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FRENCH DIAGNOSTIC REFERENCE LEVELS IN DIAGNOSTIC RADIOLOGY, COMPUTED TOMOGRAPHY AND NUCLEAR MEDICINE: 2004–2008 REVIEW

P. Roch* and B. Aubert
PRP-HOM/SER/UEM, Institut de Radioprotection et de Sureté Nucléaire, BP 17, 92262 Fontenay-aux-Roses, France

*Corresponding author: patrice.roch@irsn.fr

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After 5 y of collecting data on diagnostic reference levels (DRLs), the Nuclear Safety and Radiation Protection French Institute (IRSN) presents the analyses of this data. The analyses of the collected data for radiology, computed tomography (CT) and nuclear medicine allow IRSN to estimate the level of regulatory application by health professionals and the representativeness of current DRL in terms of relevant examinations, dosimetric quantities, numerical values and patient morphologies. Since 2004, the involvement of professionals has highly increased, especially in nuclear medicine, followed by CT and then by radiology. Analyses show some discordance between regulatory examinations and clinical practice. Some of the dosimetric quantities used for the DRL setting are insufficient or not relevant enough, and some numerical values should also be reviewed. On the basis of these findings, IRSN formulates recommendations to update regulatory DRL with current and relevant examination lists, dosimetric quantities and numerical values.

INTRODUCTION

The basic principles of radiation protection are justification, optimisation and dose limitation. In medical practice, dose limits cannot be applied and that is why optimisation should be taken into account with even more attention.

The concept of diagnostic reference level (DRL) was introduced by International Commission on Radiological Protection (ICRP) Publication 60[1] and its use was recommended in Publication 73[2]. Additional advice was provided in 2001 through ICRP Supporting guidance 2[3].

The most recent ICRP publications 103 and 105[4, 5] summarise previous definitions and recommendations about DRLs and their different fields of application.

On the basis of ICRP recommendations, EURATOM Directive 97/43[6] defines DRLs as 'dose levels in medical radio diagnostic practice 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 not expected to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied.' As part of European directive transposition in national law, France has promoted the establishment of national DRLs by the publication of the 24 March 2003 decree[7] and the 12 February 2004 order[8] for practical aspects.

The first aim of the DRL collection is to allow professionals to optimise doses delivered to the patients. The national DRL is an indicator of the most common level of dose for a particular type of examination. It is not supposed to be exceeded, and delivered doses are required to be, as much as possible, below the DRL value. Therefore, professionals have to compare their local values with the DRL to identify unjustified exceeding of the delivered dose, and they have to use the DRLs as an optimisation tool if their results are about or above the DRL value. In this case, the origin of doses higher than the DRL values should be identified. A systematic exceeding of the dose delivered to the patients can be due to a dysfunction of the imaging device (for example: automatic exposure in radiology), to an inappropriate protocol (for example: use of adult protocol for a child), to a lack of knowledge of the radiation protection rules or to a mix of these causes. French regulation has integrated the different ways of implementing the optimisation of patient dose in imaging departments. The performance and the quality of the imaging device have to be evaluated according to the quality control regulation requirements[9–14], protocols have to be established according to French Society of Radiology (SFR) reference guidelines[15], periodical training of the professionals concerned with radiation protection of the patients is required[16], doses have to be evaluated by a medical physicist[17], doses delivered to the patients have to be included in the examination report[18]

Table 1. French DRLs for diagnostic radiology (single view).

Adult		Paediatric		
Examination	ESD (mGy)	Examination	Age (y)	ESD (mGy)
Chest (PA)	0.3	Chest (AP)	0–1	0.08
Chest (LAT)	1.5	Chest (PA)	5	0.1
Lumbar spine (AP)	10	Chest (LAT)	5	0.2
Lumbar spine (LAT)	30	Skull (PA or AP)	5	1.5
Abdomen	10	Skull (LAT)	5	1
Pelvis (AP)	10	Pelvis (AP)	0–1	0.2
Breast	10	Pelvis (AP)	5	0.9
Skull (PA or AP)	5	Abdomen (PA or AP)	5	1
Skull (LAT)	3			

DRL, diagnostic reference levels; ESD, entrance surface dose; PA, postero-anterior; LAT, lateral; AP, antero-posterior.

and dosimetric data have to be collected and compared with national DRL values.

The French DRL order defines the types of examinations, with associated DRLs numerical values, and devolves on the French Institute for Radiological Protection and Nuclear Safety (IRSN) the responsibility of collecting dosimetric data sent by diagnostic radiology, computed tomography (CT) and nuclear medicine departments to periodically update the DRLs.

Therefore, IRSN assesses collected data, analyses them and gives recommendations to the national authority to update French DRLs according to national results.

The first report was published in 2008, referring to the 2004–06 data and a second one in 2010 reviewing the 2007–08 data.

This paper presents French DRL implementation method, assesses data evolution comparing the 2004–06 and the 2007–08 collecting periods and presents the results in perspective with future evolutions of collected data on examinations and DRL values.

MATERIALS AND METHODS

Implementation of DRLs in France

Diagnostic radiology and CT DRLs

It is recommended by European Council that the 75th percentile values observed in wide-scale surveys of typical doses for common examinations be used to assess DRL values.

In 2000, because of the absence of up-to-date and wide-ranging data for France, as the first step, European DRLs[19–21] have been proposed as starting points[22]. Then, a campaign of dose measurements was carried out to establish national DRLs[23]. This study showed a good agreement between doses measured from representative French practices and European guidelines.

Table 2. French DRLs for CT per sequence.

Examination	$CTDI_w$ (mGy)	DLP (mGy cm)
Brain	58	1050
Chest	20	500
Abdomen	25	650
Pelvis	25	450

CT, computed tomography; CTDI, weighted computed tomography dose index; DLP, dose length product.

According to the study results, French authorities defined national DRLs on the basis of European Commission (EC) DRLs.

In diagnostic radiology, DRLs were set for nine adult examinations and eight paediatric examinations, for a single view (Table 1).

The reference dosimetric quantities are entrance surface dose (ESD) and dose area product (DAP) but DRL values were set only for ESD, quoted from the EC guides.

For CT, DRLs were defined for four adult common examinations, and only per sequence (Table 2). Reference dosimetric quantities chosen for this modality were weighted CT dose index ($CTDI_w$) and dose–length product (DLP).

Nuclear medicine

As defined in the EC guidance on DRLs for medical exposures[24], the definition of DRLs in nuclear medicine is quite different from that in diagnostic radiology.

Table 3. French DRLs for nuclear medicine (administered activities).

Examination	Radionuclide	AMM (MBq)	
Bone	^{99m}Tc	300–700	
Lung perfusion	^{99m}Tc	40–200	
Thyroid	^{123}I	10–15	
	^{99m}Tc	20–80	
		Stress	Rest
Myocardial perfusion	^{99m}Tc	185–250	500–750
	^{201}Tl	110	110
Left ventricular ejection fraction	^{99m}Tc	750–950	
Kidney static	^{99m}Tc	30–120	
Renography	^{99m}Tc	40–200	
Brain perfusion	^{99m}Tc	350–500	
Somatostatin analogues	^{111}In	110–220	
Positron emission tomography	^{18}F	200–500	

AMM, 'Autorisation de Mise sur le Marché', e.g. marketing authorisations.

For diagnostic radiology, the dose should be below the reference level and as low as possible regarding efficient image quality but, in nuclear medicine, the reference level should not be exceeded but also approached according to the concept of 'optimal activity'. Therefore, the DRL values should be set with reference to the experience of professional groups, as starting points.

For French DRLs, in nuclear medicine the starting points were set from marketing authorisations [Autorisation de Mise sur le Marché (AMM)] issued by the French Health Products Safety Agency (ANSM, ex-AFSSAPS) and given for radiopharmaceuticals as a range of administered activities.

DRLs were set for 10 standard adult examinations, in terms of total administered activities (Table 3).

Data collection and analysis

Medical professionals of diagnostic radiology and nuclear medicine send DRL data to IRSN by postal mail, e-mail or fax, using forms established by IRSN for each modality (diagnostic radiology, CT and nuclear medicine).

A dedicated internet website (www.nrd.irsn.fr) gives all information necessary to promote collection of DRL data in diagnostic imaging departments: regulatory texts, internet ESD calculator (MICADO), reports and collection forms.

Professionals must select two examinations in the list defined in the 2004 order, collect dosimetric data for at least 20 standard-sized patients (from 60 to 80 kg) and send these data to IRSN each year. The two examinations chosen for the consecutive years should be different.

IRSN verify the data coherence and saves it in Excel® sheets for posterior analysis.

Because of the increase in the amount of data sent in the last several years, IRSN has developed a web-access database (https://basenrd.irsn.fr). This new way of sending DRL data has been available since March 2011.

Analyses consist in:

- assessment of statutory text implementation: number of departments having sent data for each modality;
- assessment of the number of each type of examination in radiology, computed tomography and nuclear medicine;
- statistical calculations on data examination: number of data, mean, 75th percentile, min, max, standard deviation (SD), number of data above DRL/2*DRL/4*DRL;
- comparison of the results with the recommendations of professional societies and DRLs.

RESULTS

Diagnostic radiology

'2004 DRL order' application

The number of diagnostic radiology departments in France is estimated to be ~5000. Between 2004 and 2008, the percentage of departments implementing the '2004 DRL order' increased from <1 to 23 % (Figure 1).

Examination distribution

The most transmitted data (Figure 2) correspond practically to the most frequent examinations

carried out in general diagnostic radiology departments. Even though professionals are free to choose two examinations each year in the 2004 order, the distribution is quite similar to the examination frequency as shown in the 'medical ionising radiation exposure of the French population in 2007' IRSN report[25].

Chest, lumbar spine, abdomen and pelvis are the most represented anatomical regions in the examinations.

Despite the ease of obtaining breast doses (part of the mandatory quality control on mammography), it represents only 6.2 % of the data.

A very small number of data concerning paediatric examinations were sent between 2004 and 2008 (about 3 %).

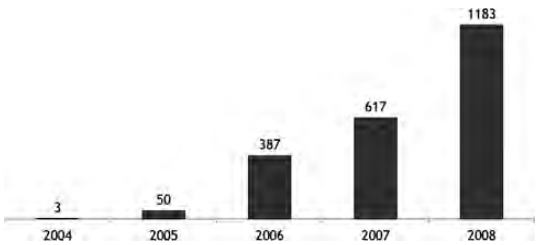

Figure 1. Number of radiology departments implementing 2004 DRL order from 2004 to 2008.

Examination data analysis

For all the examinations defined in the 12 February 2004 order, the doses distributions were plotted (complete report available at http://nrd.irsn.fr/index.php?page=radiologie). Only a representative examination (adult chest) is presented in this paper to show the methodology of analysis in detail.

Two main ways of determination of ESDs are used by professionals: calculation from acquisition parameters (43.5 % of ESD) or from DAP (53.8 %). Only 1.2 % of ESD were determined by direct measurement (thermoluminescent detector for example). For 1.5 % no indication was given about the ESD determination method.

Adult chest postero-anterior

The most numerous data concern chest radiography. Analysis based on the data received by IRSN is presented in Figure 3.

More than 50 % of the ESD data are calculated from DAP measurements (<30 % in 2004–06). The 75th percentile value, calculated from parameters or DAP, is stationary with ~0.4 mGy as against 0.3 mGy for the DRL value (Table 4).

The analysis takes into account the detector type and shows a rather great heterogeneity of patient dose depending on the detector technology used to carry out the examination (Figure 4).

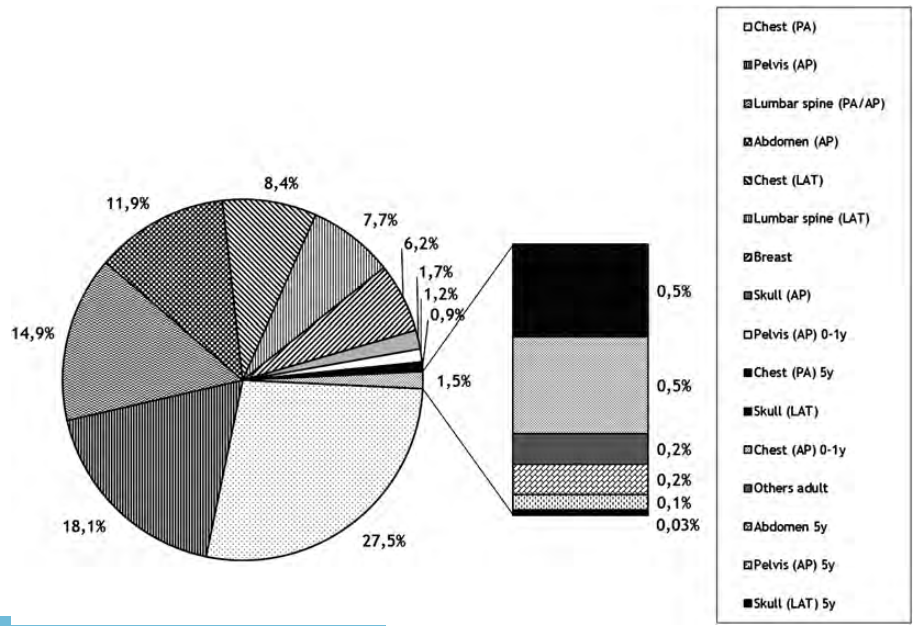

Figure 2. Distribution of examinations types sent by radiology departments in 2007-2008.

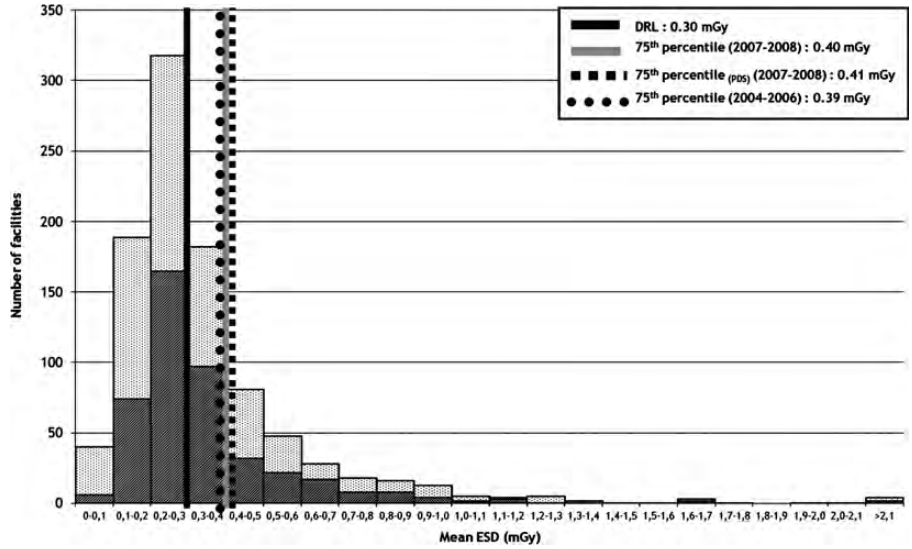

Figure 3. Distribution of radiology facilities depending on mean entrance surface dose (ESD) for chest examination (PA). ESD determined from DAP appears in point filled area. Continuous black mark refers to DRL, point mark refers to the 75th percentile of the 2004–2006 review, continuous grey mark refers to the 75th percentile of the 2007–2008 review in terms of ESD, square mark refers to the 75th percentile of the 2007–2008 review in terms of ESD calculated from DAP.

Table 4. Statistical data of facilities distribution depending on mean entrance surface dose for chest examination (PA).

Examination	Adult chest (PA)
Number of facilities	960 (318)[a]
DRL	0.30 mGy
75th percentile	0.40 mGy (0.39)
Mean $\pm$ 1 SD	0.36 $\pm$ 0.31 mGy (0.38 $\pm$ 0.31)
Minimal value	0.04 mGy (0.05)
Maximal value	4 mGy (2.1)
Number of departments above DRL	415 (43 %) [136 (43 %)]
Number of departments above 4*DRL	19 (2 %) [12 (3.8 %)]

[a]In brackets: the data are from 2004 to 2006 review.

From a dosimetric point of view, storage phosphor computed radiography is the most penalizing technology. The 75th percentile value for this technology is 0.39 mGy as against 0.27 mGy for a flat panel detector.

For the DAP data (Figure 5 and Table 5), the 75th percentile is significantly above the SFR recommended value[15] (33.3 vs. 25 cGy cm^2). A huge gap between minimal and maximal values is noticed.

Generally, analyses show a wide dose spread with a max/min factor up to 100.

Summary of DRL data of other examinations

Tables 6 and 7 show the evolution of collected data and ESD and DAP 75th percentiles for the 2004–06 and 2007–08 periods for the other examinations requested by the 'DRL' order.

For the most performed examinations (chest, lumbar spine, abdomen, pelvis and breast), the increase in DRL collected data is highly significant (a factor of 3.7–7) in improving statistical results (Table 7).

However, even if skull data present a highly relative increase, the absolute data number is weak because of a poor clinical indication for this examination.

On a dosimetric point of view, 75th percentile results are in quite a good agreement with regulatory DRL values (comparable or lower) except for chest postero-anterior (PA) examinations (0.4 vs. 0.3 mGy).

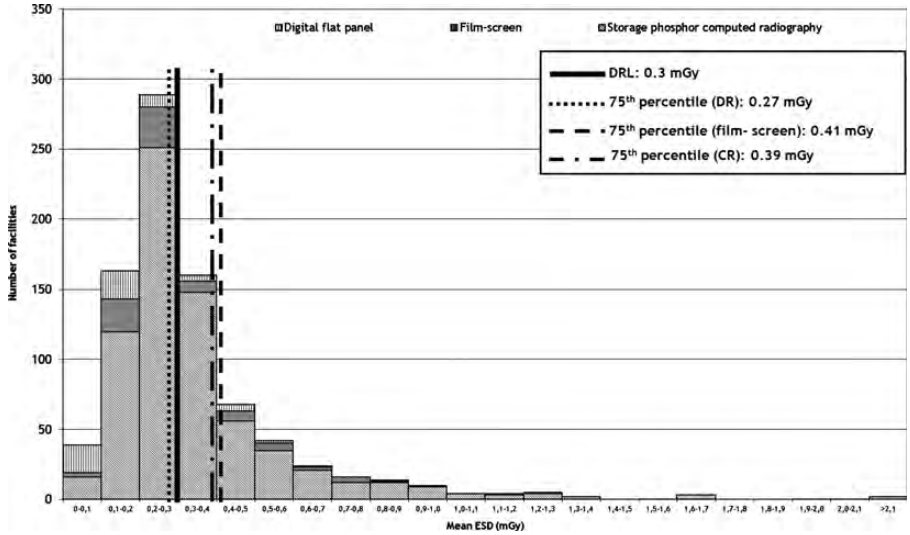

Figure 4. Distribution of radiology facilities depending on mean entrance surface dose and detector type for chest examination (PA). ESD from Computed Radiography (CR) appear in hatched area, ESD from film appear in grey and ESD from Digital Radiography (DR) appear in line filled area. Continuous black mark refers to DRL, short discontinuous mark refers to the ESD 75th percentile calculated for CR, discontinuous large mark refers to the ESD 75th percentile calculated for film and discontinuous square mark refers to the ESD 75th percentile calculated for DR.

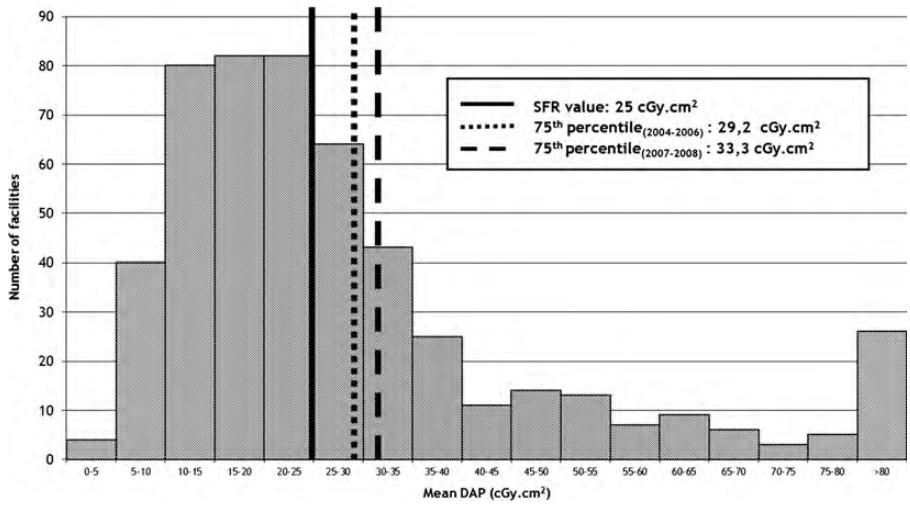

Figure 5. Distribution of radiology facilities depending on dose area product for chest examination (PA). Black mark refers to the SFR recommendation, short discontinuous mark refers to the 75th percentile of the 2004–2006 review, and large discontinuous mark refers to the 75th percentile of the 2007–2008 review.

For paediatric examinations, the number of collected data is so poor that no statistical analyses could be performed with acceptable margins of error.

As for ESD results, DAP 75th percentile results are in quite a good agreement with the SFR recommended values (comparable or lower) except for chest PA examinations (25 vs. 33 cGy cm^2). In the

Table 5. Statistical data of facilities distribution depending on mean DAP for chest examination (PA).

Examination	Adult chest (PA)
Number of facilities	514 (79)
SFR-recommended value	25 cGy cm^2
75th percentile	33.3 cGy cm^2 (29,2)
Mean $\pm$ 1 SD	31.2 $\pm$ 30.6 cGy cm^2 (29.5 $\pm$ 30.1)
Minimal value	4.6 cGy cm^2 (4.6)
Maximal value	326 cGy cm^2 (186)

DAP, dose area product; SFR, French Society of Radiology.

same way, the 2007–08 data strengthen the 2004–06 results.

Computed tomography

'2004 DRL order' application

The number of CT departments in France was estimated at 872 at the end of 2008. Between 2004 and 2008, the percentage of departments implementing the '2004 DRL order' increased from <1 to $\sim$50 % (Figure 6).

Examination distribution

As in diagnostic radiology, the most frequent data (Figure 7) are related to the most frequent

Table 6. Synthesis of data number and ESD 75th percentiles for adult diagnostic radiology examinations.

Examination	Number of departments		DRL (ESD mGy)	75th percentile (ESD mGy)	
	2004–06	2007–08		2004–06	2007–08
Chest (PA)	318	962	0.3	0.39	0.4
Chest (LAT)	56	295	1.5	1.33	1.21
Lumbar Spine(AP/PA)	139	520	10	10	10
Lumbar spine (LAT)	46	269	30	24	26
Abdomen (AP)	92	417	10	7.9	8.4
Pelvis (AP)	141	634	10	9.2	8.9
Breast	31	217	10	8	7
Skull (AP)	8	59	5	4.6	4.8
Skull (LAT)	2	18	3	ND	2.6

Number of departments and ESD 75th percentile for the 2004–06 and 2007–08 reviews are presented for the examinations in accordance with the 2004 DRL order and compared with respective DRL values. ND, not defined.

Table 7. Synthesis of data number and DAP 75th percentiles for adult diagnostic radiology examinations.

Examination	Number of departments		SFR-recommended values (DAP cGy cm^2)	75th percentile (DAP cGy cm^2)	
	2004–06	2007–08		2004–06	2007–08
Chest (PA)	79	514	25	29.2	33
Chest (LAT)	12	134	100	57	76
Lumbar Spine (AP/PA)	35	288	700	423	455
Lumbar spine (LAT)	6	132	1000	594	671
Abdomen (AP)	25	213	700	550	508
Pelvis (AP)	38	360	700	592	558
Breast (AGD)	4	59	2.5	1.7	1.62
Skull (AP)	3	30	—	ND	128
Skull (LAT)	2	10	—	ND	113

Number of departments and DAP 75th percentile for the 2004–06 and 2007–08 reviews are presented for the examinations in accordance with the 2004 DRL order and compared with respective SFR recommended values. AGD, average glandular dose (mGy).

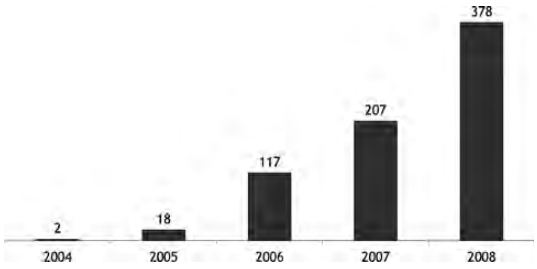

Figure 6. Number of CT facilities implementing 2004 DRL order from 2004 to 2008.

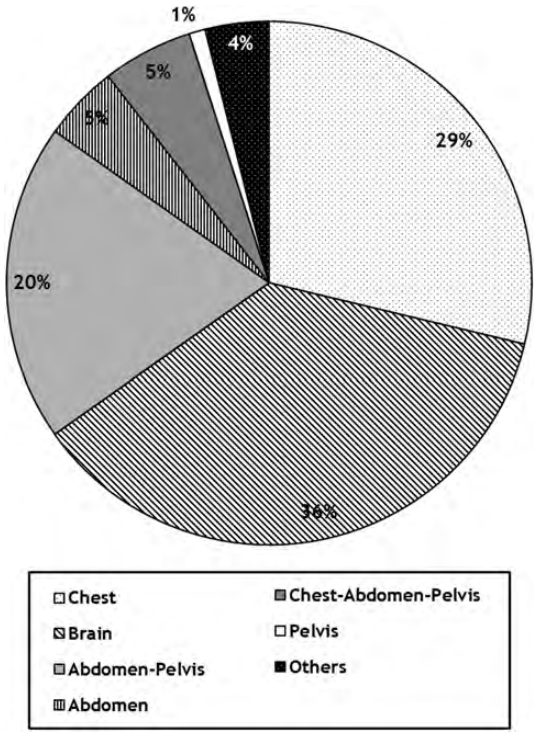

Figure 7. Distribution of examinations transmitted by CT departments in 2007 and 2008.

examinations carried out in general CT departments. For brain, chest and abdomen–pelvis (AP), similar frequency and DRL data percentages are highlighted[25]. These three examinations represent 84 % of the received DRL data and 76.3 % of the total CT examinations in France. The low difference is probably due to the lack of lumbar spine examination in the 2004 DRL order (frequency: 12.3 %).

Chest and brain CT examinations represent almost two-thirds of collected data.

AP CT is the third most sent examination (20 %), whereas it does not appear in the 2004 DRL order, as well as chest–AP (CAP) CT, which is more represented than abdomen and pelvis alone.

'Others' refers to examinations out of the range of the 2004 DRL order [sinus, lumbar spine, cervical spine, positron emission tomography (PET)-CT, radiotherapy] and too few to obtain statistical significant results.

Examination data analysis

For all the examinations defined in the 12 February 2004 order, the doses distributions were plotted. The complete results are available at http://nrd.irsn.fr/index.php?page=radiologie. Only a representative examination (brain) is presented in this paper to show the methodology of analysis in detail.

By a statutory point of view, DRLs are defined for a single sequence, not for the whole examination.

The presented results compare the 75th percentiles with the DRL values and although show analysis according to volume CT dose index ($CTDI_{vol}$) because this dosimetric quantity is now systematically available on CT machines.

Brain CT

Brain CT is the most collected examination. Analyses based on the data received by IRSN are presented in Figures 8–10.

Five times more data were collected in 2007 and 2008 than from 2004 to 2006 (Table 8). The $CTDI_w$ 75th percentile (58.2 mGy) was comparable with the DRLs (58 mGy) in 2004–06 and was reduced to 44.6 mGy in 2007–08. In the same way, DLP was above DRL (1150 vs. 1050 mGy) in 2004–06 and was reduced to 1042 mGy cm in 2007–08. The same decrease is observed for $CTDI_{vol}$ (74.3–62 mGy).

From 2004 to 2006, brain CT was the only examination presenting dosimetric data above the DRL value (DLP). The 2007–08 data show a consistent reduction of doses.

Summary of DRL data of other CT examinations

Tables 9–11 show the evolution of collected data and $CTDI_w$, DLP and $CTDI_{vol}$ 75th percentiles for the 2004–06 and 2007–08 periods. For the most performed examinations (chest and brain), the increase in DRL collected data is highly significant (a factor of 4–6) improving best statistical results.

For single abdomen and pelvis examinations, the number of data is very weak because of a poor

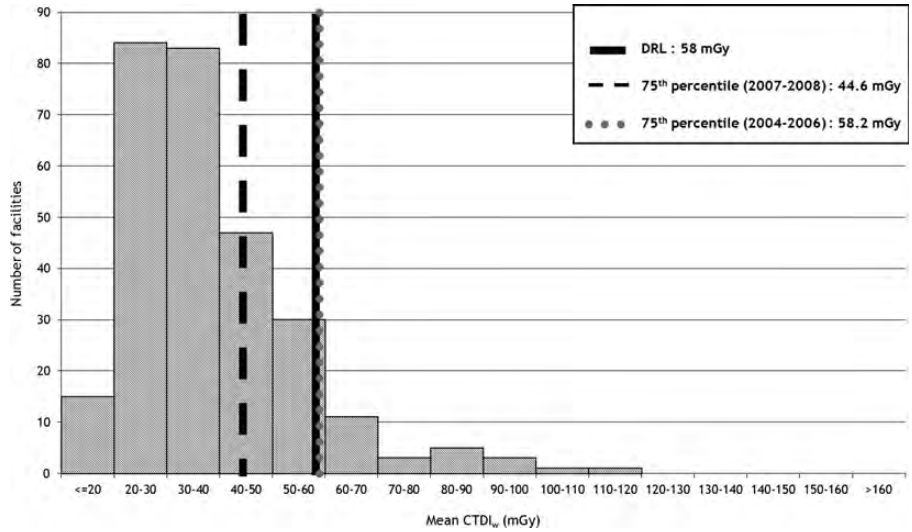

Figure 8. Distribution of CT facilities depending on CTDIw for brain examination. Black mark refers to DRL, point grey mark refers to the 75th percentile of the 2004–2006 review, and large black mark refers to the 75th percentile of the 2007–2008 review.

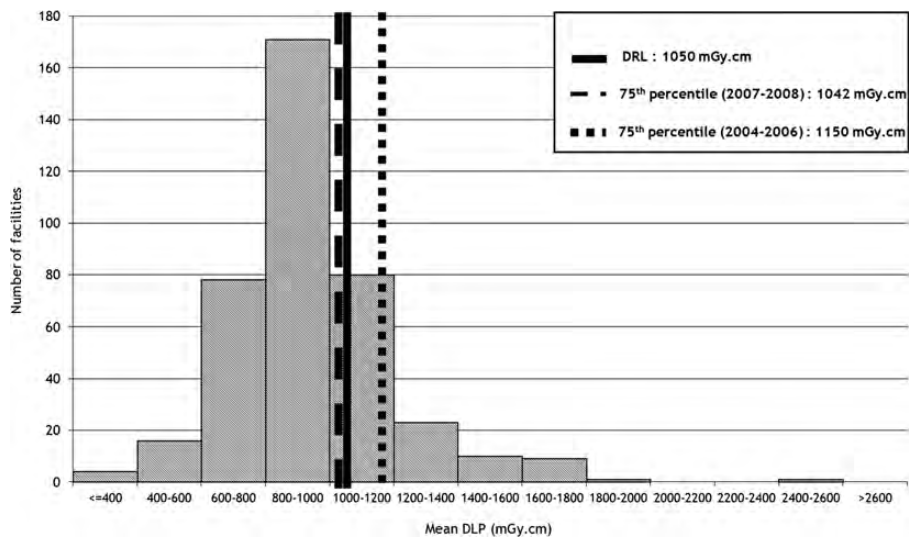

Figure 9. Distribution of CT facilities depending on DLP for brain examination. Black mark refers to DRL, square black mark refers to the 75th percentile of the 2004–2006 review, large black mark refers to the 75th percentile of the 2007–2008.

clinical indication for these examinations which have been replaced by AP and CAP examinations.

On a dosimetric point of view, the 75th percentiles results are consistent with statutory DRL values: comparable for brain CT and significantly inferior for chest, AP and CAP examinations.

Nuclear medicine

'2004 DRL order' application

The number of nuclear medicine departments in France was estimated at 202 at the end of 2008. Between 2004 and 2008, the percentage of

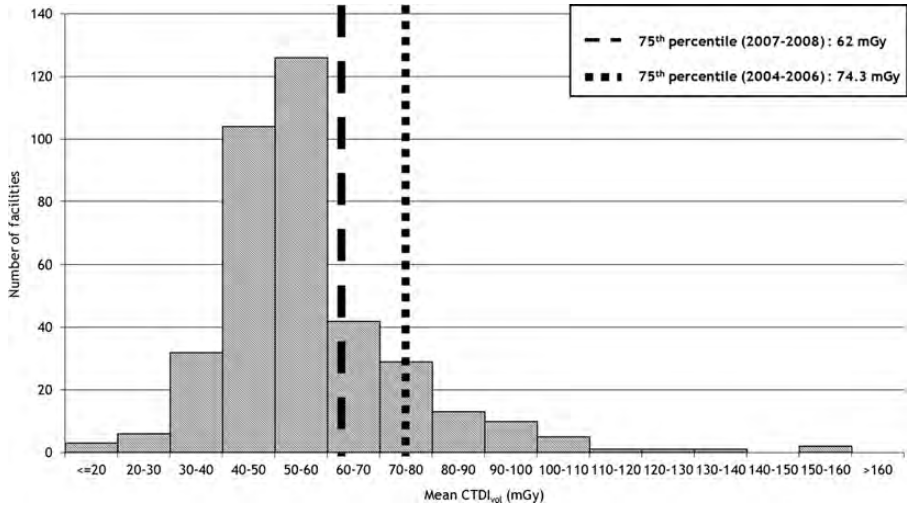

Figure 10. Distribution of CT facilities depending on CTDIvol for brain examination. Short discontinuous mark refers to the 75th percentile of the 2004-2006 review and large discontinuous mark refers to the 75th percentile of the 2007-2008 review.

Table 8. Statistical data of facilities distribution depending on $CTDI_{vol}$, $CDTI_w$ and DLP for brain CT examination (PA) per acquisition.

Examination period dosimetric quantities	Brain					
	2004–06 (80 facilities)			2007–08 (399 facilities)		
	$CTDI_{vol}$ (mGy)	$CTDI_w$ (mGy)	DLP (mGy cm)	$CTDI_{vol}$ (mGy)	$CTDI_w$ (mGy)	DLP (mGy cm)
Number of facilities	75	48	77	375	283	393
DRL	—	58	1050	—	58	1050
75th percentile	74.3	58.2	1150	62	44.6	1042
Mean ± 1 SD	62.9 ± 25.4	49.6 ± 28.6	998 ± 336	56.4 ± 17.7	38.6 ± 16	944 ± 252
Minimal value	34.1	22.6	426	13,5	11,1	259,6
Maximal value	152	152	2439	152	115,8	2436
>DRL	—	12 (25 %)	29 (38 %)	—	32 (11 %)	96 (24 %)
>2*DRL	—	2 (4.2 %)	2 (2.6 %)	—	0	1 (0.3 %)

Percentages values in parenthesis refer to the proportion of departments above the DRL and twice DRL.

Table 9. Synthesis of data number and wedged computed tomography dose index ($CTDI_w$) 75th percentiles for adult CT examinations.

Examination	Number of facilities		DRL (mGy)	75th percentile	
	2004–06	2007–08		2004–06	2007–08
Chest	57	229	20	18.8	16
Brain	48	283	58	58.2	44.6
Abdomen	9	37	25	19.6	18.9
Pelvis	0	7	25	ND	16.8
AP[a]	23	167	25[a]	22.7	20.9
CAP[a]	3	50	20[10]	ND	20

AP, abdomen–pelvis; CAP, chest–abdomen–pelvis.

[a]The AP (abdomen–pelvis) and CAP (chest–abdomen–pelvis) values are deduced from single chest, abdomen and pelvis DRL values.

Table 10. Synthesis of data number and dose length product (DLP) 75th percentiles for adult CT examinations.

Examination	Number of facilities		DRL (mGy cm)	75th percentile (mGy cm)	
	2004–06	2007–08		2004–06	2007–08
Chest	86	314	500	475	467
Brain	77	393	1050	1150	1042
Abdomen	11	51	650	423	550
Pelvis	0	11	450	ND	485
AP	33	214	1100	798	781
CAP	3	61	1600	ND	952

Table 11. Synthesis of data number and CT dose index to the volume ($CTDI_{vol}$) 75th percentiles for adult CT examinations.

Examination	Number of facilities		75th percentile	
	2004–06	2007–08	2004–06	2007–08
Chest	82	296	14.4	13.5
Brain	75	375	74.3	62
Abdomen	12	50	14.1	15.6
Pelvis	0	10	ND	19.4
AP	33	207	16.8	17
CAP	3	60	ND	18.8

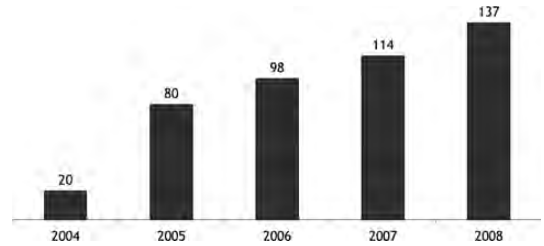

Figure 11. Number of nuclear medicine departments implementing 2004 DRL order from 2004 to 2008.

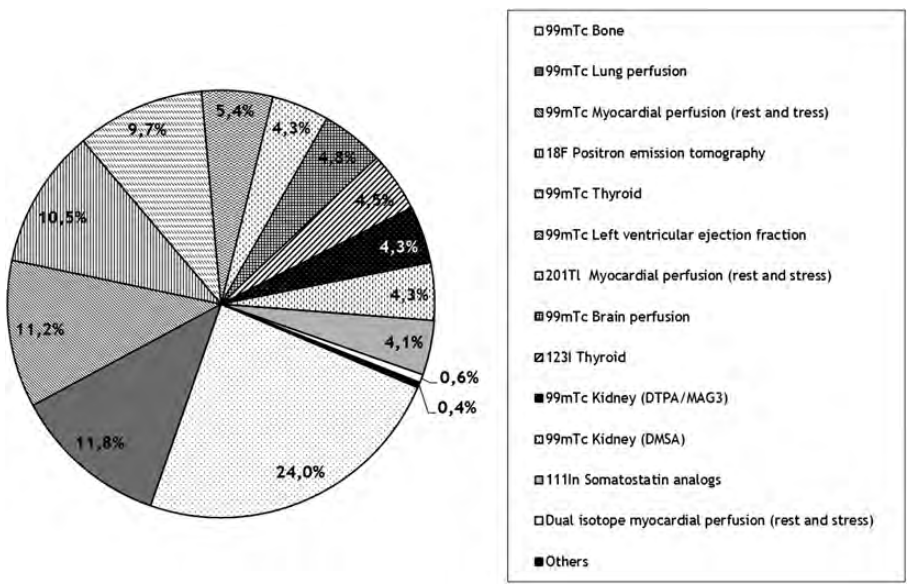

Figure 12. Distribution of examinations types sent by NM departments in 2007-2008.

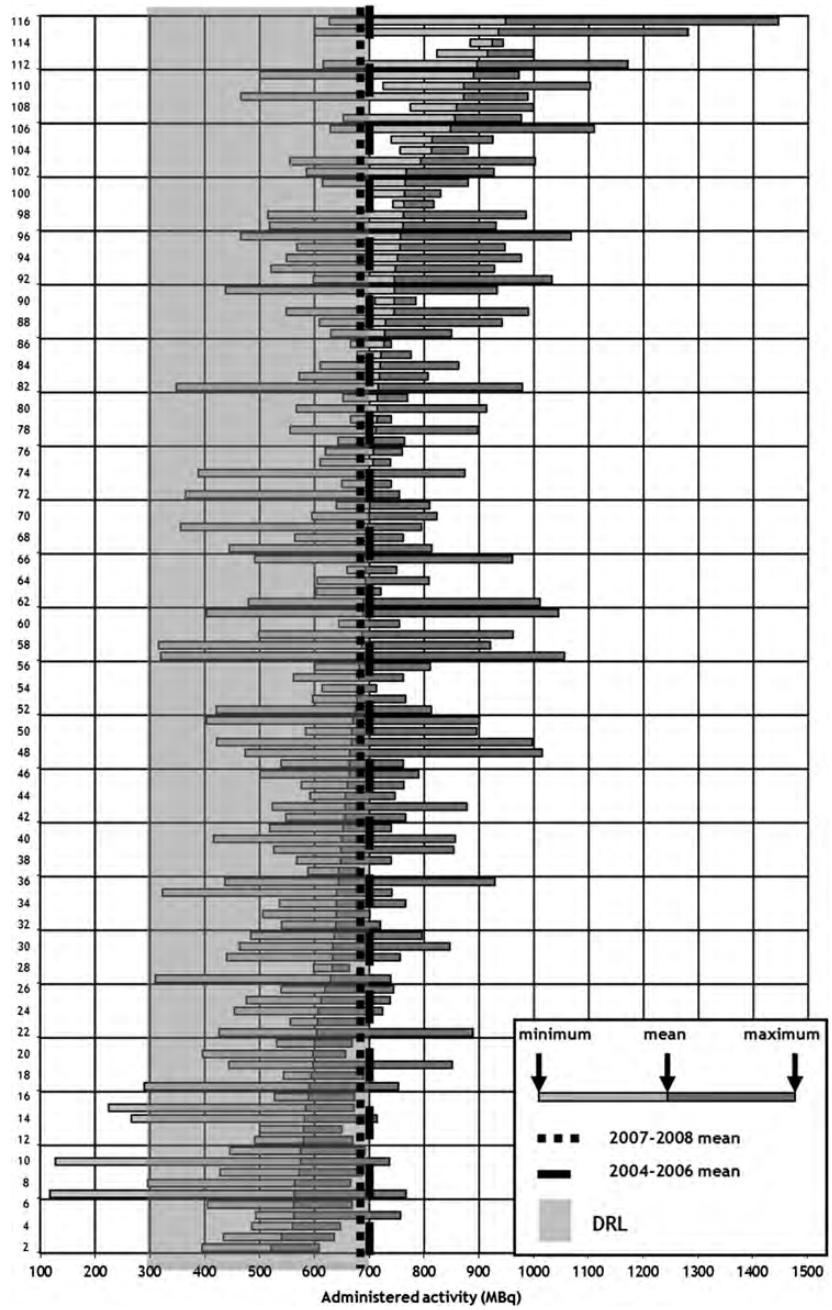

Figure 13. Distribution of nuclear medicine departments depending on total administered activities for bone examination. The grey area represents the DRL range of administered activity, large discontinuous black mark refers to the 2004-2006 review mean of administered activity and short discontinuous black mark refers to the 2007–2008 review mean of administered activity. Each line represents a department, the left extremity refers to the minimal administered activity of the 20 patients, the middle one refers to the mean administered activity and the right one refers to the maximal activity.

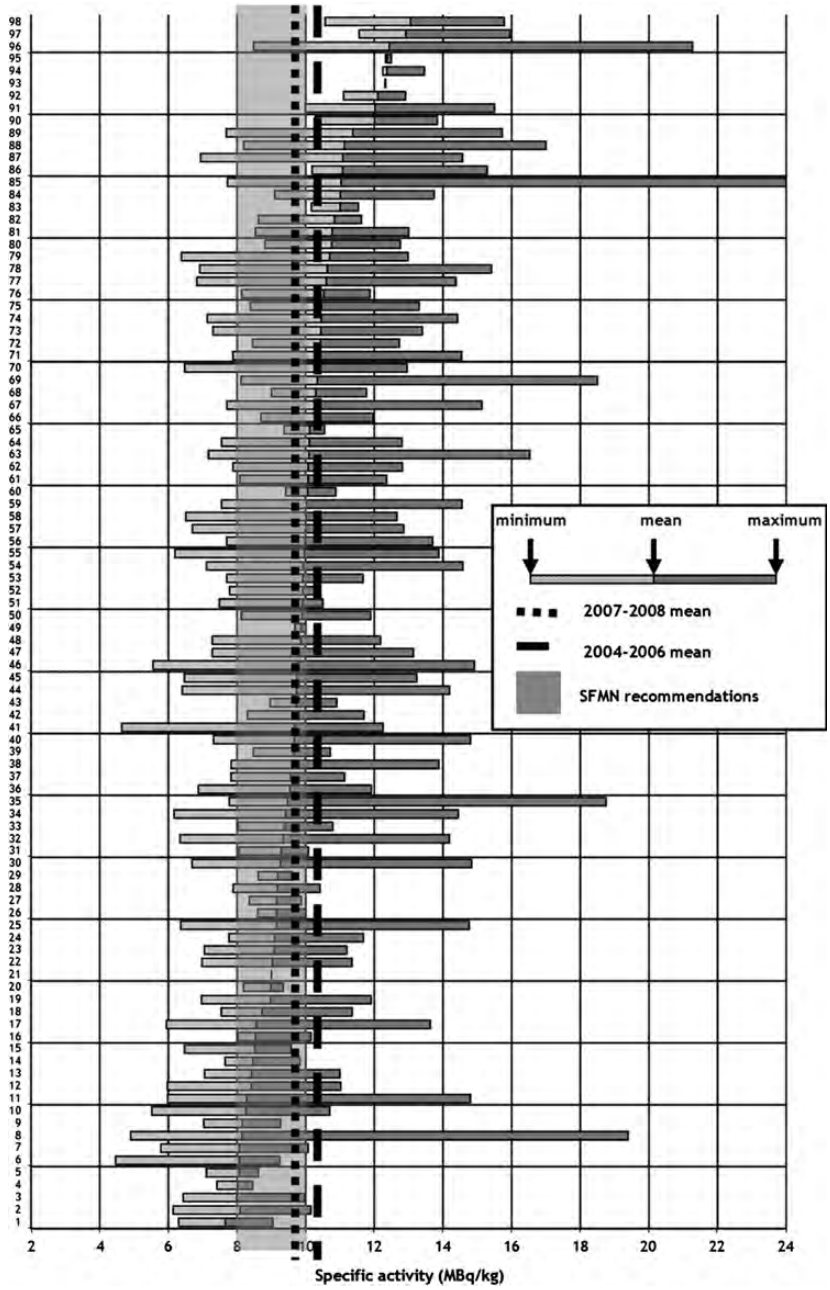

Figure 14. Distribution of nuclear medicine departments depending on specific administered activities for bone examination. The grey area represents the SFMN recommended range of administered activity, large discontinuous black mark refers to the 2004-2006 review mean of administered activity and short discontinuous black mark refers to the 2007-2008 review mean of administered activity. Each line represents a department, the left extremity refers to the minimal administered activity of the 20 patients, the middle one refers to the mean administered activity and the right one refers to the maximal activity.

departments implementing the '2004 DRL order' increased from 10 to ~65 % (Figure 11).

Examination distribution

As in diagnostic radiology and CT, the most sent examinations (Figure 12) are practically the most frequent examinations carried out in general nuclear medicine departments.

The six most sent examinations are the same as the six most frequent, but in a different order except for the first (bone) and the second (heart). Therefore, as nuclear medicine (NM) professionals can choose the two examinations they want to evaluate for DRLs, and as they are asked to change the examination each year, the repartition is more homogeneous than the frequency. For example, bone examination represents 41.9 % in frequency[25] but 24 % of the DRL data, in the same way, the heart frequency is 24 % as against 16.1 % for DRLs.

'Others' refers to examinations out of the range of the 2004 DRL order (parathyroid or DATScan for example) and too few to obtain statistical results.

Examination data analysis

For all the examinations defined in the 12 February 2004 order, the distribution of administered activities was plotted. The complete results are available at http://nrd.irsn.fr/index.php?page=medecine. Only a representative examination (bone) is presented in this paper to show the methodology of analysis in detail.

By a statutory point of view, only one dosimetric quantity is used to set DRL in nuclear medicine: the total administered activity of radiopharmaceutical.

The results presented compare the mean values of administered activities with the DRL values and the French Society of Nuclear Medicine (SFMN) recommendations. In the diagrams showing the results, each nuclear medicine department is represented with a horizontal line. The left extremity refers to the minimal administered activity of the 20 patients, the middle one refers to the mean administered activity and the right one refers to the maximal activity. The DRL range and the average values of administered activity for the 2004–06 and 2007–08 periods are represented.

Bone scintigraphy

Bone scintigraphy (whole body scan for adult) is the most collected examination.

A DRL is set in total administered activity and the SFMN has recommended a guidance activity value in terms of specific administered activity. When the patient's weight was mentioned in the transmitted data, the specific administered activity was calculated and compared with the SFMN recommendations.

Table 12. Statistical data of department's distribution depending on total administered activities for bone examination.

Examination	^{99m}Tc bone scintigraphy	
Period	2004–06	2007–08
Number of departments	114	115
DRL	300–700 MBq	
Mean ± 1 SD	705 ± 95 MBq	693 ± 91 MBq
Minimal value	476 MBq	521 MBq
Maximal value	1064 MBq	948 MBq
>DRL	58 (50.8 %)	47 (40.8 %)

Table 13. Statistical data of department's distribution depending on mass administered activities for bone examination.

Examination	^{99m}Tc bone scintigraphy	
Period	2004–06	2007–08
Number of departments	96	98
SFMN recommendations	8–10 MBq kg^{-1}	
Mean ± 1 SD	10.3 ± 1.4 MBq kg^{-1}	9.8 ± 1.2 MBq kg^{-1}
Minimal value	4.7 MBq kg^{-1}	7.6 MBq kg^{-1}
Maximal value	14.9 MBq kg^{-1}	13 MBq kg^{-1}

Analyses based on data received by IRSN are presented in Figures 13 and 14. The number of collected data is quite stable for the two periods, so results can be easily compared (Tables 12 and 13). The average of total administered activities is in the same order of magnitude around 700 MBq as well for the specific administered activity around 10 MBq kg^{-1}. About 40 % of the NM departments administer a value of activity superior to the upper level of DRL range (700 MBq).

Two groups can be distinguished between the different data:

- One showing a large range of administered activities, presuming that the total activity was determined according to the patient's weight.
- A second, wherein the distribution of administered activities is in a narrow range and in which it can be supposed that the activity value is independent of the patient weight, in opposition to SFMN recommendations.

Summary of DRL data of other examinations

Table 14 shows the evolution of the collected data and the mean of administered activities for the

Table 14. Synthesis of data number, total and mass administered activities for adult nuclear medicine examinations, compared with DRL values and SFMN recommendations.

Examination	Radiopharmaceutical	DRL (MBq)	SFMN recommendations	Mean (MBq)		Number of departments	
				2004–06	2007–08	2004–06	2007–08
Bone	^{99m}Tc-MDP/HDP/DPD	300–700	8–10 MBq kg^{-1}	705 (10.3 MBq kg^{-1})[a]	693 (9.8 MBq kg^{-1})[a]	114	115
Lung perfusion	^{99m}Tc-MAA	40–200	40–300 MBq	239	238	40	57
Kidney static	^{99m}Tc-DMSA	30–120	<100 MBq	137	136	11	21
Thyroid	^{123}I	10–15	7–20 MBq	9	8,8	19	23
	^{99m}Tc	20–80	70–110 MBq	151	146	34	46
Renography	^{99m}Tc-DTPA	37–370	<300 MBq	149	266	3	1
	^{99m}Tc-MAG3	40–200	<200 MBq	208	151	13	20
Brain perfusion	^{99m}Tc-ECD	370–1110	900–1100 MBq	868	785	6	14
	^{99m}Tc-HMPAO	350–500	750–900 MBq	929	750	2	9
Somatostatin analogues	^{111}In-pentetreotide	110–220	—	168	166	6	20
PET	^{18}F-FDG	200–500	150–550 (2–6)[b]	350	337	30	51
Myocardial perfusion							
First injection	^{201}Tl-chloride	<110	<110 (1.5[b])	116 (5.1[b])	114 (4.8[b])	33	18
Second injection	^{201}Tl-chloride	<37	<40 (0.5[b])	44 (0.58[b])	39 (0.52[b])	7	4
First injection (1 d)	^{99m}Tc-tetrofosmin, ^{99m}Tc-SESTAMIBI	185–250	<250 (3.7[b])	307 (4.1[b])	300 (4.33[b])	24	31
Second injection	^{99m}Tc-tetrofosmin, ^{99m}Tc-SestaMIBI	500–750	<750 (11[b])	825 (11[b])	797 (10.9[b])	28	33
Left ventricular ejection fraction	^{99m}Tc-pertechnetate, ^{99m}Tc-RBC	185–1000	550–1100	862	833	23	27

SFMN, French Society of Nuclear Medicine; PET, positron emission tomography.
[a]Specific activity.
[b]Specific activity in MBq kg^{-1}.

2004–06 and 2007–08 periods for other examinations.

For 8 of the 16 examinations, the mean value of administered activity is above the upper level of DRL range. Two examinations present a very high or almost a systematic exceeding of the DRL: ^{99m}Tc thyroid scintigraphy and myocardial perfusion tomography (^{201}Tl and ^{99m}Tc).

Some examinations exceed the DRL and are in accordance with the SFMN recommendations (lung perfusion scintigraphy for example), but these two references are often quite different.

Some results cannot be considered representative of the French nuclear medicine practice because of the very low number of data: diethylene triamine pentaacetic acid (DTPA) renography or HMPAO brain perfusion, for example.

DISCUSSION

Number of data

Six years after the publication of the French DRL order, its implementation by the diagnostic imaging professionals is still limited but regularly increases with ~25 % of the radiology departments and 50 % of the CT departments. The implementation in nuclear medicine has been faster, 65 % of the departments have transmitted data in 2008 and almost all the departments have, at least once, transmitted data since 2004.

Diagnostic radiology

For radiology, the collected data suggest some modifications of the DRLs. Firstly, DRLs should be set in DAP per radiography to avoid calculation errors of the ESD due to an imprecise knowledge of the field skin size. The definition of DRL per radiography is a usefull starting point to initiate an optimisation process in radiology departments, but in a second time it should be essential to set DRL in DAP for complete examinations, taking into account the fluoroscopy dose and the number of radiographies.

The distribution of examination types shows the necessity of updating the DRL examination list. On the one hand, skull examinations are no longer practised and on the other hand, examination of the cervix and dorsal spine or hips is often practised but not mentioned in the DRL order.

With regard to DRL values, the analysis of collected data shows the possibility of decreasing the DRL value (ESD) for a few examinations (chest lat., lumbar spine lat., abdomen, pelvis, breast).

When the 75th percentile calculated with the collected data is above the regulatory DRL but identified as an achievable level, the DRL value is kept unchanged. Even though DAP values were not set in the 2004 order, data were transmitted enabling definition of DAP values. When no data were available ESD and DAP values were calculated with PCXMC 2.0[26] on the basis of SFR recommended parameters of acquisition, and validated with literature data[27].

Adult examination types and associated ESD and DAP per radiography DRL values recommended by IRSN are presented in Table 15.

For paediatrics, the small number of collected data does not allow update of DRLs. The main difficulty reported by professionals is to collect a sufficient number of children of the same age (1,5 y). Moreover, the weight variability at the same age is very high, so the doses cannot be compared.

Table 15. IRSN recommendations for the DRL order update in adult radiology.

Examination	ESD (mGy)	DAP (cGy cm^2)
Chest PA	0.3	25
Chest LAT	1.2	90
Lumbar spine PA	10	450
Lumbar spine LAT	25	800
Abdomen	8	600
Pelvis AP	9	700
Breast	8 (ESAK: 7 mGy; AGD: 1.8 mGy)	
Cervical spine AP, LAT or 3/4	4	45
Thoracic spine AP	5	125
Thoracic spine LAT	7	200
Hips AP or LAT	8.5	200
Panoramic dental radiograph	—	20

ESAK, entrance surface air kerma; AGD, average glandular dose.

Table 16. IRSN recommendations for the DRL order update in paediatric radiology.

Examination	ESD (mGy)	DAP (cGy cm^2)
Chest AP newborn	0.08	1
Chest AP 10 kg (~1 y)	0.08	3
Chest AP 20 kg (~5 y)	0.1	5
Chest PA 30 kg (~10 y)	0.2	7
Chest LAT 20 kg	0.2	6
Chest LAT 30 kg	0.3	8
Pelvis 10 kg	0.2	4
Pelvis 20 kg	0.9	20
Pelvis 30 kg	1.5	40
Abdomen 20 kg	1	35
Abdomen 30 kg	1.5	70

Table 17. Comparison between IRSN recommendations for French DRLs and national DRLs from different countries in radiology for adults.

Examination: adult	IRSN	Germany (2010)[34]	UK (2005)[32]	Sweden (2002)[43]	Switzerland (2011)[33]	Italy (2000)[44]	USA (2005)[45]
Entrance skin dose per radiograph (mGy)							
Chest PA	0.3		0.15		0.15	0.4	0.25
Chest LAT	1.2		0.6		0.75	1.5	
Lumbar spine AP	10		5		7	10	5
Lumbar spine LAT	25		11		10	30	
Abdomen AP	8		4		10	10	4.5
Pelvis AP	9		4		3.5		
Breast (AGD)	1.8	2.5		1.3			
Cervical spine AP or LAT	4						1.25
Thoracic spine AP	5		4				
Thoracic spine LAT	7		7				
DAP per radiograph (cGy cm^2)							
Chest PA	25	16	11		15		
Chest LAT	90	55	30		60		
Lumbar spine AP	450	230	160		235		
Lumbar spine LAT	800	420	250		415		
Abdomen AP	600	300	260				
Pelvis AP	700	300	210	400	250		
Thoracic spine AP	125	130	90				
Thoracic spine LAT	200	170	140				
Panoramic dental radiograph	20		8.2				

AGD,average glandular dose.

Table 18. Comparison between IRSN recommendations for French DRLs, national DRLs from different countries and results of a European survey in paediatric radiology.

Examination: paediatric	IRSN	Germany (2010)[34]	Austria (2010)[30]	European survey (2008)[29]
Entrance skin dose per radiograph (mGy)				
Chest new-born	0.08		0.055	0.135 (0.062–0.353)
Chest 10 kg/1 y	0.08		0.07	0.240 (0.042–0.607)
Chest 20 kg/5 y	0.1		0.082	0.228 (0.043–0.423)
Chest 30 kg/10 y	0.2		0.108	0.434 (0.054–0.660)
Chest LAT 20 kg	0.2			
Chest LAT 30 kg	0.3			
Abdomen AP 20 kg	1		0.511	0.275–0.752
Abdomen AP 30 kg	1.5		0.966	0.6–0.882
Pelvis 10 kg	0.2			0.048–0.420
Pelvis 20 kg	0.9			0.475–2.15
Pelvis 30 kg	1.5			0.807–2.73
DAP per radiograph (cGy cm^2)				
Chest newborn/3.5 kg	1	0.5	1.7	8.8 (1.1–38.6)
Chest 10 kg/1 y	3	1.5	2.3	13.6 (1.4–35.8)
Chest 20 kg/5 y	5	2.5	2.6	23.3 (2.2–39.8)
Chest 30 kg/10 y	7	3.5	3.7	39.5 (2.2–57)
Chest LAT 20 kg/5 y	6	4		
Chest LAT 30 kg/10 y	8	6		
Abdomen AP 20 kg/5 y	35	25	11	8.4–10
Abdomen AP 30 kg/10 y	70	35	36	
Pelvis 10 kg	4			
Pelvis 20 kg	20	15		
Pelvis 30 kg	40	25		

That is why IRSN recommends the definition of paediatric DRLs in terms of weight instead of age.

ESD and DAP levels are determined from the collected data, PCXMC calculations and literature data[28–31].

Paediatric examination types and associated ESD and DAP per radiograph DRL values are presented in Table 16.

Table 19. IRSN recommendations for the DRL order update in adult CT.

Examination	$CTDI_{vol}$ (mGy)	DLP (mGy cm)
Chest	15	475
Brain	65	1050
AP	17	800
CAP	20	1000
Lumbar spine	45	700

AP, Abdomen–pelvis; CAP, chest–abdomen–pelvis.

Tables 17 and 18 show a comparison of the IRSN suggested DRLs and the most recent published DRLs of other countries, when it was possible. Tables 17 and 18 present the comparison for adults and children, respectively.

For adults, the proposed values are consistent with DRLs of other countries but are mostly higher than those of the UK[32] and Switzerland[33], which are set both in ESD and DAP and have been recently updated. The use of ESD is discarded in Germany since the last update of DRLs, nowadays DRLs are set only in terms of DAP[34].

Some comparisons were not possible for several DRLs because some countries, for example Sweden[34], have set their DRLs for complete examinations and not per radiography.

The high values of French DRLs can be explained by two points:

- Concerning the values set according to a large number of data, for example thorax AP, the value can be considered representative of the practice.

Table 20. IRSN recommendations for DRLs update in paediatric CT.

Examination	Weight: 10 kg (1 y)		Weight: 20 kg (5 y)		Weight: 30 kg (10 y)	
	$CTDI_{vol}$ (mGy)	DLP (mGy cm)	$CTDI_{vol}$ (mGy)	DLP (mGy cm)	$CTDI_{vol}$ (mGy)	DLP (mGy cm)
Brain	30	420	40	600	50	900
Facial bones	25	200	25	275	25	300
Petrosal bone	45	160	70	280	85	340
Chest	3	30	4	65	5	140
AP	4	80	5	120	7	245

Table 21. Comparison between IRSN recommendations for French DRLs and national DRLs from different countries in CT.

Examination: Adult	IRSN	Germany (2010)[34]	UK (2003)[46]	Sweden (2002)[43]	Switzerland (2011)[47]	Ireland (2010)[48]	USA (2008)[52]
Volume computed dose index ($CTDI_{vol}$) per sequence (mGy)							
Brain	65	65	65[a]/100[b]	75	65	66/58	75
Chest	15	12	13[a]/14[b]	20	15	9	
AP	17				15	12	
CAP	20		12[a]/14[b]		15	10/12	
Lumbar spine	45	42–16		55	30		
Dose length product (DLP) per sequence (cGy cm^2)							
Brain	1050	950	930	1200	1000	940	
Chest	475	400	580	600	450	390	
AP	800				650	600	
CAP	1000		940		1000	850	
Lumbar spine	700	250[c]/500[d]		800	850		

[a]Single-slice CT (SSCT).
[b]Multi-slice CT (MSCT).
[c]Intervertebral disc (axial).
[d]Bone (helical).

Table 22. Comparison between IRSN recommendations for French DRLs and national DRLs from different countries in paediatric CT.

Examination Paediatric	IRSN	Germany (2010)[34]	UK (2003)[46]	Switzerland (2011)[47]
Volume-computed dose index (CTDIvol) per sequence (mGy)				
Brain 10 kg/1 y	30[a]	33[a]	30[a]	33[a]
Brain 20 kg/5 y	40[a]	40[a]	45[a]	40[a]
Brain 30 kg/10 y	50[a]	50[a]	50[a]	50[a]
Facial bones 10 kg/1 y	25[a]			11[a]
Facial bones 20 kg/5 y	25[a]			13[a]
Facial bones 30 kg/10 y	25[a]			17[a]
Chest 10 kg/1 y	3[b]	4[b]	12[a]	3.5[b]
Chest 20 kg/5 y	4[b]	7[b]	13[a]	5.5[b]
Chest 30 kg/10 y	5[b]	10[b]	20[a]	8.5[b]
AP 10 kg/1 y	4[b]	7[b]		5[b]
AP 20 kg/5 y	5[b]	12[b]		8[b]
AP 30 kg/10 y	7[b]	16[b]		13[b]
Dose length product (DLP) per sequence (cGy cm^2)				
Brain 10 kg/1 y	420[a]	400[a]	270[a]	390[a]
Brain 20 kg/5 y	600[a]	500[a]	470[a]	520[a]
Brain 30 kg/10 y	900[a]	650[a]	620[a]	710[a]
Facial bones 10 kg/1 y	200[a]			95[a]
Facial bones 20 kg/5 y	275[a]			125[a]
Facial bones 30 kg/10 y	300[a]			180[a]
Chest 10 kg/1 y	30[b]	30[b]/60[a]	200[a]	55[b]
Chest 20 kg/5 y	65[b]	65[b]/130[a]	230[a]	110[b]
Chest 30 kg/10 y	140[b]	115[b]/230[a]	370[a]	210[b]
AP 10 kg/1 y	80[b]	85[b]/170[a]		145[b]
AP 20 kg/5 y	120[b]	165[b]/330[a]		255[b]
AP 30 kg/10 y	245[b]	250[b]/500[a]		475[b]

[a]'Head' 16-cm diameter CT dosimetry phantom.
[b]'Body' 32-cm diameter CT dosimetry phantom.

So the principle of optimisation is probably not implemented sufficiently by professionals. A frequent use of a phosphor detector, which enables obtaining a useful image with a wide dose range, is probably one of the main causes of dose exceeding.

- Concerning the values set according to calculation results, the SFR-recommended parameters of acquisition used for the calculation can be considered referring to old technologies. In fact, the SFR recommendations[15] were published in 2001 and flat panel detectors, which require a lesser dose than do film or phosphor detectors, were very weakly used at that time.

For paediatric radiology, the number of DRLs set in other countries is limited. The suggested DRLs are also consistent with Austrian DRLs[30] and the results of a survey in 12 European centres[29]. The IRSN-proposed DRLs are about twice above German DRLs[34], which have been recently decreased.

Computed tomography

For CT, as well as for radiology, the results show the necessity to update the examination list and to modify the dosimetric quantities required for DRL setting.

In the current DRL order, CT doses are represented by $CTDI_w$ and DLP for a sequence. The definition of DRL in $CTDI_{vol}$ would allow taking into account the pitch, which is an influential factor of patient dose. Moreover, $CTDI_{vol}$ is displayed on the control panel, not the $CTDI_w$.

DLP for complete examination should also be set. Indeed, DRLs can be adhered to but if the examination includes too many sequences, the patient dose optimisation is not effective.

Examinations initially defined in the regulation were based on EC guides published in 1999[21] but clinical practice and CT technology have massively changed. So on the one hand, examinations such as those of single abdomen or single pelvis are no longer performed, and on the other hand, AP, CAP and lumbar spine CT are now very common examinations.

Propositions of new numerical values of $CTDI_{vol}$ and DLP are based on the analysis of collected data.

No paediatrics examinations were set in the 2004 DRL order, whereas children are a very radiation-sensitive population and CT the most radiation exposing diagnostic modality. As no data were

Table 23. IRSN recommendations for the DRL order update in adult NM examinations.

Examination	Total activity (MBq)	Specific activity (MBq kg^{-1})
^{99m}Tc skeleton	700	10
^{9m}Tc lung perfusion	200	—
^{99m}Tc thyroid	80	—
^{99m}Tc left ventricular ejection fraction (any radiopharmaceutical)	850	—
^{99m}Tc kidney static	120	—
Renography (MAG 3)	150	—
Renography (DTPA)	370	—
^{99m}Tc brain perfusion (ECD)	800	—
^{99m}Tc brain perfusion (HMPAO)	500	—
^{99m}Tc myocardial perfusion: first injection	250	4
^{99m}Tc myocardial perfusion: Second injection 1-d protocol Rest or stress injections 2-day protocol Stress injection dual isotope protocol	750	11
^{201}Tl myocardial perfusion: rest or stress injections	110	1.5
^{201}Tl myocardial perfusion: second injection	40	0.5
^{18}F-FDG positron emission tomography	350	5
^{123}I thyroid	10	—
^{111}In somatostatin analogues	170	—

Table 24. IRSN recommendations for the DRL order update in paediatric nuclear medicine.

Examination		Administered activity (MBq) depending on children weight (kg)				
		3.5	10	20	30	40
^{99m}Tc skeleton		40	95	170	240	310
^{99m}Tc lung perfusion		10	15	30	40	50
Thyroid	^{123}I	3	3	5	8	10
	^{99m}Tc	10	15	30	40	50
^{99m}Tc left ventricular ejection fraction		80	150	270	400	500
Renography	^{99m}Tc (MAG3)	15	25	35	45	50
Normal renal function:	^{99m}Tc (DTPA)	35	70	100	125	150
Abnormal renal function		20	40	70	100	125
Brain perfusion	^{99m}Tc (ECD)	110	110	155	220	285
	^{99m}Tc (HMPAO)	100	140	250	355	460
^{18}F-FDG positron emission tomography	15	40	70	100	125	

available from DRL collecting, IRSN suggests, in a first step, to use the results of the 2007–08 IRSN-SFIPP (French-speaking Society for Paediatric and Prenatal Imaging) study[35]. The purpose of the study was to evaluate current exposure levels from paediatric CT examinations. A survey was conducted at hospital sites affiliated to the SFIPP. Values of theoretical $CTDI_{vol}$ and calculated PDL were obtained for three age groups (1, 5 and 10 y) for typical scanning indications of different anatomical regions.

Tables 19 and 20 present the IRSN recommendations for the DRL order update in CT scan.

The comparison of these recommendations (Tables 21 and 22) with DRLs from other countries shows quite a good agreement between the values.

Nuclear medicine

For nuclear medicine, the list of regulatory examinations is quite representative of the clinical procedures currently performed. Therefore, this list should specify the type of radiopharmaceutical because one examination can be performed with different radiopharmaceuticals, and each of them can require radically different levels of activities.

Table 25. Comparison between IRSN recommendations for French DRLs and national DRLs from different countries in nuclear medicine for adults.

Examination	Radio-pharmaceutical	IRSN	Finland (2009)[49]	Bulgaria (2009)[49]	Germany (2003)[50]	UK 2006 rev.2011[51]	Sweden (2007)[53]	Switzerland (2006)[38]	Greece (2011)[54]
		Administered activity (MBq)							
Bone	^{99m}Tc MDP, HDP, DPD	700	700	640 planar 740 SPECT	500 benign 600 malign	600 800 SPECT	600	700	735
Lung perfusion	^{99m}Tc MAA	200	150	150	100	100	125	180	180
Renography	^{99m}Tc MAG3	150	150	150	100	100	110	100	183
	^{99m}Tc DTPA	370	300	185	150	300	200	200	540
Kidney static	^{99m}Tc-DMSA	120	—	—	70	80	80	120	—
Myocardial perfusion, SPECT	^{99m}Tc MIBI/ Tetrofosmin	250+750 1000	1100 2×600	1100 560	1000 —	800 800	1200 2×600	300+900 2×600	— —
	^{201}Tl	110	—	—	—	80	—		111
Left ventricular ejection fraction	^{99m}Tc RBC	850	800	—	—	800	—	750	—
Brain perfusion, SPECT	^{99m}Tc HMPAO/ ECD	500/800	—	—	550	500	1000/800	800	—
Thyroid	^{99m}Tc pertechnetate	80	150	100	75	80	150	75	183
	^{123}I	10	—	—	—	20	—	—	—
Positron emission tomography	^{18}F FDG	350	370		370 2D	400	—	—	—

The definition of the DRLs as a single value of activity instead of a large range based on marketing authorisations would be suitable. The difference between minimal and maximal values is too large to give a guidance value to professionals. Moreover, the incoherence between DRLs and SFMN recommendations for some examinations sometimes makes the DRL optimisation tool quite ineffective.

The determination of activity to be administered to patient should be based on the weight, when it is justified (bone, heart, PET). Table 23 presents the IRSN recommendations for the DRL order update in adult nuclear medicine.

In the 2004 DRL order, no paediatric DRLs were set for nuclear medicine and the need to define has been considered a priority.

As no sufficient data were collected since 2004, IRSN decided to recommend paediatric activities calculated with the 2008 European Association of Nuclear Medicine (EANM) method[36]. A DRL value was proposed for the most frequent examinations for five representative weights (3.5, 10, 20, 30 and 40 kg). Table 24 presents the IRSN recommendations for the DRL order update in paediatric nuclear medicine.

In Table 25, a comparison of IRSN-suggested DRLs in nuclear medicine for adults with other countries shows good agreement and no significant difference between the values. For children, no data were available in the literature in terms of total administered activities except in an Irish study[37]. For four similar examinations concerning bone, kidney and thyroid, the Irish DRLs are comparable with IRSN-proposed DRLs. In Switzerland, fractions of the adult activity were published as DRLs, on the basis of the 1990 EANM recommendations[38, 39].

Limitation and perspective of the study

IRSN proposes an update of current DRLs taking into account the results of the data collection since 2004. The scope of the modifications is, for this first update of the regulation, restricted by a lack of participation of radiology departments, which leads to a very weak number of data for several examinations (for example: paediatrics). As a consequence, some DRL values have been set according to calculation results and literature data that are not purely representative of the French practice. Imaging departments and professionals have to be permanently reminded of the importance of the DRL data collection for a better implementation of dose optimisation: on the one hand, for a better representativeness of the DRLs and on the other hand, for a better radiation protection of patients regarding the steady increase in the number of examinations performed in France. So the participation of the professionals has to be encouraged by professional societies and required by authority. It is the only way for the French DRLs to be revised more frequently in the future to induce a dose decrease as it was observed in the UK[32]. The evolution of DRLs is a long-term process, which started recently in France (2004) and the example of the UK shows that British DRLs have needed ~20 y for a dose decrease by a factor of 2.

After the first updating of the French DRLs that were initially taken from European DRLs and which consists in a huge revision of the regulation, the next step of this work will be to introduce DRL values for complete examinations including fluoroscopy in radiology, all sequences in CT and other imaging modalities in nuclear medicine[40]. In the future, a proposal for DRLs for interventional radiology is expected[41].

CONCLUSION

On the basis of the 2004–08 data, IRSN published periodic reports presenting all the analyses and recommendations to update regulatory DRL texts.

Six years after the publication of the DRL order, the periodic review allows IRSN to promote a continuous process of dose reduction by updating examination types and DRL values according to the national results.

The 2004 French DRL order was updated in January 2012[42], taking into account current and common clinical practice and facilities. This update modifies some collected dosimetric quantities and examination lists. Some new DRL numerical values based on the collected data are proposed in radiology, CT and nuclear medicine.

The lack of data in several examinations, especially in paediatrics, does not allow IRSN to propose an update of the DRLs. But, on the basis of the observation of the frequency of imaging examinations performed on children[25], IRSN considers the definition of paediatric DRL a huge priority. Therefore, values from the literature or calculation are proposed as starting points.

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