INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

H4.SMR/773-29

College on Medical Physics:
Radiation Protection and Imaging Techniques

5 - 23 September 1994

Image Quality Criteria Status of the CEC Project

R. Padovani

Istituto di Fisica Sanitaria
Ospedale S. Maria della Misericordia
Udine, Italy

DIAGNOSTIC RADIOLOGY IN THE EUROPEAN COMMUNITY

~ 320 million inhabitants

~ 200 million radiological examinations per year

~ 500 million radiographic films per year

300 to 1500 μSv	contribution to the exposure of each person of the general public per year in the various Member States
500 μSv	average value for the European Community

PRACTICES IN DIAGNOSTIC RADIOLOGY AND QUANTITIES FOR POPULATION EXPOSURE

CEC Member States	Number of X-ray examinations per 1000 inhabitants per year (1)	Mean number of film per examination	GSD μ Sv	EDE μ Sv (2)	References
Feder.Rep.Germany	1200	2.2	~ 400	~1000	F.E.Stieve 1989
France	825	3.6	295	1580	C.Maccia et al., 1988
Great Britain	444	2.3	120	282	B.Wall et al., 1981
Ireland	460	2.2	164	-	J.Cunningham et al., 1988
North-East Italy	665	3.1	248	763	G. Contento et al., 1988
Spain	730	2.2	270	1050	E.Vaño et al., 1988 L. Arranz, 1989

(1) without dental examinations

(2) remainder organs included

GSD = Genetically Significant Dose

EDE = Effective Dose Equivalent per caput

Table 3. Level of provision of medical radiology staff and facilities in three European countries [Co88].

Staff and facilities/10^6 inhabitants	Britain (1983)	France (1982)	NE Ita (1983
Radiologists	28	91	84
Radiographers	143	340	330
X-ray tubes*	198	244	310
CT scanners (1986)	1.7	1	4

(*): Excluding those of private dentists and CT scanners

12 (1993)

Table 4. Contributions to the UK collective effective dose equivalent from all medical and dental X-ray examinations (NRPB, 1990).

Examination	Frequency (%)	Collective dose (%)
Computed tomography	2.0	17
Lumbar spine	3.3	15
Barium enema	0.9	14
Barium meal	1.6	12
Intravenous urography	1.3	11
Abdomen	2.9	8
Pelvis	2.9	6
Chest	24	2
Limbs and joints	25	1.5
Skull	5.6	1.5
Thoracic spine	0.9	1
Dental	25	1

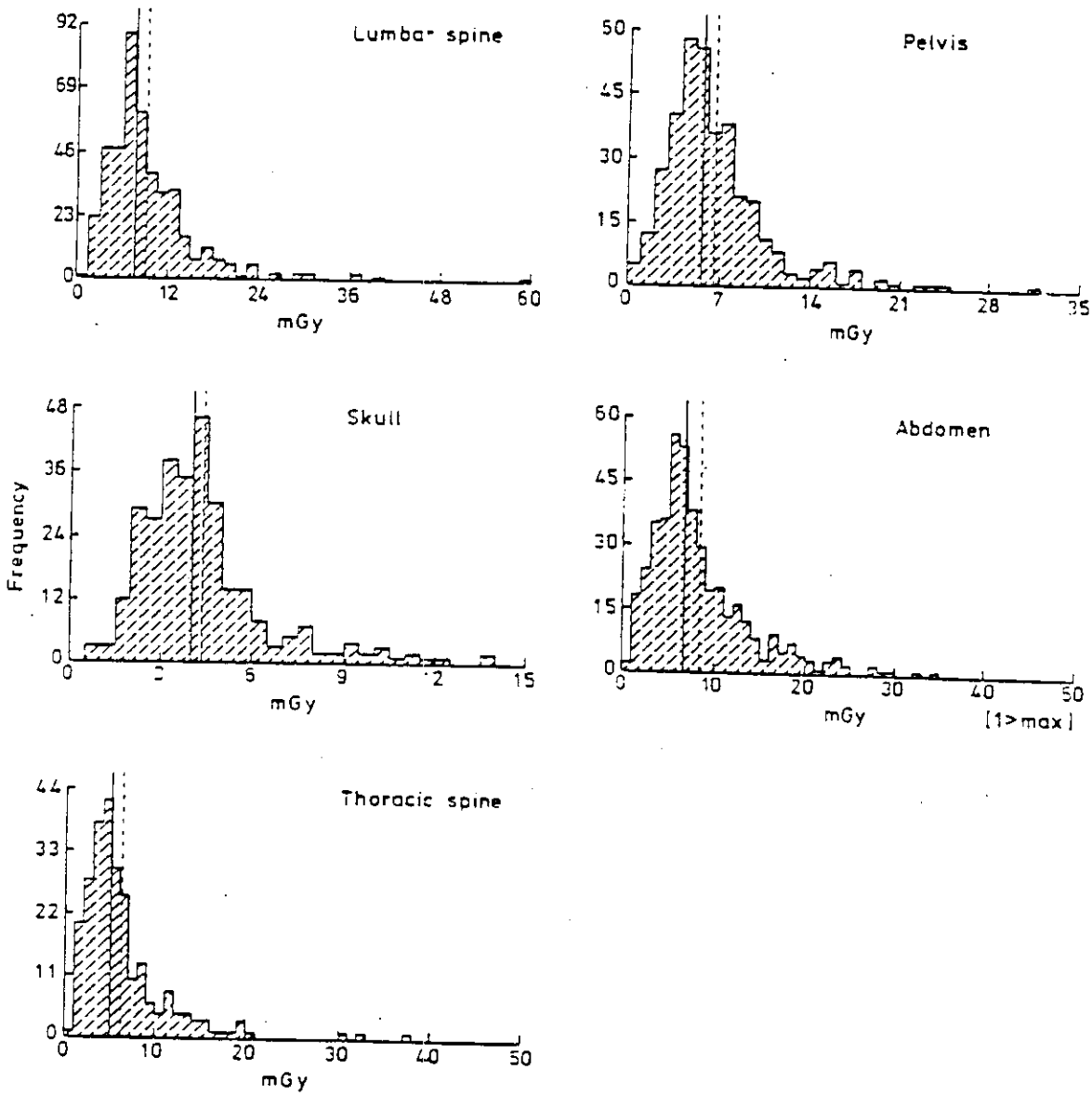


Figure C15 Entrance skin dose per film: AP projections. The maximum observed dose of 62.4 mGy has been omitted from the histogram for abdomen examination

[FENDEL 91]

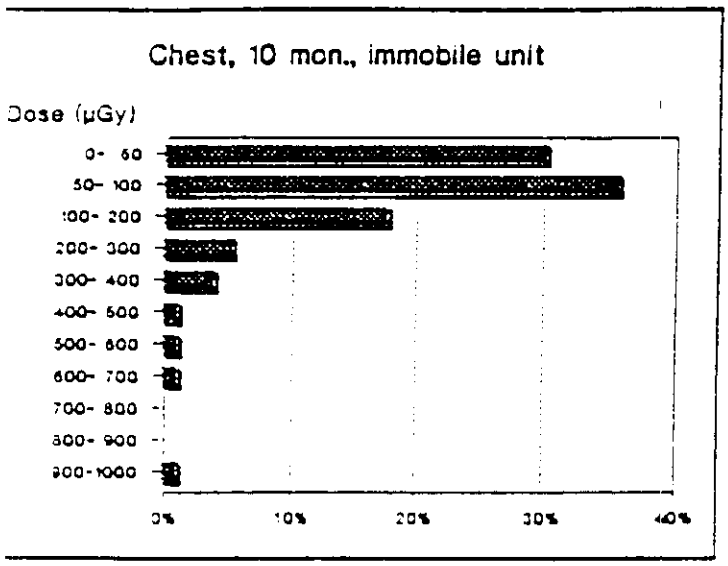


Fig. 2 Dose distribution, chest ap/pa

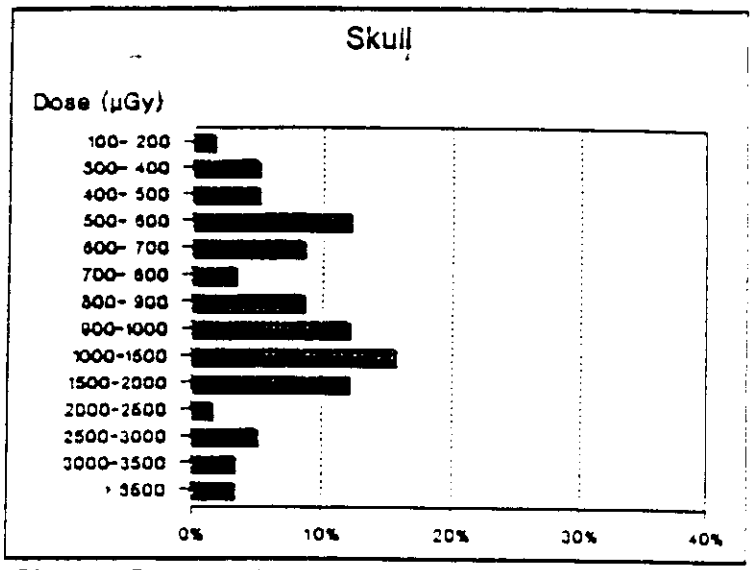


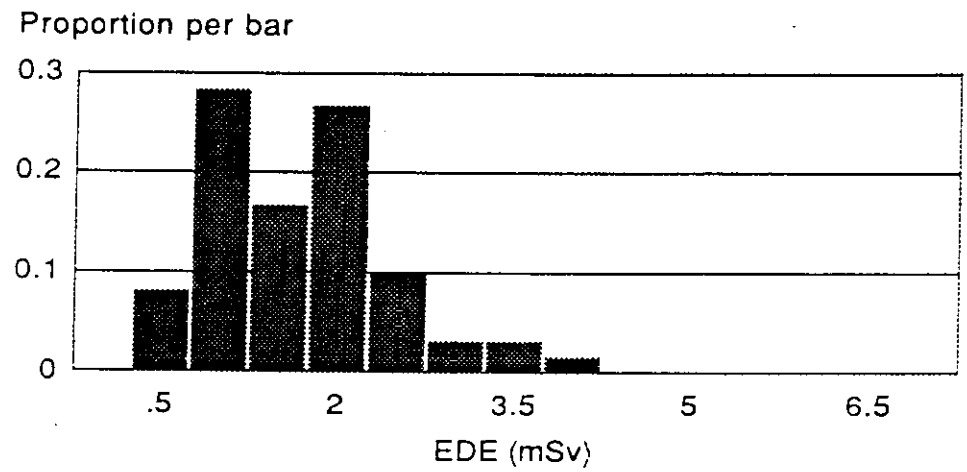
Fig. 3 Dose distribution, skull ap/pa

	Entrance surface dose (µGy)					N
	min.	max.	mean	median	ratio	total
Abdomen	77	3210	650.5	440.0	1: 42	45
Skull ap	152	4514	1252.7	926.0	1: 30	57
Chest ap/pa	21	979	131.3	74.0	1: 47	69
Spine	107	4351	1128.0	875.0	1: 41	31
Pelvis	18	1369	401.1	274.5	1: 76	50
Chest, newborn, mob.	11	386	67.8	43.5	1: 35	64
Chest, infant, mob.	34	718	128.5	90.0	1: 21	37

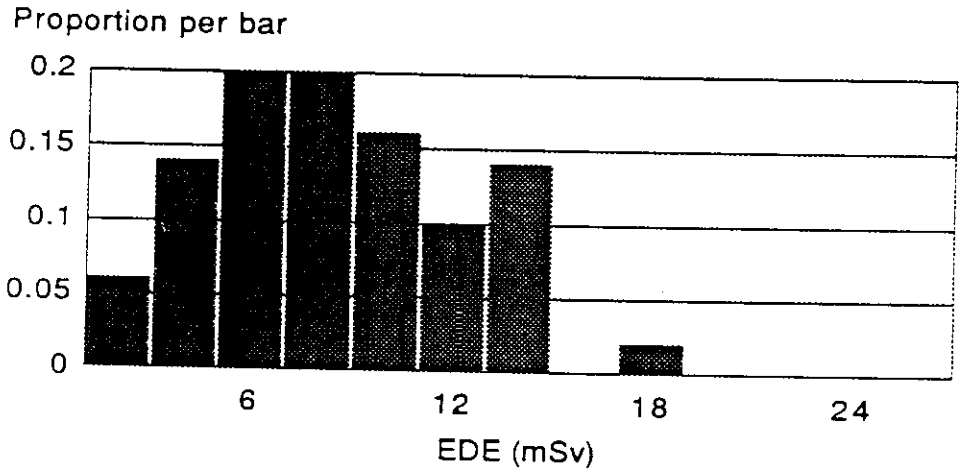
Tab. 6 Entrance surface dose statistics

CT EXAMINATION:

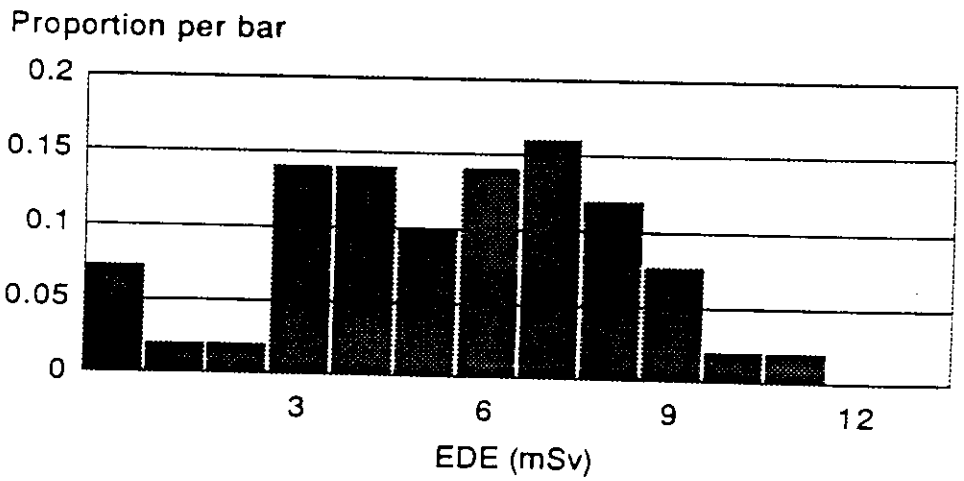
Head



Chest



Abdomen



CEC Directives and Guidelines

- **Council Directive 84/466/Euratom on measures for radiation protection of persons undergoing medical examination or treatment.**

  - The regulation require that every exposure has to be justified and optimised in respect to the patient exposure.

  - That only persons who have received adequate training may direct a medical exposure.

  - Quality control of equipment has to be performed

- **Guideline: "Quality Criteria for Diagnostic Radiographic Images", Draft document of 1990**

- **Guideline: "Quality Criteria for Diagnostic Radiographic Images in Paediatrics", Draft of 1991**

- **European Guidelines for Quality Assurance in Mammographic Screening, Report EUR 14821 EN,1993**

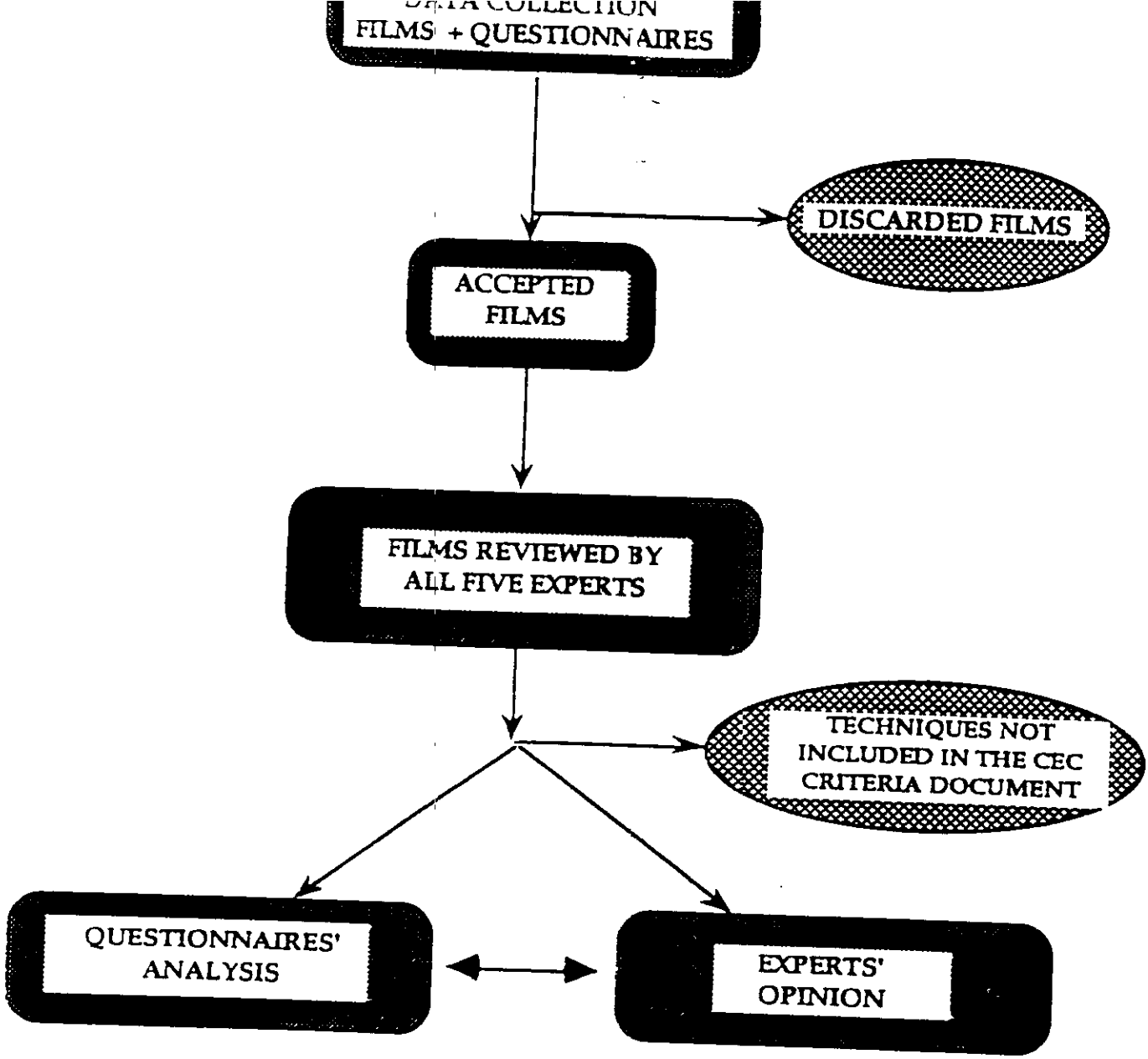


Table 1 : General information describing the CEC Trial (1991)

NUMBER OF COUNTRIES :	16
NUMBER OF X-RAY DEPARTMENTS :	83
NUMBER OF PATIENTS :	1,108
NUMBER OF FILMS :	2,088
NUMBER OF DOSE MEASUREMENTS :	2,136
NUMBER OF EXPERT RADIOLOGISTS :	15
NUMBER OF DOSIMETRY LABORATORIES :	3

Figure 3 : Number of patients included in the Trial by country

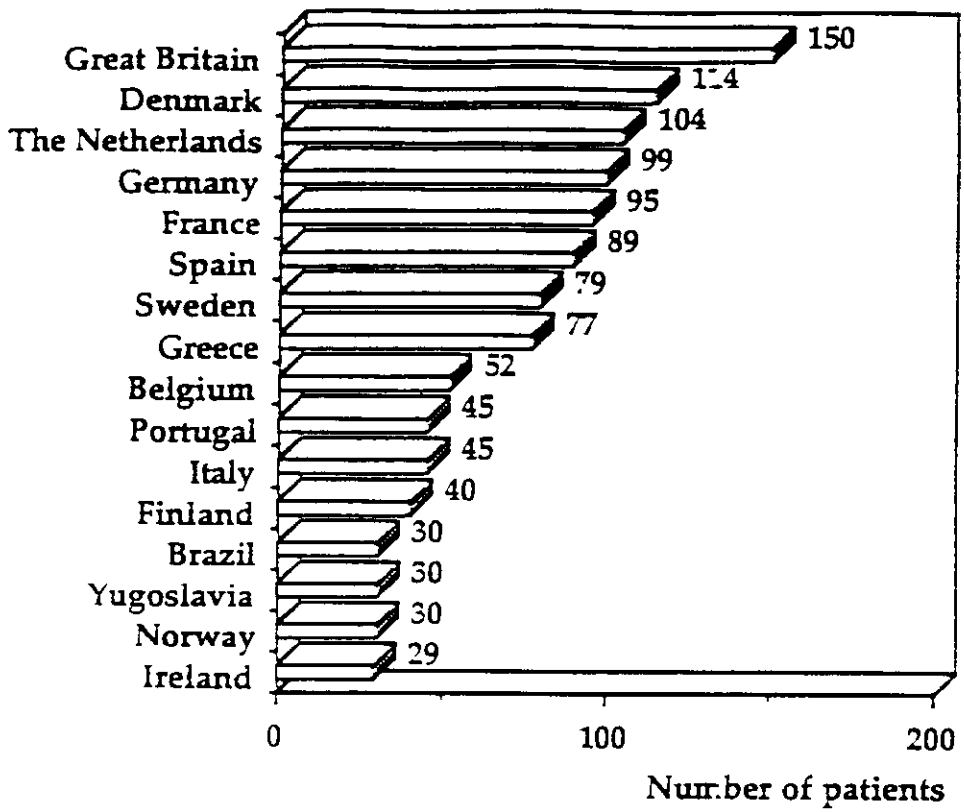


Table 3 : Number of films and dose measurements collected by type of examination and projection

	Projection	Number of films	Number of dose measurements
BREAST	Cranio-Caudal	320	369
	Lateral	359	408
	Total	679	777
CHEST	PA	364	354
	Lateral	267	257
	Total	631	611
LUMBAR SPINE	AP or PA	305	301
	Lateral	312	308
	L5 - S1	161	139
	Total	778	748

	CHEST		BREAST		LUMBAR SPINE		
Type of Projection	PA	Lat	CC	Lat	AP or PA	Lat	L5-S1
Number of measurements	354	257	369	403	301	308	139
Minimum	0.03	0.13	1	0.5	0.5	0.9	2.7
Mean ± 1 S.D.	0.36±0.75	1.31±2.9	7.8±5.4	9.2±7.3	7.8±6.8	18.7±13.3	34.6±20.3
Maximum	11.99	37.94	41.8	54.5	63.9	68.5	119.9
Third quartile	0.39	1.22	10.04	11.99	9.99	26.49	45.7
CEC reference	0.3	1.5	7	7	10	30	40

Table 9 : Compliance rates with the CEC dose requirements

Examination Type	Projection	Hospitals in which all dose values exceed CEC dose level (%)	Hospitals whose mean dose exceeds CEC dose level (%)	Hospital mean dose equal to or less than the CEC dose level (%)	Hospitals with all doses less than the CEC dose level (%)
CHEST	PA	11.7	29.4	70.6	41.2
	Lateral	3.4	13.8	86.2	72.4
BREAST	CC	7.9	52.6	47.4	15.8
	Lateral	9.5	69.1	30.9	11.9
LUMBAR SPINE	AP or PA	12.9	25.8	74.2	29
	Lateral	6.1	15.2	84.8	60.6
	L5-S1	11.1	33.4	66.6	33.3

Table 10 : Compliance rates with the CEC Image Criteria

Examination Type	Projection	Number of image criteria	Films meeting all image criteria (%)	Percentage of image criteria met by films (%)
Chest	PA	9	33.1	85.8
	Lateral	4	80.8	93
Breast	CC	4	72.9	91.3
	Lateral	4	67.8	89.6
Lumbar Spine	AP/PA	7	57.3	89.2
	Lateral	7	53.6	87.4
	L5-S1	4	70.9	91.9

Figure 35 : Histogram of patient doses

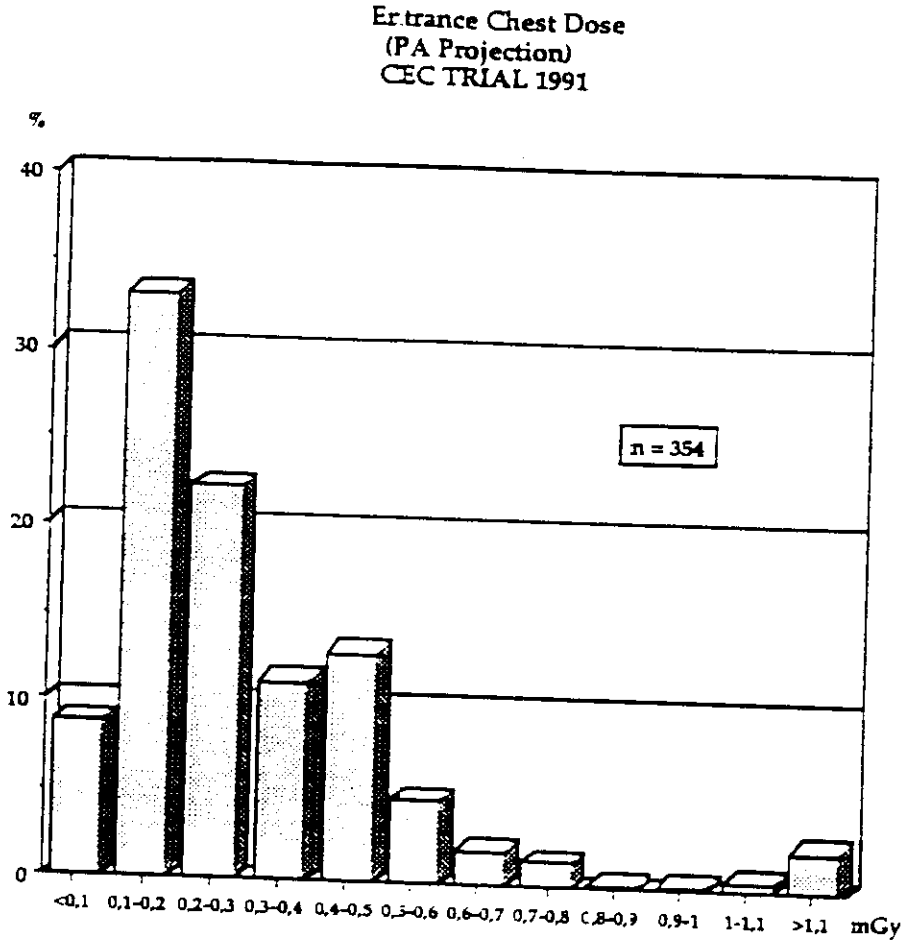


Figure 36 : Variations of the Chest dose by hospital (PA Projection)

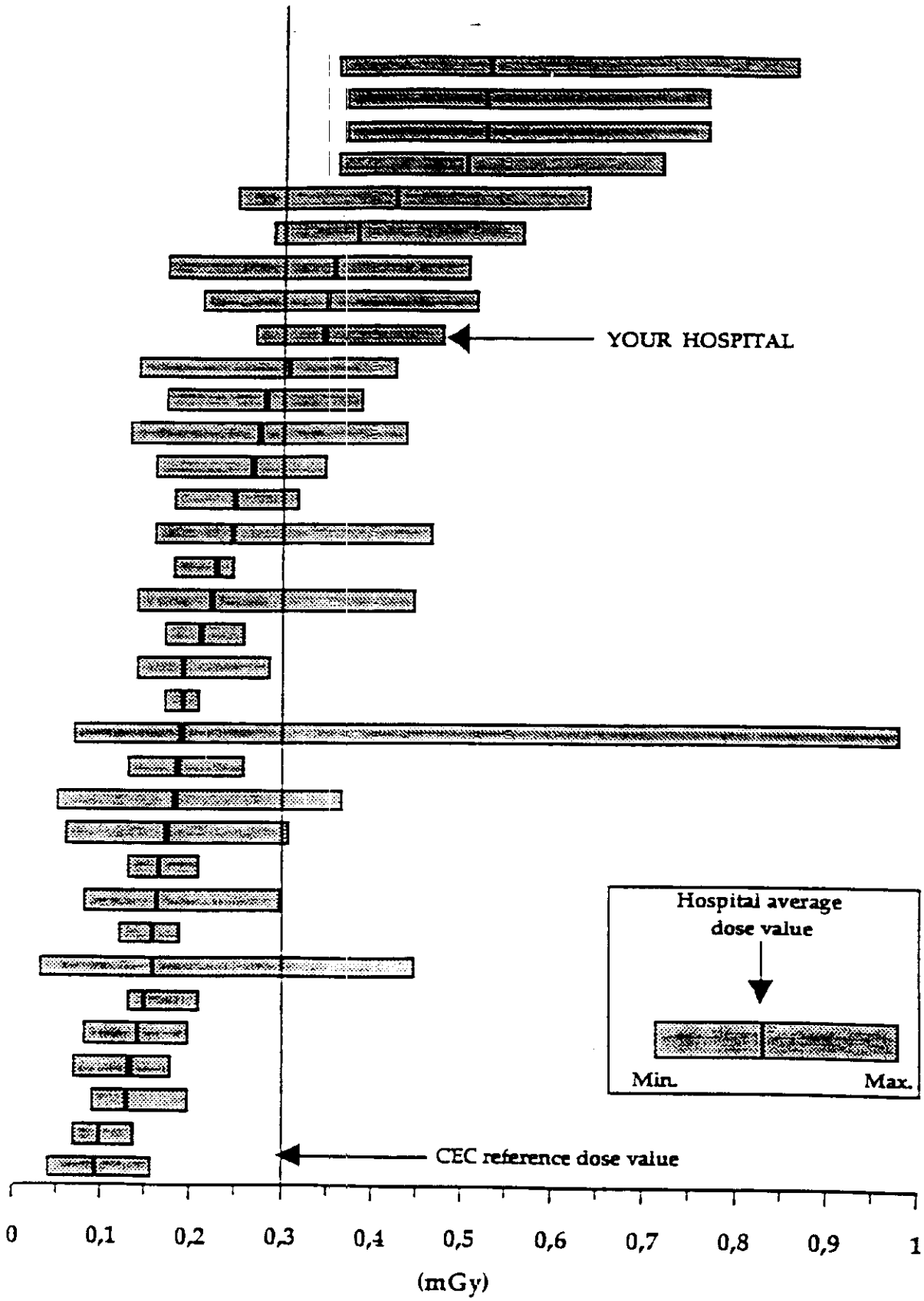


Figure 18 :

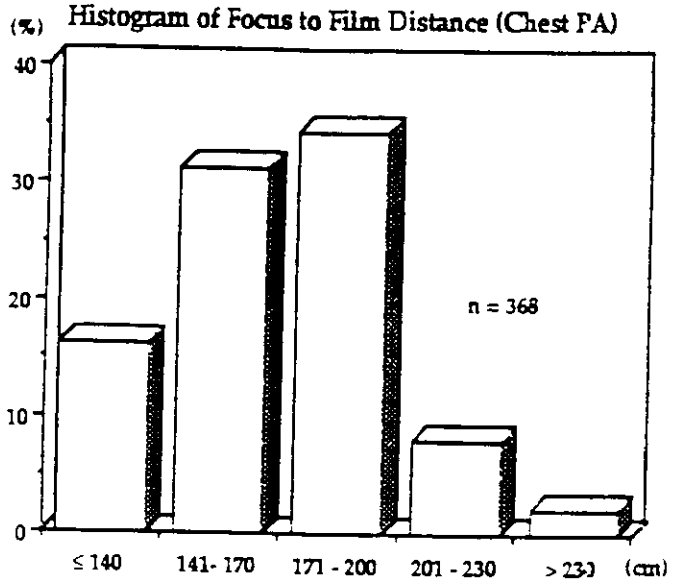


Figure 19 :

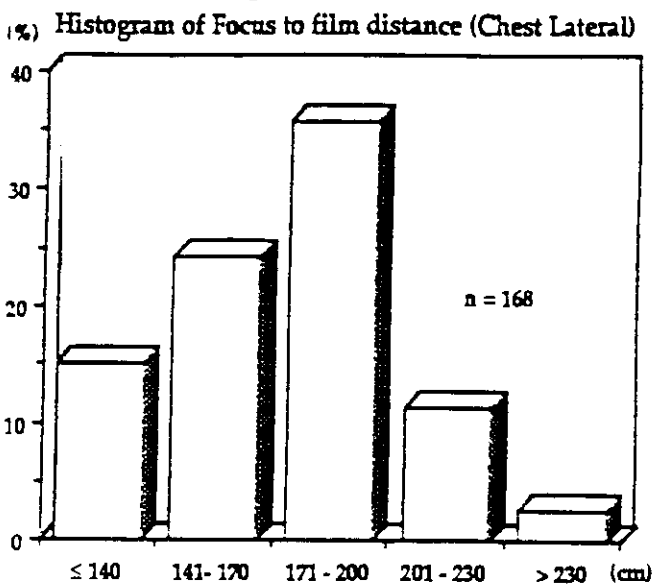


Figure 20 : Distribution of Automatic Exposure Control system - Chest examination

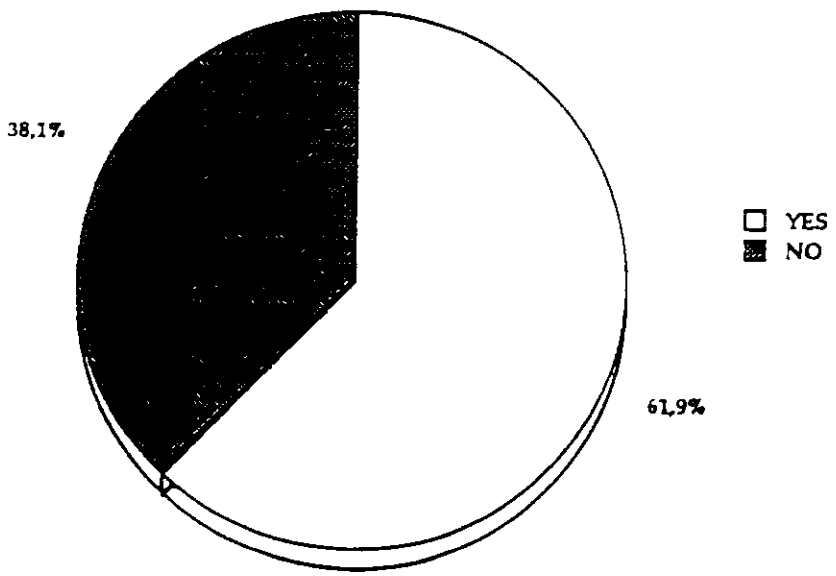


Figure 14 :

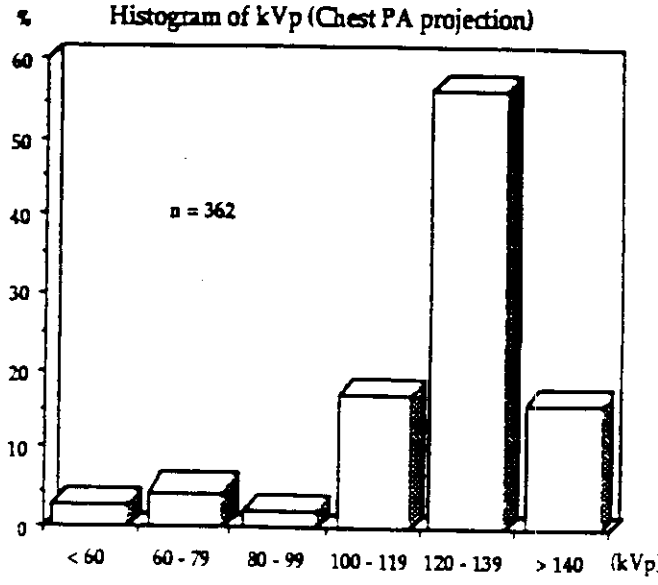


Figure 15 :

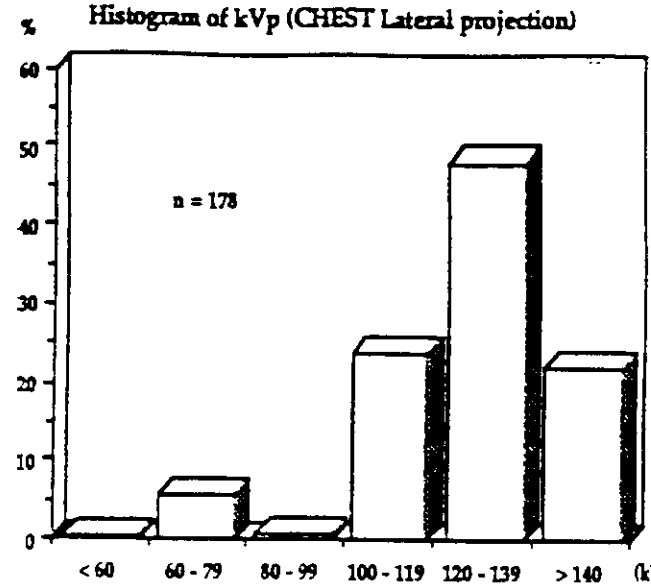


Figure 16 :

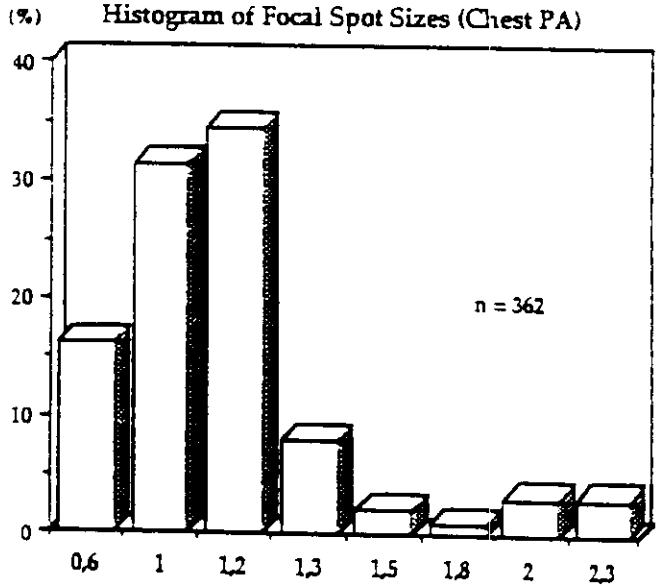
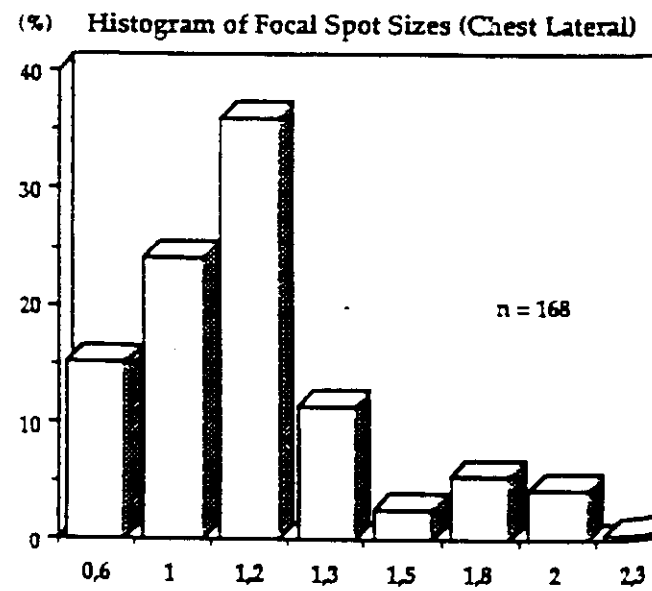
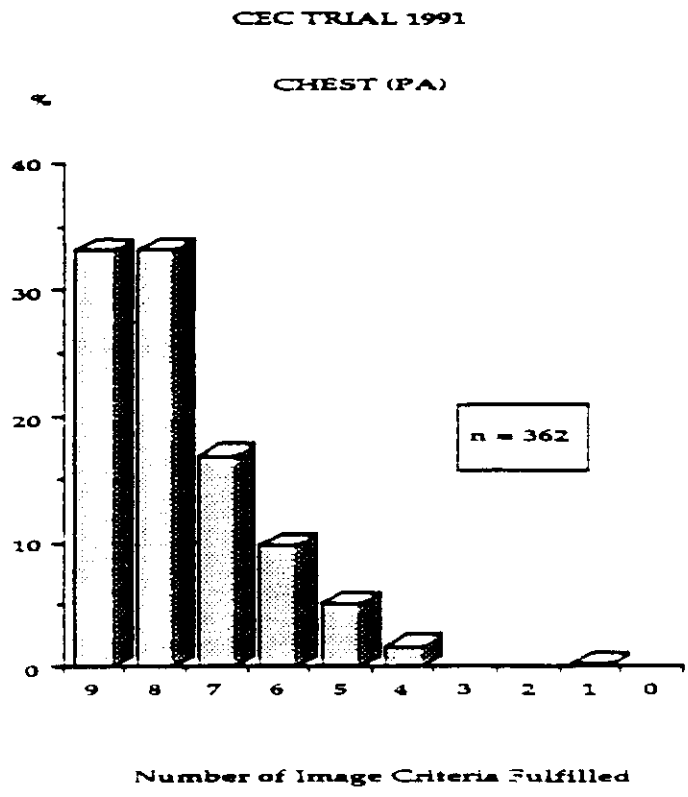


Figure 17 :

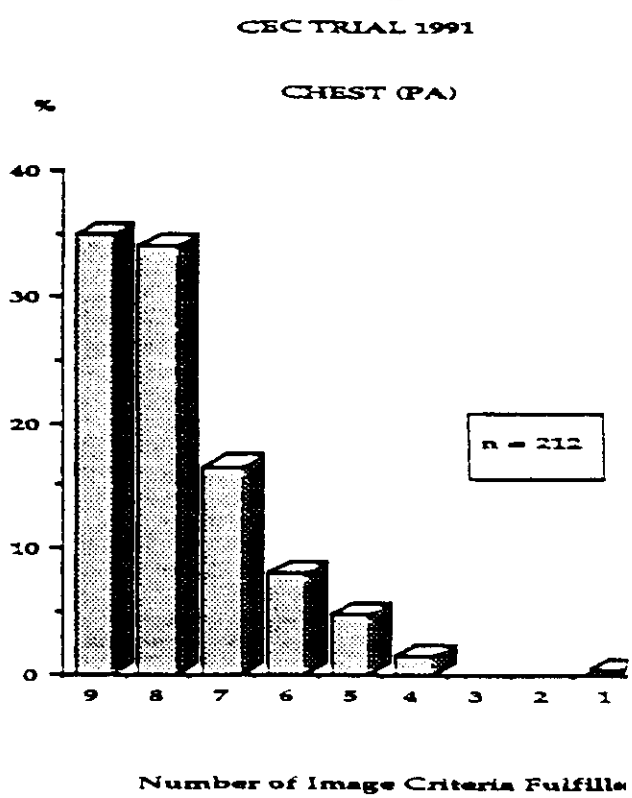


Figures 49 - 52 : Chest Projections : Image Quality Criteria

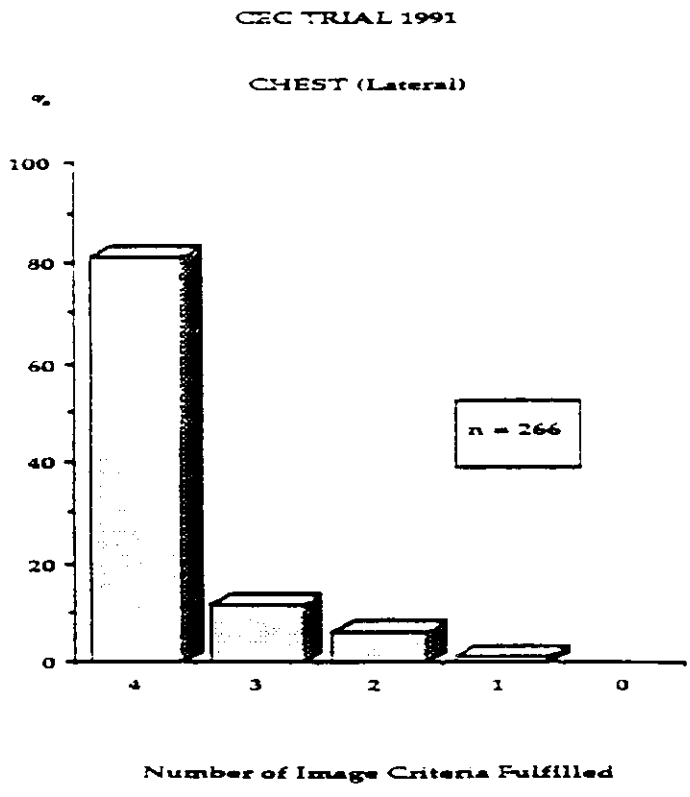
All films acceptable for diagnosis seen by field radiologists



Subset viewed by all experts



All films acceptable for diagnosis seen by field radiologists



Subset viewed by all experts

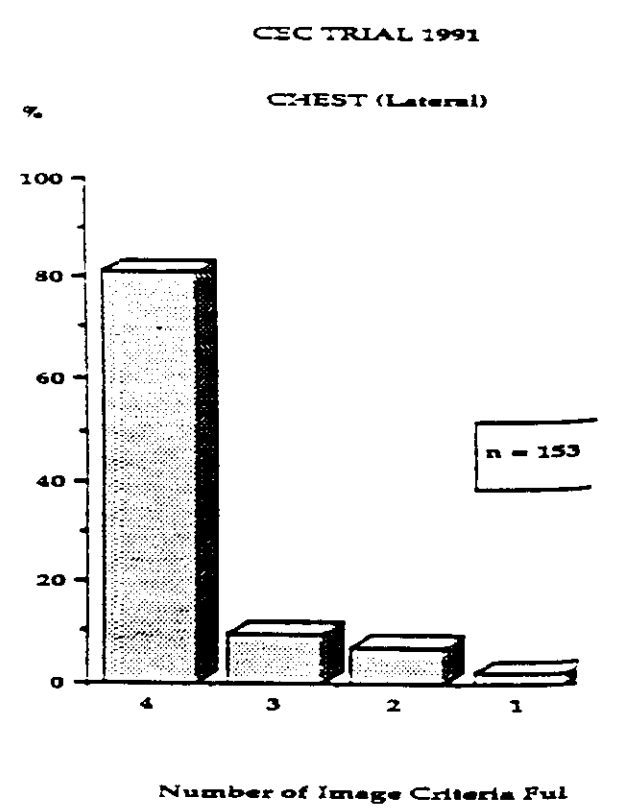


Figure 109: Average dose as a function of the number of image criteria fulfilled : field radiologists' ratings for chest PA projection

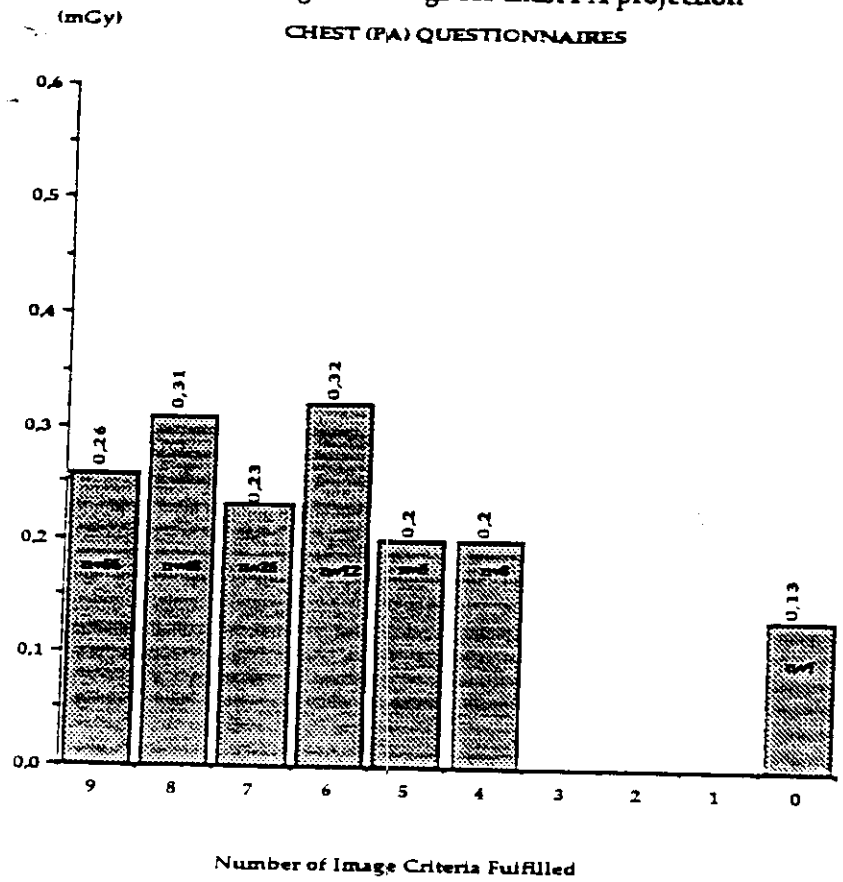
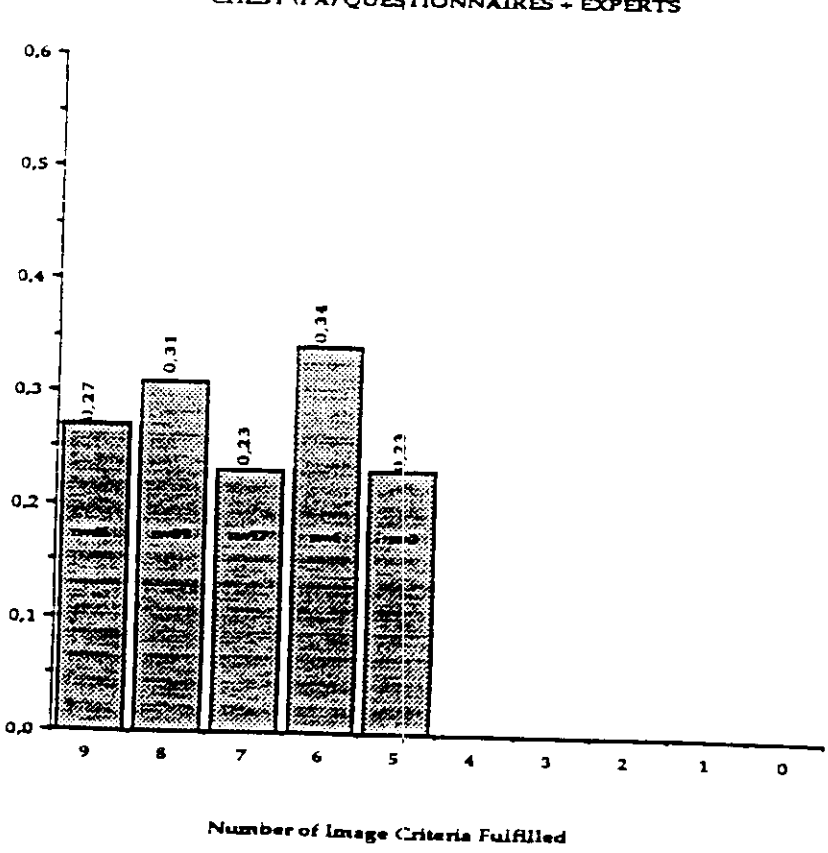


Figure 110 : Average dose as a function of the number of image criteria fulfilled : experts' ratings for chest PA projection (first quartile excluded)



Conclusions

- Results of recent trials confirm a wide variation in patient exposure in adult and pediatric examinations
- Methods for the optimisation of procedures are not well defined and only in a few cases applied
- Quality control and quality assurance methods are now well defined but only in a few EC countries they are applied in radiological practice
- CEC Guidelines seem useful documents to introduce, in every radiological department,
  - elements of optimisation of the practice (Image quality criteria and Example of good radiographic technique)
  - and, instruments for patient protection (Reference level of Entrance Skin Dose).

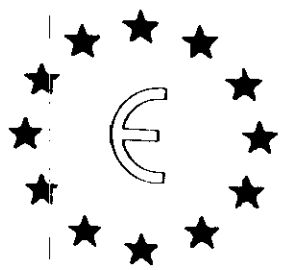
- Working Document -

2nd edition - June 1990

QUALITY CRITERIA

FOR

DIAGNOSTIC RADIOGRAPHIC IMAGES



XII/173/90

CONTENTS

INTRODUCTION

The three basic principles of radiation protection are: justification, optimisation and dose limitation(1) (2). It is accepted that no diagnostic exposure of a patient is justifiable without a valid clinical indication, no matter how good the imaging performance may be. Guidance on referral criteria for adult and paediatric patients can be found in WHO Reports 689 (3) and 757 (4) respectively and guidelines for making the best use of a department of radiology are available from the Royal College of Radiologists, London (5).

In respect to diagnostic examinations there are no dose limits, therefore, once a diagnostic X-ray examination has been clinically justified, the subsequent process of imaging and interpretation must be optimised. The optimal use of ionising radiation involves the interplay of three important aspects of the imaging process:

- the diagnostic quality of the radiographic image
- the radiation dose to the patient
- the choice of the radiographic technique.

This Document provides guidance on all three of these aspects for a number of selected radiographic projections used in the course of routine types of X-ray examination.

OBJECTIVES

Guidance, presented in this Document, is primarily directed to the technical and clinical staff involved in taking the radiographs and in reporting on them. It will also be of interest to those responsible for the design of X-ray imaging equipment and for the maintenance of its functional performance. It will be helpful to competent authorities who have responsibility for equipment specification and purchase.

The guidance presented in this Document is a demonstrably achievable standard of good practice which can be used as a basis for further development by the radiological community.

The image quality criteria presented for a particular type of image are those deemed necessary to produce a radiograph of standard quality. No attempt has been made to define the degree of acceptability for particular clinical indications.

The Guidelines on Radiation Dose to the Patient represent values, which with equipment currently in use, have been demonstrated to be at a level not exceeded in 75 % of examinations. They therefore can be

taken as a base-line from which progress might be pursued to possibly lower dose levels in line with the ALARA (As Low As Reasonably Achievable) principle.

The Examples of Good Radiographic Technique included in this Document have evolved from the results of the first European trial of the Quality Criteria. Compliance with the image quality criteria and the patient dose guidelines was associated with the employment of these technique factors.

To encourage widespread use, the image quality criteria have been expressed in a manner requiring personal visual assessment rather than checking compliance by using sophisticated measuring equipment.

Assessment of compliance with the Guidelir Radiation Dc the Patient for a specific examination unavoidably involves some form of dose measurement. This requires random sampling of the patient population. A variety of dose measurement methods are described in Appendix I.

Adherence to the guidelines presented in this Document will help to achieve:

- good image quality, comparable throughout Europe;
- low radiation dose per radiograph;
- accurate radiological interpretation of the image.

It is hoped that the application of these guidelines will provide the framework for their expansion to other types of X-ray examination.

GENERAL PRINCIPLES ASSOCIATED WITH GOOD IMAGING PERFORMANCE

The following general principles are common to all radiographic X-ray examinations. All those who either request, carry out, or report on the results of diagnostic X-ray procedures should be aware of them.

Specific aspects of these principles are discussed in greater detail in a number of publications by national and international organisations, some of which are listed in references (1) to (9) (see page 9).

Quality Control of X-ray Imaging Equipment

Quality control programmes form an essential part of dose-effective radiological practice. Such programmes should be instigated in every medical X-ray facility and should cover a selection of the most important physical and technical parameters associated with the types of X-ray examination being carried out. Limiting values for these technical parameters and tolerances on the accuracy of their measurement will be required for meaningful application of the Examples of Good Radiographic Technique presented in this Document. BIR Report 18 (8) provides useful information on this subject, e.g. Table VI of paper H.-St. Stender and F.-E. Stieve "The relationship between medical diagnostic requirements and limiting values of technical and physical parameters for image production". Similarly it is envisaged that a scheme for effective evaluation of image quality employing measurements of physical parameters could usefully underpin this Document.

Technical innovations

Technical innovations have enabled dose reduction to be achieved through the use of:

- rare earth screens,
- carbon fibre products in table tops grid facing and interleaving, and cassette fronts,
- digital radiography,
- use of advanced photographic emulsions,

and which may also be accompanied by improvement of image quality.

Patient Positioning

Correct patient positioning plays a major role in determining the success of any radiological examination. Routine positioning may need to be altered in the light of specific clinical circumstances, in order to delineate an area of special interest. Correct positioning of the patient is the responsibility of the person who is physically directing the examination. The use of suitable immobilisation and compression techniques can have an important role to play in the production of satisfactory images. Training programmes as well as ongoing multidisciplinary evaluation programmes within a medical X-ray facility should regularly address these areas.

X-ray Beam Limitation

Image quality is improved and the radiation dose to the patient is reduced by limiting the X-ray beam to the smallest field giving the required diagnostic information. Limitation of the radiation beam should also consider the need to exclude radiosensitive organs from primary irradiation whenever possible. On no occasion should the X-ray beam fall outside the image receptor area. The use of an automated beam limitation device is of help. A requirement to visualise beam limitation on the radiograph is an alternative.

Protective Shielding

For radiation protection purposes radiosensitive tissues or organs should be shielded wherever possible. In particular, for patients of reproductive capacity, testes or ovary shields should be used in examinations which are likely to give a high radiation dose to the gonads.

Radiographic exposures per examination

The number of radiographic exposures within one examination must be kept to a minimum consistent with obtaining the necessary diagnostic information. This requires that those factors which can lead to high reject or retake rates are subject to reject analysis. This will help to delineate the areas of concern in each medical X-ray facility.

Film Processing

Optimal processing of the radiographic film has important implications both for the diagnostic quality of the image and for the radiation dose to the patient. Film processors should be maintained at their optimum operating conditions as determined by regular and frequent (i.e. daily) quality control procedures. Consistent imaging performance is not necessarily an indication of optimal performance, e.g. the developer temperature may well be set too low.

Image viewing conditions

The proper assessment of image quality and accurate reporting on the diagnostic information in the radiographs can only be achieved when the viewing conditions meet the following requirements:

a) The person viewing the radiographs requires an incident light intensity of about 100 cd/m². To achieve this uniform illuminance of the film illuminator a brightness of at least 2000 cd/m² is necessary;

b) The colour of the illumination should be white or blue and should be matched throughout a complete set of film illuminators;

c) Means should be available to restrict the illuminated area to the area of the radiograph to avoid dazzling;

d) Means for magnifying details in the displayed radiographic image should be available. These means should magnify by a factor of 2 to 4 and contain provisions to identify small image details of sizes down to 0.1 mm.

e) For viewing exceptionally dark areas in the radiographic image ar additional spotlight with iris diaphragm providing a brightness of at least 10,000 cd/m² should be available.

f) A low level of ambient light in the viewing room is essential.

GUIDANCE ON IMPLEMENTATION

Quality Criteria are presented for a number of selected radiographic projections used in the course of routine types of X-ray examination. They apply to adult patients of standard size with the usual presenting symptoms for the type of examination being considered.

However, image quality criteria of this nature cannot be applied to all cases. For certain clinical indications a lower level of image quality may be acceptable, but this should always be associated with a lower radiation dose to the patient.

Under no circumstances should an image which fulfils all clinical requirements but does not meet all image quality criteria ever be rejected.

For each selected radiographic projection the criteria are divided into three parts:

1. Diagnostic requirements

   These list image criteria which in most cases specify important anatomical structures and details that should be visible in a radiograph to enable accurate diagnosis. A qualitative guide to the necessary degree of visibility of these essential structures and details is provided in the Description of Terms overleaf. These criteria can be used by radiologists as they report on radiographs to make a personal visual assessment of the image quality.

2. Criteria for good imaging performance

   These criteria provide quantitative information on the minimum sizes at which important anatomical details should become visible in the radiographic image. Some of these anatomical details may be pathological and therefore may not be present. Reference values are also provided for the entrance surface dose to a standard-sized patient. The derivation of these values is discussed in Appendix I.

   These criteria are to be used by radiologists, radiographers, and medical physicists, as a check on the performance of the entire imaging process and as an aid in identifying desirable technical specifications of X-ray equipment.

3. Example of good radiographic technique

   This provides an example of one set of radiographic technique parameters that has been found to result in good imaging performance that will meet all the above Quality Criteria. Details are also given of a suitable combination of accessory devices geometrical conditions and loading factors using current X-ray imaging technology. If radiologists and radiographers find that Diagnostic Requirements or Criteria for Good Imaging Performance are not met then the Example of Good Radiographic Technique can be used as a guide to how their techniques might be improved.

DESCRIPTION OF TERMS USED ON FOLLOWING PAGES

1. DIAGNOSTIC REQUIREMENTS

Image criteria

These refer to characteristic features of radiological images with a specific degree of visibility. At the present time there are no internationally accepted definitions. For the purpose of this Document the following are used:

Visualisation:	-	an anatomical feature is detectable but details are not fully reproduced
Reproduction:	-	[illegible] tomical features are visible but not necessarily clearly defined
Visually sharp reproduction	-	the anatomical details are clearly defined

2. CRITERIA FOR GOOD IMAGING PERFORMANCE

2.1 Important image details - define the minimum limiting dimensions in the image at which specific normal or abnormal anatomical details should be recognised.

2.2 Entrance surface dose for standard-sized patient - expressed as the absorbed dose (mGy) at the point of intersection of the X-ray beam axis with the surface of a standard-sized adult patient (or an equivalent phantom), backscatter radiation included. For further information see Appendix I.

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1 Radiographic device - device supporting the film-screen cassette and the anti-scatter grid.

3.2 Nominal focal spot value - defined as the edge length (mm), measured under specific conditions as indicated by the manufacturer.

3.3 Total filtration - the aluminum equivalence of the inherent and added filtration.

3.4 Anti-scatter grid - specified in terms of grid ratio 'r' and number of absorbing strips per cm.

3.5 Film-screen combination - the sensitivity of film screen combinations is defined in speed (see ANSI/ISO PH2-31, DIN 6867 (1985)). The speed of the film-screen combination is one of the most critical factors affecting the radiation dose to the patient. For convenience in this Document speed classes are used to take into account the variation in sensitivity which can occur with changes in X-ray beam energy for individual film-screen combinations (E. Borcke, BIR Report 18 (8)). Users should be encouraged to measure the absolute speeds of their film-screen combinations under standard conditions resembling those used in practice, to see how closely they match up to the manufacturers quoted values. Speed classes of 200 and above usually require the use of rare-earth or equivalent intensifying screens. Users are also encouraged to measure the resolution of their film-screen combination since this varies within any speed class.

3.6 FFD - Focus-to-film distance (cm). Numbers shown in brackets indicate equally satisfactory values. If a focussed grid is used, FFD must be within the range indicated by the manufacturers.

3.7 X-ray tube voltage - expressed as the peak kilo-voltage (kV) applied to the X-ray tube, preferably with a 6-pulse, 12- or multipulse or constant potential high voltage generator.

3.8 Automatic exposure control - the recommended selection of the measurement chamber in the automatic exposure control device.

3.9 Exposure time - the time indicated for the duration of the exposure (ms).

REFERENCES

The following is a limited reference list. References (7) to (9) contain extensive reference lists.

(1) ICRP Publication 34, Protection of the Patient in Diagnostic Radiology, 1982 (Pergamon Press, Oxford)

(2) Council Directive of 3 September 1984 lay ng down basic measures for the radiation protection of persons undergoing medical examination or treatment (84/466 EURATOM) O.J. Nr L 265, p. 1, 05.10.1984

(3) WHO Report 689 "A Rational Approach to Radiographic Investigations"

(4) WHO Report 757 "Rational Use of Diagnostic Imaging in Paediatrics"

(5) Booklet on "Making the Best Use of a Department of Radiology", 1989 (Royal College of Radiologists, London)

(6) WHO Report "Quality Assurance in Diagnostic Radiology", 1982 (WHO, Geneva)

(7) Criteria and Methods for Quality Assurance in Medical X-ray Diagnosis, BJR Supplement No. 18, 1985

(8) Technical and Physical Parameters for Quality Assurance in Medical Diagnostic Radiology; Tolerances, Limiting Values and Appropriate Measuring Methods", BIR Report 18, 1989

(9) "Optimisation of Image Quality and Patient Exposure in Diagnostic Radiology", BIR Report 20, 1989

PA PROJECTION

1. DIAGNOSTIC REQUIREMENTS

Image criteria

1.1 Performed at deep inspiration (as assessed by the position of the ribs above the diaphragm - either 6 anteriorly or 10 posteriorly) and with suspended respiration

1.2 Symmetrical reproduction of the thorax

1.3 Medial border of the scapulae to be outside the lung fields

1.4 Reproduction of the whole rib cage above the diaphragm

1.5 Reproduction of the vascular pattern in the whole lung, particularly the peripheral vessels

1.6 Visually sharp reproduction of

a) the trachea and proximal bronchi, the borders of the heart and aorta

b) the diaphragm and costo-phrenic angles

1.7 Visualisation of the retrocardiac lung and the mediastinum

2. CRITERIA FOR GOOD IMAGING PERFORMANCE

2.1 Important image details

Small round details in the whole lung, including the retrocardiac areas:

high contrast : 0.7 mm diameter

low contrast : 2 mm diameter

Linear and reticular details out to the lung periphery:

high contrast : 0.3 mm in width,

low contrast : 2 mm in width

2.2 Entrance surface dose for a standard-sized patient : 0.3 mGy

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1	Radiographic device	:	vertical stand with stationary or moving grid
3.2	Focal spot size	:	$\leq$ 1.3 mm
3.3	Total filtration	:	$\geq$ 3.0 mm Al equivalent
3.4	Anti-scatter grid	:	r = 12; 40/cm
3.5	Film-screen combination	:	speed class 200 - 400
3.6	FFD	:	180 (140 - 200) cm
3.7	Radiographic voltage	:	100 - 150 kV
3.8	Automatic exposure control	:	chamber selected - lateral
3.9	Exposure time	:	< 20 ms

LATERAL PROJECTION

1. DIAGNOSTIC REQUIREMENTS

Image criteria

1.1 Performed at deep inspiration and with suspended respiration

1.2 Arms should be raised clear of the thorax

1.3 Visually sharp reproduction of the posterior border of the heart, aorta, mediastinum, trachea, diaphragm, sternum and thoracic spine

2. CRITERIA FOR GOOD IMAGING PERFORMANCE

2.1 Important image details

Small round details in the whole lung, including the retrocardiac area:

high contrast : 0.7 mm diameter

low contrast : 2 mm diameter

Linear and reticular details out to the lung periphery:

high contrast : 0.3 mm in width,

low contrast : 2 mm in width

2.2 Entrance surface dose for a standard-sized patient : 1.5 mGy

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1	Radiographic device	:	vertical stand with stationary or moving grid
3.2	Focal spot size	:	$\leq$ 1.3 mm
3.3	Total filtration	:	$\geq$ 3.0 mm Al equivalent
3.4	Anti-scatter grid	:	r = 12; 40/cm
3.5	Film-screen combination	:	speed class 200 - 400
3.6	FFD	:	180 (140 - 200) cm
3.7	Radiographic voltage	:	100 - 150 kV
3.8	Automatic exposure control	:	chamber selected - central
3.9	Exposure time	:	< 40 ms

PA PROJECTION

or AP Projection if PA not possible

1. DIAGNOSTIC REQUIREMENTS

Image criteria

1.1 Symmetrical reproduction of the skull, particularly cranial vault, orbits and petrous bones

1.2 Projection of the apex of the petrous temporal bone into the centre of the orbits

1.3 Visually sharp reproduction of the frontal sinus, ethmoid cells and apex of the petrous temporal bones and the internal auditory canals

1.4 Visually sharp reproduction of the outer and inner tables of the cranial vault

2. CRITERIA FOR GOOD IMAGING PERFORMANCE

2.1	Important image details	:	0.3 - 0.5 mm
2.2	Entrance surface dose for a standard-sized patient	:	5.0 mGy

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1	Radiographic device	:	grid table special skull unit or vertical stand with stationary or moving grid
3.2	Focal spot size	:	0.6 mm
3.3	Total filtration	:	$\geq$ 2.5 mm Al equivalent
3.4	Anti-scatter grid	:	r = 8(12): 40/cm
3.5	Film-screen combination	:	speed class 200
3.6	FFD	:	115 (100 - 150) cm
3.7	Radiographic voltage	:	65 - 85 kV
3.8	Automatic exposure control	:	chamber selected - central
3.9	Exposure time	:	< 200 ms

LATERAL PROJECTION

1. DIAGNOSTIC REQUIREMENTS

Image criteria

1.1 Visually sharp reproduction of the outer and inner tables of the cranial vault, the floor of the sella, and the apex of the petrous temporal bone

1.2 Superimposition respectively of the contours of the frontal cranial fossa, the lesser wing of the sphenoid bone, the clinoid processes and the external auditory canals

1.3 Visually sharp reproduction of the vascular channels, the vertex of the skull and the trabecular structure of the cranium

2. CRITERIA FOR GOOD IMAGING PERFORMANCE

2.1	Important image details	:	0.3 - 0.5 mm
2.2	Entrance surface dose for a standard-sized patient	:	3.0 mGy

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1	Radiographic device	:	grid table, special skull unit or vertical stand with stationary or moving grid
3.2	Focal spot size	:	0.6 mm
3.3	Total filtration	:	$\geq$ 2.5 mm Al equivalent
3.4	Anti-scatter grid	:	r = 8(12); 40/cm
3.5	Film-screen combination	:	speed class 200
3.6	FFD	:	115 (100 - 150) cm
3.7	Radiographic voltage	:	65 - 85 kV
3.8	Automatic exposure control	:	chamber selected - central
3.9	Exposure time	:	< 100 ms

AP/PA PROJECTIONS

1. DIAGNOSTIC REQUIREMENTS

Image criteria

1.1	Linear reproduction of the upper and lower-plate surfaces in the centred beam area and visualisation of the intervertebral spaces
1.2	Visually sharp reproduction of the pedicles
1.3	Visualisation of the intervertebral joints
1.4	Reproduction of the spinous and transverse processes
1.5	Visually sharp reproduction of the cortex and trabecular structures
1.6	Reproduction of the adjacent soft tissues, particularly the psoas shadows

2. CRITERIA FOR GOOD IMAGING PERFORMANCE

2.1	Important image details	:	0.3 - 0.5 mm
2.2	Entrance surface dose for a standard-sized patient	:	10 mGy

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1	Radiographic device	:	grid table or vertical stand with stationary or moving grid
3.2	Focal spot size	:	$\leq$ 1.3 mm
3.3	Total filtration	:	$\geq$ 3.0 mm Al equivalent
3.4	Anti-scatter grid	:	r = 12(8); 40/cm
3.5	Film-screen combination	:	speed class 400
3.6	FFD	:	115 (100 - 150) cm
3.7	Radiographic voltage	:	70 - 90 kV
3.8	Automatic exposure control	:	chamber selected - central
3.9	Exposure time	:	< 400 ms

REMARKS Radiation protection, where appropriate, gonad shields should be employed for male patients, and for female patients if possible.

LATERAL PROJECTION

1. DIAGNOSTIC REQUIREMENTS

Image criteria

1.1 Linear reproduction of the upper and lower-plate surfaces in the centred beam area and visualisation of the intervertebral spaces

1.2 Full superimposition of the posterior vertebral edges

1.3 Reproduction of the pedicles and the intervertebral foramina

1.4 Visualisation of the intervertebral joints

1.5 Visually sharp reproduction of the cortex and trabecular structures

1.6 Reproduction of the adjacent soft tissues

2. CRITERIA FOR GOOD IMAGING PERFORMANCE

2.1 Important image details : 0.5 mm

2.2 Entrance surface dose for a standard-sized patient : 30 mGy

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1	Radiographic device	:	grid table or vertical stand with stationary or moving grid
3.2	Focal spot size	:	$\leq$ 1.3 mm
3.3	Total filtration	:	$\geq$ 3.0 mm Al equivalent
3.4	Anti-scatter grid	:	r = 12(8); 40/cm
3.5	Film-screen combination	:	speed class 400 - 800
3.6	FFD	:	115 (100 - 150) cm
3.7	Radiographic voltage	:	90 - 100 kV
3.8	Automatic exposure control	:	chamber selected - normally central
3.9	Exposure time	:	< 1000 ms

REMARKS Radiation protection, where appropriate, gonad shields should be employed for male patients, and for female patients if possible.

LATERAL PROJECTION OF LUMBO-SACRAL JUNCTION

This Projection may be indicated if the lumbc-sacral junction is not adequately visualised on the Lateral Projectic n of the lumbar spine

1. DIAGNOSTIC REQUIREMENTS

Image criteria

1.1 Reproduction by tangential projection of the inferior end plate of L 5 and the superior end plate of S 1

1.2 Visualisation of the anterior border of the upper sacrum

1.3 Reproduction of vertebral pieces of the upper sacrum

2. CRITERIA FOR GOOD IMAGING PERFORMANCE

2.1 Important image details : 0.5 mm

2.2 Entrance surface dose for a standard-sized patient : 40 mGy

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1	Radiographic device	:	grid table or vertical stand with stationary or moving grid
3.2	Focal spot size	:	$\leq$ 1.3 mm
3.3	Total filtration	:	$\geq$ 3.0 mm Al equivalent
3.4	Anti-scatter grid	:	r = 12(8); 40/cm
3.5	Film-screen combination	:	speed class 400 - 800
3.6	FFD	:	115 (100 - 150) cm
3.7	Radiographic voltage	:	90 - 110 kV
3.8	Automatic exposure control	:	chamber selected - central
3.9	Exposure time	:	< 1000 ms

REMARKS Radiation protection, where appropriate, gonad shields should be employed for male patients, and for female patients if possible.

AP PROJECTION

1. DIAGNOSTIC REQUIREMENTS

Image criteria

1.1 Symmetrical reproduction of the pelvis

1.2 Visualisation of the sacrum and its intervertebral foramina

1.3 Visualisation of the pubic and ischial rami

1.4 Visualisation of the sacroiliac joints

1.5 Reproduction of the necks of the femora which should not be distorted by foreshortening or rotation

1.6 Reproduction of spongiosa and corticalis, and visualisation of the trochanters

2. CRITERIA FOR GOOD IMAGING PERFOFMANCE

2.1 Important image details 0.5 mm

2.2 Entrance surface dose for a standard-sized patient : 10 mGy

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1	Radiographic device	:	grid table
3.2	Focal spot size	:	$\leq$ 1.3 mm
3.3	Total filtration	:	$\geq$ 3.0 mm Al equivalent
3.4	Anti-scatter grid	:	r = 12(8); 40/cm
3.5	Film-screen combination	:	speed class 400
3.6	FFD	:	115 (100 - 150) cm
3.7	Radiographic voltage	:	70 - 90 kV
3.8	Automatic exposure control	:	chamber selected - central or both lateral
3.9	Exposure time	:	< 400 ms

REMARKS Radiation protection, where appropriate, gonad shields should be employed for male patients, and for female patients if possible.

AP PROJECTION

Before administration of contrast medium

1. DIAGNOSTIC REQUIREMENTS

Image criteria

1.1 Reproduction of the area of the whole urinary tract from the upper pole of the kidney to the base of the bladder

1.2 Reproduction of the kidney outlines

1.3 Visualisation of the psoas outlines

1.4 Visually sharp reproduction of the bones

2. CRITERIA FOR GOOD IMAGING PERFORMANCE

2.1 Important image details : 1 mm

2.2 Entrance surface dose for a standard-sized patient : 10 mGy

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1	Radiographic device	:	grid table
3.2	Focal spot size	:	$\leq$ 1.3 mm
3.3	Total filtration	:	$\geq$ 3.0 mm Al equivalent
3.4	Anti-scatter grid	:	r = 12(8); 40/cm
3.5	Film-screen combination	:	speed class 400 - 800
3.6	FFD	:	115 (100 - 150) cm
3.7	Radiographic voltage	:	70 - 90 kV
3.8	Automatic exposure control	:	chamber selected - central or both lateral
3.9	Exposure time	:	< 100 ms

Remarks Radiation Protection, where appropriate gonad shields should be employed for male patients.

After administration of contrast medium

1. DIAGNOSTIC REQUIREMENTS

Image criteria

Image criteria are to be referred to a series of radiographs

1.1 Increase in parenchymal density (nephrographic effect)

1.2 Visually sharp reproduction of the renal pelvis and calyces (pyelographic effect)

1.3 Reproduction of the pelvi-ureteric junction

1.4 Visualisation of the area normally traversed by the ureter

1.5 Reproduction of the whole bladder

2. CRITERIA FOR GOOD IMAGING PERFORMANCE

2.1 Important image details : 1 mm

2.2 Entrance surface dose for a standard-sized patient : 10 mGy per radiograph

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1	Radiographic device	:	grid table or vertical stand with moving grid
3.2	Focal spot size	:	$\leq$ 1.3 mm
3.3	Total filtration	:	$\geq$ 3.0 mm Al equivalent
3.4	Anti-scatter grid	:	r = 12(8); 40/cm
3.5	Film-screen combination	:	speed class 400 - 800
3.6	FFD	:	115 (100 - 150) cm
3.7	Radiographic voltage	:	70 -90 kV
3.8	Automatic exposure control	:	chamber selected - central or both lateral
3.9	Exposure time	:	< 100 ms

REMARKS Satisfactory reduction of overlying bowel gases and faeces is essential for adequate urinary tract reproduction. If reproduction is inadequate tomography or zonography might be useful.

Fulfillment of image criteria might require more than one PROJECTION

1. DIAGNOSTIC REQUIREMENTS

Image criteria

1.1 Visually sharp reproduction of the whole glandular breast

1.2 Visually sharp reproduction of the cutis and subcutis

1.3 Nipple should be parallel to the film

2. CRITERIA FOR GOOD IMAGING PERFORMANCE

2.1	Important image details	: round details	:	3 mm diameter
		micro-calcifications	:	0.2 mm
2.2	Entrance surface dose for a standard-sized patient, 4.5 cm compressed breast, with anti-scatter grid		:	7 mGy

3. EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE

3.1	Radiographic device	:	specially dedicated equipment Anode material : Mo
3.2	Focal spot size	:	$\leq$ 0.6 mm
3.3	Total filtration	:	0.03 mm Mo or 0.5 mm Al equivalent
3.4	Anti-scatter grid	:	specially designed moving grid (see REMARKS) might be necessary
3.5	Film-screen combination	:	dedicated high resolution film-screen combination with dedicated processing
3.6	FFD	:	$\geq$ 60 cm
3.7	Radiographic voltage	:	25 - 35 kV
3.8	Automatic exposure control	:	chamber selected - specially positioned
3.9	Exposure time	:	< 2 s
3.10	Breast compression	:	should be applied to a level which the patient can tolerate

REMARKS

The choice of anode material, total filtration, tube voltage and the use of moving grid required to obtain satisfactory image quality at an acceptable level of average entrance surface dose will be greatly affected by the density and thickness of the breast under investigation:

- For more dense and/or thicker breasts (in excess of 6 cm compressed) a tungsten anode, aluminum or other special filtration, higher tube voltages and use of an anti-scatter grid might be preferable.
- For thinner breasts (less than 4 cm) the use of an anti-scatter grid will not be necessary.

GUIDELINES ON RADIATION DOSE TO THE PATIENT

Objective

The Criteria for Good Imaging Performance contained in the List of Quality Criteria for the selected radiographic projections include a reference value for the Entrance Surface Dose for a standard-sized patient. It is intended that this reference dose value is used as a guide to the level of radiation protection of the patient. If this value is significantly exceeded then investigations must be made to justify this level of patient exposure, or if it cannot be justified, to reduce it.

Reduction of doses below the reference value should always be pursued (ALARA principle) but attention should be paid to potential loss of clinical information with any dose reduction.

Derivation of the Reference Dose Values

The patient Entrance Surface Dose including backscatter is the preferred dose quantity because it can be measured comparatively easily and much information is already available in terms of this quantity from recent patient dose surveys in Europe. Other dose quantities exist which may be more closely related to the radiation risk to the patient, eg. effective dose equivalent or the total energy imparted to the patient. They cannot however be measured directly and the various assumptions and uncertainties involved in their estimation can lead to ambiguity in their expression. Moreover, it was not possible to find sufficient data on typical European values for these dose quantities for the radiographic projections considered in this Document, to allow the derivation of suitable reference dose values.

For each of the selected radiographic projections dealt with in this Document (where the size and position of the radiation field is often defined in the Diagnostic Requirements), the patient Entrance Surface Dose is the most critical factor affecting the radiation risk. It therefore provides a realistic, easily measured guide to the relative level of patient protection being provided by the imaging techniques used in different facilities for the same projection.

A comprehensive survey of Entrance Surface Dose was carried out in Britain in 1983/1984 when measurements were made on 3200 patients undergoing 10 types of routine X-ray examination at 20 randomly selected hospitals[1]. As usual, wide variations in dose were observed (see Table 1) and the reference doses quoted in the Criteria for Good Imaging Performance have been provisionally set to coincide approximately with the 3rd quartile dose values. It is argued that if 75% of X-ray departments can operate satisfactorily below a certain dose level, then the remaining 25% should be made aware of their less than optimal performance and should be encouraged to alter their radiographic equipment or techniques to bring their doses in line with the majority. At the same time adherence to the image criteria will ensure

[1] P.C. Shrimpton, B.F. Wall, D.G. Jones, E.S. Fisher, M.C. Hiller, G.M. Kendall, R.M. Harrison: "Dose to patients from routine diagnostic X-ray examinations in England", BJR 59 : 749-758, 1986

that diagnostic efficacy does not suffer. The median dose values quoted in Table 1 could form a desirable aim for further dose reductions.

Mammography was not included in the 1983/84 British patient dose survey. The values of Entrance Surface Dose shown for the breast examination in Table 1 were derived from a 1989 survey of about 30 British mammography screening centres by the UK Mammography Physics Group[2]. At each centre the Entrance Surface Dose required to obtain a satisfactory radiograph of a 4.5 cm compressed breast was estimated using a Perspex phantom (Polymethylmethacrylate). The doses for the breast examination in Table 1 consequently do not show such a wide variation as the individual patient dose measurements made for the other types of examination. All the mammography centres used anti-scatter grids and X-ray tubes with molybdenum anodes.

In a trial of the Quality Criteria at 20 hospitals spread throughout Europe in 1988[3], performed to help the preparation of this Document, measurements indicated that on average 30% rather than the previous 25% of X-ray departments failed to meet the reference dose criteria. This difference is not considered to be sufficiently great to warrant change in the provisional reference dose levels, except for the Lateral Projection of the Lumbo-Sacral Junction where the 3rd quartile dose value was in fact lower than in the British survey, at a value of about 40 mGy.

Methods of Dose Measurement to Check Compliance with the Guidelines

The objective of the measurements is to obtain a reliable indication of the Entrance Surface Dose that would be delivered to an average-sized adult patient using the radiographic technique parameters that are being tested against the Quality Criteria. Due to the different types of X-ray and dosimetric equipment that will be available in the various radiology departments, a number of alternative methods are suggested involving measurements on patients, phantoms or free-in-air and using either TLDs or ionisation chambers.

All of these are considered equally valid and should lead to comparable results as long as all values are quoted in terms of absorbed dose to soft tissue (ICRU[4] muscle is recommended) and the effect of radiation backscattered from the patient is included.

Measurements on patients are most easily achieved by TLDs attached directly to the skin at a point coincident with the centre of the incident X-ray beam. Since a patient of exactly standard size (assumed to be 20 cm AP trunk thickness and 70 kg weight) is unlikely to be available, measurements on a statistically significant sample of patients (minimum of 10) of close to standard size are recommended, preferably with an average weight that is 70 $\pm$ 3 kg. The mean value of these dose measurements can be taken as an estimate of the dose to a standard-sized patient for comparison with the reference dose in the Quality Criteria. Such measurements should form part of an ongoing quality assurance programme.

---

[2] D.R. Dance, Royal Marsden Hosp., London, personal communication

[3] C. Maccia, B.M. Moores, U. Nahrstedt, R. Padovani, B.F. Wall, CEC Quality criteria for diagnostic radiographic images and patient exposure trial, Report EUR 12952 1990

[4] ICRU = International Commission on Radiological Units and Measurements

Phantoms consisting of the appropriate thickness of tissue-equivalent plastic or water can be used as a substitute for a standard-sized patient with suitable positioned TLDs for measuring the dose. Mammographic examinations are one area where the use of phantoms is particularly appropriate. It is recommended that a Perspex slab, 4.5 cm thick and of similar cross-sectional area to a compressed breast, is used as the dosimetric phantom in mammography. Entrance Surface Doses can be measured either with TLDs attached to the incident surface of the phantom or with a small volume ionisation chamber recessed into the incident surface of the phantom so that it receives the same degree of backscattered radiation as the TLDs. Care must be taken to ensure that the sensitivity of the dosemeter is known at the low X-ray qualities used in mammography. For the purpose of checking compliance with these guidelines, Entrance Surface Doses for mammography can be expressed in terms of absorbed dose to air. Since "muscle" is an inappropriate tissue for breast dosimetry.

For X-ray equipment employing manual selection of the tube potential, tube current and exposure time, it is possible to select the parameters that would be used for a standard-sized patient and to make a free-in-air dose measurement without any patient or phantom in the X-ray beam. The dosemeter should be positioned on the beam axis at a point coincident with the entrance surface of the patient. Either TLDs or suitable ionisation chambers can be used, calibrated in terms of absorbed dose to soft tissue. Dosemeters should be held in a scatter-free support. The measurement of absorbed dose to muscle, free-in-air, will have to be corrected to Entrance Surface Dose by multiplying by an appropriate backscatter factor. Backscatter factors vary between about 1.3 and 1.4 for the X-ray qualities used for the projections included in the List of Quality Criteria (except for mammography) so a single average value of 1.35 can be used in most situations without appreciable error. For mammography using X-ray tubes with molybdenum anodes (HVL < 0.45 mmAl) backscatter factors of between 1.05 and 1.10 would be appropriate.

Table 1
Entrance Surface Doses observed in British survey in 1983/1984
(Reference 1, p. 21)

Examination		Entrance surface dose (mGy)				
		Min. value	1st quartile	Median value	3rd quartile	Max. value
Chest	PA	0.03	0.13	0.18	0.26	1.43
Chest	LAT	0.14	0.49	0.99	1.46	10.6
Skull	PA	1.82	3.26	4.25	5.49	13.1
Skull	LAT	0.36	1.42	2.19	2.85	9.09
Lumbar spine	AP/PA	0.83	5.65	7.68	11.2	59.1
Lumbar spine	LAT	2.38	12.7	19.7	30.1	106
Lumbo-sacral junction	LAT	7.40	24.0	34.5	50.7	131
Pelvis	AP	0.85	4.19	5.67	7.86	31.6
Urinary tract	AP	0.71	4.69	6.68	10.5	62.4
Breast*		2.9	4.0	5.8	7.1	10.2

* Ref. 2, p. 22

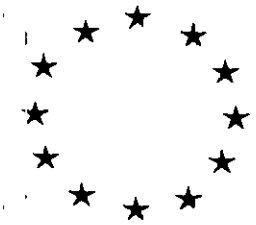
LIST OF PARTICIPANTS IN THE CEC STUDY GROUP

ON

"QUALITY CRITERIA FOR DIAGNOSTIC RADIOGRAPHIC IMAGES"

1.	J.J.	BROERSE	Radiobiological Inst.. TNO - Rijswijk (NL)
2.	J.H.E.	CARMICHAEL	Liverpool (GB)
3.	F.	CORLOBE	Hôpital Saint-Louis, Paris (F)
4.	G.	DREXLER	Institut für Strahlenschutz, GSF - München (D)
5.	P.	ELSAKKERS	ISRRT, Leiden (NL)
6.	H.	ERISKAT	CEC, DG XI/A/1, Radiation Protection, Luxembourg (L)
7.	H.	FENDEL	Haunersches Kinderspital, Univ. - München (D)
8.	M.	LAVAL-JEANTET	Hôpital Saint-Louis, Paris (F)
9.	C.	MACCIA	CAATS-INSERM, Cachan (F)
10.	B.M.	MOORES	Radiation Protection Service, Liverpool (GB)
11.	R.	PADOVANI	Ospedale "Maria della Misericordia", USL No 7 - Udine (I)
12.	W.	PANZER	Institut für Strahlenschutz, GSF - München (D)
13.	H.	SCHIBILLA	CEC, DG XII/D/3, Radiation Protection Programme, Brussels (B)
14.	TH.	SCHMIDT	Klinikum der Stadt Nürnberg, Nürnberg (D)
15.	F.E.	STIEVE	Institut für Strahlenschutz, GSF - München (D)
16.	B.F.	WALL	NRPB - Chilton (GB)
17.	J.	ZOETELIEF	Radiobiological Inst., TNO - Rijswijk (NL)

Draft
- Working Document -



QUALITY CRITERIA

FOR

DIAGNOSTIC RADIOGRAPHIC IMAGES

IN PAEDIATRICS

CEC RADIATION PROTECTION PROGRAMME

EUROPEAN SOCIETY OF PAEDIATRIC RADIOLOGY

(Lake Starnberg Group)

XII/307/91

- June 1992 -

CONTENTS

QUALITY CRITERIA FOR DIAGNOSTIC RADIOGRAPHIC IMAGES IN PAEDIATRICS

INTRODUCTION

With a view to promoting the radiation protection of the patient in diagnostic radiology, a study group, established by the Commission of the European Communities, prepared a Working Document "Quality Criteria for Diagnostic Radiographic Images". This document aims to provide guidance for optimization of image quality and patient dose.

For a number of selected radiodiagnostic procedures most frequently used in standard X-ray examinations, the Document specifies criteria with respect to the three important quality elements of the imaging process:

- the diagnostic quality of the radiographic image
- the radiation dose to the patient
- the choice of the radiographic technique.

In the course of their considerations the members of the Study Group recognized that such guidance frequently can apply only to adult patients. Paediatric patients need a number of special criteria. Therefore, it seemed appropriate to develop a complementary document defining quality criteria for diagnostic radiographic images in paediatrics. The present Document should, on the one hand, follow as far as possible the structure of the Working Document for adults, and on the other hand, when necessary, add or adapt criteria suitable for the special conditions and needs of diagnostic imaging in paediatric patients.

The following Working Document was prepared by a Study Group of European paediatric radiologists, members of the committee for optimization of paediatric radiology of the European Society of Paediatric Radiology, in collaboration and in continuous mutual exchange with the Study Group for the adult quality criteria. It should be used as a supplement when paediatric patients are examined. With respect to the principles as well as details of image quality assurance, good radiographic performance, and patient dose assessment, the following preamble does not supersede the text of the Document for adults but should be used in conjunction with it.

PREAMBLE

Particular importance of radiation protection for paediatric patients

Based on the renewed analysis of dosimetric data and long-term follow-up studies on surviving victims of the atomic bombings, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) emphasized in its last report to the general assembly (1988) that in children there is an additional hazard.

It has long been recognized that because of their longer life expectancy, the risk of suffering from late manifestations of detrimental radiation effects is greater in children than in adults. The recent UNSCEAR report indicates that the radiation risk itself depends strongly on the age at which exposure occurred. This applies to both the absolute (additive) risk model for radiation induced leukaemia and

bone tumours as well as to the relative (multiplicative) model for other tumours. For these other tumours, radiation exposures in the first ten years of life are estimated to have an attributable life-time risk three to four times greater than that after exposures between the ages of 30 - 40 years, and five to seven times greater when compared with exposures after the age of 50 years of life.

This impressively higher individual somatic radiation risk in the younger age groups has been previously ignored or only inadequately considered in radiation protection. It is, therefore, essential to respond to these new risk estimations.

If radiation protection of the patient is important, it is particularly so for paediatric patients. Whilst radiological examinations are indispensible throughout childhood from birth to adolescence, their justification and optimization, which provide the basis for radiation protection, are of far greater importance in these age groups than in adults.

Principles of justification

A written and signed request with clinical information about the patient must be available before an examination is performed.

Justification is the most effective radiation protection, particularly in paediatric patients. Every examination must result in a net benefit for the patient or for the public health. This only applies when it can be anticipated that the examination will influence the efficacy of the decision of the physician with respect to all of the following:

- diagnosis
- patient management and treatment
- final outcome for the patient,

and it also applies in so far as the necessary results cannot be achieved with other methods which would be associated with lower risks for the patient.

Some examinations may be justifiable for public health purposes.

Although the results of the examination may not have an efficacy in this strict sense already considered, justification may still be possible in selected cases when

- consulting physicians are provided with knowledge necessary for genetic counselling of parents or relatives, "genetic counselling efficacy",
- beneficial medical knowledge and experience can be essentially improved, "scientific efficacy".
- there is a non-medical benefit, e.g. claims for damages against third parties, "non-medical, e.g. legal efficacy",
- an influence on the attitude and behaviour of patients, relatives or consulting physicians can be expected where there is a persistent known abnormality or progressive disease, "base line efficacy".

Such justification must not allow routine verification examinations and must have, for each case, a precise validation and informed consent of the patient or the legal representative. Where the justification is scientific efficacy, the consent of an ethical review panel and the supervising authorities must be obtained.

Justification requires that the selected imaging procedure is reliable, i.e. its results are reproducible and have sufficient sensitivity, specificity, accuracy, and predictive value with respect to the particular clinical question.

Justification necessitates that the radiologist responsible for the examination must have enough knowledge and experience to enable accurate evaluation of its results. This implies that the examination is performed by a qualified physician or by an appropriately trained technician.

The principles of justification and optimization overlap in many respects. An imaging procedure which is not optimized is per se not justified and, since all quality criteria depend on a valid clinical indication, an examination which is not justified cannot be optimized.

Justification is most important for radiation protection in paediatric patients. It has been shown that, particularly in these age groups, many radiodiagnostic examinations could be avoided if the above mentioned efficacy-oriented principles were strictly observed.

The Working Document cannot deal in detail with the practical application of justification in paediatric diagnostic imaging. Useful guidance for the rational use of diagnostic imaging in paediatric patients is contained in the respective Technical Report 757 of the World Health Organization (1987).

Specific image criteria for paediatric patients

The anatomical features and body proportions vary due to the developmental process in infancy, childhood and adolescence. They are different in the respective age groups and are distinct from those of a mature patient. The Working Document presupposes knowledge of the changing radiographic anatomy of the developing child. The term "consistent with age" indicates that the respective image criteria essentially depend on the age of the patient.

The smaller body size, the age dependent body composition, the lack of co-operation and many functional differences (e.g. higher heart rate, faster respiration, inability to stop breathing on command, increased intestinal gas etc.) preclude the production of radiographic images in paediatric patients to which standard adult image criteria can be applied. This, however, does not imply that all quality criteria are inappropriate; they must be adapted to paediatric imaging.

Correct positioning of paediatric patients may be much more difficult than in co-operative adult patients. Effective immobilization often necessitates the use of auxiliary devices. Sufficient skill and experience of the imaging staff and ample time for the particular investigation are the imperative prerequisites to fulfill this quality criterion in infants and younger children. No diagnostic radiation exposure should be allowed unless there is a high probability that the exact positioning will be maintained. Incorrect positioning is the most frequent cause of inadequate image quality in paediatric radiographs. Image criteria for the assessment of adequate positioning (symmetry and absence of tilting etc) are much more important in paediatric imaging than in adults.

The reasons for diagnostic imaging in paediatrics are essentially different from those in adult medicine. They vary in the different paediatric age groups. Image quality must be adapted to the particular clinical problem. In paediatric diagnostic imaging, image quality must be a constant preoccupation; nevertheless, more often than in adults, a lower level of image quality may be acceptable for certain clinical indications. An inferior image quality cannot be justified unless this has been intentionally designed and must always be associated with a lower radiation dose. The fact that the X-ray was taken

from a non-co-operative paediatric patient (anxious, crying, heavily resisting) is not an excuse for producing an inferior quality film which is often associated with an excessive dose.

Criteria for good imaging performance

Important image details

The Working Document for adult patients describes numerically the minimum limiting dimension of important image details at which specific normal or abnormal anatomical details should be recognized. Comparable values for radiographs in the different paediatric age groups and for the various clinical situations in paediatrics are not available.

Sometimes the size of the decisive elements of paediatric radiographic patterns is much smaller than any important detail of an adult image, e.g. the reticulo-granular lung pattern of a premature baby with idiopathic respiratory distress syndrome, the minute corner fracture of an abused infant etc. In many cases of standard paediatric imaging, however, larger image details and a coarser pattern is fully adequate for diagnosis or follow-up studies, e.g. the position of the proximal femur in congenital dislocation of the hip, disposition and size of the gastro-intestinal tract etc. Whereas in adult patients image details of defined minimum dimensions should always guarantee that even unexpected findings will not be missed, the acceptable minimum size of paediatric image details essentially depends on the particular clinical question. Consequently, the clinical indication for the imaging procedure must always be taken into consideration when decisions are to be made as to whether or not the respective image is acceptable.

Therefore, in contrast to the Working Document on quality criteria for diagnostic radiographic imaging in adults, the paediatric Document will not give numerical values for the minimum limiting dimensions of the important image details. The fulfilment of the appropriate image criteria and the adherence to the examples of good radiographic technique ensure that important pathological image details will not be missed.

Entrance surface dose

As a second criterion for good imaging performance the adult Document specifies a reference value (in mGy) for the entrance surface dose for a standard-sized patient. The paediatric Document cannot provide such dose values because a standard-sized paediatric patient does not exist. Entrance surface dose values for the selected radiographic procedures in paediatric patients of all age groups are not yet available. An overview of the state of knowledge and reference values for infants are given in Appendix 1.

GUIDANCE ON IMPLEMENTATION OF THE PAEDIATRIC QUALITY CRITERIA

1. Image Criteria

The listed image criteria allow an immediate evaluation of the quality of the respective radiograph. Under adequate image viewing conditions (see the Working Document for adults) no special instruments are needed for the assessment of these image criteria. They are appropriate for the most frequent requirements of radiodiagnostic imaging of paediatric patients. Where necessary, specific clinical questions and situations are taken into account.

Guidance presented here is primarily directed to the technical and clinical staff involved in taking the radiographs and in reporting on them. It may provide the standard for internal quality assurance programmes and also serve as a basis for self-education and training in good imaging practice.

The image criteria should be used in an analytical way and as objectively as possible. This kind of image quality evaluation should replace informal judgement based on subjective global impressions which often induce a false sense of security and confidence.

When one particular image criterion is systematically or frequently not fulfilled the reasons for this failure should be explored and the necessary corrections carried out.

However, the statement already made in the adult Document should be emphasized and even more strictly obeyed in paediatric patients:

under no circumstances should an image which fulfills all clinical requirements but does not meet all image quality criteria ever be rejected.

Consequently, the decision to repeat an exposure must only be made by a physician responsible for that imaging procedure after critically viewing the film and, if necessary, consulting the referring colleague. All rejected films should be retained so they can be used for the planning of appropriate optimization.

Where established, external quality assurance and quality control programmes include the assessment of X-ray films of patients, the quality criteria of this Document may be used for this purpose. Emphasizing again the great importance of the particular clinical problem, external paediatric image quality assessments cannot be performed without a sufficient knowledge of the relevant clinical data. Moreover, knowledge and practical experience of paediatric radiology is essential for members of a panel authorized to assess image quality for paediatric patients.

2. Factors influencing paediatric image quality

Patient positioning and immobilization

Patient positioning must be exact whether or not the patient co-operates. In infants, toddlers and younger children immobilization devices, properly applied, must ensure that:

- the patient does not move,
- the beam can be centred correctly,
- the film is obtained in the proper projection,
- accurate collimation limits the field size exclusively to the required area,
- shielding of the remainder of the body is possible.

In fluoroscopy, immobilization - when necessary - allows shorter examination times.

Immobilization devices must be easy to use, and their application atraumatic to the patient. Their usefulness should be explained to the accompanying parent(s).

Where physical restraint by parents or an other accompanying person is unavoidable, they must know exactly what is required of them. They must be provided with protection from scattered radiation and be absolutely outside the primary beam of radiation applied to the patient. Pregnant women must not be allowed to assist. Radiological staff members should only exceptionally hold a patient.

Even in quite young children the time allocation for an examination must include the time to explain the procedure not only to the parents but also to the child. It is essential that both co-operate, and time taken to explain to a child what will happen is time well spent in achieving an optimized examination fulfilling the necessary quality criteria.

Field size and collimation

Inappropriate field size is the most important fault in paediatric radiographic technique. A field which is too small will immediately degrade the respective image criteria. A field which is too large will not only impair image contrast and resolution by increasing the amount of scattered radiation but also - most importantly - result in unnecessary irradiation of the body outside the area of interest.

Consequently, the anatomical areas specified by the respective image criteria define the minimal and the maximal field sizes. Although some degree of latitude is necessary to ensure that the entire field of interest is included, this cannot be accepted as an excuse for repeatedly using too large a field size in paediatric patients.

Correct collimation requires proper knowledge of the external anatomical landmarks by the technician. These differ with the age of the patient according to the varying proportions of the developing body. In addition, the size of the field of interest depends much more on the nature of the underlying disease in infants and younger children than in adults (e.g. the lung fields may be extremely large in congestive heart failure and emphysematous pulmonary diseases; the position of the diaphragm may be very high in intestinal meteorism, chronic obstruction or digestive diseases). Therefore, a basic knowledge of paediatric pathology is required for radiographers and other technical assistants to ensure proper collimation in these age groups.

The acceptable minimal field size is set by the listed recognizable anatomical landmarks for specific examinations. Beyond the neonatal period, the tolerance for maximal field size should be less than 2 cm greater than the minimal. In the neonatal period, the tolerance level should be reduced to 1.0 cm.

In paediatric patients, evidence of the field limits should be apparent by clear rims of unexposed film. This is of particular importance; beam-limiting devices automatically adjusting the field to the full size of the cassette are inappropriate for paediatric patients. Discrepancies between the radiation beam and the light beam must be avoided by regular assessment. Even minimal deviations may have a large effect in relation to the usually small field of interest.

Film blackening

Film blackening has a major influence on image quality. For the same radiographic projection it depends on many factors: radiation dose, radiation quality, patient size, radiographic technique, image receptor sensitivity and film processing. It determines the optical densities of a radiographic film. The optimal range of the optical density (D) is between $D = 0.8$ and $D = 1.2$ (net density, i.e. over fog and base), with a mean optical density of $D = 1.0$. Films with a mean optical density of less than $D = 0.4$ or more than $D = 2.0$ usually possess an inferior information content. The optical densities of fog and film base should not exceed $D = 0.25$.

Whereas the latter can be easily - and should be routinely - measured, objective measurement of the mean optical density of the film of a patient requires some expenditure and is not practicable in daily work. Even in external quality control programmes assessors usually base their judgement on subjective and global impressions rather than measurements. For a more precise assessment, the definition of

one or a few critical points of the particular radiographic projections would be desirable where the optical density of a specific anatomical feature - and its contrast relative to the surrounding image - could be measured.

The optimal film blackening also depends to a high degree on the suspected pathology (e.g. surrounding soft tissues in suspected bone injury, the nidus of an osteoid-osteoma, opacities or cavities superimposed on a dense pleural effusion etc). Apart from this, film blackening is subject to the personal preference of the individual radiologist. A darker film may be associated with a relatively higher patient dose. In this respect the preference for darker films should be supported by rational arguments.

A film which has been taken and is found to be too dark should be lightened by copying in the darkroom before a decision is made to repeat the examination.

3. Examples of good radiographic technique

Radiographic technique in paediatric patients differs essentially from that in adult patients. Newborns, infants and children are not only smaller but special and their specific needs are not always fully recognized. Many radiological technicians and other technical assistants have insufficient education, training and experience in paediatric radiology, while some have none at all. This Document is not a training manual, reference must be made to appropriate textbooks. The Report 68 "Radiation Protection in Pediatric Radiology" of the National Council on Radiation Protection and Measurements (1981) still gives a lot of most useful information and instructions, even though it was published some years ago.

A list of parameters follows for standard radiographic technique which is designed to meet the selected image criteria with the lowest possible patient dose. These parameters correspond to specific radiographic examinations. They may be changed for special reasons, but such changes should be justified when associated with a higher dose or an inferior image quality.

It has been shown that patient dose is affected far more than image quality by the radiographic technique. Radiographic images with identical quality criteria may be associated with significantly higher patient doses when the radiographic technique is not carefully selected and optimized.

Patient position

Where this item is not mentioned, patient position may be chosen depending on the standard technique, the age and the available radiographic device. For chest examinations, an upright position is usually preferable, but, as in all other examinations, a horizontal patient position which allows exact positioning, centring, collimation and radiation protection - and avoids a needless ordeal for the patient - is better than any inappropriate attempts to hold a resistant infant or child upright.

Radiographic device

In this context, distinction between 'table' and 'grid table' is made. The term 'table' means that the patient lies on the cassette which has been placed on the table. With the 'grid table' the cassette is mounted in the cassette holder beneath the moving grid. The grid table is often used because it is more comfortable for the child and easier for the staff to position the child directly on the grid table than directly on the cassette, but this entails using a grid where none is necessary. This results in an increase in patient dose.

The same is true for vertical chest stands. Here the cassette can be mounted on the front by use of a simple and inexpensive cassette holder when a grid is not necessary. Unfortunately for paediatric patients, few manufacturers have sustained interest in development of special radiographic devices to allow grid-free examinations of the skull and parts of the trunk in newborns and younger infants. Skill and endeavour in the imaging team as well as home-made auxiliary devices can often overcome these deficiencies.

Focal spot size

Usually a focal spot size between 0.6 and 1.3 mm edge length is suitable for paediatric patients. When bi-focal tubes are available, the focal spot size which allows the most appropriate setting of exposure time and radiographic voltage at the chosen focal film distance should be used. This may not always be the smaller one.

Additional filtration

The soft part of the radiation spectrum which is completely absorbed in the patient is useless for the production of the radiographic image and contributes unnecessarily to the patient dose. Part of it is eliminated by the inherent filtration of the tube, tube housing, collimator etc., but this is insufficient. Additional filtration can further reduce unproductive radiation and thus patient dose.

For paediatric patients, total radiation dose must be kept low, particularly when high speed film-screen combinations or image intensifying techniques for photographs are used. Not all generators allow the short exposure times that are required for higher kV technique. Consequently, very low radiographic voltage is frequently used for paediatric patients. This results in comparatively higher patient doses.

Adequate additional filtration allows the use of higher radiographic voltage with the shortest available exposure times, thus overcoming the limited capability of such equipment for short exposures. This makes the use of high speed film-screen combinations and image intensifier photography possible.

Filter materials (molybdenum, holmium, erbium, gadolinium or other rare-earth material) with absorption edges at specific wave-lengths have no advantages compared to simple and inexpensive aluminium-copper (or aluminium-iron) filters, which can easily be home-made. All tubes used for paediatric patients in stationary, mobile or fluoroscopic equipment should have the facility for adding additional filtration and for changing it easily, when appropriate. Usually, the additional filtration of 1 mm aluminium plus 0.1 mm - 0.2 mm copper is appropriate. For standard diagnostic radiographic voltages, every 0.1 mm copper equals about 3 mm aluminium.

Anti-scatter grid

In infants and younger children the use of a grid or other anti-scatter measures is often unnecessary. The examples for good radiographic technique specify when grids are superfluous. Not using grids will then avoid excessive patient dose. Where anti-scatter measures are necessary, grid ratios of 1:8 and line numbers of 40/cm should not be exceeded, even at higher radiographic-voltages. Grids incorporating low attenuation materials such as carbon fibre or other non-metallic material are preferable. Moving grids may present problems in very short exposure times. Quality control of moving grid devices for paediatric patients must take this into consideration. The accurate alignment of grid, patient and radiation beam, as well as careful attention to the correct focus-grid distance is of particular importance.

A grid is rarely necessary for fluoroscopic examinations and spot films of paediatric patients. Only fluoroscopic equipment with the potential for quick and easy removal of the grid should be used in these age groups. Removable grids are not only desirable for fluoroscopic work; ideally, all equipment used for paediatric patients should have this facility.

Film-screen combinations

Among the technical parameters, the selection of higher speed classes (400 - 800) of film-screen combination has the greatest impact on dose reduction. In addition, it allows shorter exposure times that minimize motion unsharpness, which is the most important cause of blurring in paediatric imaging. The reduced resolution of higher speed screens is comparatively insignificant for the majority of clinical indications. For special purposes (e.g. bone details) speed classes of 200 - 400 may be required. Two different sets of cassettes should be available, the one - for special indications - with screens of the lower speed and higher resolution, the other for general use.

The relationship between the speed class of the film-screen combination, the dose requirement at the image receptor (μGy), and the lower limit of visual resolution (line pairs per mm) is given in the table. The values quoted were obtained at 80 kV and with a 25 mm Al phantom. It must be emphasized that values vary with kV and filtration. Ostensibly similar film-screen combinations vary between manufacturers.

Speed class	Dose requirement at image receptor (μGy)	Lower limit of visual resolution (LP/mm)
25	40.00	4.8
50	20.00	4.0
100	10.00	3.4
200	5.00	2.8
400	2.50	2.4
800	1.25	2.0

It must be mentioned that intermediate values are common, but no universal method of assessment is yet agreed. Therefore, the given values provide only approximate guidance. (See BÄK, 1989: DIN 6868 — section 50, ANSI/ISO PH2-31)

Low attenuation materials

Recent developments in materials for cassettes, grids, table-tops and front plates of film-changers using carbon fibre and some new plastics enable significant reduction in patient doses. This reduction is most significant in the radiographic voltage range used in paediatric patients and may reach 40%. Use of these materials should be encouraged

Focus-film distance (FFD)

Regarding this item there are no differences from adult patients. The FFD is usually approximately 115 cm for over-couch tubes on grid tables and 150 cm for vertical stands. The correct adjustment of the grid to FFD must be observed. When no grid is used and the cassette is placed upon the table, a FFD of about 100 cm should be chosen (i.e. the same tube-table distance as with a grid). Longer distances - indicated in parentheses - may be used for special reasons.

In all fluoroscopic examinations, patient to film and patient to image intensifier distances should be kept as short as possible to reduce patient dose. This has particular significance when using automatic brightness control.

Radiographic voltage

As already mentioned, lower radiographic voltage is too often used in paediatric patients. Lower settings than the limits specified in this Document should be avoided wherever possible.

It must be remembered that the effective radiographic voltage depends on the type and age of the generator. Considering the very short exposure times, a nearly rectangular radiation waveform and a minimal amount of ripple are desirable for paediatric patients. 1-, 2- and 6-pulse generators cannot provide this. 12- pulse or multipulse or constant potential generators are required. This means - and this is often misunderstood - that the smallest patients need the most powerful machines.

For mobile equipment multipulse generators are preferable. The disadvantage of capacitor discharge generators is that radiographic voltage decrease over the exposure time (for common exposure times, approximately 1 kV/mAs). One- and two-pulse generators should no longer be used. For a 10 months old infant, a chest X-ray with identical film blackening requires an exposure nearly 20-times longer and gives 2.15-times higher entrance surface dose, when a 1-pulse is used instead of a multipulse generator.

The preset radiographic voltage and effective radiographic voltage may not be identical. In very short exposure times even small discrepancies may have an impact on image quality. When short exposure settings are inconstant, they will effectively influence film blackening and patient dose. Quality control programmes should be meticulous in this regard when assessing equipment for paediatric patients. Generators which do not fulfil requirements for proper and stable calibration (within a tolerance range of about ± 10%) should not be used for paediatric patients and should be replaced as soon as possible.

The radiation emitted by the tube requires a certain time to reach its peak voltage. With the longer exposures used in adult patients, this pre-peak radiation is insignificant. With the very short exposure times in paediatric radiography, pre-peak times must be taken into consideration. Some old generators have pre-contact phases in which soft radiation may be emitted. Added filtration eliminates this which is another reason for advocating its use.

Automatic exposure control

Adult patients vary in size, but their variation is minimal compared to the range in paediatric patients - premature infants, weighing considerably less than a thousand grams, to adolescents approaching 70 kg. Those investigating paediatric patients must be able to adapt to this range. One would expect that a device for automatic exposure control (AEC) would be helpful. However, many of the systems commonly available are not satisfactory. They have relatively large and fixed ionization chambers. Neither their size nor their shape nor their position is able to compensate for the many variations of body size and body proportion in paediatric patients. In addition, the usual ionization chambers of AECs are built in behind a grid. Consequently, their use is inevitably associated with the use of the grid, (where the grid is not removable) which - as previously mentioned - is frequently unnecessary. The optimal adaptation of the radiographic technique to the clinical needs requires the use of film-screen combinations of different speeds and different switch-off doses at the image receptor. Screens and AEC chambers are wavelength dependant, particularly in the lower range of radiographic voltage, but these dependencies do not correspond with each other. AECs lengthen the minimal exposure times. All these factors must be considered when AECs are used in paediatric patients. They are complicated to use and result in many unsatisfactory examinations.

Its position can be selected with respect to the most important region of interest. This must be done extremely carefully, as even minor patient movement may be disastrous. The high speed of modern screens allows a minute dose at the cassette front. Consequently, the detector behind the cassette has to work in the range of a fraction of 1 µGy. It is nearly impossible to provide constancy and reproducibility in this range.

Much safer, easy-to-use and less expensive are exposure charts corresponding to radiographic technique and patient's weight - the so-called body index - when X-raying the trunk, or patient's age for the extremities. In the future, small and simple computers may incorporate multifactorial parameters for this purpose. A learning "intelligent" unit would be ideal for paediatric patients.

The Example of Good Radiographic Technique indicates when the AEC may be used and which chamber should be selected.

Automatic brightness control

Automatic brightness control has to be switched off during fluoroscopic examinations where there are relatively large areas of positive contrast material to avoid excessive dose rates, e.g. full bladders.

Exposure time

In paediatric imaging, exposure times must be short. This is only possible with powerful generators and tubes, as well as optimal rectification and accurate time switches. The equipment must work and provide constancy in the shortest time range. For old generation generators, exposure time settings lower than 4 ms - although desired - should not be used and are explicitly not considered under the example of good radiographic technique. Constant timing at these low settings (< 4 ms) may be a problem. The pre-peak times (> 2 ms) interfere, to a relatively greater degree, with short preset exposures. In this respect, multipulse, constant high potential and capacitor discharge generators allow the use of lower settings.

For these extremely short exposure times, the cable length between the transformer and the tube is important. The cable works as a capacitor and may - depending on its length - produce a significant surge of radiation after the generator has been switched off. This post-peak radiation may last for 2 ms or more.

Accurately reproducible exposure times around 1 ms with a rectangular configuration of dose rate and wavelength of radiation - practically without pre- and post-radiation - may be achieved with grid controlled tubes.

These are problems associated with the lower limits of the exposure time. For most equipment used for paediatric patients, however, the difficulty is in obtaining optimal short exposure times. Unless it is possible to adapt the available equipment to use the recommended range of exposure times, the equipment should not be used for paediatric patients.

Radiation protection

For all examinations of paediatric patients, the example for good radiographic technique includes lead-rubber shielding of the body in the immediate proximity of the diagnostic field. Thus the body is protected against external scattered and extrafocal radiation. For exposures of 60 - 80 kV, a dose reduction of about 30 to 40% can be obtained by shielding with 0.25 mm lead equivalent rubber 4

— 6 cm away from the boundary of the primary beam. However, this is only true when the protection is placed correctly at the field limit. Lead-rubber covering further away is less effective, and at a distance of more than 6 cm is completely ineffective. This may have a psychological effect but provides no radiation protection at all

The gonads in "hot examinations", i.e. when they lie within or close (nearer than 5 cm) to the primary beam, should be protected whenever this is possible without impairing necessary diagnostic information. It is best to make one's own lead contact shields for girls and lead capsules for boys. They must be available in varied sizes. The testes must be protected by securing them within the scrotum to avoid upward movement caused by the cremasteric reflex. By properly adjusted capsules, the absorbed dose in the testes can be reduced by up to 95%. In girls, shadow masks within the diaphragm of the collimator are as efficient as direct shields. They can be more exactly positioned and do not slip as easily as contact shields. When shielding of the female gonads is effective, the reduction of the absorbed dose in the ovaries can be about 50%.

There is no reason to include the male gonads in the scrotum within the primary radiation field for radiographs of the abdomen. The same applies, usually, for films of the pelvis and micturating cystourethrographies. The testes should be protected with a lead capsule, but kept outside the field. In abdominal X-rays gonad protection for girls is not possible. In practice, the great majority of pelvic films show that female gonad protection is completely ineffective. The position of all sorts of lead material is often ludicrous. There are justifiable reasons for omitting gonad protection for pelvic films in girls, e.g. trauma, incontinence, abdominal pain, etc.

The eyes should be shielded for X-ray examinations involving high absorbed doses in the eyes, e.g. for conventional tomography of the petrous bone, when patient co-operation permits. The absorbed dose in the eyes can be reduced by 50% - 70%. In any radiography of the skull the use of PA-projection rather than the AP-projection can reduce the absorbed dose in the eyes by 95%. PA-projection, therefore, should be preferred as soon as patient age and co-operation permit prone or erect positioning.

As developing breast tissue is particularly sensitive to radiation, exposure must be limited. The most effective method is by using the PA-projection, rather than the AP. While this is well accepted for chest examinations, the greatest risk is during spinal examinations, and here PA-examinations must replace AP.

It should also be remembered that thyroid tissue should be protected, whenever possible, e.g. during dental and facial examinations.

4. Definition of terms used for the diagnostic requirements for image criteria
(these are the same as in the Working Document for adult radiology)

These refer to characteristic features of radiological images with a specific degree of visibility. At the present time there are no internationally accepted definitions. For the purpose of this Document the following are used:

Visualization

an anatomical feature is detectable but details are not fully reproduced

Reproduction

the details of anatomical features are visible but not necessarily clearly defined

Visually sharp reproduction

the anatomical details are clearly defined

REFERENCES

The following is a limited reference list. References (1) to (3) contain extensive reference lists.

(1) National Council on Radiation Protection and Measurements (NCRP). Radiation Protection in Pediatric Radiology. Report No. 68. Bethesda: NCRP Publications 1981

(2) World Health Organization (WHO). Rational Use of Diagnostic Imaging in Paediatrics. WHO Technical Report Series 757. Geneva: World Health Organization 1987

(3) United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR): Sources, Effects and Risks of Ionizing Radiation, Report 1988

(4) BÄK, Bundesärztekammer. Leitlinien der Bundesärztekammer zur Qualitätssicherung in der Röntgendiagnostik. Dt. Ärztebl. 86, Heft 27, 1989

(5) Schneider K, Fendel H, Bakowski C, Stein E, Kellner M, Kohn MM, Schweighofer K & Cartagena G. Results of a Europe-wide Dosimetry Study on Frequent X-ray Examinations in Paediatric Populations. Paper presented at the Seminar on Dosimetry in Diagnostic Radiology, Luxembourg, March 1991.

Review of Radiation Dosis to Paediatric Patients

Objective

The CEC Quality Criteria Document for adult radiography includes reference dose values for selected types of radiographs as a guide to X-ray department staff on acceptable levels of patient exposure.

This review discusses the particular problems that occur in defining acceptable doses for paediatric radiography and seeks to provide data to aid such decisions.

Derivation of the reference dose values

Patient doses for the same type of examination inevitably vary enormously throughout the paediatric age range because of the wide variation in patient size. It is consequently essential that paediatric doses are known and quoted for tightly specified age groups.

A few reports have been published giving doses to children for selected types of X-ray examinations and age groups (e.g. Ruiz et al. 1991, Tautz and Brandt, 1988), but they are very few in number and the sizes of the measurement samples are far too small to be representative for Europe.

It was therefore necessary for the CEC Study Group that produced this Working Document to collect information on patient doses and techniques in paediatric radiology from a representative sample of X-ray departments throughout Europe. A widespread survey was consequently started in 1989 which included 89 X-ray departments, headed by paediatric radiologists, in children's clinics and general hospitals from 11 European countries (Schneider et al. 1992). In each of these departments Patient Entrance Surface Doses (ESDs) were measured by using thermoluminescent dosemeters (TLDs) sent by post together with a questionnaire used to collect technical information on the examinations performed.

CaF_2:Dy-TLDs proved to be most suitable for this purpose because of their high sensitivity. The well known pronounced energy dependence of this material was less disturbing because the energy response curve is rather flat in the energy range to be considered in paediatric radiology (tube voltages between 50 and 90 kV). On the contrary, this energy dependence turned out to be advantageous because the higher energetic background radiation was drastically underrated. Thus it finally became possible to measure doses far lower than the doses due to background radiation during the turnover period of the TLDs.

The survey was necessarily confined to selected X-ray examinations and age groups of paediatric patients. Those selected were:

Skull	PA/AP	fixed unit	10 month infant
Chest	AP/PA	fixed unit	10 month infant
Chest	AP	mobile unit	10 month infant
Abdomen	AP	fixed unit	10 month infant
Spine	Lateral	fixed unit	10 month infant
Chest	AP	mobile unit	1000g premature baby
Pelvis (hip)	AP	fixed unit	4 month infant

with suspected congenital hip dysplasia.

As in the CEC Quality Criteria Document for adults the patient entrance surface dose including backscatter is the preferred dose quantity because it can be measured comparatively easily by attaching a suitably sensitive TLD directly to the patient's skin. Other dose quantities exist which are more closely related to the radiation risk to the patient, e.g. organ doses, effective dose or the total energy imparted to the patient. They cannot, however, be measured directly and the various assumptions and uncertainties involved in their estimation can lead to ambiguity in their expression.

For the selected projections included in this Document, the patient ESD is the most critical factor affecting the radiation risk. It therefore provides a realistic, easily measured guide to the relative level of patient protection being provided by the imaging techniques used in different facilities for the same projection.

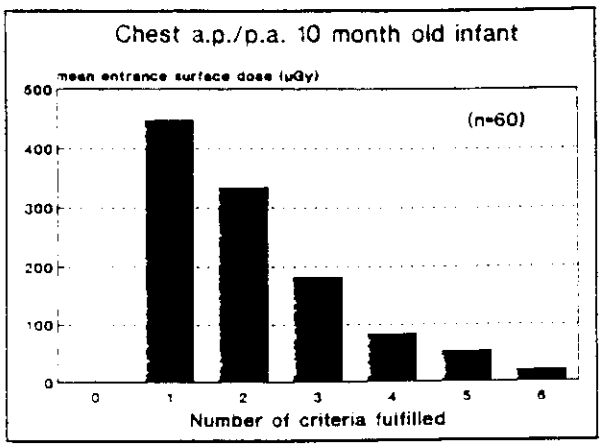
As usual, and in spite of the homogeneous age and size of the patients in this study, a wide variation in doses were observed. Characteristics of the dose distributions observed are shown in Table 1.

	Entrance Surface Dose (μGy)					
	min	1st quartile	median	mean	3rd quartile	max
Skull AP/PA (10 months)	152	600	930	1260	1690	4514
Chest AP/PA fixed (10 months)	21	45	75	132	135	979
Chest AP mobile (10 months)	34	55	90	129	150	718
Chest AP (1000g)	11	25	45	68	80	386
Abdomen AP (10 months)	77	260	440	651	700	3210
Spine lateral (10 months)	107	450	880	1128	1500	4351
Pelvis (Hip) AP (4 months)	18	100	260	398	640	1369

Table 1. Entrance Surface Doses observed in the CEC trial on paediatric radiology for a selection of projections and age groups.

It is proposed that the reference doses should initially be based on rounded values of the 3rd quartiles shown in the table. It is argued that if 75% of the X-ray departments can easily operate below these dose levels, then the remaining 25% should be made aware of their less than optimal performance and should be urgently encouraged to alter their radiographic equipment and techniques to bring their doses in line with the majority. At the same time adherence to the image criteria will ensure that diagnostic efficacy does not suffer. The recommended reference doses are shown in the second column of Table 2.

From further analysis of the survey data it can be shown that, when the criteria for good radiographic technique defined in this Document were followed, the measured ESD values were significantly reduced. Figure 1 shows for the example of the chest examination of a 10 month old baby with stationary equipment, that the more of these technique criteria were fulfilled, the lower the mean ESD. A similar result obtained for the skull examination is given in Appendix 2.



Focal spot size is assumed to be correct unless explicitly stated > 1.3 mm

Additional filtration is explicitly stated to be more than 1 mm Al + 0.1 mm Cu or similar materials (≥ 4 mm Al equivalent)

Anti-scatter grid is not used

Film-screen combination speed class is explicitly stated to be ≥ 400

Focus-film distance is assumed to be correct unless explicitly stated < 100 cm for tables, < 150 for stands

Radiographic voltage is explicitly stated to be ≥ 60 kV

Fig. 1. Impact of fulfilment of good radiographic technique criteria (listed on the right) on dose.

In the EXAMPLE OF GOOD RADIOGRAPHIC TECHNIQUE given for each type of radiograph in this Document, values of settings for 10 technical parameters are included, but only six of them are influencing ESD (as listed alongside Figure 1).

The third column of Table 2 shows the mean ESD values for those cases from the survey sample where at least five out of these six technical parameters were fulfilled. These values represent the potential target dose that can be obtained using modern equipment and optimum procedure and it is proposed that they be referred to as "Achievable Doses".

	Reference Entrance Surface Dose (μGy)	Achievable Entrance Surface Dose (μGy)
Skull AP/PA (10 months)	1700	800
Chest AP/PA (10 months)	150	70
Chest AP (1000g)	80	30
Abdomen AP (10 months)	700	400
Pelvis (Hip) AP (4 months)	200 [1]	50

Table 2. Reference and achievable Entrance Surface Doses for a selection of projections and age groups.

[1] this reference dose is based on only those examinations without grid

Achievable Doses are generally about a half of the Reference Doses in Table 1, except for the pelvic examination on 4 month old patients, where it can be much lower. This is because a large number of X-ray departments in the survey used an antiscatter grid for pelvic examinations which is not recommended in the criteria for this age of patient.

The lateral spine examination is not included in Table 2 because there were too few data in the survey sample to be representative and the examination procedure was not well defined.

Checking compliance with the guidelines

It is recommended that X-ray departments measure the entrance surface doses that they are delivering to a representative sample of children of the specified age (±2 months, with the exception of the premature baby and the 4 months infant) for the selected types of radiographs, and compare the mean dose for the sample with the doses in Table 2. If they are above the reference doses they should make immediate investigations to determine the reasons for such high doses. The investigations should lead to improvements in their equipment or techniques to reduce doses to below the reference value or, in exceptional circumstances, must lead to thorough justification of the need for such high levels of patient exposure in that particular clinical situation.

The achievement of mean doses below the reference level should not be construed as an indication of satisfactory or optimum performance per se. It may be well possible to reduce doses further without detriment to the diagnostic value of the examination and such reductions should always be pursued in line with the ALARA ("As Low As Reasonably Achievable") principle. The "Achievable Dose" level (3rd column Table 2) represents an acceptable dose, readily attained with modern techniques and equipment.

At the present time there are insufficient data to recommend reference doses for other age groups or examinations. The ages and examinations included in this study, however, represent a substantial fraction of the workload of a typical paediatric X-ray department and compliance with these alone will help to ensure satisfactory performance throughout the department.

There is an urgent need for more paediatric dose data for other well defined age ranges and for other types of examination. Staff in X-ray departments that deal with large numbers of paediatric patients are encouraged to perform surveys of patient dose and radiographic technique and to publish their results or send them to the CEC Study Group so that the existing database can be extended. It would be helpful if all surveys were to use the same patient age bands so that results are comparable. The following age bands are recommended:

1. 0 - 1 month neonates
2. 1 - 12 months
3. 1 - 5 years
4. 5 - 10 years
5. 10 - 15 years

If patients are grossly underweight or overweight for their age it may be appropriate to allocate them to another age band more indicative of their size and weight.

Since suitably sensitive TLDs might not always be available, there may be more convenient alternative methods according to the equipment and the possibilities in a department: Dose area product meters can be used routinely to measure and control dose to patients. Their use is recommended also in the field of paediatric X-ray examinations.

Records of tube voltage, filtration, film-processing and focus-
measurement of dose free in air at the focus to skin distance by means of suitable ionization dosemeters or for the estimation of this dose on the basis of graphs and tables from the literature. If they are to be comparable with the doses quoted in this Document, doses free in air are to be corrected to account for backscatter from the patient.

References

Ruiz M.J., Gonzalez L., Vaño E. and Martinez A., 1991. Measurement of radiation doses in the most frequent simple examinations in paediatric radiology and its dependence on patient age. Brit. J. Radiol., 64, 929-933.

Schneider K., Fendel H., Bakowski C., Steiner E., Hohn M.M., Kellner M., Schweighofer K., Cartagena G., Padovani R., Panzer W., Scheurer C., Wall B., 1992. Results of a dosimetric study in the European Community on frequent X-ray examinations in infants. Radiation Protection Dosimetry, in press.

Tautz M., and Brandt G.A., 1988. Abschätzung von Organdosen bei standardisierten Röntgen-untersuchungen im Kindesalter. Radiol. Diagn., 29, 169-179

Workshops and Seminars
CEC (Radiation Protection Programme)

Workshops and Seminars promoted by CEC (Radiation Protection Programme) are considered as important events in European Community countries for Radiation Protection and Quality Assurance in diagnostic radiology and were useful arena where discuss results and experiences coming from research and practical activities

1981 "Patient Exposure to Radiation in Medical X-ray Diagnosis", Munich

1984 "Criteria and Methods for Quality Assurance in Medical X-ray Diagnosis", Udine

1988 "Technical and Physical Parameters for Quality Assurance in Medical Diagnostic Radiology", Brussels

1988 "Optimisation of Image Quality and Patient Exposure in Diagnostic Radiology", Oxford

1991 "Dosimetry in Diagnostic Radiology", Luxembourg

1992 "Quality Assurance and Radiation Protection in Digital Radiography", Mannheim

1992 "Test Phantoms and Optimisation in Diagnostic Radiology and Nuclear Medicine", Wurzburg

1993 "Data Analysis in Quality Control and Radiation Protection of the Patient in Diagnostic Radiology and Nuclear Medicine", Grado