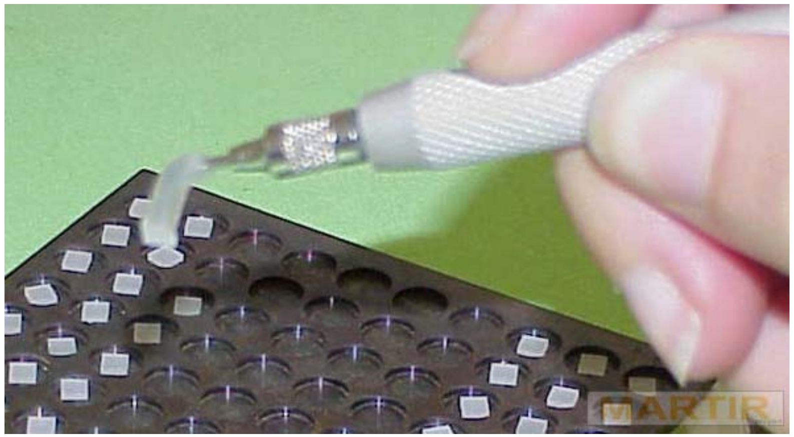
- Tension U (kV)
- Charge Q (mAs)
- Distance 'Source-skin' DSS(m)
- Coefficient K_0 (mGy/mAs à 1m) characteristic of the installation: dose rate in air
- Factor BSF (between 1,2 and 1,5)

Calculation : $De = 0{,}15 \times (U/100)^2 \times Q \times (1/DSS)^2$

Measurement:

Immediate with electronic detectors

Delayed with TLDs



The choice of DRL parameter in classical radiology (5)

Calculation of De : $De = 0{,}15 \times (U/100)^2 \times Q \times (1/DSS)^2$

Example for Abdomen X ray

$0.15 \times (75/100)^2 \times 66 \times (1/0.75)^2$
10 mGy

Tension U kV	Charge Q mAs	DSS m	De mGy
75	66	0,75	10*
75	80	0,75	12
75	30	0,80	4
80	30	0,80	4,5
80	40	0,75	6,8
70	75	0,75	9,8

x 1.2 (Charge Q: 66 → 80)

x 1.2 (De: 10 → 12)

x 1.06 (Tension U: 75 → 80)

$x1.06^2 = 1.12$ (De: 4 → 4,5)

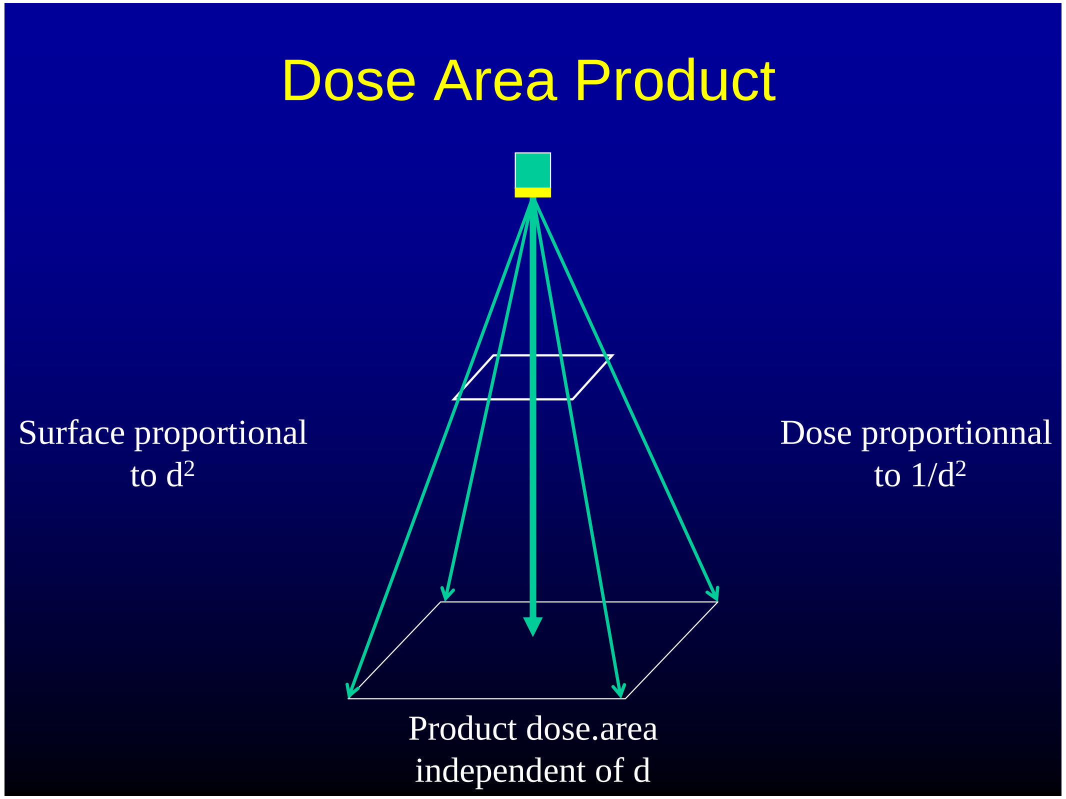
$0.15 \times (70/100)^2 \times 75 \times (1/0.75)^2$
9.8 mGy

* NRD value for abdomen X ray

→ *patient thickness: 25cm (DSS =0,75m) or 20cm (DSS =0,80m)*

The choice of DRL parameter in classical radiology (6)

Dose area product : DAP



Units !

1 Gy.cm^2

= 100 cGy.cm^2

= 1000 mGy.cm^2

The choice of DRL parameter in classical radiology (7)

Calculation of De from DAP : De = (DAP/Ae) x BSF

Examples for abdomen (BSF = 1.35)

DAP		Length	Width	De
Gy.cm^2	mGy.cm^2	cm *(skin)*	cm *(skin)*	mGy
7	7000	31,5	30	**10***
2,08**	2080	31	29	**3,12**
0,90**	900	34	27	**1,32**
4,5 Gy.cm²	**4.5 x 1000 mGy.cm²**	**30 cm**	**30 cm**	**6.75 mGy**
		30 x 30 = 900 cm²		

De = (4500/900) x 1.35

* *DRL value for abdomen X ray*

** *measurement in Val de Grâce hospital*

The choice of DRL parameter in classical radiology (8)

Calculation of De from DAP : **De = (DAP/Ae) x BSF**

Examples for abdomen (BSF = 1.35)

DAP		Length	Width	De
Gy.cm^2	**mGy.cm^2**	**cm** *(skin)*	**cm** *(skin)*	**mGy**
7	7000	31,5	30	**10***
2,08**	2080	31	29	**3,12**
0,90**	900	34	27	**1,32**
4.5	4500	30	30	**6.75**
3 Gy.cm²	**3000**	**30 cm**	**20 cm**	**6.75 mGy**

30 x 20 = 600 cm²

De = (3000/600) x 1.35

* *DRL value for abdomen X ray*

** *measurement in Val de Grâce hospital*

The choice of DRL parameter in classical radiology (9)

Calculation of De from DAP : **De = (DAP/Ae) x BSF**

Examples for abdomen (BSF = 1.35)

2 different DAP values

		Length	Width	De
	$mGy.cm^2$	**cm** *(peau)*	**cm** *(peau)*	**mGy**
	7000	31,5	30	10*
2,08*	2080	31	29	3,12
0,90*	900	34	27	1,32
4,5	**4500**	**30**	**30**	**6,75**
3	**3000**	**30**	**20**	**6.75**
3	**3000**	**30**	**30**	**4,5**

Different surfaces

Identical De

* *DRL value for abdomen X ray*

** *measurement in Val de Grâce hospital*

Diagnostic reference levels in medical practice

The choice of DRL parameter in classical radiology (10)

Calculation of De from DAP : **De = (PDS/Ae) x BSF**

Same DAP

Examples for abdomen (BSF = 1.35)

DAP		Length	Width	De
[illegible]y.cm^2	mGy.cm^2	cm *(skin)*	cm *(skin)*	mGy
7	7000	31,5	30	10*
[illegible],08**	2080	31	29	3,12
[illegible],90**	900	34	27	1,32
4,5	**4500**	**30**	**30**	**6,75**
3	**3000**	**30**	**20**	**6.75**
3	**3000**	**30**	**30**	**4,5**

Different Surfaces

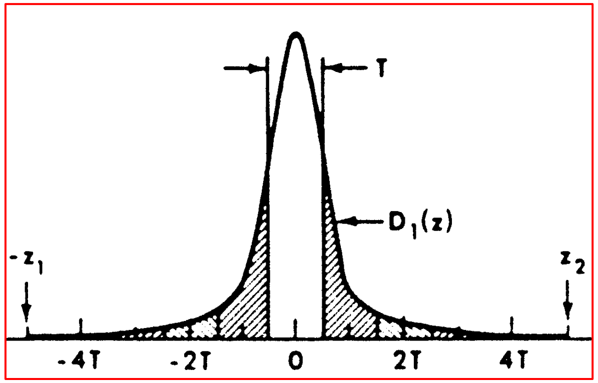
Different De

* *DRL value for abdomen X ray*

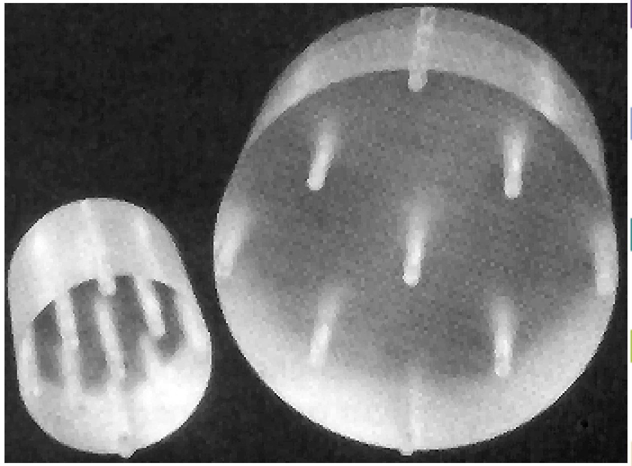
** *measurement in Val de Grâce hospital*

The choice of DRL parameter in CT radiology (1)

- CTDI : computerized tomographic dose index (measured in air, in phantoms at the center and periphery, normalized for 100 mAs)
- $CTDI_w$: weighted CTDI (normalized)
- $CTDI_{vol} = CTDI_w$ / Pitch (helix mode)
- DLP: Dose x Length product (Gy.cm)
- Effective dose : E (mSv)



$$CTDI = \frac{1}{T}\int_{-\infty}^{+\infty} D_1(z)\,.dz$$



$CTDI_W = 1/3\ CTDI_C + 2/3\ CTDI_P$

The choice of DRL parameter in CT radiology (2)

Interest of $CTDI_{vol}$

- Defined in norm CEI 60601-2-44 and $CTDI_{vol}$ value in mGy must be displayed on the screen
- $CTDI_{vol}$ is measurable
- $CTDI_{vol}$ is a good indicator of dose : best represents the mean absorbed dose in the exposed volume
- Linked to a given protocol of examination (kV, mA, s)

The choice of DRL parameter in CT radiology (3)

Dose x Length Product in helix mode *mGy x cm*

$$DLP = {}_{n}CTDI_{W} \times A \times t \times n \times T$$

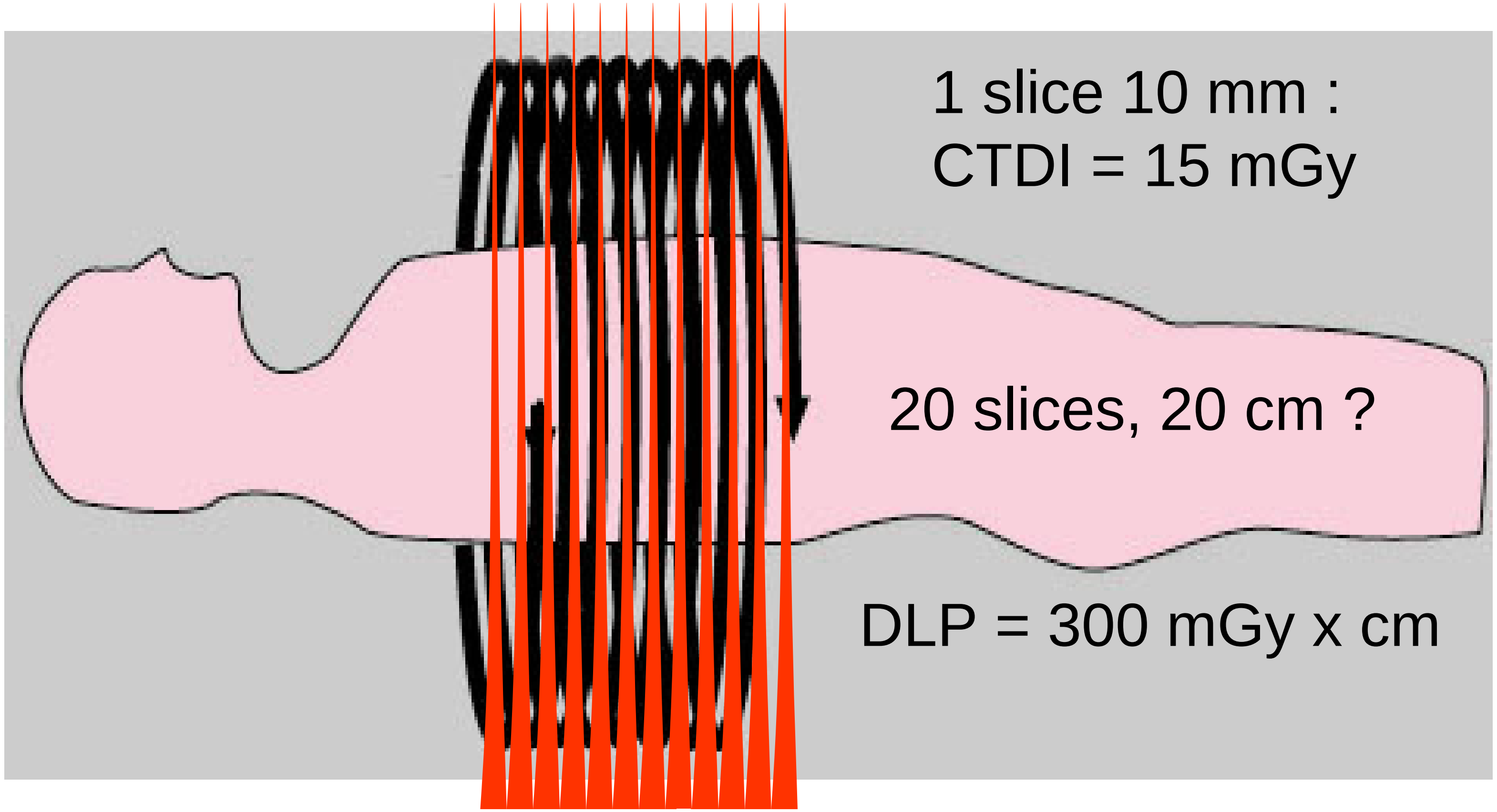
- ${}_{n}CTDI_{W}$: $CTDI_{W}$ normalized (mGy/mAs)
- A : intensity (mA)
- t : time per rotation (s)

  } **Charge (mAs)**
- n : number de rotations
- T : width of collimation (cm)
  (width of one slice x number of slices per rotation)

$$DLP = CTDI_{vol} \times \text{Length explored}$$

The choice of DRL parameter in CT radiology (4)

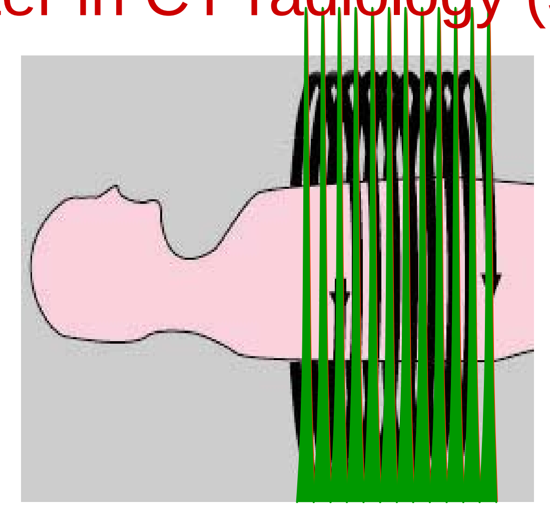
Necessity of a parameter for clinical use : DLP



Dose x Length product (DLP)

The choice of DRL parameter in CT radiology (5)

Standard chest protocol: influence of mAs



- CT Scanner 16 slices
  - U = 120 kV
  - 200 mAs
  - Slice thickness : 5 mm
  - pitch = 1
  - length : 30 cm

$CTDI_{vol}$ = 7 mGy

DLP = 210 mGy.cm

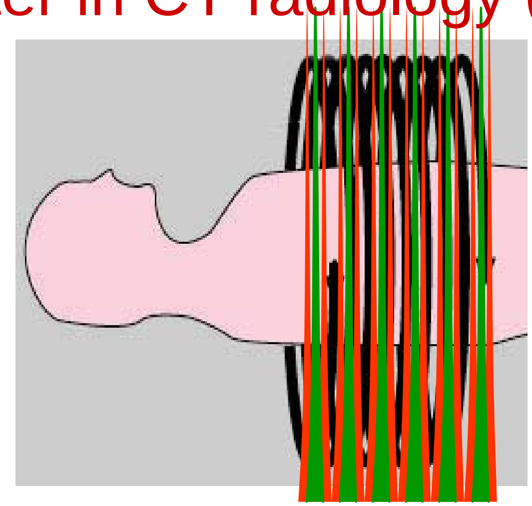
300 mAs

$CTDI_{vol}$ = 10,5 mGy

DLP = 315 mGy.cm

The choice of DRL parameter in CT radiology (6)

Standard chest protocol :
influence of pitch



- CT Scanner 16 slices
  - U = 120 kV
  - 200 mAs
  - Slice width : 5 mm
  - pitch = 1
  - length : 30 cm

$CTDI_{vol}$ = 7 mGy

PDL = 210 mGy.cm

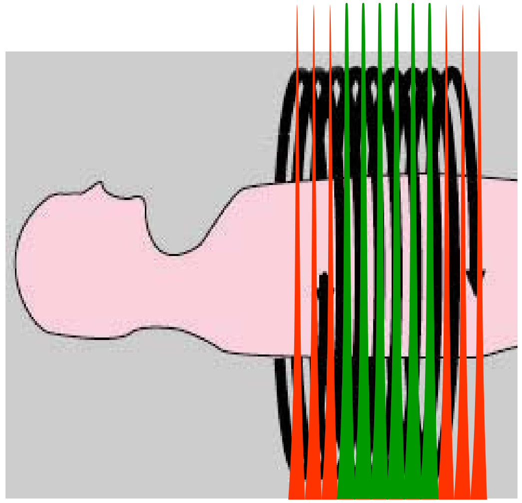
pitch = 2

$CTDI_{vol}$ = 3,5 mGy

PDL = 105 mGy.cm

The choice of DRL parameter in CT radiology (7)

Standard chest protocol : influence of explored length



- CT Scanner 16 slices
  - kV = 120 kV
  - 200 mAs
  - Slice thickness : 5 mm
  - pitch = 1
  - length : 30 cm

$CTDI_{vol}$ = 7 mGy

PDL = 210 mGy.cm

---

length = 15 cm

$CTDI_{vol}$ = 7 mGy

PDL = 105 mGy.cm

The choice of DRL parameter in CT radiology (8)

Conversion DLP ➔ effective dose E

European Factor

	CTDIw	DLP mGy.cm	X	f_{pdl} mSv/mGy.cm²	=	E mSV
Head	58	1050		0.0021		2.2
Neck	12	350		0.0052		1.8
Chest	27	650		0.017		9.1
Abdomen	33	770		0.015		9.5
Pelvis	33	570		0.016		9.1

The final choice of dosimetric parameters as DRLs

In classical radiology

- Entrance dose (De) in mGy for one exposure
- Dose Area Product (DAP) in $Gy.cm^2$ for one exposure or for a complete examination

In CT

- *CTDIw* in mGy for one exposure
- Product dose x length (PDL) in mGy.cm for one acquisition and a complete examination

The final choice of dosimetric parameters as DRLs

Why did not we select the effective dose as a DRL ?

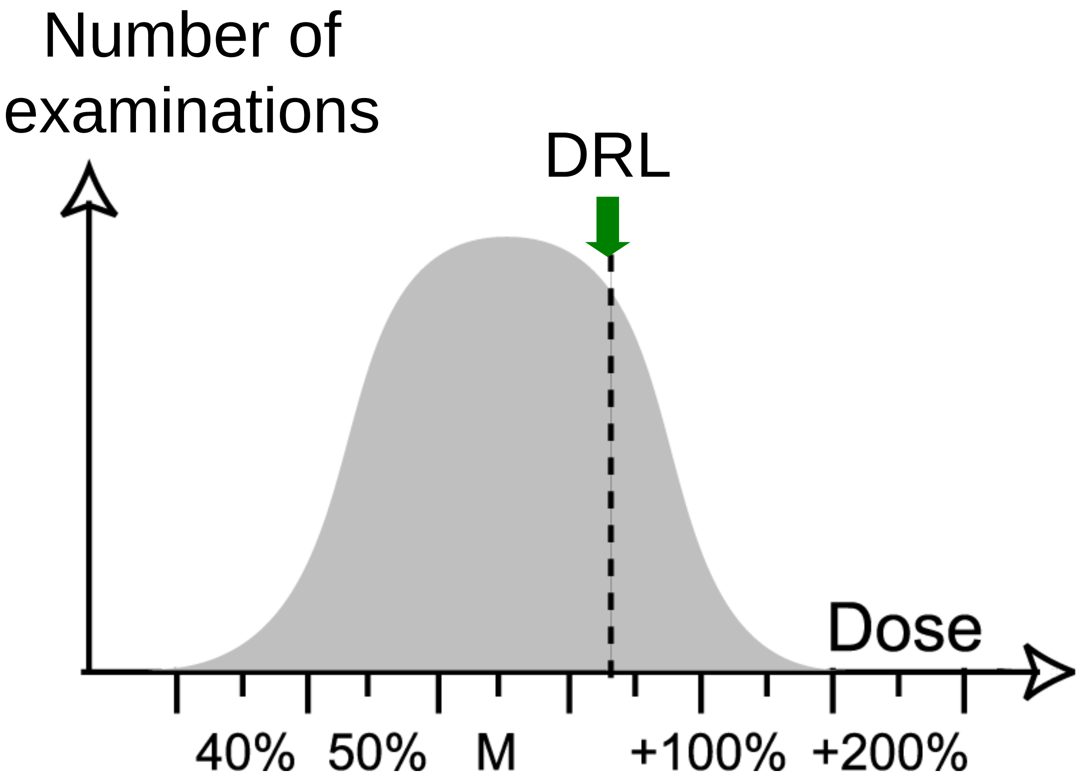
- Not a measurable physical entity
- No link with the parameters of the examination
- Not helpful for optimizing medical procedures
- Can be calculated from DRLs parameters

Diagnostic reference levels
Their determination (1)

- From dosimetric studies, a national dose distribution is established for each DRL parameter
- DRLs are fixed nationally by experts representing the medical and scientific community who decide the values to be retained

Diagnostic reference levels
Their determination (2)

The DRL is the 3rd quartile of the dose distribution



- In theory, the dose distribution is obtained and representative of the practice in the country
- European recommendation

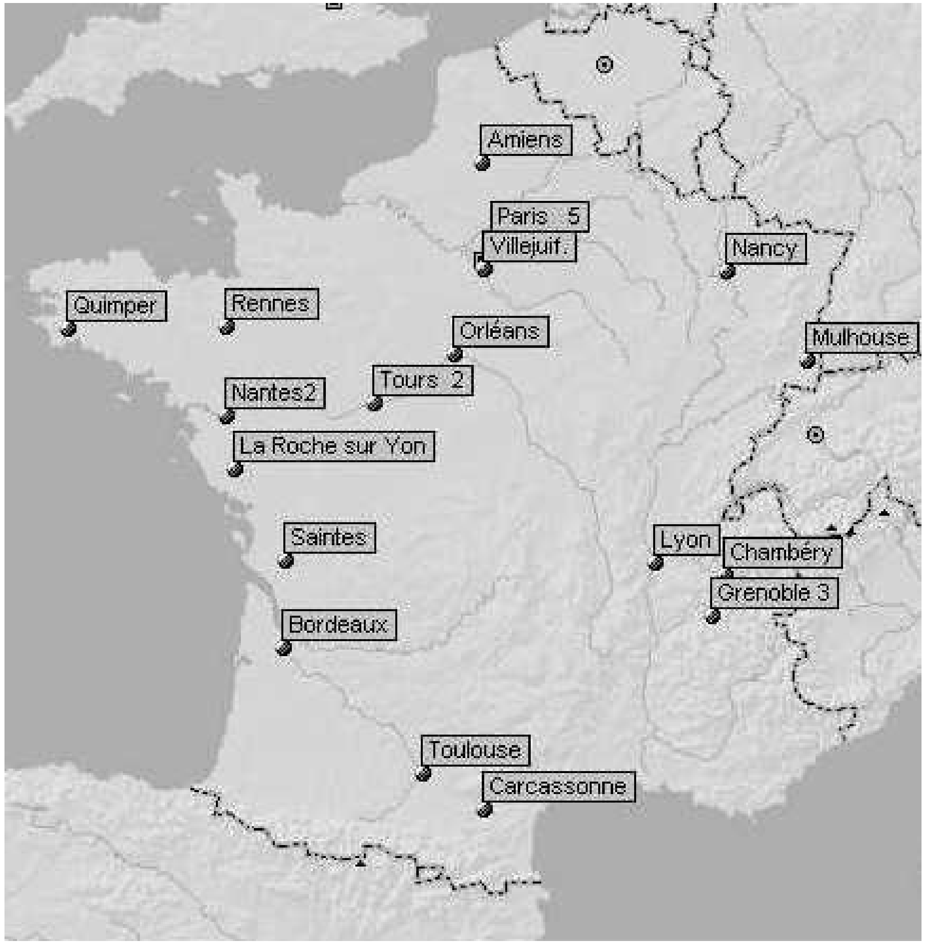
Diagnostic reference levels
Their determination (3)

- In France, the 3rd quartile method was not applicable because we did not benefit from an accurate dose distribution for each DRL parameter
- Then, the ASN organized in 2001-2003, with the expertise of IRSN, a national campaign of dose measurements with the help of the learned societies of radiologists (SFR), medical physicists (SFPM) and technologists (AFPPE)

Diagnostic reference levels
Their determination (4)

The national campaign (2001-2003)

The departments of radiology involved in the dosimetric study



Diagnostic reference levels in France
In classical radiology

Examination	Chest P/A	Abdomen	Lombar spine F	Lombar spine P
Number of services	24	21	11	11
Number of patients	511	331	195	194
Mean De * (mGy)	0,28	5,2	8,2	19,5
3rd quartile* (mGy)	0,35	6	10,4	24
Ratio **	7,8	4,3	3,7	3,8
European DRL (mGy)	0,30	10	10	30

* For all patients
** Ratio of Mean De max and Mean De min

Diagnostic reference levels in France

Values in classical radiology

Examination	**De in mGy for one exposure**
Chest face (postero anterior)	0,3
Chest profile	1,5
Lumbar spine face	10
Lumbar spine profile	30
Abdomen	10
Pelvis face (postero anterior)	10
Mammography	10
Skull face	5
Skull profile	3

Diagnostic reference levels in France

Values in classical radiology (children)

Examination	Age y	De in mGy for one exposure
Chest (antero posterior)	0-1	0,08
Thorax (postero anterior)	5	0,1
Chest (lateral)	5	0,2
Skull	5	1,5
Crâne (latéral)	5	1
Pelvis (antero posterior)	0-1	0,2
Pelvis (antero posterior)	5	0,9
Abdomen	5	1

Diagnostic reference levels in France

In CT

Examination	Chest standard	Chest high resolution	Abdomen standard	Brain standard
Number of services	15	12	15	13
Mean CTDIw (mGy)	13,8	24,5	14,6	47,3
European DRL CTDIw	27	----	33	58
French DRL CTDIw	20	---	25	58
Mean PDL (mGy.cm)	316	81	384	735
European DRL PDL	650	----	770	1050
French DRL PDL	500	---	650	1050

Diagnostic reference levels in France
Values in CT

Examination	CTDIw (mGy)	PDL (mGy.cm)
Brain	58	1050
Chest	20	500
Abdomen	25	650
Pelvis	25	450

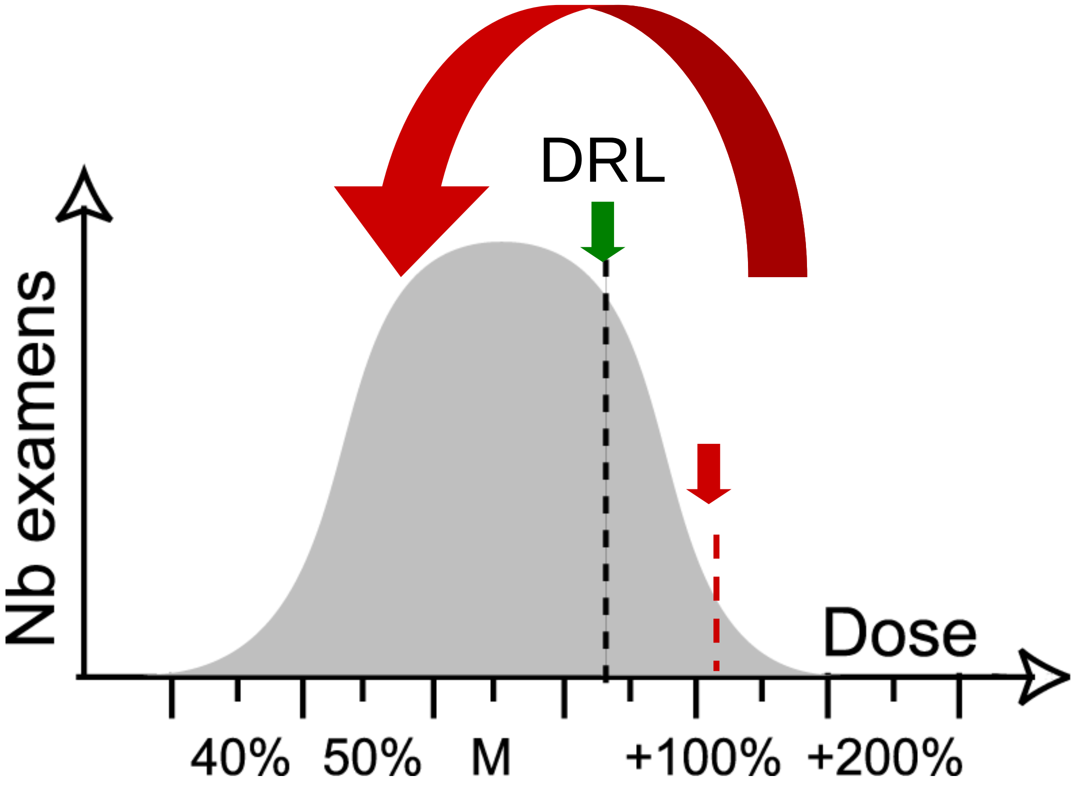
Diagnostic reference levels

How to collect your own local DRLs ?

- In each medical department
- Measurement of the parameters (De, DAP, CTDIw or PDL) for a series of 20 standard size patients or phantoms
- The average value of each parameter can be considered as the local DRL

Diagnostic reference levels
Their optimisation

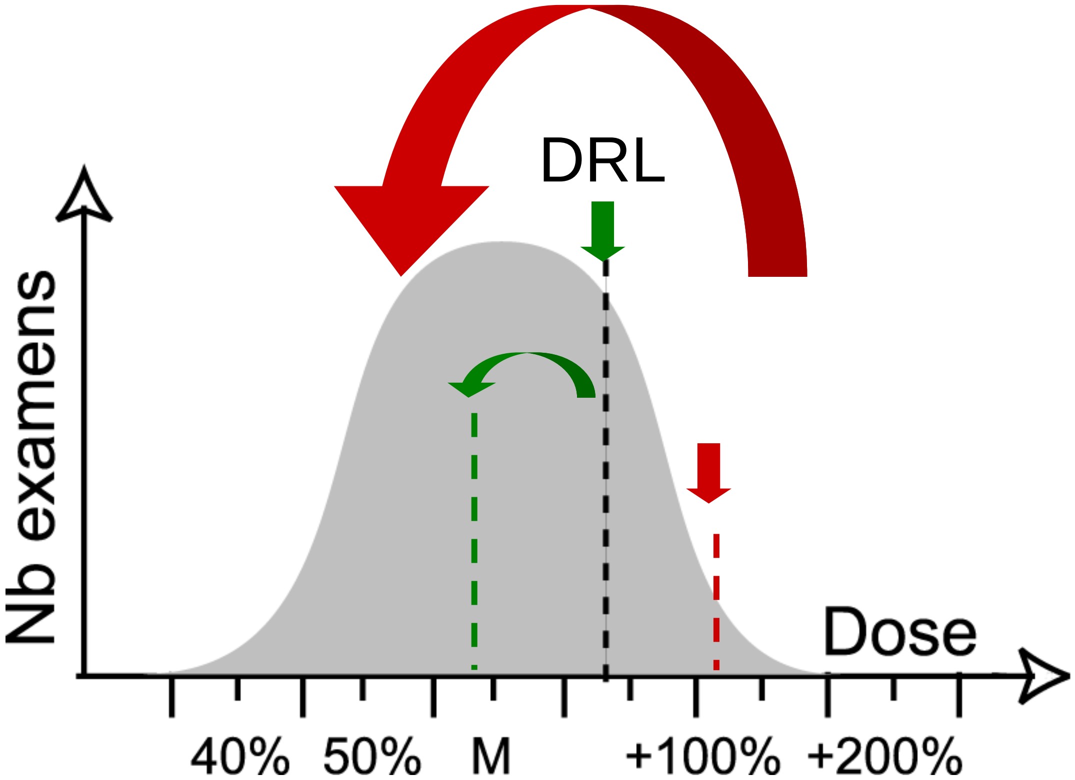
The DRL is a tool for optimisation



- If a local DRL value is above the national DRL, some optimisation is possible after searching the reasons why the local value is high

Diagnostic reference levels
Their optimisation

The DRL is a tool for optimisation



- If local DRLs decrease, the national DRLs should also decrease
- Continuous dynamic process of optimisation

Diagnostic reference levels
National strategy for optimisation

- DRL parameters are measured in each institution
- DRLs are established nationally
- Local reviews of DRL parameters are undertaken routinely
- Comparison of local DRLs is made with national values
- Actions are taken if local DRLs are exceeded consistently

Diagnostic reference levels
The future

- The DRL strategy implies a continuous dynamic process
- National DRLs can be compared at the European / International level for optimisation
- National DRLs must be optimised :
  - more values are needed
  - instrumentation is changing
- European DRLs to be re-established

Diagnostic reference levels
The future in France

- Mandatory measurements of local DRLs by ministerial order 12 February 2004
- Collection of data by IRSN to periodically re-establish national DRLs
- So far, contributions of 59% of nuclear medicine departments, but only 25 % of radiology departments !
- Changes take time !!

Diagnostic reference levels in medical practice

asn

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

NIVEAUX DE REFERENCE DIAGNOSTIQUES SCANOGRAPHIE

(arrêté du 12 février 2004)

Date : ……………… **Etablissement :** ……………………………………………………………………………..

Nom et prénom du radiologue responsable : …………………………………………………………………

Nom, prénom et coordonnées de la personne à contacter : …………………………………………………..
……

Marque et modèle de l'installation : ………………………………………………………………………..…..

Type : Mono-coupe ☐ Multi-coupes ☐

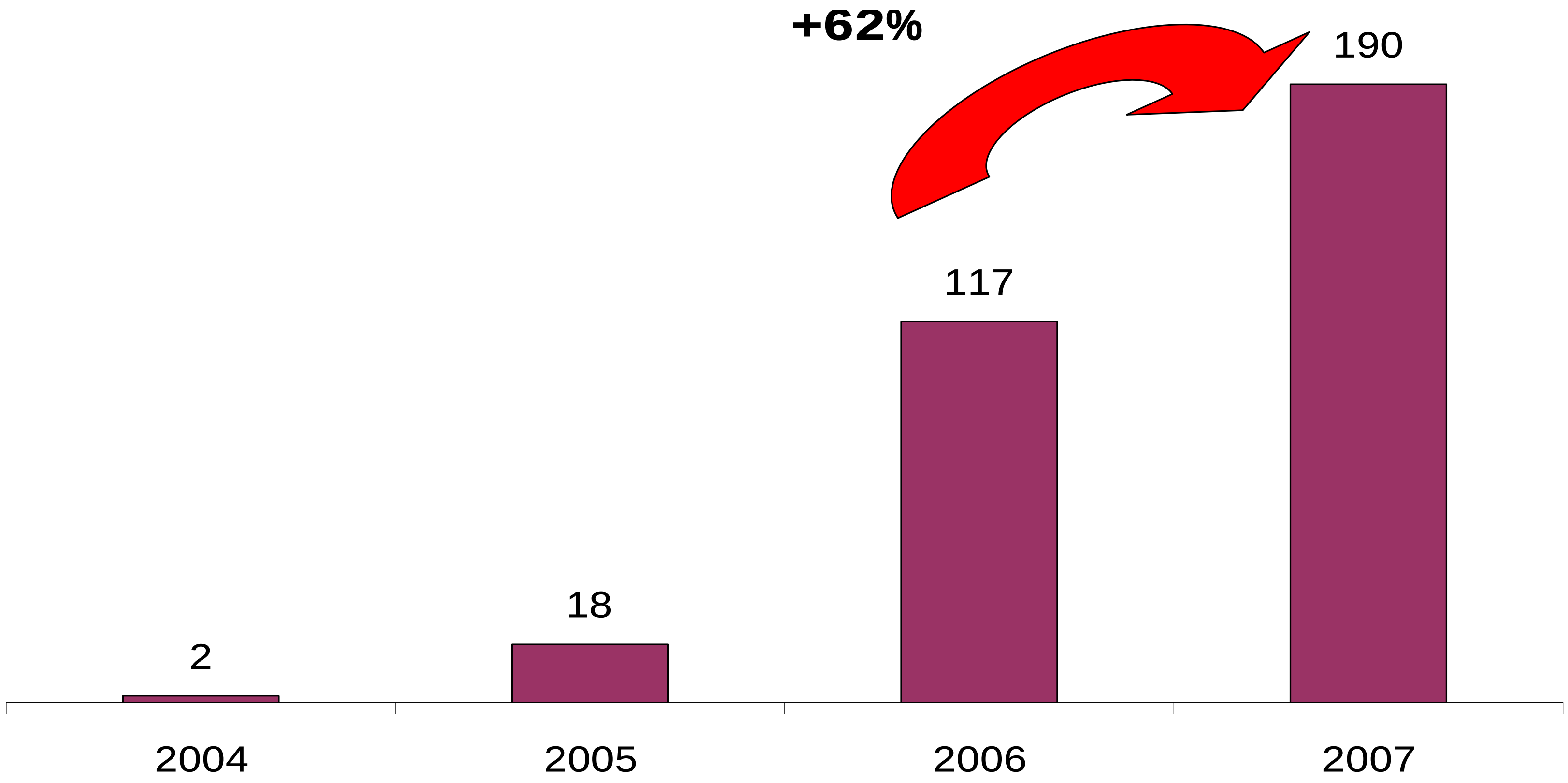
Préciser l'examen radiologique retenu pour le NRD :

Encéphale	☐	Thorax	☐	Abdomen	☐	Pelvis	☐

Période de recueil des données : du ……………….. au …………………..

Patient	Sexe	Age	Poids	Taille	kV	mAs (ou mA + tps de rotation)	Epaisseur de coupe (mm)	Config. de collimation (ex. 4x1 mm)	Pitch	Longueur d'acquisition (cm)	CTDI vol* (mGy)	PDL (mGy.cm)
1												
2												
3												

DRLs reports to IRSN : CT scan



25,1% of centers

Source IRSN

CT – DRLs in France 2008

EXAMINATION	CTDI (mGy)				CTDIv (mGy)		
	Centers	DRL	75th centile	Centers >DRL	Centers	75th centile	DRL proposed
Chest	57	20	18,8	19%	82	14,4	15
Brain	48	58	58,2	25%	75	74,3	75
Abdomen	9	25	19,6	2/9	12	14,1	15
Pelvis	0	25	NA	0%	0	NA	-
AP	23	25	22,7	13%	33	16,8	17
TAP	3	20	NA	0%	3	NA	15

Proposal to replace CTDI by CTDIv as DRL

Source IRSN

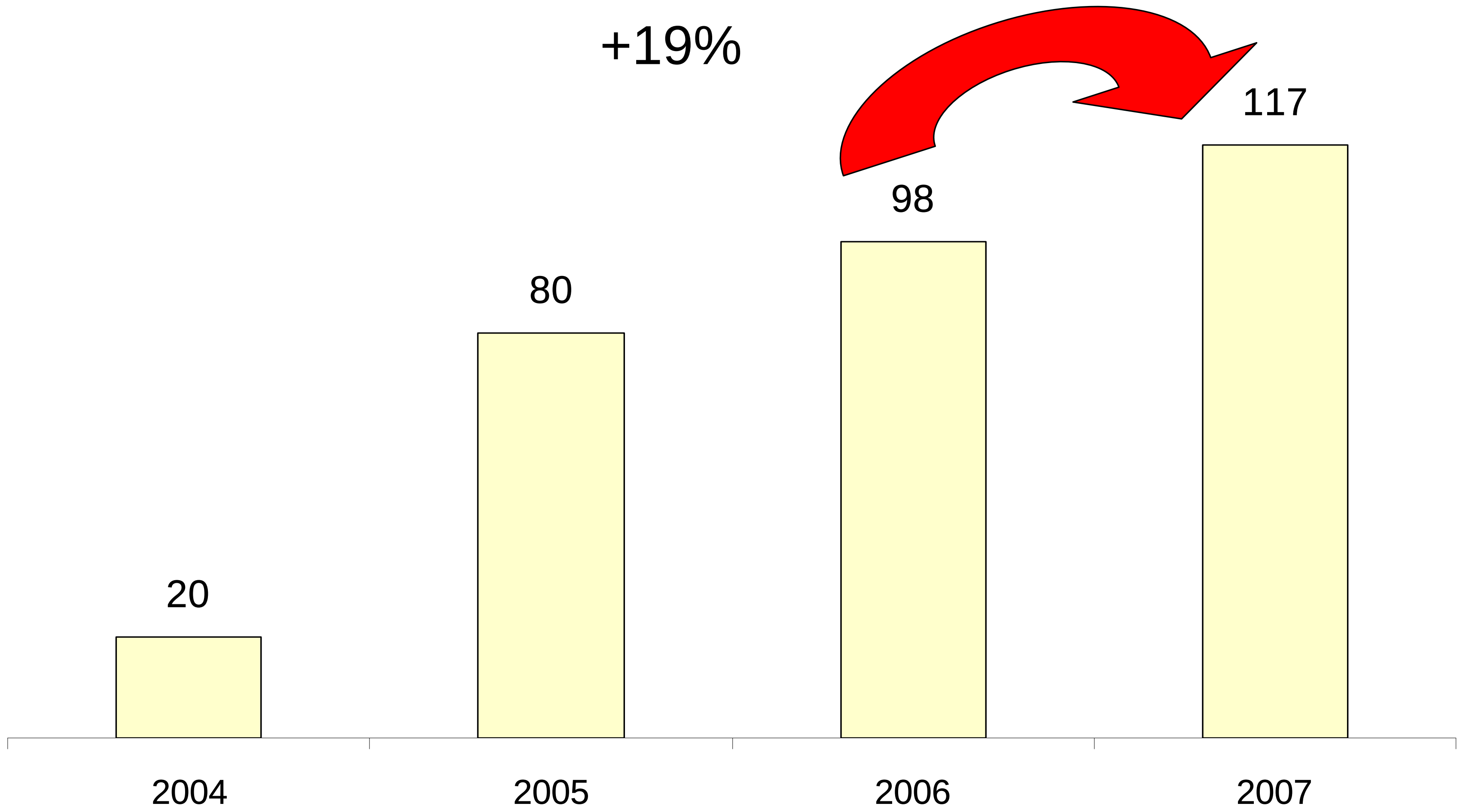
CT – DLPs in France 2008

Examination	Centers	DRL	75th centile	DRL proposed	Centers > DRLs
Chest	**86**	**500**	**475**	**475**	**20%**
Brain	**77**	**1050**	**1150**	**1050**	**38%**
Abdomen	**11**	**650**	**423**	**450**	**0%**
Pelvis	**0**	**450**	**NA**	**-**	**0%**
A + P	**33**	**1100**	**798**	**800**	**6%**
C + A + P	**3**	**1600**	**NA**	**1300**	**0%**

Proposal to decrease DRLs for all examinations except for the brain

Source IRSN

DRLs reports to IRSN : Nuclear medicine

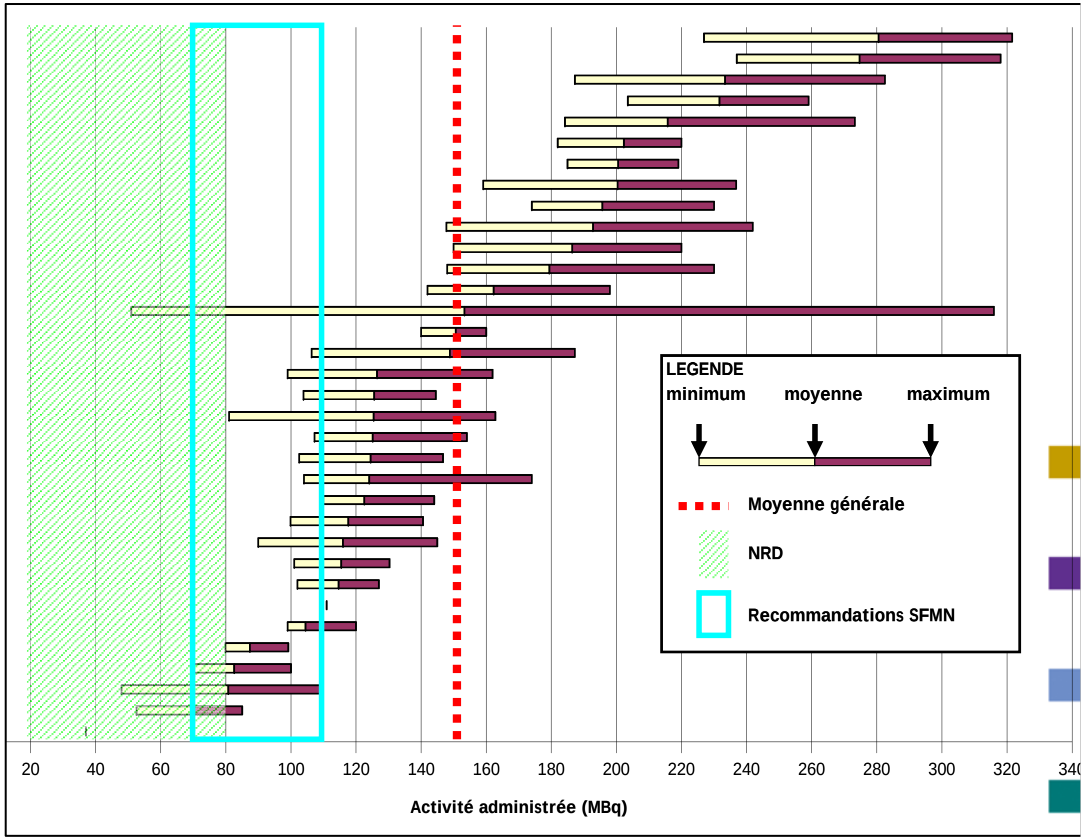


59% of centers

Source IRSN

Nuclear medicine DRL: thyroïd scan with ^{99m}Tc

Number of centers	**34**
DRLs (Recommended by manufacturer)	**20 à 80 MBq**
Recommendations SFMN	**70 à 110 MBq**
Mean	**151 ± 58 MBq**
Min	**37 MBq**
Max	**281 MBq**
Number of centers > DRLs	**32 (94%)**



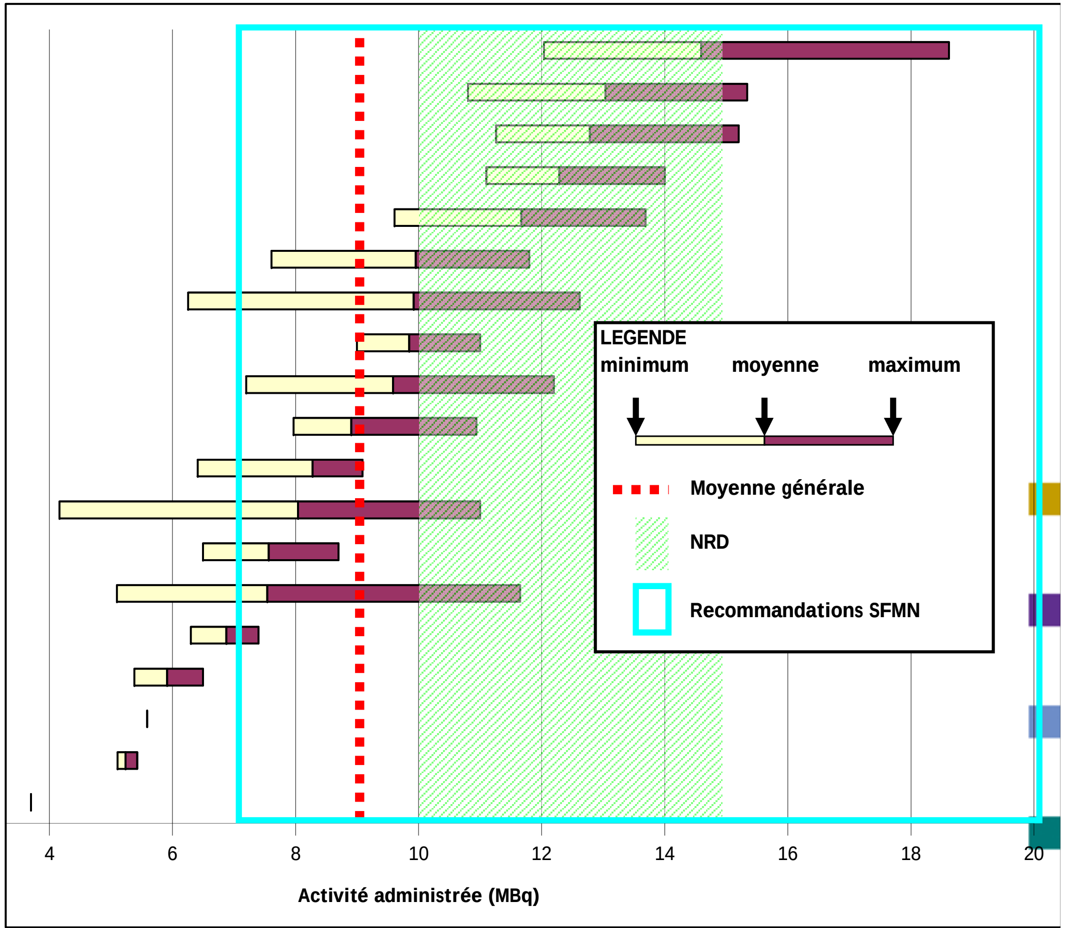
Large gap between manufacturers' DRL values and SFMN values

Almost all centers above

Source IRSN

Nuclear medicine DRL: thyroïd scan with ^{123}I

Number of centers	**19**
DRLs (Recommended by manufacturer)	**10 à 15 MBq**
Recommendations SFMN	**7 à 20 MBq**
Mean	**9,0 ± 2,9 MBq**
Min	**3,7 MBq**
Max	**14,6 MBq**
Number of centers > DRLs	**0**
Number of centers < DRLs	**14 (74%)**



Gap between manufacturers' values and SFMN values

All centers below maximum value

Source IRSN

Conclusions

- The DRL strategy constitutes a clever mechanism for the optimisation of doses in medical imaging
- DICOM headers of images will be helpful since they contain most information needed
- The process must continue at national and international level
- But do not forget that only useful examinations need to be optimized and unjustified examinations should not be performed !