



Comments to the regulations and general advice (SSI FS 2002:2) of the Swedish Radiation Protection Authority on diagnostic standard doses and reference levels within x-ray diagnostics

These comments can be regarded as a complement to the general advices and give among other things the background to these advices in more detail.

Introduction

Medical x-ray diagnostics is an indispensable practice for patients to be taken care of in an adequate way. The benefit for the patient is normally much larger than the negative points as e.g. the radiation risk. This doesn't imply that the radiation risk can be neglected – the patients have the right that this risk is minimised as far as possible, i.e. that the examination is optimised such that the radiation dose and with that the radiation risk is not higher than necessary to achieve the intended diagnostic result. Since 1994 formal requirements exist in SSI's regulations that all examinations must be justified and optimised.

A number of surveys have shown that the patient doses for the same type of examination vary very much between different hospitals and examination stands. There are reasons to suspect that where the highest doses are found deficiencies exist with respect to optimisation. That is where the concept of diagnostic reference levels fits in, the major purpose of which is to identify and if possible to take measures against the presence of high patient doses. In this way it is expected that the patient doses and the spread between them will be reduced on a long view. The measured standard doses must be comparable with each other, i.e. must have been derived with the same methods and with sufficient accuracy. Therefore it is important that the procedures described in the present regulations are followed as far as possible and that the (dose-) measuring instruments are calibrated in a satisfactory way.

The documentation of patient and investigation data is necessary for the follow-up of the patient doses. When investigating high doses an analysis of these data may provide direct indications on the cause for the high dose and on suitable measures. Also when comparing different x-ray laboratories in the same or in different hospitals these data can provide information on which possible improvements could be performed for reducing the patient dose.

The effective dose E is a quantity directly correlated with the radiation risk. For a normal population this risk is taken as 5×10^{-5} radiation induced cancer deaths for an effective dose of 1 mSv. For an accurate calculation of E detailed knowledge is needed regarding the irradiation geometry, the beam quality and the patient's anatomy, which is mostly difficult, not to say impossible to achieve. The purpose here of estimating the radiation risk is more to estimate the relative risk between examinations and different techniques or procedures than to assess the absolute risk for individual patient. For this purpose it is fully satisfactory to use generalised standard calculations with established conversion factors.

In chapter 1 such conversion factors are given for the various examination types which allow the calculation of the effective dose based on the diagnostic standard dose. Chapter 2 and 3 are describing the background and giving the definitions for the quantities for the diagnostic standard doses applicable for computed tomography and mammography more extensively.

1 Effective dose

1.1 Conventional x-ray examinations

The quantity dose-area-product (DAP) is correlated with the total radiation energy that is deposited in the patient. The effective dose E is dependent on the irradiation geometry (which part of the body is irradiated) and on the radiation quality. For different types of examinations conversion factors have been calculated, based on how the examination is performed normally with respect to irradiation geometry and radiation quality. The effective dose is calculated with the simple formula

$$E = E_{\text{DAP}} \times \text{DAP} \quad (\text{mSv})$$

The conversion coefficients E_{DAP} are shown for some examinations in table 3.

Table 3: Conversion coefficients E_{DAP} ¹⁾ for the calculation of the effective dose by means of the value for the dose-area-product.

Examination	Conversion factor E_{DAP} mSv/Gy×cm ²
Heart and chest, chest health check	0,18
Coronary angiography (one or more vessels)	0,18
Barium enema with double contrast	0,28
Urography with urethra compression	0,18
Lumbar spine and SI joints	0,21
Pelvis	0,29

¹⁾ From the Nordic report series on radiation protection issues, No 5 - Nordic guidance levels for patient doses in diagnostic radiology, 1996

Remark: Instead of DAP the more correct denomination KAP (kerma-area-product) was used frequently in the past. In accordance with international practice DAP is used here which makes the quantity more comprehensible among those who are no experts in radiation protection.

1.2 Computed tomography examinations

For a certain anatomical region E can be calculated according to the formula

$$E = E_{\text{DLP}} \times \text{DLP} \quad (\text{mSv})$$

with E_{DLP} being a conversion factor depending on the anatomical region.

Table 4: Conversion coefficients for calculating the effective dose by means of the DLP²⁾

Anatomical region	Conversion coefficient E_{DLP} (mSv/(mGy×cm))
Head	0,0023
Neck	0,0054
Thorax	0,017
Abdomen	0,015
Pelvis	0,019

²⁾ From European Commission, European guidelines on quality criteria for computed tomography. (1999) EUR 16262

1.3 Mammography

For examinations with mammography the average glandular dose in the breast is directly related to the radiation risk – the effective dose is not a suitable quantity. The risk for radiation induced breast cancer death is between $4\text{--}20 \times 10^{-6}$ per mGy AGD.

2 Dose quantities for computed tomography

The basic quantity is the Computed Tomography Dose Index, CTDI. It is defined as the integral over the dose profile (for one revolution of the x-ray tube) along a line parallel with the axis of rotation divided with the nominal slice thickness d .

$$\text{CTDI} = \frac{1}{d} \int_{-a}^{+a} D(z) dz \quad (\text{mGy}) \quad (1)$$

$D(z)$ = air kerma along a line parallel with the axis of rotation

d = nominal slice thickness

In the literature different integration limits, dose quantities and phantom materials are used. Here we use the integration limit ± 50 mm, the dose quantity air kerma and a phantom of PMMA with a diameter of 160 mm and 320 mm for simulation of the head and the trunk, respectively. The direct measured dose quantity is

$$\text{CTDI}_{100} = \frac{1}{d} \int_{-50\text{mm}}^{+50\text{mm}} D(z) dz \quad (\text{mGy}) \quad (2)$$

The average value for CTDI_{100} in a volume in the phantom with the thickness d is called the weighted CTDI-value CTDI_w and is calculated according to

$$\text{CTDI}_w = 1/3 \text{CTDI}_{100C} + 2/3 \text{CTDI}_{100P} \quad (\text{mGy}) \quad (3)$$

CTDI_{100C} = CTDI_{100} -value measured in the centre of the standard phantom and

CTDI_{100P} = CTDI_{100} -value measured in the periphery of the standard phantom, 10 mm beneath the surface.

The equations (2) and (3) are valid for axial scans. For the calculation of the average absorbed dose in the irradiated volume from a scan series, CTDI_{vol} , CTDI_w and also the pitch factor is needed. The pitch factor P is equal with the ratio between the patient table movement between two consecutive revolutions of the x-ray tube and the nominal slice thickness, a definition that is applied here both for conventional axial and for helical technique.

CTDI_{vol} is calculated according to:

$$\text{CTDI}_{vol} = 1/P \times \text{CTDI}_w \quad (\text{mGy}) \quad (4)$$

DLP is calculated according to the formula:

$$\text{DLP} = N \times d \times \text{CTDI}_w \quad (\text{mGy} \times \text{cm}) \quad (5)$$

N = number of revolutions of the x-ray tube.

DSD and DRL for DLP are referring to the value for the total examination. If the examination consists of more than one series DLP for the total series, DLP_{TOT} , is the sum of DLP for the various series:

$$DLP_{TOT} = \sum_i DLP_i \quad (\text{mGy}\times\text{cm}) \quad (6)$$

However, DSD for $CTDI_{vol}$ is referring to the value from that series that is giving the highest value.

Remark 1: Certain multi-slice equipments are displaying a pitch factor that is calculated according to a different definition. For the dose calculations described here the above mentioned definition shall be used.

Remark 2: For examinations with helical technique "d" in the formulas above is referring to the nominal slice thickness with respect to the irradiation geometry, which may differ from the slice thickness in the images reconstructed. That also applies to helical technique with multi-slice equipment, where "d" refers to the nominal value of the total width of the active detectors.

3 Dose quantities for mammographic examinations

DSD for patients

DSD as well as DRL for mammography is given as the quantity average absorbed dose in glandular breast tissue (AGD) in the unit mGy. AGD is determined indirectly through calculation by means of a number of measured or recorded parameter. The method is described in detail in the European protocol on dosimetry in mammography. European Commission, (1996) EUR 16263. It comprises the following steps:

1. Measurement of the half-value-layer in mm Al for all clinical relevant radiation qualities (= combinations tube voltage, filtration and anode material) beneath the compression plate along a line from the focal spot to a point 60 mm from the chest wall in the imaging plane along the mid-line of the image receptor.
2. The radiation output (air kerma free in air) beneath the compression plate as a function of the tube loading is determined for all relevant radiation qualities in a well defined distance from the focal spot, e.g. 45 mm above the breast support.. The radiation output is measured along the line from the focal spot that is intercepting the imaging plane 60 mm from the chest wall along the mid-line of the image receptor.

For patient examinations the following parameters are recorded:

3. Tube voltage (kV), filtration and anode material
4. Tube loading (mAs)
5. Thickness of the compressed breast.

Note: If the compression plate is sagging the breast thickness is given as the distance between compression plate and breast support 60 mm from the chest wall.

By means of the values recorded for the breast thickness, the tube loading and the measured output the air kerma free in air is calculated for the entrance plane of the breast (ESAK = entrance surface air kerma). Note that corrections according to the inverse square law have to be made for the different breast thicknesses.

With the conversion factors according to table 5 for the relevant half-value-layer the average absorbed dose to the glandular breast tissue AGD is calculated for the respective exposure. The coefficients are applicable for breasts with a composition 50% adipose and 50% glandular tissue, but the difference between different compositions is small and is not important in this context.

$$AGD = g \times E_{SAK} \quad (\text{mGy}) \quad (7)$$

For every patient the average breast thickness, the average AGD-value per exposure and the average AGD-value per breast is calculated.

Table 5: Conversion coefficient g (mGy/mGy) for the calculation of the average dose to the glandular breast tissue (AGD) from E_{SAK}-values for various breast thicknesses and radiation qualities ¹⁾.

HVL (mmAl)	Thickness of the compressed breast (mm)					
	30	40	50	60	70	80
0,25	0,234	0,174	0,137	0,112	0,094	0,081
0,30	0,274	0,207	0,164	0,135	0,114	0,098
0,35	0,309	0,235	0,187	0,154	0,130	0,112
0,40	0,342	0,261	0,209	0,172	0,145	0,126
0,45	0,374	0,289	0,232	0,192	0,163	0,140
0,50	0,406	0,318	0,258	0,214	0,177	0,154
0,55	0,437	0,346	0,287	0,236	0,202	0,175
0,60	0,466	0,374	0,310	0,261	0,224	0,195
0,65	0,491	0,399	0,332	0,282	0,244	0,212

¹⁾ European protocol on dosimetry in mammography. European Commission, (1996) EUR 16263

The dosimeter used for the measurement of the half-value-layer and the radiation output must be calibrated according to common practice. The device that indicates the thickness of the compressed breast must be calibrated. The inaccuracies for measurements of the individual patient should be estimated and recorded.

DSD for phantoms

According to SSI FS 2000:2, 19 § and table 1 item 6 the reference doses with the standard phantom shall be measured at least once a year. These reference doses are the standard breast doses AGD_{FK} and AGD_{F0} with clinically used film density and net density 1,0, respectively, measured with a 45 mm thick PMMA-phantom. For the measurement the phantom is placed on the breast support. An exposure is performed with exposure settings corresponding to a normal-sized breast (50 mm thick). The radiation quality and the tube loading is recorded and E_{SAK} is calculated. Then the tube loading is varied such that the exposure is producing a net film density of 1,0 on the film. The standard breast dose AGD_{FK} (for clinically used film density) respectively AGD_{F0} (for net film density 1,0) is calculated according to:

$$AGD_{FK} = g_F \times E_{SAK_{FK}} \quad (\text{mGy}) \quad (\text{for clinically used film density}) \quad (8a)$$

$$AGD_{F0} = g_F \times E_{SAK_{F0}} \quad (\text{mGy}) \quad (\text{for net film density 1,0}) \quad (8b)$$

The conversion coefficients g_F are given in the following table 6.

Table 6: Conversion factors g_F (mGy/mGy) for calculation of AGD for a 50 mm thick standard breast by means of the ESAK-value measured with a 45 mm thick PMMA phantom. ¹⁾

Half-value-layer (mm Al)	0,25	0,3	0,35	0,4	0,45	0,5	0,55	0,6	0,65
g_F (mGy/mGy)	0,149	0,177	0,202	0,223	0,248	0,276	0,304	0,326	0,349

¹⁾ European protocol on dosimetry in mammography. European Commission, (1996) EUR 16263