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QUALITY CONTROL TECHNIQUES AND X-RAY DOSIMETRY

PhD Thesis Abstract

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CLUJ-NAPOCA

2010

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INTRODUCTION

For over one hundred years, the usage of ionizing radiation in medicine has grown spectacularly over the world, becoming an invaluable tool in diagnosis and treatment of diseases. Although the radiation doses involved in medical diagnostic radiology are relatively small, increasing the number of radiological procedures applied population makes risks becoming increasingly high.

The quality control techniques in radiological practice have to ensure an adequate system of protection for people exposed to X-radiation. These techniques form part of a quality assurance program for radiological examinations and are designed to correct problems relating to equipment and radiological practices, to obtain radiological images (informations) of high quality and to reduce the unnecessary exposures. In such a quality assurance program in medical diagnostic radiology, the medical physicist has a major role to assure the proper functioning of the equipment and work methodologies and to constantly seek to obtain a sensible benefit-risk report in radiological procedures.

Evaluation with a good accuracy of radiation dose in radiological procedures is of great importance in radiation protection. The Monte Carlo simulation technique of radiation transport and of dose depositions applied for these radiological investigations can achieve this goal.

TL dosimetry is a special technique used to assess radiation dose, that can be applied both in individual dosimetry and monitoring the radiation environment.

Secondary radiation produced simultaneously with the primary radiation emitted by an X-ray tube, do not contribute to the formation of beneficial radiological image, but rather deteriorates the quality of this information by reducing contrast and lack detail. Therefore, it is required ongoing monitoring of the secondary radiation, which is parasitic in nature and harmful for radiological image.

The check of the physical parameters of X-ray devices and the quality control HVL test of X-radiation are an integral part of quality assurance program aimed at detecting errors in radiological practice and to achieve high-quality radiological images and low doses to patients.

CHAPTER II: APPLICATION OF X-RAYS IN RADIODIAGNOSTIC

2.2 Evolution of medical irradiation in Cluj county during 1970-2000

Currently, as outlined in the UNSCEAR reports, the applications in medical radiology and the doses involved in these activities constitute the largest source of artificial radiation exposure of the population. Therefore, it is required serious analysis to accurate estimate the radiological practices and their directions of development. The need for such analysis is based on the involvement of new factors emerged in radiological practice such as the growth of population, the urbanization, the increasing life expectancy, all resulting in acceleration of the investigations in medical radiology.

2.2.1 Results concerning the population exposure from Cluj county in 30 years radiological practice

The large volume of data accumulated 30 years of radiological practice in Cluj County, gives the opportunity to highlight the magnitude of the population exposures from medical diagnostic radiology. The dynamic of the radiological examination distributions by type of procedures allows the knowledge of changes in a such period of time and the positive trends by using the X-rays in medical diagnostic.

Statistical data have the baseline year 1970, as the refference year for medical X-ray irradiation in Cluj County.

It has been investigated the most radiological units and it has been analyzed the annual distribution of all radiodiagnostic procedures every 10 years (1970, 1980, 1990, 2000), on anatomical regions, age groups and sex based on retrospective surveys. It has been processed the data extracted from the records of the radiology offices, totaling a volume of 2586446 procedures. Figure 1 shows the evolution of radiological examinations in the period 1970-2000 considering 1970 as base year (100%).

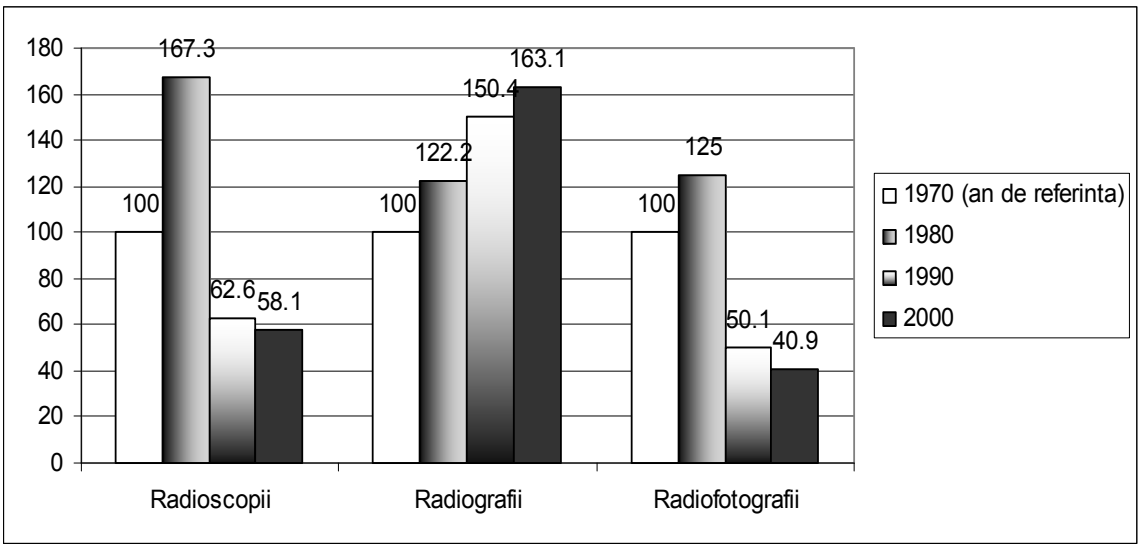

Fig. 1 **Evolution of radiological examinations during 1970-2000**

If in the first decade it has been obtained a massive increase in number of fluoroscopic examinations (with 67.3%), followed by radiophotographies (with 25%) and radiographies (with 22.2%), over the next two decades (1980-1990, 1990-2000) it has been reduced the number of fluoroscopic and radiophotographic examinations, with direct effect in reducing population doses.

The large number of lung fluoroscopy in decade 1970-1980 was due to a large number of annual inspections required by our legal system at that time. The continuing reduction of fluoroscopy in the last two decades is part of the effort made by most level 1 countries to reduce the fluoroscopy compared with the radiography.

Radiography followed an ascending line in the 30 years of radiological practice, being increased by 22.2% in 1980, by 50.4% in 1990 and by 63.1% in 2000 compared with the base year 1970 and with a tendency to gradually replace the fluoroscopic examination.

The appreciable reduction in the annual number of radiographic skull examinations was caused by the appearance in the radiological practice of new types of highly performance radiodiagnostic devices, namely CT, which took much of radiological activity for that kind of anatomical region.

Mammography has been developed continuously, both in our country and in almost all countries of the world, as stated in the UNSCEAR reports in 1993 and 2000, as a method of screening for early detection of breast cancer.

Radiophotography (MRF) presents a significant setback on the one hand due to inefficiency of this method in pulmonary tuberculosis and on the other hand due to the

appreciable doses (5-10 times higher compared with a simple chest x-ray) involved in this type of radiological examination.

The present study showed that the radiological activity Cluj County from 1970-2000 are particularly complex. There are also significant differences in radiological activities in the countries of the same level as medical radiology is practiced in very different conditions. To find out where the radiological practice from Cluj is placed worldwide, it was made a comparison of our radiological activities with the corresponding radiological activities from a number of countries having the same level of care (level 1). It has been shown that in Cluj county it is practiced around the same number of radiological examinations per 1000 inhabitants as in Finland and Poland, less than in Germany, Japan and Croatia but more than in Holland, England and Romania (at national level).

2.4 Quality assurance program for medical radiology

World Health Organization (WHO) has defined the concept of "quality assurance" in medical diagnostic radiology since 1986 as an organized effort of all stakeholders involved in human exposure to ionizing radiation, for achieving high quality radiological images with a lower cost and with minimum exposure to the patient.

2.4.1 Own quality assurance program for medical radiodiagnostic

Since 1999 it was started an experimental quality assurance program for four medical units in the city of Cluj-Napoca, with the highest influx of population and considerable radiological activities for adults and children: ”Centrul de Diagnostic şi Tratament Adulţi”, ”Centrul de Diagnostic şi Tratament Copii”, ”Clinica Medicală 1”, ”Spitalul Clinic Municipal Clujana”. To quickly and accurately perform all quality control tests and the calculation of organ and effective doses of patients by Monte-Carlo simulations of radiation transport, it has been designed a computer program called IradMed, written entirely in Java.

The quality assurance program includes a series of specific activities and quality control techniques such as: checking the total filtration tube X and radiation quality (HVL test), the reproducibility and accuracy of high voltage and exposure time, the mAs linearity, the light field/X-ray field alignment and the radiographic film quality.

It was found that only at the ”Spitalul Clinic Municipal Clujana” the total equivalent filtration of X-ray tube, derived by applying the HVL test, is in good agreement with the total

filtration given in the X-ray device manual. These values of total equivalent filtrations will play an important role for the calculation of the organ and effective doses received by patients.

All physical parameters measured at the Philips equipment from ”Clinica Medicala 1”, are within the limits allowed by current CNCAN norms. The reproducibility of peak voltage exceeds the maximum permitted value of 5% for the X-ray device from ”Spitalul Clinic Municipal Clujana” and the accuracy of exposure time exceeds the maximum permitted value of 10% throughout the range of tested values for the X-ray device from ”Centrul de Diagnostic şi Tratament Adulți”. The mAs linearity exceeds the maximum permitted value of 0.1 for the X-ray device from ”Centrul de Diagnostic şi Tratament Adulți” and ”Spitalul Clinic Municipal Clujana”.

The HVL value depends mainly on three physical parameters: peak voltaj, total filtration and anode angle. Also, HVL depends on other parameters, but to a lesser extent, such as: waveform ripple and anode material. Results obtained by applying the HVL test are presented in Table 1.

Table 1 **X-ray beam quality expressed by HVL, HVL2 and hommogenity factor ρ for the tested X-ray devices**

Medical unit	X-ray device	Results	HVL (mm Al)	HVL_2 (mm Al)	ρ
CDT Copii	TUR D300	Experimental	1.93 +/- 0.10	2.05 +/- 0.10	0.94 +/- 0.07
		Theoretical	2.32 +/- 0.12	3.36 +/- 0.17	0.69 +/- 0.05
CDTAdulți	Diagnomax M125	Experimental	0.93 +/- 0.05	1.27 +/- 0.06	0.73 +/- 0,05
		Theoretical	1.33 +/- 0.07	1.75 +/- 0.09	0.76 +/- 0.05
Clinica Medicala 1	Philips	Experimental	2.93 +/- 0.15	4.70 +/- 0.24	0.62 +/- 0.04
		Theoretical	2.64 +/- 0.13	3.97 +/- 0.20	0.66 +/- 0.05
SCM Clujana	TUR D800-1	Experimental	2.97 +/- 0.15	3.99 +/- 0.20	0.74 +/- 0.05
		Theoretical	2.64 +/- 0.13	3.97 +/- 0.20	0.66 +/- 0.05

Statistical analysis of theoretical and experimental results highlights several shortcomings due to the advanced wear of radiological equipment and the improper X-ray working technique.

In the case of ”TUR D300” X-ray device from ”Centrul de Diagnostic şi Tratament Copii”, the HVL and HVL_2 values are significantly lower than the corresponding theoretical

values. Assuming that all parameters (kVp, mAs, total filtration, anode) are appropriate, one can states that X-ray spectrum is not hommogenous having mainly low-energy photons, which leads to a higher patient dose than that generated by a similar radiological equipment having an optimal functioning state. Thus, the absorption of radiation in tissue is strong, which results in a low image contrast on film. As a result, the processed radiological films are underexposed, leading to a possible repetition of the examination. The first half value layer, HVL, is below the minimum permitted value of 2.1 mmAl corresponding to the test conditions.

The values of HVL and HVL_2 for the ”Diagnomax M125” X-ray device from ”Centrul de Diagnostic şi Tratament Adulţi” are significantly lower than the theoretical values. Therefore, the predictions of patient dose and radiological images are the same as for the ”TUR D300” X-ray device. The radiological images and the patient doses can be improved by fine adjustements such as: increasing kVp, decreasing mAs and/or by introducing additional filters.

In the case of ”Philips” X-ray device from ”Clinica Medicala 1”, the values of HVL and hommogenity factor are not significantly different from the theoretical values. The value of HVL_2 is significantly higher than the corresponding theoretical value. Therefore, the X-ray spectrum is hommogenous having an slightly increased number of high-energy photons than the theoretical X-ray spectrum. As a result, it is possible that the absorption of radiation in the depths tissues, especially for the fat patients, to be insufficient, altering the image contrast of that organs. The radiological films can present slightly overexposures and the patient doses are expected to be comparable with (or a little lower) the corresponding doses generated by a similar radiological equipment having an optimal functioning state. Therefore, it can be done fine adjustements such as: decreasing kVp, increasing mAs and/or by removing additional filters. According to IAEA standard, the HVL value is higher than the minimum permitted value of 2.3 mmAl corresponding to the test conditions.

The ”TUR D800-1” X-ray device from ”Spitalul Clinic Municipal Clujana” does not provide a good match between theoretical and experimental value of the first half layer HVL. The values HVL_2 and hommogenity factor are not significantly different from the theoretical values. One can states that the X-ray spectrum is hommogenous having an slightly increased number of medium-energy and high-energy photons than the theoretical X-ray spectrum. After the first reduction of radiation at half, some of the low-energy and medium-energy photons are removed, leading to a proper distribution of photon energies and the resulting X-ray spectrum is similar with the corresponding theoretical spectrum. The absorption of radiation in the tissues from the vicinity of the radiation entrance surface is insufficient, altering the image contrast of that organs, and the patient doses are expected to be comparable with (or a little lower) the

corresponding doses generated by a similar radiological equipment having an optimal functioning state. Therefore, it can be done fine adjustements such as: decreasing kVp, increasing mAs and/or by removing additional filters. According to IAEA standard, the HVL value is higher than the minimum permitted value of 2.3 mmAl corresponding to the test conditions.

Another objective included in the experimental quality assurance program for radiography is to verify the light field/X-ray field alignment for the tested X-ray devices. According to IAEA standard, the alignment coefficient in both directions (horizontal and vertical) of the field should not exceed 2% of the focus-film distance. The verification of this parameter in the four X-ray medical units, included in the experimental QA program, revealed that the only X-ray device that does not meet the IAEA standard is ”TUR D300” from ”Centrul de Diagnostic şi Tratament Copii”, since it presents an alignment coefficient higher than 2% of the X-ray source-image received distance (3.7%).

The entrance surface dose, the organ doses and the effective doses, involved in various radiological examinations using the tested X-ray devices, were calculated using the IradMed program.

As expected from the HVL test, the patient doses generated by the ”TUR D300” X-ray device form ”Centrul de Diagnostic şi Tratament Copii” are higher than the reference levels.

In the case of ”Diagnomax M125” X-ray device from ”Centrul de Diagnostic şi Tratament Adulți” it was shown that the patient doses are much higher than the reference levels, except for the LLAT lombosacrat column examination. Although it was expected to obtain higher doses from the HVL test evaluation, the magnitude of these doses leads to the conclusion that, in addition, the physical parameters set to the console for common radiological examinations (kVp, exposure time, mAs, FSD) are improper. However, these parameters can be intentionally chosen in such a way that radiological images are of good quality for accurate diagnosis of patients, even if they are received large doses.

Regarding the ”Philips” X-ray device from ”Clinica Medicala 1” it was found that the involved dose values are lower than the reference levels, as expected from the the HVL assessment test, so that one can conclude that the physical parameters set to the console (kVp, exposure time, mAs, FSD) are suitable for all common radiological examinations.

All procedures for assessing the performance of radiology equipment in the medical units included in the experimental quality assurance program has been made in order to determine if there are irregularities in the operation of radiological equipment and to apply corrective measures. The results revealed serious deficiencies in some X-ray devices, both on their wear

and in application of working techniques. All of these problems regarding the functioning of radiological equipment were seriously analysed and it was applied some remedies, of course, whenever possible.

The second phase of our program relates to assessing the effectiveness of the program itself, which is achieved by studying the repetition rate of the radiological examinations and the causes that produce them. The repetition of the examination implies an unnecessary exposure to the patient.

The number of repeated radiological examinations in one year (2000), for each medical unit concerned, was based on data taken from primary records of these units and are presented in Table 2.

Table 2 **Percentage of repeated radiographies in one year**

Medical unit	X-ray device	Total number of radiographies/year	Total number of repeated radiographies/year	Repetitions (%)
CDT Copii	TUR D300	5964	679	11.4
CDT Adulți	Diagnomax M125	7093	536	1.5
Medicala 1	Philips	1944	19	<1.0
SCM Clujana	TUR D800-1	6300	1092	17.3

The highest (negative) results were found, surprisingly, at the ”Spitalul Clinic Municipal Clujana” (17.3%) and at the ”Centrul de Diagnostic şi Tratament Copii” (11.4%). Unlike the X-ray devices from ”Centrul de Diagnostic şi Tratament”, the X-ray device from ”Spitalul Clinic Municipal Clujana” performed better in the tests of physical parameters and the HVL test, so the cause of these repetitions consists mainly in a defective processing of the radiological films. Applying corrective measures due to the inconsistencies found in the studied medical units will lead to improved quality of radiological images and thus reducing the repetitions of the examinations. However, it is required urgent replacement of the ”TUR D300” X-ray device from

”Centrul de Diagnostic şi Tratament Copii” with a proper installation, to ensure adequate protection of children investigated radiologically.

For other radiological equipment included in the experimental QA program ”Diagnomax M125” (”Centrul de Diagnostic şi Tratament Adulți”) and ”Philips” (”Clinica Medicala 1”), the percentage of repeated radiological procedures is low, 1.5% respectively below 1%, which shows a great care and an increased attention of the personnel in performing exposures and film processing.

The last objective introduced in the experimental quality assurance program for medical radiography is to verify the quality of the processed radiological films. For the evaluation of the processed films' quality, it was measured the optical density using a densitometer type X-RITE 331 and it was established some subjective standards related to the difference from the desired optical density for some reference points on the image of tissue or organ of interest. It was proposed four qualifiers: underexposed, good, optimal, overexposed. According to the opinion of the physician radiologist, these desired optical densities are appropriate for obtaining radiological images of high quality.

Table 3 **Evaluation of the radiological films' quality**

Medical unit	Quality of radiological film	Number of radiological films	Percentage (%)
CDT Copii	underexposed	23	25.3
	good	44	48.3
	optimal	16	17.6
	good+optimal	**60**	**65.9**
	overexposed	8	8.8
CDT Adulți	underexposed	3	4.3
	good	13	18.6
	optimal	49	70.0
	good+optimal	**62**	**88.6**
	overexposed	5	7.1

It is noted that X-ray films processed at the ”Centrul de Diagnostic şi Tratament Adulți” have an adequate quality at a rate of 88.6%, which shows that both exposure and film processing is correct and, therefore, the number of repeated examinations is reduced as it was previously

demonstrated. However, these high-quality radiological images imply, as counter-effect, a significantly higher patient irradiation compared to that generated by a similar X-ray device having an optimal functioning state, as it was reflected from the estimation of the patient dose and the assessment of the HVL test.

In the case of ”Centrul de Diagnostic şi Tratament Copii” about one quarter of the films processed (25.3%) are underexposed, confirming the predictions of the HVL test assessment. Here, the radiological films have a little contrast which can explain the large proportion (more than 10%) of film rejections and it is confirmed once again the poor quality of the radiological equipment in that medical unit.

Quality assurance for radiological units is not just a collection of tests and measurements, but a laborious and lengthy process, that includes multiple activities with the effect of radiological image quality and size of doses given to patients, performed by physicists, radiologists, IT scientists and technicians.

CHAPTER III: TECHNIQUES INVOLVED IN X-RAY DOSIMETRY

The main purpose of X-ray dosimetry is the knowledge of the radiation dose received by humans and thus the achieving of an adequate protection. Therefore, the X-ray dosimetry related to the medical exposures has become an important part in optimizing the protection of the population.

3.1 Monte Carlo technique for dose evaluations

In order to apply the Monte-Carlo simulation technique for radiological investigations and also for rapid calculation and interpretation of the quality control tests for radiological equipment, it has been designed a computer program, called IradMed, written entirely in Java. This program allows assessment of organ and effective doses in patients who are irradiated with photon energies (X-rays) in 10 - 150 keV range, specific for medical diagnostic radiology.

Three major radiological procedures, mammography, radiography and computer tomography (CT) are considered. Other types of radiological investigations, regarding the system geometry, can be reduced to the three cases considered. Thus, the mammography and the radiography imply a simple geometry, a projection of photons beam on the breast and on an anatomical region of the human body respectivly. The only difference between these two

examinations is the phantom type used in Monte-Carlo simulation. For CT examinations, the tube X has a well defined movement around the patient. Here, the phantom is scanned on slices (sections) of small thickness (0.1 - 10 mm) and at every complete rotation a single slice is scanned. The continuous or helicoidal scan is not a special case for dose assessment, having only influence on the image capture and image interpretation mode regarding the image reconstruction. It is noted that the fluoroscopy usually involves an irregular geometry and therefore it is neglected. However, a rough estimation of radiological doses involved in this procedure may be accomplished by considering the fluoroscopic examination as consisting of a series of several radiographic examinations applied in different human body regions.

The interactions between radiation and matter are well known and rigorously implemented algorithmically, therefore, the accuracy of the calculations depends on the anatomical model used to describe actual patients and on the characterization of the radiation field applied in X-ray examination. In IradMed subroutines, the MIRD-5 mathematical phantom developed by Oak Ridge National Laboratory is used for simulating the radiographic examinations and the computation of the interest doses are done for several phantom types. All organ doses calculated by IradMed are given as function of the patient entrance air kerma (free in air, without backscatter) at the point where the central axis of the X-ray beam enters the patient.

Mathematical phantom used for radiographic and CT examinations

The MIRD-5 phantom takes into account three main tissue types with different densities and compositions: lungs, skeleton and soft tissue (having the density of about 1 g/cm^3, such as the muscle tissue). The description of the hermaphrodite phantom is presented for several standard patient ages: new born, 1 year, 5 years, 10 years, 15 years and adult (over 30 years). Each phantom consists of three major sections: an elliptical cylinder representing the trunk and arms, two truncated circular cones representing the legs and feet and a circular cylinder on which sets an elliptical cylinder capped by half an ellipsoid representing the neck and head. All organ descriptions are relative to a reference coordinate system, set at the base of the trunk. The z-axis is directed upward toward the head, the x-axis is directed to the phantom's left and the y-axis is directed toward the posterior side of the phantom.

Based on the tissue composition of the phantom, it was calculated the mass attenuation coefficients and the mass energy absorption coefficients, for each X-ray photon energies, in

order to construct an adequate database for further linear interpolations used in Monte Carlo simulation's routine.

Due to mammography specific geometry, the corresponding phantom is considered to be an adjustable right cylinder with a standard 4.20 cm thickness and a 7.00 cm radius having a soft tissue composition.

X-ray spectrum and the examination geometry

An example of a X-ray spectrum generated by IradMed is shown in Figure 2.

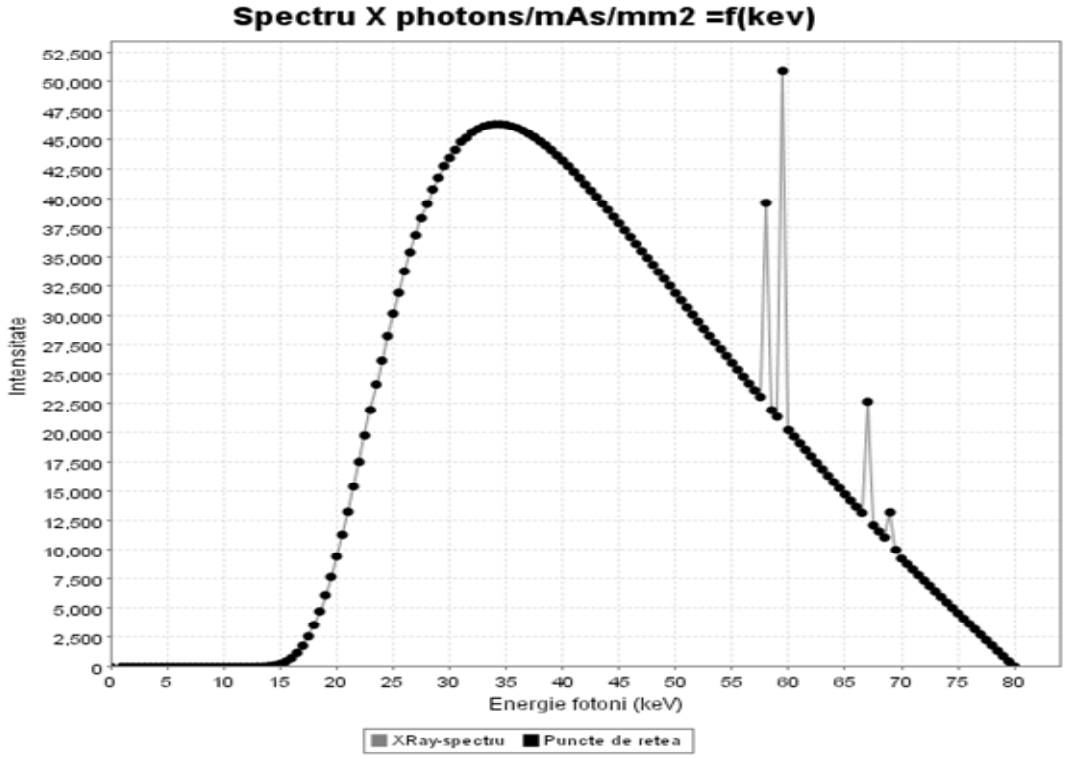

Fig. 2 **X-ray spectrum generated by a Röntgen tube having a waveform ripple of constant potential, 80 kVp, anode angle of 17 degrees, anode material of tungsten and a total filtration of 2.5 mmAl**

The X-ray spectra are estimated either by using a pre-build database, named SRS78, taking into account the tube high voltage (kVp), the anode angle, the total filtration, the anode material (tungsten, molybdenum, rhodiu) and the waveform ripple. Based on preliminary measurements of HVL and HVL_2, the total equivalent filtration of the tube may be used as input

data. If the HVL test was not performed, the total filtration of the tube, noted in the technical installation manual and having a typical value of 2.5 mmAl, may be used as input data.

In mammography case, the center of the coordinate system of the phantom is chosen on the symmetry axis at the top of the cylinder. The z-axis is directed downward in the initial photon direction (see fig 3).

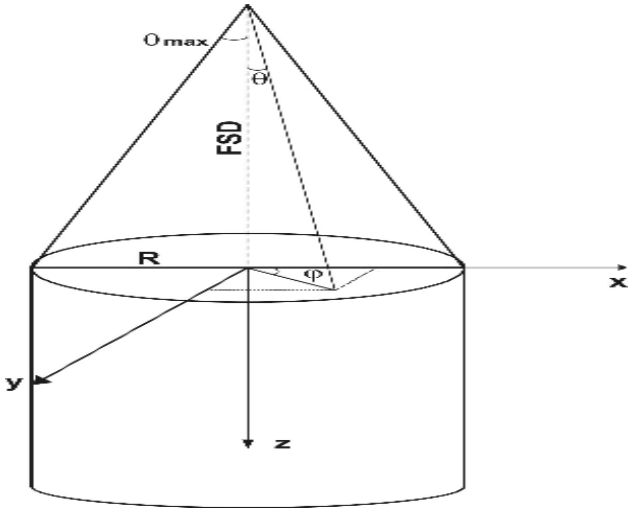

Fig. 3 **Geometry used in mammographic examinations**

The IradMed program generates a random number in the [0,1] range and it is determined, by a relatively simple calculation (sampling the cosines of the polar angle), a polar angle θ for each history of the incident photons. The azimuth angle, φ, is in the [0,2π] range and follows the uniform distribution. The initial directional cosines depend on polar angle θ and azimuth φ having the expressions:

$$u_x = \sin\theta\cos\varphi\ ;\ u_y = \sin\theta\sin\varphi\ ;\ u_z = \cos\theta \qquad (1)$$

In radiography case, the incident photon direction relative to phantom depends on the examination projection type: AP-anterior posterior, PA- posterior anterior, LLat- left lateral or RLat- right lateral. Using the mathematical description of phantom, it is computed the z-coordinate of the X-ray field center and the X-ray field dimensions at entrance surface. The next step is the computation of the z-coordinate and one of x and y coordinates of the incident photon at entrance surface, by using a random number generator. The remaining coordinate (x or y) is assessed assuming that the photon hit the phantom, thus by solving the corresponding equations for the specific region.

It is considered two angles which define different kinds of projection types. The first angle is the projection angle having for RLat the value of 0^o, for AP the value of 90^o, for LLat the value of 180^o and for PA the value of 270^o. This angle is given by the direction of the central axis of the beam relative to the horizontal axis which crosses the median plane of the phantom from the phantom's right to the phantom's left. The second angle is the cranio-caudal one and it is defined by the central axis of the beam relative to the vertical axis of the phantom. The cranio-caudal angle has a value of 90^o for all the four projection types taken into account. Let ξ be the skull-caudal angle and let λ be the projection angle. It can be shown that the values for directional cosines of the incident photons having directions normal at the entrance surface (if the photon direction is parallel with the beam central axis) are:

$$u_{x0} = \sin\xi\cos\lambda \; ; \; u_{y0} = \sin\xi\sin\lambda \; ; \; u_{z0} = \cos\xi \tag{2}$$

It can be shown that the new directional cosines are:

$$u_x = \sin\theta\cos\varphi \; ; \; u_y = \sin\theta\sin\varphi \; ; \; u_z = SIGN(u_{z0})\cos\theta \tag{3}$$

if $u_{z0} > 0.9999$ and, in general case:

$$\begin{aligned} u_x &= \frac{\sin\theta}{\sqrt{1-u_{z0}^2}}[u_{x0}u_{z0}\cos\varphi - u_{y0}\sin\varphi] + u_{x0}\cos\theta \\ u_y &= \frac{\sin\theta}{\sqrt{1-u_{z0}^2}}[u_{y0}u_{z0}\cos\varphi + u_{x0}\sin\varphi] + u_{y0}\cos\theta \\ u_z &= -\sin\theta\cos\varphi\sqrt{1-u_{z0}^2} + u_{z0}\cos\theta \end{aligned} \tag{3'}$$

In CT case, it can be considered that each individual slice scan is composed of four radiographic RLat, AP, LLat and PA projections having the same weight in computation of the dose. The sum of entrance exposures for each projection type is regarded as the CT entrance dose. Usually, for this input data it is considered the CT specific physical quantity named CTDI (periferical free in air). All mathematical considerations are therefore identical to those involved in the corresponding radiographic projection types.

Interaction sampling

For radiodiagnostic energy range it is taken into account three photon interactions with matter: the photoelectric effect, the incoherent Compton scattering and the coherent Rayleigh scattering. The interaction probability for photoelectric effect is computed based on the mass attenuation coefficients and on the photon energy:

$$p_f = \frac{\mu_f}{\mu_t} \tag{4}$$

where μ_t is the total mass-attenuation coefficient at a specific photon energy.

If $r_1 \leq p_f$, where r_1 is a random number, then the photon is considered to be absorbed by photoelectric effect. Otherwise, it is computed the coherent Rayleigh scattering probability, p_{coh}:

$$p_{coh} = \frac{\mu_{coh}}{\mu_t - \mu_f} \tag{5}$$

If $r_2 \leq p_{coh}$, where r_2 is a random number, then the photon will suffer a coherent Rayleigh scattering, otherwise an incoherent (Compton) scattering will occur.

By photoelectric effect, all photon energy is considered to be locally absorbed and deposited in the organ, in other words, it is assessed that the absorbed dose is equal with the kerma in organs (the kerma approximation). The boundary effects would have a little effect in the determination of average dose to the larger organs. The one exception for the organs under study would be the active bone marrow, where a small increase in dose due to the size of the marrow cavities is expected to appear from increased photoelectron emission by surrounding bone. The evaluation of energy deposited in active bone marrow is separately treated and depends only by energy deposition in different skeleton regions.

Based on the effective cross sections of Rayleigh and Compton interaction, the IradMed program calculates the polar and the azimuth scattering angles using advanced numerical algorithms. Several methods used for sampling the Compton scattering which avoid the solving of Klein-Nishina equation are: Classic method, Kahn method and, recently, the Wielopolski-Arinc method. A more accurate algorithm for polar angle sampling, named EGS, was used for the first time in EGSnrc Monte Carlo routines.

A preliminary study for polar angle sampling using these four algorithms has been made by choosing a 15 degrees step in the 0 – 180 degrees range. For each interval, 0- 15, 15 – 30, …,165 – 180 degrees, the angle probability of occurrence (in %) was calculated for several incident photon energies: 0.1 MeV, 0.7 MeV, 1.5 MeV and 2.6 MeV. The best probability distribution over the entire interval range was obtained for EGS algorithm at each photon energy. This is followed by the Kahn and the "classic" ones and the worst angle distribution was obtained using the Wielopolski algorithm. For instance, the 0.7 MeV angle distribution is presented in fig.4.

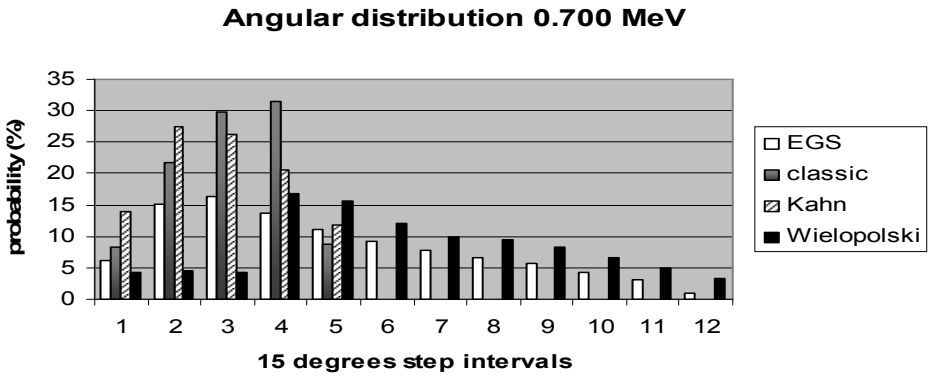

Fig 4 **The Compton scattering (polar) angle distribution in 15 degrees step intervals covering 0-180 degrees range by using different algorithms**

Pathlength sampling

It can be shown that the photon traversed distance in a medium until the next interaction will occur is:

$$d = -\frac{1}{\mu}\ln(r) \qquad (6)$$

where r is a random number in the [0, 1] range and μ is the linear total attenuation coefficient corresponding to the photon energy.

At each interaction site, IradMed computes in what organ this interaction takes place relative to the main (phantom) coordinate system. The interaction is always sampled in the particle coordinate system.

If d is the distance to the new interaction site (computed by relation 6) then the updated coordinates as function of the old ones in the main coordinate system are given by:

$$x = x_0 + u_x d \; ; \; y = y_0 + u_y d \; ; z = z_0 + u_z d \tag{7}$$

The values of polar and azimuth angles are determined by interaction sampling, and the new values of the directional cosines are given by relations (3) and (3 ').

The IradMed program calculates the absorbed doses for approximately 30 organs and anatomical regions, then estimates the effective dose by multiplying each organ dose with the corresponding tissue weighting factor and performing the sum of these weighted doses.

It is used the kerma approximation for dose calculation involved in all radiological examinations. However, due to the simple cylindrical geometry of mammography, the IradMed program can perform a complete Monte-Carlo simulation taking into account the electron interaction with matter and computing kerma and the deposited energy in medium. This complete Monte-Carlo simulation is based on EGSnrc subroutines, is time consuming, but the results are extremely accurate. The differences in results obtained by the two modes of calculation (kerma approximation and the complete Monte-Carlo simulation) for mammography proved to be insignificant. The validity of kerma approximation has also been demonstrated by using another own computer program, written in Java, called GES_MC, created especially for performing complete Monte-Carlo simulations in any cylindrical geometry, particularly useful for calculating the efficiency of radiation detection for beta and gamma detectors, computing the attenuation coefficients and the cross sections of all photons and electrons interactions with the matter, radiological applications for cylindrical geometry and more.

The organ doses and the effective dose generated by the IradMed program using the Classic or Kahn algorithms, for the polar angle sampling from the Klein-Nishina distribution, are in good agreement with values given by similar programs or data from literature. The differences can be explained by using different types of the mathematical phantoms.

Using the EGS algorithm, were obtained doses having values lower than those obtained by using the Kahn or Classic selection algorithms. However, the patient dose values calculated by IradMed have a much higher confidence level when are estimated by using EGS algorithm (both in kerma approximation for radiography and CT and in complete Monte-Carlo simulation for sampling the mammography examination).

3.2 Entrance surface dose, organ doses and effective dose in radiography

It was studied 29 X-ray devices from medical units having the highest influx of population and considerable radiological activities for adults and children. The considered medical units are from Transylvania region (Cluj-Napoca, Turda, Huedin, Dej, Miercurea Ciuc, Odorheiul Secuiesc, Oradea).

The entrance surface doses with and without backscatter received by adults during radiological examinations are presented in Table 4. It was calculated the minimum, maximum and average dose of these values in order to estimate the irradiation of the population.

Table 4 **Entrance surface dose received by adults in radiographies (average, minimum and maximum values) - partially**

Radiological examination type	Projection	Entrance free in air dose (mGy)	Entrance free in air dose with backscatter (mGy)	Reference dose level (mGy)
Head region	AP	3.129 (1.347 – 7.726)	4.067 (1.751 – 10.044)	5.0
	PA	5.574 (1.908 – 9.239)	7.250 (2.489 – 12.011)	5.0
	LAT	3.629 (0.819 – 7.897)	4.717 (1.408 – 10.260)	3.0

The study of doses distribution, specifically by calculating the statistical moments of high order (mean, variance, skewness and kurtosis) showed that the mean is not significantly different from the median so that the arithmetic mean is a good estimator (as the median) of the average of these values.

The analysis of the entrance surface dose measurements for adults in radiographic examinations revealed the following:

- a series of examinations, such as those of lumbar spine, lombosacral spine, pelvis, femur, knee, scapula-humeral present mean radiation doses below the reference dose levels which shows that these types of radiological procedures are correctly executed.

- the chest radiographies in PA and LAT projections imply mean doses of 6.7 times respectivly 8.0 times higher than the reference dose levels. The skull radiographies in PA and LAT projections imply mean doses with 45% respectivly 57% higher than the reference dose levels.

The relatively high values compared with the reference dose levels in the lung and skull radiographies are mainly due to the inaccuracies of the physical parameters namely voltage, exposure time, FSD, anode, mAs, total filtration from a series of radiological units: ”Spitalul Municipal Dej”, ”Policlinica Huedin”, ”Spitalul Clinic Municipal Clujana”, ”Clinica TBC Cluj-Napoca”, ”Clinica Medicala 1 Cluj-Napoca”.

The entrance surface average doses free in air with backscatter, obtained for a representative number of radiological units, can be considered as reference levels. In addition, these reference dose levels might be proposed for application in radiological units from Transylvania.

The organ doses and the effective dose represent the most complete assessment of population exposure to radiations. Using the IradMed program, it was calculated the absorbed doses for 23 organs and anatomical regions that are received by patients during X-ray examinations. The average organ dose results obtained for all common types of radiographies and for all studied radiological units are listed in Table 5.

Table 5 **The average organ doses received by adults in radiographies - partially**

Radiological examination type	Anatomical region	Organ dose (x 10^{-3} mGy)	Anatomical region	Organ dose (x 10^{-3} mGy)
Head region, AP	breasts	0.070	liver	0.006
	bones	44.056	lungs	0.639
	red bone marrow	22.852	thymus	0.174
	brain	197.427	thyroid	24.770
	heart	0.072	remainder	70.225

Radiological procedures induce appreciable absorbed dose into various radiosensibile organs. Knowledge of organ doses received by patients undergoing various radiological procedures is essential for calculating the effective dose and assessing of the radiation induced detriment. Knowledge of detriment is necessary to assess the benefits resulting from the application of radiological procedures. The benefit is considered to be sufficient if the exposure

is justified and optimized according to the principle of ALARA (As Low As Reasonably achievable).

The effective dose is the best parameter to describe the amount of radiation received by a patient to undergoing a radiological diagnostic examination. The values of the effective doses for all adults' radiographies, which are performed in the representative medical units taken in the survey, were calculated using the IradMed program and are presented in Table 6.

Table 6 **Effective doses for adults in radiographies (average, minimum and maximum values - partially**

Radiological examination type	Projection	Effective dose (mSv)	Effective dose (mSv)-guidance level
Head region	AP	0.0242 (0.0111 – 0.0400)	0.07
	PA	0.0500 (0.0210 – 0.0790)	0.07
	LAT	0.0340 (0.0103 – 0.0724)	-

The effective dose values exceeding the reference levels were obtained for abdominal examination (1.20 mSv), radiography of the hip (0.96 mSv) and PA chest examination (0.12 mSv).

The values of effective dose for the radiological procedures taken into study are comparable with data obtained by similar studies in Germany, Japan or Norway.

The probabilities of cancer incidence and cancer mortality were computed by IradMed program using the BEIR VII model. The minimum values are: 2 cases/1 million population for cancer incidence rate and 1 case/1 million population for cancer mortality rate. The maximum values are: 138 cases/1 million population for cancer incidence rate and 70 cases/1 million population for cancer mortality rate.

Children are more sensitive than adults to the action of ionizing radiation. Therefore, application of diagnostic radiological examinations must be a executed only if absolutely necessary and the radiographic technique used is accurate. The study was conducted in several pediatric units, with significant flow of patients in the cities of Cluj-Napoca and Oradea: "Pediatrie 1", "Pediatrie 2", "Pediatrie 3", "Centrul de Diagnostic şi Tratament Copii",

”Pediatrie TBC”, all from Cluj-Napoca and ”Policlinica de Copii”, ”Spitalul de Copii” from Oradea.

It was found that all involved doses for the newborn examinations are comparable to those involved in X-ray examinations of 1 year child. It is also noted that the dose values increase systematically from a lower age to a higher age, since the working parameters increase as the child's age increases, in order to obtain an adequate radiological image.

The maximum doses were obtained for radiographies of skull, thoracic spine and pelvis, all these examinations being executed in AP projection and for 15 years age category.

The minimum values of cancer risks, computed by IradMed using the BEIR VII model, are:: 4 cases/1 million population for cancer incidence rate and 2 cases/1 million population for cancer mortality rate. The maximum values are: 90 cases/1 million population for cancer incidence rate and 40 cases/1 million population for cancer mortality rate.

It is noted that all dose values for all pediatric units taken into study, with one exception, the ”Pediatrie 1” from Cluj-Napoca, are higher than the corresponding reference levels. Also, the average dose calculated from all these units are higher than reference levels. This means that the physical parameters set at the console (kVp, mAs, exposure time, FSD) are improper. Therefore, it is required a serious review of the working techniques and the maintenance for the involved X-ray devices in order to obtain dose values in good agreement with the guidance levels issued by the international standards.

3.3 Dose free in air, absorbed dose, average glandular dose and effective dose in mammography

Mammography is the most efficient radiological examination for early detection of breast cancer. In early stages, the breast cancer may be only a slight injury with a very low contrast compared with normal tissue. Therefore, it is needed a X-ray spectrum with low energy (which results in increased dose absorbed in the breast) to ensure sufficient image contrast to these lesions in order to become visible. Meanwhile, the glandular tissue is particularly sensitive to the action of X-rays, so the dose that a patient receives during the mammographic examination must be maintained at reasonable levels, according to the principle of ALARA.

The survey was performed on a representative radiological unit having a significant flow of patients, namely ”Spitalul Cilinic Județean” from Cluj-Napoca.

The entrance surface dose was determined in standard working conditions. The absorbed dose and the effective dose were calculated by IradMed program using the complete Monte-

Carlo simulation option. Also, the average glandular dose was calculated according to standard IAEA on the basis of HVL value (0.42 mmAl) determined in advance by performing the HVL test. Results are shown in Table 7.

Table 7 **Doses in mammography**

Entrance surface dose free in air (mGy)	Entrance surface dose free in air (mGy) Guidance level	Absorbed dose (mGy)	AGD (mGy)	AGD (mGy) Guidance level	Effective dose (mSv)
12.77	13.0	2.73	2.97	2.8	0.14

It is noted that the absorbed dose calculated by IradMed program applying the complete Monte-Carlo technique and average glandular dose, AGD, calculated in accordance with IAEA standards are not significantly different according to ”3 sigma” statistical test. In addition, these doses are not significantly different from the corresponding reference doses, therefore the radiological procedure is applied correctly, respecting the principle of ALARA. Also, it was found that these doses are comparable with mammography results in a number of different countries like England, Belgium, Canada, Germany, Sweden and the U.S.

Typical values for the assesments of the cancer risk, computed by IradMed using the BEIR VII model, are: 4 cases/1 million population for cancer incidence rate and 1 case/1 million population for cancer mortality rate.

The risk assesements are based on the average dose in glandular tissue, but the risk is extremely small compared with the benefits derived from applying the mammographic examination as a method of screening for early detection of breast cancer.

3.4 CTDI, organ doses and effective dose in CT

Computed tomography (CT) is widely recognized as a valuable tool for medical diagnostic radiology as soon as the third and the fourth generations of CT scanners of high performances have been developed. The main advantage of this procedure is the achievement of

radiological image having a far superior quality, but patient doses are much higher compared with those of conventional radiography.

Dosimetric measurements were performed on the axis of rotation of the two types of CT scanners, GE CT PACE from ”Institutul Oncologic” Cluj-Napoca and CT Picker PQ from the ”Spitalul Militar” Cluj-Napoca. The effective doses (and the organ doses) were calculated using the IradMed program and the results are included in Table 8.

Table 8 **CTDI and effective dose in CT**

X-ray device	Region	CTDI (mGy/mAs)	CTDI (mGy)	CTDI (mGy) Guidance level	CTDI peripherical (mGy/mAs)	Effective dose (mSv)	Effective dose (mSv) Guidance level
CT PACE	skull	0.275	41.25	60.00	0.445	1.10	1.8
	chest	0.300	45.00	30.00	0.486	7.06	7.8
	abdomen	0.300	45.00	35.00	0.486	7.56	7.6
CT PICKER	skull	0.219	32.85	60.00	0.355	0.93	1.8
	chest	0.402	60.30	30.00	0.651	10.13	7.8
	abdomen	0.416	62.40	35.00	0.674	11.29	7.6

Applying the ”3 sigma” statistical test, it is noted that skul examinations imply CTDI values and effective doses below the reference levels and chest and abdominal examinations imply doses above these guidance levels. However, the effective doses involved in examinations of the chest and abdomen generated by the CT PACE scanner are comparable with the reference levels issued by IAEA. Therefore, it is required a review of working parameters for CT Picker scanner from ”Spitalul Militar” Cluj-Napoca.

The probabilities of cancer incidence and cancer mortality were computed by IradMed program using the BEIR VII model. The minimum values are: 99 cases/1 million population for cancer incidence rate and 50 cases/1 million population for cancer mortality rate. The maximum values are: 1203 cases/1 million population for cancer incidence rate and 612 cases/1 million population for cancer mortality rate.

The average organ doses generated by the X-ray devices taken into study are presented in table 9.

Table 9 **Organ doses in CT - partially**

Radiological examination	Organ	Organ dose (x 10^{-3} mGy)	Organ	Organ dose (x 10^{-3} mGy)
Skull region	breast	24.135	liver	1.609
	bones	1741.738	lungs	98.891
	red marrow	1143.688	thymus	50.729
	brain	9008.628	thyroid	1587.516
	heart	15.182	remainder	2081.489

The effective doses from CT examinations for skull region, lungs region and abdomen are about 33, 28 to 9 times higher than those involved in conventional radiography. The cancer risks are with one order of magnitude higher than those associated with the conventional radiography. Therefore, the CT examination must be performed with particular attention and should be recommended only when the benefit outweighs the risks.

3.5 Dose rate in fluoroscopy

Fluoroscopy involves an irregular examination geometry and therefore an accurate determinations of organ and effective doses using Monte-Carlo simulation can not been made. Therefore, for fluoroscopy, the international standards have established that the only physical quantities, measured directly and having an acceptable level of precision, are the dose rate (kerma) free in air for standard conditions of examinations and the maximum dose rate (kerma) free in air for the most disadvantageous conditions such as placing the detector close to the tube and far away from the image intensifier.

The fluroscopic devices taken into study belongs to severeal representative medical units for adults and childred from Cluj-Napoca, Miercurea-Ciuc, Odorheiul Secuiesc and Oradea. According to IAEA standard, the average values of dose rates have been computed. The arithmetic mean is the best estimator for distribution mean as it was demonstrated by the skewness statistical test. The results are presented in table 10.

According to IAEA standard, the reference levels for standard rate in fluoroscopy are: low dose fluoroscopy, 10 mGy/min; medium dose fluoroscopy, 20 - 25 mGy/min; high dose fluoroscopy, 40 - 100 mGy/min. The maximum dose rate should not exceed 50 mGy/min for

most fluoroscopic devices and 100 mGy/min for X-ray devices having automatic exposure control (AEC).

Table 10 **Standard dose rate (average) and maximum dose rate involved in fluoroscopy**

Patient	Standard dose rate (mGy/min)	Maximum dose rate (mGy/min)
Adult	12.88	19.25
Child	31.05	51.33

The average values presented in Table 10 shows that the standard dose rate for adults are classed as low to medium dose fluoroscopy and standard dose rate for children are classed as medium to high-dose fluoroscopy.

The fluoroscopic examinations applied to children involve significantly higher doses compared to adults. Adults may also received doses much higher than those received during the radiographies if the total time of exposure (exploration) is high (minutes) as often happens in practice.

CHAPTER IV: Thermoluminescent dosimetry

Thermoluminescence (TL) is a physical phenomenon based on property of crystals to emit light during heating, if they were previously exposed to natural or artificial radiation. A complete system of thermoluminescent dosimetry (TLD) is composed of a TL detector, a reader and a measurement cycle, following the results to be mathematically processed. Some TL materials (LIF-100, CaSO4: Tm, LIF: Mg, Cu, P) show remarkable dosimetric qualities, for which are used both in individual dosimetry and monitoring the environment radioactivity. In addition, the TL dosimetry can be applied in medical irradiation area to measure the actual skin dose of patients thus avoiding the use of specific adjustment factors (backscatter). Also, the doses measured using TL dosimeters inside phantoms can indicate the absorbed dose in different organs and tissues and these values are as accurate as the precision of human phantom construction. However, as it happens most often in practice, the difficulty of constructing such physical phantoms, their price and difficulties in setting the experimental assembly lead to the

fact that organ doses can not be measured with good precision and the only method being accurate enough for dose assessments is the Monte Carlo simulation technique.

4.1 Measurement of radiation dose using LiF-100 and $CaSO_4$:Tm powders

It was studied two TL materials having good results in dosimetric practice, namely LiF-100 and $CaSO_4$:Tm powder, acquired from Harshaw Chemical Company and Technical University Budapest.

The experimental results showed that for the same amount of exposure, the CaSO4: Tm powder is two orders of magnitude more sensitive (TL signal higher) than the LIF-100 and this fact was confirmed by other researchers. As a result, the CaSO4: Tm powder can be used to measure low doses of environment radiation.

It is very important to know the stability of dosimeters in different climatic conditions with respect to the time, named fading, in order to make the necessary corrections for the time passed between exposure (irradiation) and reading (measurement). The fading depends on several factors such as temperature, humidity or light. It was studied the two powders TL fading for a month keeping the dosimeters irradiated under normal temperature and humidity in complete darkness condition. The results show that after 1 month of storage the fading of LIF-100 powder is much better than the fading of CaSO4: Tm powder. The TL signal for LIF-100 decreases by only 3.1%, while the TL signal for CaSO4: Tm is reduced by 25.8%. These percentages are taken into account for the correction of the experimental results.

TL dosimetry was applied to measure the skin dose received by a radiological examined patient in the renal region. Urography is a comprehensive examination consisting of a simple radiography, followed by two radiographies made at different time intervals by injecting a contrast substance, which means that a patient received three consecutive exposures. Measurements were performed on a ”Diagnomax M125” X-ray device using a standard working procedure. It were exposed two groups of 5 TLD dosimeters of each powder type and the results of measurements (integrated three consecutive exposures) are:

D(LiF-100) = **26.40 +/- 2.82 mGy** and D($CaSO_4$:Tm) = **28.00 +/- 1.27 mGy**

The ”3 sigma” statistical test confirmed that the results are comparable with each other and comparable with the IAEA standard reference dose for urography (10 mGy per radiograph). The small uncertainty for dose provided by CaSO4: Tm powder is the direct result of its higher

sensitivity. In addition, the results show good reproducibility and are consistent with the doses associated with similar radiological examinations.

4.2 The physical characteristics of LiF:Mg,Cu,P thermoluminescent powder

Thermoluminescent materials of LIF: Mg, Cu, P represents a leading technology in TL dosimetry and their dosimetric performances have been studied by many experts worldwide. This powder is about 25 times more sensitive than the LIF-100 powder and it is comparable to the sensitivity of CaSO4: Tm powder.

After 1 month of storage of irradiated TL dosimeters, away from moisture and light, it was not noticed any significant decrease in TL signal. So, this powder can be used in the experiments for long periods of time without fading correction.

It was studied the influence of natural light on Lif: Mg, Cu, P powder and it was found that the TL signal remained almost unchanged which means that it is not necessary to protect this type of TL powder from the action of light.

The detection limit of TL dosimeter - TL reader system can be assessed using Curie theory.

$$LD = 3.29 S_b \tag{8}$$

where S_b is the individual standard deviation of the background measurements. This equation is based on a theoretical study of the difference between blank samples and background measurements.

The computed detection limit is:

LD **= 0.00832 rad = 0.083 mGy = 83 µGy.**

This value is consistent with the literature data and its magnitude (small) leads to the possibility to use these powders TL in various low-dose applications.

In conclusion, this study confirms the very good physical characteristics of thermoluminescent powder of Lif: Mg, Cu, P, which can be applied to assess the entrance skin dose received by patients undergoing medical exposures, evaluating the exposure of professionals and radiation environment monitoring.

CHAPTER V: Physical factors involved in dose magnitude

In order to achieve a fair balance between the radiation dose received by a patient and the radiological image quality it is necessary to know all the physical factors involved in radiological practice.

5.1 The HVL test for quality control of X-ray device

The HVL test is the basic test for the quality control of X-ray devices. This test checks whether there is an optimal filtration to counter the increasing of dose due to low energy photons and, on the other hand, to ensure the obtaining of a radiological image having a good quality.

In order to compute the experimental HVL value and to perform automatic results evaluation (e.g. the statistic significance of the difference between the experimental and theoretical values) it was used the IradMed program which can also evaluate the patient doses from usual radiological procedures, compute and interpret a wide range of quality control tests for X-ray devices.

For experimental computation of HVL, the air doses corresponding to different thickness of high purity aluminum plates are measured. These aluminum plates are placed between focus and dosimeter but as closed as possible to the X-ray tube in order to avoid the scattering effect. Between detector and radiological table it was placed a thin lead plate to minimize the backscatter.

HVL depends mainly on three factors: voltage, total filtration of the X-ray tube and anode angle. Also, IradMed take account of anode material and the waveform ripple in order to calculate the theoretical HVL value. It is used a database, called SRS 78, which represents the unfiltered X-ray spectrum (the photon weight according to their energy spectrum) and theoretical values of HVL is calculated by successive iterations based on the total filtration (given in equivalent mm Al). Total filtration can be calculated for a range of different types of filters or combinations of filters.

According to IAEA standard, the human body is composed especially of soft tissue, thus an adult patient of standard size can be considered to have a thickness of 20 cm water equivalent. Supposing a frequently used voltage of 100 kVp, 17 degrees anode angle, anode material of tungsten and a constant potential waveform ripple, the theoretical values of HVL and HVL_2 using a 200 mm soft tissue as absorber (HVL of 8.21 mm Al, HVL_2 of 9.27 mm Al) are almost the same as in the case of using a 18 mm thickness of Al as absorber (HVL of 8.25 mm Al

respectiv HVL_2 of 9.20 mm Al). This correlation of 200 mm soft tissue to 18 mm aluminum has also been found for other values of kV ripple, anode angle and anode material, thus it presents a general aspect. Based on these data, it is clear that interpretation of the HVL test result must take into account the thickness of the absorber corresponding to a reduction of the radiation intensity at 25% (QVL). It is therefore necessary and sufficient to perform the HVL test interpretation based on the HVL, HVL_2 and uniformity factor values. The current reference IAEA standard has issued recommendations only for HVL value without consideration of HVL_2, being therefore incomplete because there may be cases in which the HVL value is appropriate but, due to the possible HVL_2 and uniformity factor values deviations from the theoretical values, it is possible to obtain a radiation spectrum of poor quality and/or large patients doses.

The expressions for HVL_2 and homogeneity factor are:

$$HVL_2 = QVL - HVL; \rho = HVL / HVL_2 \tag{9}$$

Because the X-ray spectrum is not monoenergetic, the attenuation curve of the radiation intensity as function of absorber thickness has not an exponential shape. This fact represents the so-called hardening effect. Also, it is obvious that in semilogarithmic scale, the attenuation curve has not a straight line shape. Therefore, the computation of HVL value, as it is presented in various publications, by a simple linear interpolation between the corresponding points of the attenuation curve in semilogarithmic plot is not rigorous and even inaccurate in many cases.

It is extremely useful to plot the value of dose and the corresponding absorber thickness (in mmAl) as follows: dose on X-axis and absorber thickness (mmAl) on Y-axis in order to make further interpolations (with polynomial or spline functions). This graph is called the reverse representation. Based on this representation, the HVL and QVL values are calculated directly from the fitted functions of the attenuation curve and then, the values of HVL_2 and homogeneity factor are computed applying relations (9). An example of attenuation curve in reverse representation is shown in figure 5.

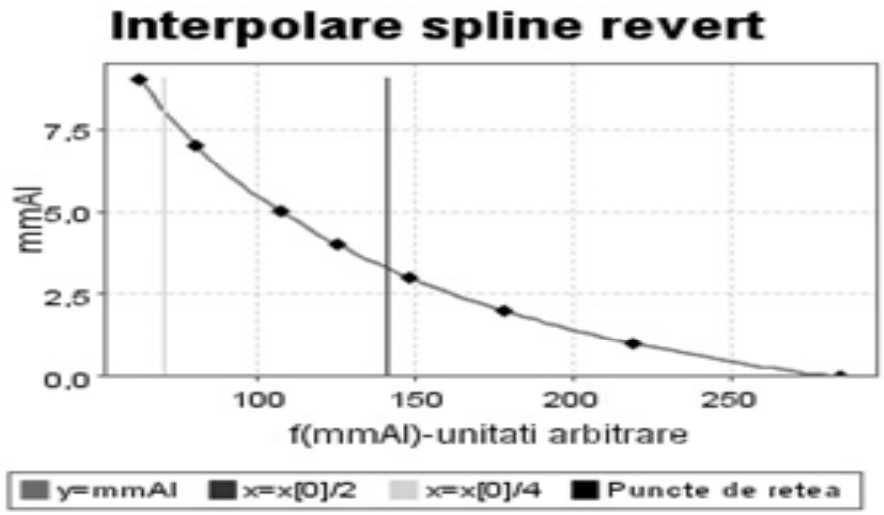

Fig. 5 **The atenuation curve obtained by spline interpolation for HVL calculation; absorber thickness (aluminum) as function of dose (arbitrary unit)**

In direct representation where dose is placed on Y-axis and absorber thickness is on X-axis, the calculation of HVL and QVL is performed by solving the following equations:

$$f(x) = y_0 / 2; f(x) = y_0 / 4 \tag{10}$$

where f(x) is the polynomial function (in the case of polynomial interpolation) or the spline functions (in the case of spline interpolation) corresponding to the intervals which encompass the HVL value and QVL value.

Relations (10) are solved by numerical methods such as: secant, Newton, succesive iterations, Birge-Viete or in the case of spline functions by solving the Cardano's formulas.

After determining the experimental values of HVL, HVL_2 and homogeneity factor, one can estimate the total equivalent filtration of the X-ray tube. The total filtration of the tube is calculated based on the unfiltered spectrum X, at the same physical parameters which were used for calculating the experimental HVL and QVL (kVp , anode angle, anode material and ripple waveform), using the SRS database 78, by successive iterations in order to obtain a beam intensity reduction of 50% corresponding to the experimental HVL value, respectively, a reduction at 25% corresponding to the experimental QVL value. It is obtained two values, f_1 and f_2, of this parameter which often are different from each other. The next step is to assign weights to the two obtained filtrations in order to estimate the final total filtration value. The total filtration deduced from the HVL test has a major importance because it is later used in Monte-

Carlo simulation to determine the patient doses. Therefore, the two quantities f_1 and f_2 are correlated with the patient to be investigated and therefore the weighted total filtration is called equivalent total filtration. In other words, the total equivalent filtration depends on both the tube and the patient. Specifically, let g be the thickness plane of interest associated with the patient, given in mm soft tissue or in mm aluminum equivalent. As shown above, if it is considered the phantom median plane as plane of interest (regarded as mediation by the depth of various organs) then g will be 100 mm tissue or 9 mm Al and if it is considered the whole body depth as plane of interest then g will be 200 mm tissue or 18 mm Al. These values are for standard patient undorgoing a radiological examination with AP or PA projection. For LAT projections, the above values are doubled. The weights of HVL_2 and HVL, p_2 respectively p_1, for the total equivalent (weighted) filtration will be:

$$p_2 = \frac{g - HVL}{g}, g > HVL; p_2 = 0, g \le HVL\ ;\ p_1 = 1 - p_2 \tag{11}$$

If g is given in mm tissue then this value must be transformed in equivalent aluminum or the HVL value is converted in equivalent tissue in order to solve relations (11).

Based on these weights, the total filtration equivalent derived from the complete HVL test and automatically calculated by IradMed is:

$$f = p_1 f_1 + p_2 f_2 \tag{12}$$

If it is known the deviations of experimental HVL value from its theoretical value, it can be determined the value of HVL for any voltage, anode angle, anode material or waveform ripple.

There are various tables of literature where for a given value of HVL and a given voltage, one can find the total filtration of X-ray tube. It should be noted that in determining the total filtration, besides HVL and kVp, the anode material, anode angle and the waveform ripple are of great importance, therefore, these tables are, at best, given for standard values of other parameters (e.g., tungsten anode with an angle of 17 degrees and constant potential). Therefore, for X-ray devices having for instance an anode angle different from the standard value (say 13 degrees), the assessment of total filtration from the above mentioned tables is inaccurate. Moreover, as noted, there is a dependency of HVL2 for total filtration of the tube. In general, the total filtration computed from HVL_2 value may differ from that considering the HVL value. Only

for the technically appropriate X-ray devices the two results are not significantly different. For this reason, considering the weight of HVL and HVL2 values, based practical on the radiological examination (patient thickness), in order to estimate the total equivalent filtration is considered to be the best solution.

Comparison of experimental with theoretical values of HVL is done by applying either the Student test for means or the ”3 sigma” test. Based on this comparison, one can make the interpretation of HVL test. For instance, if HVL and HVL_2 values are significantly higher than the corresponding theoretical values, assuming that all other physical factors used in HVL determination are suitable (kVp, total filtration, exposure time, etc.), one can predict the following: the X-ray spectrum contains mainly relative high-energy photons; the photon absorbtion is insufficient, thus the image contrast is affected (for radiography, the radiological film is over-exposed); the patient doses are expected to be smaller than those received in the same examination conditions if an optimal X-ray device has been used. Similar disscusions and interpretations can be made for all possible combinations of deviations of experimental HVL, HVL_2 and homogeneity factor from their theoretical values. However, these interpretations may not be valid if the working parameters are inappropriate. For example, measuring the HVL at 80 kV set at the console is practically done at 70 kV because the voltage accuracy is inadequate. Therefore, it must be preformed additional quality control tests such as: the reproducibility and accuracy of exposure time and peak voltage, mAs linearity and effective focal spot test and other studies for determining the high and low contrast for the radiological image.

The presented method regarding the HVL test is used by the IradMed program and it has been successfully applied for quality control of X-ray devices involved in diagnostic radiology. It was performed the complete HVL test for 40 radiological units (adults and children) from Transylvania..

Theoretical and experimental results for HVL, HVL_2 and homogeneity factor, ρ, for some of the X-ray devices taken in the study are included in Table 11.

Analysis of theoretical and experimental values obtained by HVL test shows a very wide variety of results. The investigated radiological installations present numerous discrepancies between the experimental values compared with the theoretical ones.

Table 11 **HVL, HVL_2 and homogeneity factor of X-ray devices - partially**

Medical unit	X-ray device	Results	HVL (mmAl)	HVL_2 (mmAl)	ρ
Centru D.T. Cluj	Diagnomax M125	Theoretical	1.33 +/- 0.07	1.75 +/- 0.09	0.76 +/- 0.05
		Experimental	0.93 +/- 0.05	1.27 +/- 0.06	0.73 +/- 0.05
Centru D.T. Cluj	Eltex	Theoretical	1.74 +/- 0.09	2.33 +/- 0.12	0.75 +/- 0.05
		Experimental	2.07 +/- 0.10	2.35 +/- 0.12	0.88 +/- 0.06
Maxilofacială Cluj	Eltex 400	Theoretical	2.45 +/- 0.12	3.60 +/- 0.18	0.68 +/- 0.05
		Experimental	3.03 +/- 0.15	2.51 +/- 0.13	1.21 +/- 0.09
Medicala 1 Cluj	Philips	Theoretical	2.64 +/- 0.13	3.97 +/- 0.20	0.66 +/- 0.05
		Experimental	2.93 +/- 0.15	4.70 +/- 0.24	0.62 +/- 0.04

All results obtained in this study and the proposals for remediations of the reported deficiencies were submitted to the concerned medical units, so that the proposed improvement solutions to be applied in order comply the quality of radiological equipment with the applicable rules and regulations.

Although the HVL test is widely regarded as the most important, for a complete examination of the X-ray device, it must be performed a series of quality control tests, such as: accuracy and reproducibility of voltage and exposure time, mAs linearity test, determination of the focal spot size and focus-image distance, tests for image quality.

5.2 Physical parameters of X-ray device

The verification of the physical parameters for a röntgendiagnostic X-ray device is part of the quality control in medical diagnostic radiology. In addition, the qualitative and quantitative results of the complete HVL test depend on these physical parameters, therefore it was made a number of control tests such as reproducibility and accuracy of voltage and exposure time using a multi-function tool RMI A 240 meter, mAs linearity using a dosimeter RADCHECK plus 06-256, light field/X-ray field alignment using a radiological film and 4 metal markers, computation of the focal spot size and the focus-film distance using a radiologocal film and an RMI 112B tester and assesements of high and low contrast of radiological image using RMI 151 tester and RMI 141 tester.

All these quality control tests were applied, in accordance with IAEA standards, to a total number of 31 X-ray devices which belong to representative radiological units, with high the influx of population, from Cluj-Napoca, Dej, Huedin, Turda, Miercurea Ciuc, Odorheiu Secuiesc and Oradea.

Reproducibility of peak voltage, kVp, and exposure time, t, is determined by the coefficient of variation, CV (%), which is defined as:

$$C.V.(\%) = 100\frac{\sigma}{\mu} \tag{13}$$

wheren σ is the individual standard deviation for succesive measurements values of kVp or t, μ is the mean of these values. The measurements were performed setting a voltage of 70 kVp, tube load of 20 mAs and it was made 5 exposures. According to CNCAN norms, the coefficient of variation given by relation (13) shold not exceed the maximum permitted value of 5%.

Accuracy (precision) of peak voltage and exposure time is obtained from the relative difference of measured value to set value (at the X-ray console) by applying the following relation (measured value is considered as reference):

$$diff\,(\%) = 100\frac{|x_m - x_s|}{x_m} \tag{14}$$

where x_m is the measured value for kVp ot t, x_s is the set value for kVp or t.

It were set several values for kVp and t covering a large range such as: 60 kV, 70 kV, 80 kV, 90 kV, 100 kV and 120 kV. The value of relative difference given by relation (14) should not exceed the maximum permitted value of 10%.

The mAs linearity was computed setting 70 kVp at the console, gradually increasing the tube load (mAs) and recording the corresponding exposure. It were obtained pair-data for 20 mAs, 40 mAs, 60 mAs, 80 mAs and 100 mAs. For each mAs value, it was computed the tube output defined by:

$$R = D/mAs \tag{15}$$

where D is the measured dose (or exposure, etc) and mAs is the tube load value set at console. Obviously, the value of R should be constant. It was determined the minimum value, R_{min}, and the maximum value, R_{max}. The linearity coefficient, k, is defined by:

$$k = \frac{R_{\max} - R_{\min}}{R_{\max} + R_{\min}} \tag{16}$$

and it should be less than the maximum permitted value of 0.1.

The focal spot size was determined based on the last line-pair group still visible on the image of the tester taking into account the magnification factor. The focal spot tester is placed on a film casette and it is performed an exposure choosing the required physical parameters to obtain a net optical density of 0.8 - 1.4 D.O. On each side of the film casette where the light field is focused, it can be placed 4 metal markers in order to determine the light field/X-ray field alignment The focus-tester distance, d_{tf} is given by the difference between the focus-film distance, d_{ff} and the height of the tester, h_t. The distance between the holes measured on the film, $d_{of,}$ and the known distance between the holes on the tester, d_{ot} determines the measured magnification factor. The image magnification, M_s and the measured (real) magnification, M_m, are given by:

$$M_s = d_{ff} / d_{tf}; M_m = d_{of} / d_{ot} \tag{17}$$

The focus-film distance computed from geometrical considerations is:

$$d_{ff}^m = M_m h_t /(M_m - 1) \tag{18}$$

This value should not differ from the set distance with more than 2%.

The effective size (in millimeters) of the focal spot, f^s_i, f^s_{i-1}, corresponding to the last two groups of line-pairs still visible (f_i, f_{i-1}, in line pairs per mm) are calculated based on the real magnification factor. The estimated effective focal spot size will be given by the arithmetic mean of these two values.

$$f_{i-1}^s = M_m /(f_{i-1}(M_m - 1)); f_i^s = M_m /(f_i(M_m - 1)); f^s = \frac{1}{2}(f_i^s + f_{i-1}^s) \tag{19}$$

The effective focal spot size is related to the nominal size of the focal spot (given by the manufacture) according to the NEMA standard. A nominal focal spot of 0.8 corresponds to the effective values in the 1.2-1.6 mm range, a nominal focal spot of 1.2 corresponds to the effective values in the 1.7-2.4 mm range and a nominal focal spot of 0.6 corresponds to the effective values in the 0.95 - 1.2 mm range.

It is measured on the same film the difference between the X-ray field edge and the marker position and it is calculated the sum of the differences for those two sides both horizontally and vertically. The total difference (horizontal and vertical) should not exceed 2% of the focus-film distance.

The high and low contrast tests are interpreted by the radiologists and the last still visible details determine the quality of the radiological image according to the tester manual.

It was plotted the sensitometric HD curve exposing the radiological film to light using an X-Rite396 sensitometer and it was measured the optical density for each film strips on the sensitometric image using an X-Rite331 densitometer. It was computed the minimum value of exposure (base+fog) which should be less than the maximum permitted value of 0.2 D.O. The gradient (or contrast) is defined as the slope in the straight-line of the sensitometric curve and it should fall in the 2.8 - 3.2 range.

Reproducibility of the high voltage, reproducibility of the exposure time and mAs linearity are presented in Table 12.

Table 12 **kVp and exposure time reproducibility and mAs linearity - partially**

Medical unit	X-ray device	kVp (C.V %)	Admittance	t (C.V %)	Admittance	mAs k	Admittance
Centru D.T. Cluj	Diagnomax M125	1.29	yes	-	-	0.36	no
Centru D.T. Cluj	Eltex	0.55	yes	0.14	yes	0.45	no
Medicala 1 Cluj	Philips	2.75	yes	2.27	yes	0.09	yes

The coefficient of variation of kVp is 5.93% for TUR D800-1 device from “Spitalul Clinic Municipal (Clujana)”. All other resluts are below the maximum permitted value. The

coefficient of variation of exposure time exceeds the maximum permitted value for: “Medicala 3 Cluj”, Siemens BDCX (6.03%); “Spitalul Municipal Dej”, Philips Medio (6.97%) and “Boli Profesionale Cluj”, Diagnomax (24.51%).

It were found mAs linearity coefficients to be 2 times higher (”Medicala 2 Cluj”, Siemens Tridorus; ”Boli Profesionale Cluj”, Diagnomax), 3 times higher (”Centrul de Diagnostic şi Tratament Adulți Cluj”, Diagnomax M125), 4 times higher (”Centrul de Diagnostic şi Tratament Adulți Cluj”, Eltex; ”Spitalul municipal Miercurea Ciuc”, EDR; ”Spitalul de Copii Oradea”, Diagnomax MS125), 5 times higher (”Pediatrie TBC Cluj”, Diagnomax M125; ”Policlinica de Copii Oradea”, Diagnomax MS125) and 7 times higher (”Spitalul municipal Miercurea Ciuc”, EDR 750B) than the maximum permitted value of 0.1.

The causes leading to these results can be diverse, such as: fluctuations of the mA current, inadequate power supply or anode degradation as in the case of the Eltex device from ”Centrul de Diagnostic şi Tratament Adulți Cluj”.

Accuracy of the high voltage and the accuracy of the exposure time is presented in table 13 (minimum and maximum difference).

Table 13 **kVp accuracy and exposure time accuracy (minimum and maximum values) - partially**

Medical unit	X-ray device	kVp (diff. %)	Admittance	t (diff. %)	Admittance
Centru D.T. Cluj	Diagnomax M125	0.18 6.02	yes	16.67 21.97	no
Centru D.T. Cluj	Eltex	31.00 56.56	no	10.80	no
Medicala 1 Cluj	Philips	1.52 4.99	yes	2.53 5.71	yes
Sp. munic. Dej	Philips Medio	8.99 17.47	partially	6.10	yes

The worst case for kVp accuracy test was found at “Centrului de Diagnostic şi Tratament Adulți Cluj-Napoca” where the Eltex device presents differences from 31% to 56% being of 3 to 6 times higher than the maximum permitted value for all tested voltage range. It was noted significant differences between the set values and the measured values of high voltage but in

moderate limits at several medical units: “Spitalul Municipal Dej”, Philips Medio; “Spitalul Miercurea Ciuc”, EDR; “Policlinica de Copii Oradea”, Diagnomax MS125.

The accuracy of exposure time is adequate for most X-ray devices taken into study with several exceptions” Diagnomax M125 from “Centrul de Diagnostic şi Tratament Adulți Cluj-Napoca”, Diagnomax from “Policlinica Huedin” and Diagnomax MS125 from “Policlinica de Copii Oradea”. For these exceptions, the differences between the set values and the measured values of the exposure time are from 2 to 3 higher than the maximum permitted value.

The light field/X-ray field alignment, the focal spot size and the focus-film distance are adequate for the most X-ray devices taken into study.

The image resolution (low contrast and high contrast test) is at least satisfactory for the most X-ray devices taken into study. The worst case was found at Diagnomax device from “Spitalul de Copii Oradea” and the best image resolution was found at Siemens device from “Policlinica Miercurea-Ciuc”. Also, as it was seen before, the complete HVL test confirmed that the Siemens device from “Policlinica Miercurea-Ciuc” is in optimal working condition.

The calculated nominal focal spot does not correspond with the value quaranted by the manufacture for: Philips Duodiagnost (testing the nominal focal spot of 0.6 mm) from “Pediatrie 1” and Siemens (testing the nominal focal spot of 1.2 mm) from “Spitalului Municipal Turda”.

The largest difference between the set focus-film distance and the measured distance (higher than the maximum permitted value of 2%) was found to be 43.14% for Siemens device from “Spitalul Municipal Turda”.

The film sensitometry was performed at “Spitalul de Copii Oradea”. The sensitometric curve, generated by IradMed program is presented in figure 6.

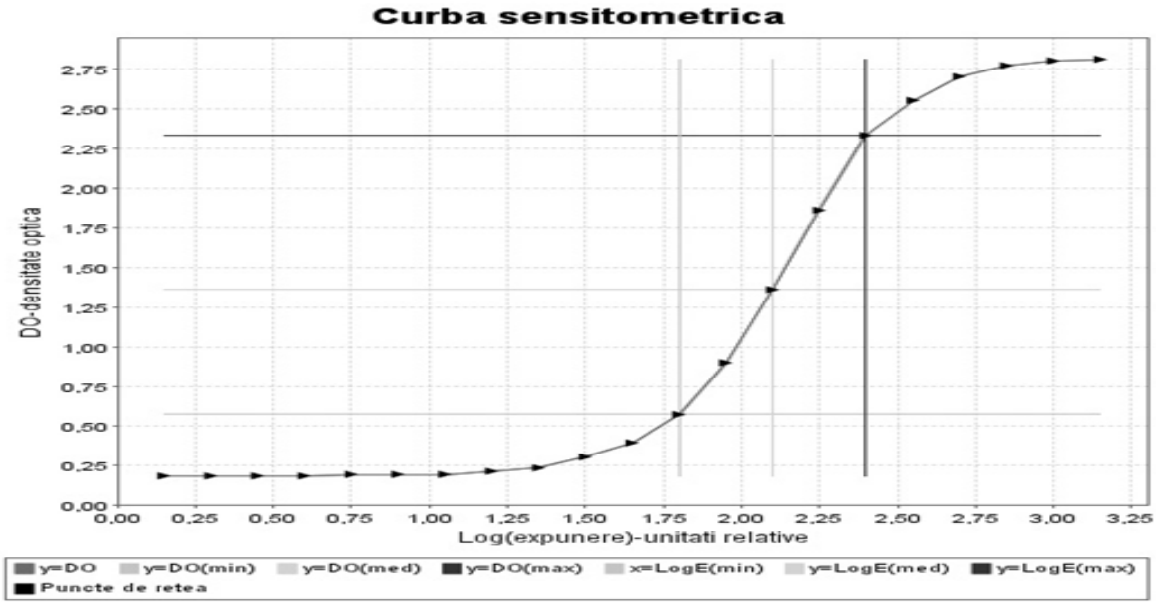

Figure 6 **Sensitometric curve of radiological films from "Spitalul de Copii" Oradea**

The base+fog optical density is 0.18 D.O., which is below the maximum permitted value of 0.2 OD. The contrast is 2.93, being in the permitted 2.8 - 3.2 range. The film speed is 1.36 OD defined as the median optical density of the straight line region. The film latitude, defined as the optical density range corresponding to the straight-line region of the sensitometric curve, was found to be 1.76 OD.

The verification of the physical parameters at a series of X-ray devices emphasized the need to improve the staff working methods to detect errors in radiological practice and the need to implement the quality control programs for radiological equipment in order to achieve a good image quality with a low irradiation of patients (ALARA).

5.3 Scattered radiation

Secondary radiation is of no value in diagnosis, it is a diffuse radiation, parasitic in nature, which was dispersed or scattered from its original path through the body. This radiation is resulting from Compton scattering and represents a serious problem for the radiological technology, as it deteriorates the image quality by reducing the image contrast and lack detail.

In radiological practice, it is frequently used the Bucky grid, placed between the patient and the image receptor, in order to absorb a part of secondary radiation emitted by the human body before it reaches the radiological film.

It was conducted an experimental study for determination of the secondary radiation generated by TUR-300 device from ” Centrul de Diagnostic şi Tratament Copii” Cluj-Napoca. It was studied the scattered radiation dependence of the physical parameters applied in those types of radiographies in which the grid Bucky is used.

Radiation dose were measured using a dosimeter RFT 27012 and it was used a paraffin phantom in order to simulate the patient.

The phantom, as source of secondary radiation, was placed on the radiographic table and the X-ray field was colimatted on a (30 x 40) cm^2 area (maximum size of radiological film) being focused in the geometric center of the phantom.

It was measured the isodoses of secondary radiation around the phantom applying at the console the maximum working parameters involved in radiographies: 90 kVp, 90 mAs and focus-table distance of 76 cm.

It was analysed the variation of exposure given by the secondary radiation (on the table, at arbitrary distances from the phantom) with the tube voltage (50 kV, 70 kV, 90kV), frequently used in practice. It was noted a a direct proportionality between the exposures with the voltage peak. This relationship allows to estimate the contribution of secondary radiation exposure for any value of X-ray tube voltage

It was studied the variation of exposure with distance by performing measurements outside the primary radiation field at 5, 10, 15 cm (arbitrarily chosen values). The results are shown in figure 7.

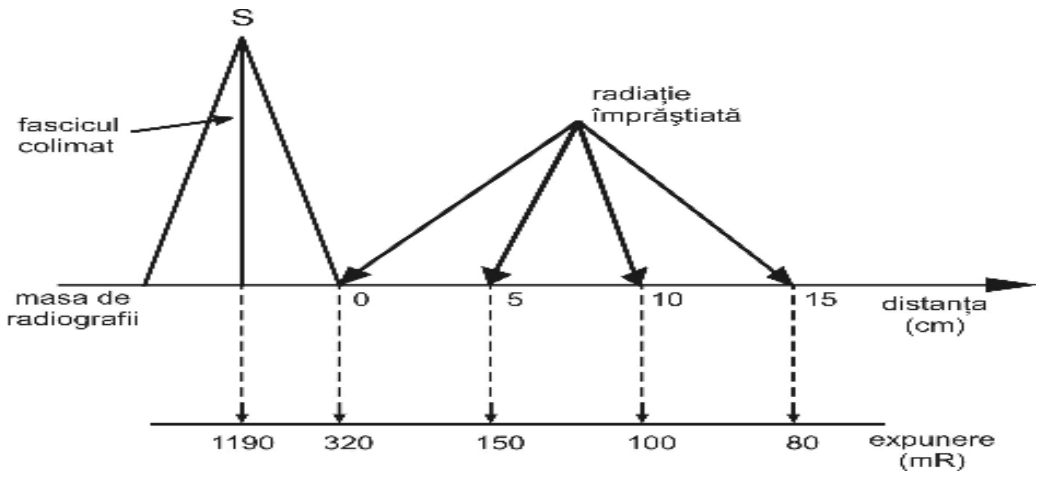

Fig. 7 **Variation of exposure due to the secondary radiation with the distance**

The measured secondary radiation is caused by the Compton scattering inside the phantom, the scattering from radiographic table and, in addition, contains the leakage radiation from the tube focus outside the colimatted area.

The X-ray device taken into study does not meet the standard requirements proposed by the IEC for secondary radiation doses.

In conclusion, the TUR-300 device should be replaced with a proper equipment. Also, it must be performed various quality control tests for all radiological equipments older than 15 years.

CONCLUSIONS

In the present study, it was developed a comprehensive quality assurance program for radiological procedures, including a series of quality control techniques necessary to correct the problems related to the radiological equipment and the radiological practice, having direct implications in reducing the dose, the unnecessary irradiations and to obtain high quality images absolutely necessary to provide a correct diagnosis.

An experimental program of quality assurance in medical diagnostic radiology has been introduced for four medical units with the highest influx of population (adults and children) from Cluj-Napoca

It has been investigated most of the radiological units from Cluj county and it was emphasized the magnitude of medical radiological procedures for a period of 30 years (1970-2000).

It has been developped a PC program, named IradMed, in order to perform accurate Monte Carlo simulations for patient dose assessments, cancer risk estimations, calculation and interpretation of various parameters involved in quality control tests for X-ray devices.

In order to estimate the performances of radiological equipments taken into sudy and the working techniques it was compared the patient doses with the corresponding refference dose levels issued by international standards. The entrance surface dose with and without backscatter as directly measurable physical quantity was used. Measurements were conducted on a large number of X-ray devices from representative medical units from Transylvania. The obtained mean doses in air with backscatter can be proposed as reference levels in radiological practice for Transylvania region. Based on these doses in air, it was calculated the organ doses and the effective doses for all types of radiological examinations (radiography, mammography and CT for both adults and children). In the mammography case, it was also calculated the average

glandular dose and in the CT case, it was measured the CTDI on central axis and then it was computed the peripherical CTDI in order to obtain a valid input data for the IradMed program. Knowledge of the organ doses and the effective doses received by patients is essential for assessing the radiation detriment and the radiation risk induced in the body.

The IradMed program is a very useful tool to estimate the patient doses, unlike other programs or data from literature, carry out Monte-Carlo simulations with high-precision for radiographies, mammographies and CT using advanced algorithms for modeling specific processes (eg EGS), can perform the complete Monte-Carlo simulation taking into account the photon and electron emissions for cylindrical geometry (mammography) and perform an accurate sampling of the X-ray spectrum generated by the tube taking into account the high voltage, the total filtration, the anode material, the anode angle and the ripple voltage waveform. In addition, it estimates the incidence and mortality risks associated with cancer, it perform the calculation and interpretation of all physical quantities involved in various quality control tests (HVL, kV, focal spot, etc.), it calculates the total filtration for different combination of filters, perform the calculation of MTF related to the image quality control tests, the evaluation of the sensitometric curve and more.

The potential risk of inducing cancer from mammography is insignificant compared to the benefits by applying this type of radiological procedure as a method of screening for early detection of breast cancer.

The CT examination involves doses and cancer risks at least one order of magnitude higher than those involved in radiographies and therefore it is required the rational use of these procedures according to the ALARA principle.

In most cases, the obtained average doses are comparable or even lower than the corresponding reference dose levels, although in some cases at some radiological units the involved doses are significantly higher than these levels, like the chest radiography case.

This study emphasizes the high values of patient doses received by children compared with values established and accepted by international standards. It is therefore absolutely necessary to implement quality standards for radiological practice in our future studies.

It was studied a number of thermoluminescent materials (LIF-100, CaSO4: Tm, LIF: Mg, Cu, P) having remarkable results in radiation dosimetry.

Using the IradMed program, the HVL test for the quality control of radiation generated by an X-ray device, was performed much faster and in a much more complex way than usual interpretations suggested by literature. The IradMed program calculates the experimental values of HVL, HVL2 and homogeneity factor, compares these quantities with the corresponding

theoretical values using various statistical methods and, finally, interprets these differences offering predictions on the magnitude of doses and image quality suggesting remedies for the radiological practice.

Due to the value of QVL for the attenuation of X radiation in human body, it is necessary and sufficient to take into account the value of HVL_2 in order to make an appropriate interpretation for HVL test, thus constituting a much more realistic and more complex way than usual interpretations imposed by international standards which are refering only to HVL value. In addition, this comprehensive test HVL is closely correlated with the patient, because it is determined a physical quantity called the total equivalent filtration being of major importance for further calculations of organ doses and effective dose.

The theoretical values of HVL, HVL_2 and homogeneity factor depends on tube voltage, tube total filtration, anode material, anode angle and waveform ripple. These quantities are accurately calculated for any X-ray device used in radiographic examinations, fluoroscopy, mammography or CT.

The experimental determination of HVL and HVL_2 values is performed using advanced mathematical methods such as polynomial interpolation or cubic spline interpolation, both in direct or reverse representations, numerical methods for solving equations and systems of involved equations. Due to the hardening effect, the calculation of experimental HVL value performed by international standards, using a simple linear interpolation between adjacent plotted points on semi-logarithmic scale, generates approximate results and presents a limited applicability (mammography). Therefore, the calculation of HVL performed by IradMed presents an improvement of those standards.

The verification of the physical parameters for X-ray devices, as part of the quality control for medical diagnostic radiology, led to the detection of errors in radiological practice, explaining the causes and the application of effective solutions to remedy these errors.

The secondary radiation generated by the patient, due to the Compton scattering, interferes with the radiological image reducing its contrast and making the image to present lack of details. This study demonstrates the need for practical implementation of a permanent control for the amount of secondary radiation, as it is parasitic in nature and disruptive for the radiological image.

The quality control tests of physical parameters (including the test for quality of radiation defined by HVL, HVL2 and homogeneity factor), the radiological image quality, the entrance surface dose, the organ doses and the effective dose for patients are in a close interdependent relationship, demonstrating the complexity of quality assurance programs necessary to optimize

the radiological practices. The beneficiary of such practices is the patient receiving a minimum dose of radiation, radiological optimized to obtain informations necessary to establish a correct diagnosis.

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