Optimization of patient protection using rare earth screen in conventional imaging procedure

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Abstract. The purpose of this study was to optimize patient protection using rare earth screen of speed 400 in place of conventional screen-film of speed 200. The entrance surface dose (ESD) for the two screen-film systems was determined for patients undergoing simple radiographic examinations (chest, lumbar spine and pelvis series). The determination of the ESD included backscatter factors. The ESD was the optimizing parameter and its trade off with the image quality assessment, which was surveyed based on the information obtained through standardized questionnaire. The estimated ESDs were compared with reference levels set by the Community of European Commission (CEC) for a standard adult patient. For chest PA, ESD estimates were lower than the CEC reference levels whilst that of lumbar spine AP and LAT and pelvis AP were high. Upon the adoption of rare earth screen of speed 400, a dose reduction of 33% for chest, 17% for lumbar spine and 28% for pelvis examinations was achieved. From the observations made from this study, some corrective actions such as equipment quality control of parameters that affect patient dose and image quality like kVp accuracy and consistency, mAs accuracy and consistency, optimal film processing conditions, regular film reject analysis to detect and minimize the root causes and contributory factors to poor image quality and periodic training of staff on dose reduction techniques must be undertaken. Regular assessment of patient dose and image quality, equipment quality control, adoption of faster rare earth screens and optimum radiographic technique are therefore recommended in order to achieve optimization goals.

KEYWORDS*:* Optimization, rare earth screen, entrance surface dose, chest, lumbar spine and pelvis.

1. Introduction

Diagnostic radiology accounts for about 14 percent of the average annual effective dose from all sources including natural radiation, it contributes to over 90 percent of that from all man-made exposures [1]. This makes radiation doses from diagnostic radiology the largest contribution to the collective dose from all man-made sources of radiation.

Radiological examinations are used to discover and define the type and extent of disease in many clinical situations. However, public and professional concern over the potential risks from radiation exposure and the increasing costs of radiographic examinations have led to studies of methods to reduce unproductive radiographic examinations, i.e., examinations that do not yield information useful to patient management. There is also the possibility of underutilization of radiography; this can result in inadequate or excessively delayed diagnosis [2].

Since the establishment of radiography as an imaging modality, continuous developments have led to improvements in technique resulting in improved image quality at reduced patient dose. Some national surveys, particularly in the United Kingdom (UK) and in the United States of America (USA) in the 1980s and 1990s, have indicated large variations in patient doses for the same diagnostic examination, in some cases by a factor of 20 or more. This arises not only owing to the various types of equipment and accessories used by the different health care providers, but also because of operational factors [3].

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Many risk reduction possibilities are predictive and speculative in nature, and so are the numbers of dose reduction approaches and optimization parameters. However, there are some definite approaches with clear impact on dose reduction. One of these is the replacement of the conventional image intensifying screens in the X-ray cassette (calcium tungstate screens) with rare earth screens. This has been shown to reduce substantially patient dose while retaining adequate image quality in a very cost-effective manner. As compared to the traditional calcium tungstate ($CaWO_4$) intensifying screens, the rare earth screens have about four times as high X-ray to light conversion efficiency (about 20% versus 5%), and also a higher X-ray absorption efficiency (about 50% versus 40% for calcium tungstate screens). Due to the high atomic number of the screen phosphors, X-ray absorption is almost entirely due to photoelectric absorption [4]. Photoelectric absorption in an atom decreases steadily with increasing X-ray energy, but increases abruptly at the K-edge of the atom. X-ray energies just above the K-edge are therefore well absorbed. Rare earth elements such as lanthanum with atomic number (Z) of 57 and gadolinium (Z=64) have K-edges at 38.9 and 50.2 keV, respectively; while tungsten (Z=74) has its K-edge at 69.5 keV. Most X-ray spectra used in conventional skeletal imaging have a mean energy between 40-50 keV, making especially lanthanum much more effective in absorbing these energies than tungsten. Screen speed values for rare earth screens vary from 200 to 1600 [4].

Even though this technology has been introduced nearly two decades ago and has been implemented in most industrialized countries, not many developing countries have switched over from the use of $CaWO_4$ screens to rare earth screens fully including Ghana with only few fast screens in existence. The reasons for non-adoption are that all the film cassettes of the department have to be replaced simultaneously, and the films used have to match the spectral emission from the screen and thus the department has to switch over to new films. Both these factors involve huge financial inputs and require strong administrative and management commitments.

Two basic principles of radiological protection as recommended by the International Commission on Radiological Protection (ICRP) are justification of the practice and optimization of protection (ICRP Publication 60) [5]. These apply to the protection of the patient as well. Justification is the first step in radiological protection. It is accepted that diagnostic exposure is justifiable only when there is a valid clinical indication, no matter how good the imaging performance may be. Every examination must result in a net benefit to the patient [3]. Once a diagnostic examination has been clinically justified, the subsequent imaging process must be optimized to obtain the required diagnostic information for a patient dose that is As Low As Reasonably Achievable (ALARA), with economic and social factors taken into account. The third principle of individual limitation of dose does not however apply to patients, as the assumption is that the benefit of any medical procedure will outweigh the risk from that procedure. In place of individual dose limits, the use of investigation levels (diagnostic reference levels, DRLs) has been recommended as a practical way of promoting the optimization of protection [6, 7].

This paper concentrates on the optimization of the protection of the patient using rare earth screens in place of conventional screens by dealing with ways that doses can be minimized by optimizing radiographic techniques without a sacrifice in image quality. The approach adopted in the optimization process is outlined in this study. The image quality was assessed from film reject analysis (FRA) before quality control intervention. The causes for poor image quality was identified and categorized. The assessment of patient dose was also carried out. The procedure was repeated after quality control intervention. The study was carried out at the Polyclinic of Korle-Bu Teaching Hospital in Accra.

2. Methodology

2.1 Film Reject Analysis

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In order to identify the causes and contributory factors to poor image quality, a FRA was done at the beginning of the study for a minimum of four weeks. The films were assigned grades A, B and C (A-clearly accepted without any remarks or reservations, B-accepted with some remarks/reservations and C-rejected). The causes for rejection of films were analysed according to the following; over and under exposure, artefacts, field size misplacement, processing problems, positioning/collimation errors, patient movement and others. Films were rejected at both the radiographer level and radiologist level.

After the FRA, corrective measures were undertaken and a repeat of the FRA was done. This was to ascertain whether there has been an improvement in the image quality after the institution of the corrective actions. The corrective actions was the appropriate choice of kVp and mAs technique to deal with over and under exposure causes to poor image quality, processor quality control to address processor problems, checking of X-ray and light field congruence to deal with positioning errors, cleanliness of cassettes and dark room hygiene to deal with artefacts and equipment repairs.

2.2 Quality Control Tests

Quality control testing was performed on the X-ray tube before the dose assessment was done in order to assess the equipment performance. Tube output and filtration were assessed with a Rad-check plus exposure meter (model 06-625, S/N 103007) and high purity aluminium half value layer (HVL) attenuator set (model GAMMEX RMI 115A, S/N 9511). The accuracy, reproducibility of kVp (i.e. kVp calibration) and timer were measured with a RMI 240A Multi-Function Meter (model GAMMEX RMI, S/N 800391-2670). For the light/radiation beam alignment test, two test tools were used; the RMI Collimator Test Tool (model 161B, S/N 800422-10388) designed to evaluate the collimator according to National Centre for Devices and Radiological Health (NCDRH) specifications [8] and, the Beam Alignment Test Tool (model 162A, S/N 800423-8791), which was used with the Collimator Test Tool to provide a simple test for beam alignment. After the QC tests, appropriate corrective actions were then made on the basis of the tests.

2.3 Patient Dose Assessment

The dosemetric quantity chosen for this study was entrance surface dose which is suitable for plain and simple single X-ray examinations [9]. Output measurements free in air was taken with a calibrated ionization chamber, which was corrected using appropriate backscatter factor (bsf) and radiographic techniques used in clinical practice to estimate the ESD. The technique factors collected included applied potential (kVp), current-time product (mAs), focus to film distance (FFD), film size, field size, screen speed and patient related data; age, sex, AP thickness and weight.

The empirical relation between ESD and technique parameters used for the estimation is shown in equation (1) below [10, 11]:

$$ESD = \left[\alpha \left(\frac{kVp}{100} \right)^{\beta} \left(\frac{100}{SSD} \right)^{2} \left(\frac{BSF}{100} \right) mAs \right] mGy \tag{1}$$

where

α and β are empirical constants which depend upon the type of x-ray generator.

ESD = entrance surface dose (mGy)

SSD = source to skin distance = film to focus distance (FFD) - patient anatomical thickness.

BSF = backscatter factors adopted from National Radiological Protection Board Report [12]

3. Results

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The results of the FRA before and after corrective actions are illustrated in Tables 1 (a, b) and 2 (a, b) for a total of 342 and 321 films analysed respectively. The causes of poor image quality for a total of 83 films graded B and C of the FRA before corrective actions is shown in Figure 1 while that of the FRA after corrective actions is shown in Figure 2 for a total of 51 films.

Table 1: Analysis of film rejects at radiographer and radiologist level before corrective actions.
(a) At radiographer level

Number of films used	324
Number rejected at radiographer level	54
% Rejected	17 %

(b) At radiologist level

Grade category	Number	Percentage (%)
A graded films	241	74
B graded films	29	9
C graded films	54	17
Total	324	100

Table 2: Analysis of film rejects at radiographer and radiologist level after corrective actions.
(a) At radiographer level

Number of films used	321
Number rejected at radiographer level	32
% Rejected	10 %

(b) At radiologist level

Grade category	Number	Percentage (%)
A graded films	270	84
B graded films	19	6
C graded films	32	10
Total	321	100

The results of the QC measurements are given in Table 3.
Table 3: Summary results from the quality control measurements taken at the start of the study.

Parameter	Range tested	SD (%)	Acceptance Criteria	Remarks
kVp accuracy	50-125 kVp	< 3	SD ≤ ± 5%	Pass
kVp reproducibility	50-125 kVp	CV < 3.6%	CV ≤ ± 5%	Pass
Output consistency	(50,60,70,81,90,102) kVp	CV < 3.6%	CV ≤ ± 5%	Pass
Timer accuracy	(32.3-412.0) ms	CV < 4.9%	CV ≤ ± 10%	Pass
Timer reproducibility	(32.3-412.0) ms	CV <	CV ≤ ± 10%	Pass

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		4.9%		
Half value layer determined @ 81 kVp = 3.9 mmAl				

A summary of the mean technique factors, patient thickness and entrance surface dose for the two screen-film systems for the three examinations with relevant projections studied are given in Table 4.

Table 4: Mean values for patient thickness, technique factors and entrance surface dose (ESD) for the 3 examinations in the study using screen-film of speed 200 and 400.

Screen-film speed	Examination	kVp	mAs	Patient thickness (cm)	FFD (cm)	ESD (mGy)	CEC Values (mGy)
200	Chest PA	105.8	4.3	21.3	180	0.3	-
	Lumbar spine AP	55.7	439.9	22.3	100	26.4	-
	Lumbar spine LAT	64.0	455.2	24.5	100	38.3	-
	Pelvis AP	55.9	279.8	24.0	100	18.0	-
400	Chest PA	102.0	2.8	21.6	180	0.2	0.3
	Lumbar spine AP	53.4	411.2	21.2	100	21.9	10
	Lumbar spine LAT	60.4	434.8	24.2	100	31.8	30
	Pelvis AP	52.5	263.4	23.3	100	13.0	10.0

The comparison of the radiographic techniques used at KBPC with that recommended by CEC is shown in Table 5 for the two screen-film combination systems used.

Table 5: Comparison of radiographic technique used at the KBPC compared with the CEC recommended technique for examination of chest PA, lumbar spine AP, lumbar spine LAT and pelvis AP.

Examination	Institution	kVp	FFD (cm)	Screen-film speed	t (ms)
Chest PA	CEC	125	180 (140-200)	400	< 20
	KBPC I	106	180	200	14
	KBPC II	102	180	400	9
Lumbar Spine AP	CEC	75-90	115 (100-150)	400	< 400
	KBPC I	58	100	200	377
	KBPC II	53	100	400	549
Lumbar spine LAT	CEC	80-95	115 (100-150)	400	< 1000
	KBPC I	64	100	200	229
	KBPC II	60	100	400	430
Pelvis AP	CEC	75-90	115 (100-150)	400	< 200
	KBPC I	56	100	200	428
	KBPC II	53	100	400	406

Note: KBPC I and KBPC II refer to radiographic techniques used for the conventional screen-film combination of speed 200 and rare earth screen-film of speed 400 respectively

Results of mean dose reduction achieved after using a rare earth screen-film combination of speed 400 instead of 200 is shown in Table 6.

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Table 6: Percentage of mean dose reduction

Exam	ESD (mGy)		CEC value (mGy)	Average dose reduction (%)
	Speed 200	Speed 400		
Chest PA	0.3	0.2	0.3	33
Lumbar spine AP	26.4	21.8	10	17
Lumbar spine LAT	38.3	31.8	30	17
Pelvis AP	18.0	13.0	10.0	28

4. Discussion

Out of a total of 324 films evaluated from the FRA before corrective actions were taken, films graded A accounted for 74% while B and C accounted for 9 and 17% respectively. Then after implementation of corrective actions, a total of 321 films were analysed out of which grade A films accounted for 84% while B and C accounted for 6 and 10% respectively. The major causes of rejects were due to over and under exposure, artefacts, field size misplacement and processing problems (Fig. 1 and 2).

Figure 1: Analysis of the causes of poor quality for grade B and C films before corrective actions.

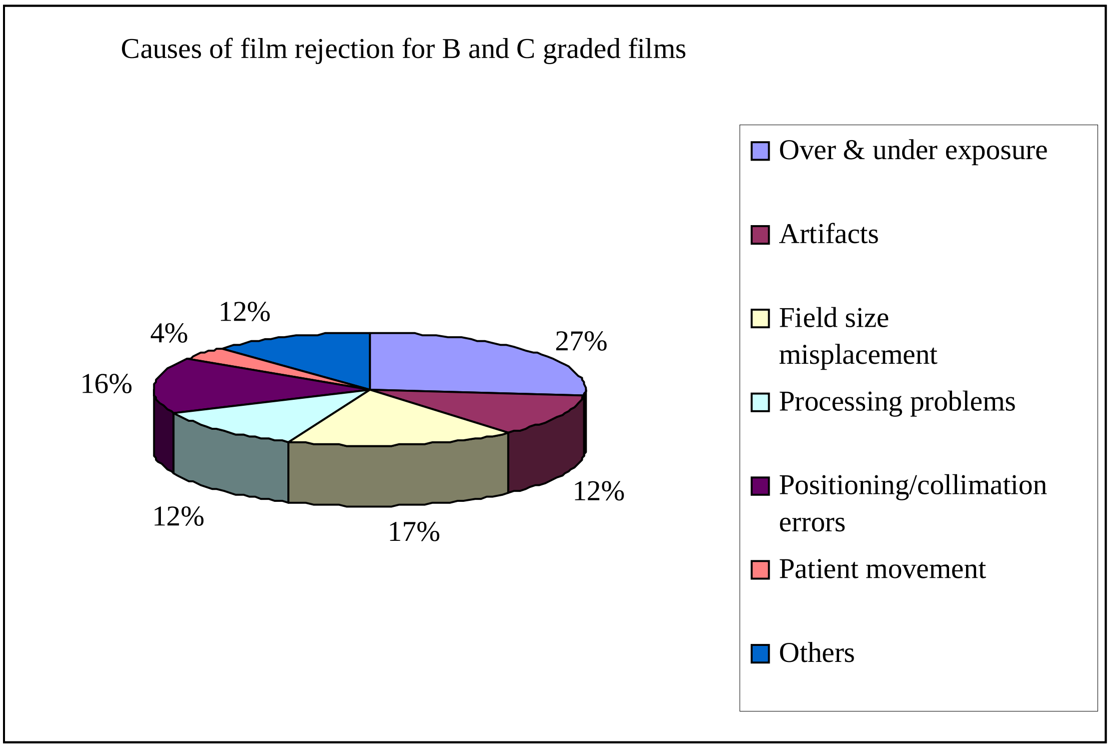

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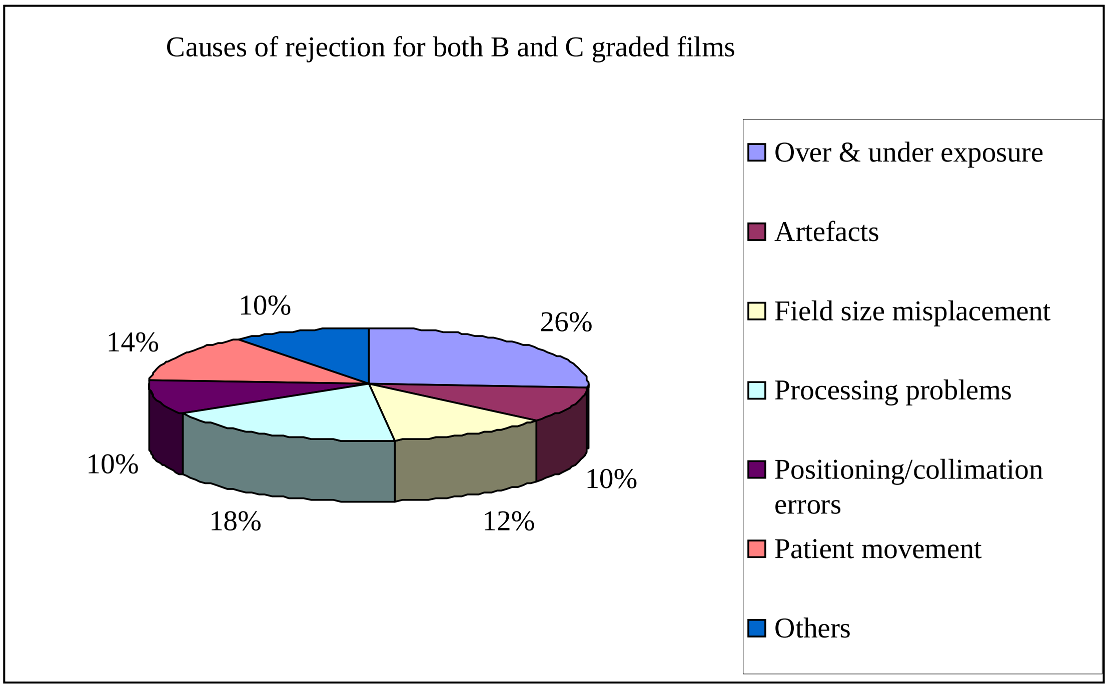
Figure 2: Analysis of the causes of poor quality for graded B and C films after corrective actions.



For Fig.1 for instance, over and under exposure accounted for the highest cause (27%) with the lowest due to others (4%). For Figure 2, over and under exposure also accounted for the highest cause (26%), with the lowest recorded for artefacts, positioning/collimation and others (10%). Films could be under or over exposed because of incorrect film processing or incorrect exposure settings or both.

For optimum yield of diagnostic image quality a maximum of 5% of grade C films should be the goal for any diagnostic department. This demands that more attention should be given to the choice of appropriate X-ray spectrum (kV, beam filtration) and mAs used to generate the radiographs and film processing for a particular radiographic examination.

It emerged from the FRA that there was an improvement in the image quality of the radiographs as the film reject rate improved after the implementation of the corrective actions. Production of grade A films improved by 10% from 74% to 84% {Table 1(b) and Table 2 (b)}. The optimum criteria can be met if particular attention is given to addressing causes of under exposure and over exposure.

From the results of the quality control measurements (Table 3), both kVp accuracy and reproducibility were within 5% and the coefficient of variation in radiation output was well within the required limits of 5%. Timer accuracy and reproducibility were also within 10%. The determined half value layer (HVL) of 3.99 mmAl @ 81 kVp indicated sufficient filtration for the X-ray tube. This indicates that the X-ray tube and accessories were performing self-consistently with respect to beam quality and kVp accuracy and reproducibility.

The ESDs for PA chest ranged from 0.1 to 0.6 mGy with a mean value of 0.3 mGy for speed 200 and 0.1 to 0.5 mGy with a mean value of 0.2 mGy for speed 400.

The ESDs for lumbar spine (AP and LAT) ranged from 10.4 to 59.9 mGy with a mean value of 26.4 mGy for speed 400 and 13.0 to 85.5 mGy with a mean value of 38.3 mGy for speed 200. The ESDs for lumbar spine (AP and LAT) for speed 400 ranged from 11.7 to 43.8 mGy with a mean value of 21.9 and 5.35 to 62.9 mGy with a mean value of 31.8 mGy respectively.

The ESDs for pelvis AP for speed 200, ranged from 5.3 to 75.8 mGy with a mean value of 18.0 mGy and for speed 400, it ranged from 4.5 to 26.6 mGy with a mean value of 13.0 mGy. The results obtained demonstrate that doses may vary significantly owing to differences in patient size. Therefore DRLs derived from large scale surveys should not be used for individual patients but for representative patient population.

Table 5 provides point by point comparison of the technique factors with those recommended by CEC as examples of good techniques for the imaging procedures. For Chest PA, the CEC recommends voltage setting of 125 kVp, while the values in this study range from 102-106 kVp. For the lumbar spine AP examination, the values used at the KBPC (53-58 kVp) were significantly lower than those in the recommended range of 75-90 kVp. Similarly, the values used for lumbar spine LAT at the KBPC (60-64) was also lower than the CEC range of 80-95 kVp. For the Pelvis examination, the kilovoltage selected at the KBPC (53-56) did not correspond with the recommended range of 75-90 kVp. Hence, the relatively large mean ESDs obtained for lumbar spine and pelvis examinations could be attributed to the use of relatively low kVp technique. This observation calls for the education and the necessary awareness of radiologists and radiographers on the need to review the technique factors being used in clinical practice. This would help to reduce and optimize patient dose without sacrificing image quality.

Table 6 indicates that a significant dose reduction was observed as a consequence to the use of the rare earth screen-film combination of speed 400 in place of the conventional screen-film combination of speed 200. For instance, a dose reduction of 33% for Chest PA, 17% for lumbar spine (AP and LAT) and 28% for pelvis AP were achieved. The least mean dose reduction for the examinations considered was 17% which corresponded with an image quality improvement of 10%.

5. Conclusion

The aim of this study was the optimization of patient protection using rare earth screens in conventional imaging procedure. From the assessment that was done at the KBPC spanning a period of 36 weeks, the following findings were obtained.

Film rejection rates before QC from the FRA amounted to about 17% for a total of 324 films analysed. The major causes of rejects were due to over and under exposure, artefacts, field size misplacement and processing problems among others; with over and under exposure accounting for the highest cause (27%). After QC, the reject rate amounted to 10% for a total of 321 films surveyed with over and under exposure factors still accounting for the highest cause. However, corrective actions such as equipment repair, film processing conditions, operator awareness and technique modifications should be undertaken to further reduce the reject rate. As part of the image quality management system, regular film reject analysis should also be instituted to monitor the causes of poor image quality and mitigate their effects on diagnostic imaging quality. The factors that contributed to poor image quality must be controlled to aim at having film reject rate of less than 5%.

Regular assessment of patient dose and quality control of parameters of an X-ray machine that affect patient dose and image quality should be instituted at this diagnostic X-ray department and all others in Ghana since patient protection is an essential element for the overall management of patient undergoing X-ray examination. Patient protection improvement was achieved as demonstrated by the mean dose reduction of up to 33% after using the rare earth screen-film combination of speed 400 in place of a conventional screen-film combination of speed 200. From this study, the optimization of patient

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protection was achieved by using a rare earth screen-film combination system of speed 400 in place of conventional screen-film combination system of speed 200.

The use of DRLs, faster rare earth screens coupled with good radiographic technique is therefore recommended in Radiology departments in Ghana in order to achieve optimization of patient protection goals. The initial capital investment would be offset by a long term sustainable balance between image quality and making patient doses to be in line with the ALARA principle.

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REFERENCES

[1] UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION, SOURCES AND EFFECTS OF IONIZING RADIATION, UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes, UN Sales Publication EOO.IX.3, New York: United Nations, (2000).

[2] Kodak's Dental Radiograph Series, Guidelines for prescribing dental radiographs (2006), http://www.kodak.com/go/dental.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Optimization of the Radiological Protection of Patients undergoing Radiography, Fluoroscopy and Computed Tomography, IAEA, Vienna, IAEA-TEDOC-1423, ISBN 92–0–113504–1, ISSN 1011–4289 © IAEA, (2004).

[4] The Encyclopaedia of Medical Imaging Volume 1, AK/HJS-(2004), Copyright General Electric Company 1997-2004, http://www.amershamhealth.com/medcyclopaedia/medical/index.asp.

[5] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna, (1996).

[6] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Radiological Protection and Safety in Medicine, ICRP Publication 73, Ann, ICRP 26(2), Pergamon Press, Oxford and New York, (1996).

[7] EC Council Director 97/43/Euratom of 30th June 1997 on health protection of individuals against the dangers of ionizing radiation in relation to medical exposures, Off, J. Eur. Commun, L180, (1997).

[8] U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, (HEW), PUBLICATION (FDA) 80-8035, Regulations for the Administration and Enforcement of the Radiation Control for Health and Safety Act of 1968, Food and Drugs Administration, (1980).

[9] HARRISON, R. M., et al., A survey of radiation doses to patients in five common diagnostic examinations. British Journal of Radiology; Vol. 56, 383-395. (1983).

[10] MATHCAD, Mathsoft Inc, Cambridge, MA, (1992).

[11] HARPEN, M. D. A mathematical spreadsheet application for production of entrance skin exposure nomograms, Medical Physics Journal 23 (2), (1996).

[12] NATIONAL RADIOLOGICAL PROTECTION BOARD/ROYAL COLLEGE OF RADIOLOGISTS, Patient Dose Reduction in Diagnostic Radiology, Doc. NRPB 1, No. 3, 1-46, (1990).

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