Innovative: International Multi-disciplinary Journal of Applied Technology
(ISSN 2995-486X) VOLUME 02 ISSUE 03, 2024

Risk Evaluation of X Ray Emitted from TV On Eyes for A Specific Time

Duaa Yousif Muhammed Amen
Department of biology, College of Science, Salahaddin University

Yousif Jasim Abd Ali
Medical Physics Department, Madenat Alelem University College

Waleed Jawad Kadhim
Department of biology, College of Science, University of Kufa

Muhammed Ali Abd
Department of Food health and Nutrition, College of Food Science, Al Qasim Green University

Kazem Salah Hadi
Department of Food health and Nutrition, College of Food Science, Al Qasim Green University

Israa Helal Karim
Medical Physics Department, Al-Mustaqbal University, Babylon, Hilla, Iraq

Sadiq Jalil Kazem
Department of Dairy Science and Technology, College of Food Science, Al Qasim Green University

Abbas Raheem Dheyab
Department of Dairy Science and Technology, College of Food Science, Al Qasim Green University

Zahraa Sadeq Abullmahdi
Department of Biotechnology, College of Applied Sciences, University of Technology

Abstract:

Cathode Ray Tube (CRT) monitors are associated with the possible emission of bremsstrahlung radiation produced by electrons striking the monitor screen Despite the widespread use of liquid crystal displays (LCDs), cathode ray tube (CRT) monitors are used extensively. They have advantages over LCD monitors, such as higher resolution, smaller motion artifacts, and higher color depth. In additional, due to the lower prices of CRT monitors, they are still widely used in some poor countries. Electromagnetic radiation in the non-ionizing range of the spectrum only has enough energy to be able to excite electrons to higher states and is insufficient to displace electrons from the atomic structure. Examples of non- ionizing radiation are visible light, infrared, radio waves, microwaves, and sunlight. Sitting in front of TV at a rate of 10 hours per day at close distances is exposed to dose higher than the permissible dose per year. The calculated doses are directly affected by time, so the longer the exposure time, the higher dose and vice versa. Also, reducing the distance between the source and the viewer leads to an increase in the absorbed dose and vice versa. It was observed that the readings of the right of the screen differ from the readings of the left of the screen, which is slightly higher, and this is due to the fact that the transducer inside the TV set is on the right side, as well as other parts that can generate X-rays. Therefore, it is preferable for the viewer to sit on the left of the screen as much as possible.

Keywords: X-rays, Cathode Ray Tube (CRT), liquid crystal displays (LCDs)

Introduction

Cathode Ray Tube (CRT) monitors are associated with the possible emission of bremsstrahlung radiation produced by electrons striking the monitor screen [1].

Despite the widespread use of liquid crystal displays (LCDs), cathode ray tube (CRT) monitors are used extensively. They have advantages over LCD monitors, such as higher resolution, smaller motion artifacts, and higher color depth. In additional, due to the lower prices of CRT monitors, they are still widely used in some poor countries [2].

CRT monitors carry a risk of exposure to operators and the environment. This risk is partly caused by the generation of an electromagnetic field (EMF) [3].

The voltages accelerate the electrons to a maximum energy of the anode–cathode voltage value. In color monitors, three guns are used to shoot the electrons to phosphor spots producing red, green and blue, which are the primary colors. The combination of these colors produces other colors. Electrons colliding with the shadow mask, phosphor layer, and the face panel glass produce Bremsstrahlung x rays. Their intensity depends on the gun current so that the white color has the maximum intensity and will result in the highest intensity of x-rays [4]. This project aims to explain and assess the effects and symptoms of highly exposure for x ray that emitted from TV screen.

Stationary electric charges produce electric fields, whereas moving electric charges produce both electric and magnetic fields. Regularly repeating changes in these fields produce what we call electromagnetic radiation, electromagnetic wave is shown in figure (1). Electromagnetic radiation transports energy from point to point. This radiation propagates (moves) through space at 299,792 km per second (about 186,000 miles per second). That is, it travels at the speed of light. Indeed, light is just one form of electromagnetic radiation [5]. Some other forms of electromagnetic radiation are X-rays, microwaves, infrared radiation, AM and FM radio waves, and ultraviolet radiation shown in figure (2). The properties of electromagnetic radiation depend strongly on its frequency. Frequency is the rate at which the radiating electromagnetic field is oscillating. Frequencies of electromagnetic radiation are given in Hertz (Hz), named for Heinrich Hertz, the first person to generate radio waves. One Hertz is one cycle per second [5].

Frequency and Wavelength

As the radiation propagates at a given frequency, it has an associated wavelength that is, the distance between successive crests or successive troughs. Wavelengths are generally given in meters (or some decimal fraction of a meter) or Angstroms (Å, 10-10 meter). Since all electromagnetic radiation travels at the same speed (in a vacuum), the number of crests (or troughs) passing a given point in space in a given unit of time (say, one second), varies with the wavelength. Since all forms of electromagnetic energy travel at the speed of light, the wavelength equals the speed of light divided by the frequency of oscillation (moving from crest to crest or trough to trough), the wave energy can be calculating using Planks equation [6]:

$$E = hf \quad \text{and} \quad f = \frac{c}{\lambda} \qquad (1)$$

Where E is the wave energy, h is Planks constant, f is the frequency, c is speed of light and λ is the wavelength.

Types and Sources of Radiation

Non-ionizing radiation

Electromagnetic radiation in the non-ionizing range of the spectrum only has enough energy to be able to excite electrons to higher states and is insufficient to displace electrons from the atomic structure. Examples of non- ionizing radiation are visible light, infrared, radio waves, microwaves, and sunlight.

Therefore, the nature and extent of the biological effects of exposure to nonionizing electromagnetic Radiation depend on factors such as: the energy of the incident radiation (which determines the penetration depth), the density of the beam, source emission characteristics, duration of exposure, environmental conditions, and the biological characteristics of the irradiated tissues, Generally, the longer the wavelength, the less an interaction with tissue will occur; and the greater the energy of the source, the greater the opportunity for tissue damage.

Global positioning systems GPS, cellular telephones, television stations, FM and AM radio, baby monitors, cordless phones, garage-door openers use non-ionizing radiation. These are defined as extremely low frequency (ELF) waves and are not considered to pose a health risk [7].

Ionizing radiation

Ionizing radiation is capable of knocking electrons out of their orbits around atoms, upsetting the electron/proton balance and giving the atom a positive charge. Electrically charged molecules and atoms are called ions.

Ionizing radiation includes the radiation that comes from both natural (terrestrial radiation and cosmic radiation) and man-made radioactive materials. There are several types of ionizing radiation (Alpha [α], Beta [β], Photon radiation (gamma [γ] and X-ray) and neutron radiation [8].

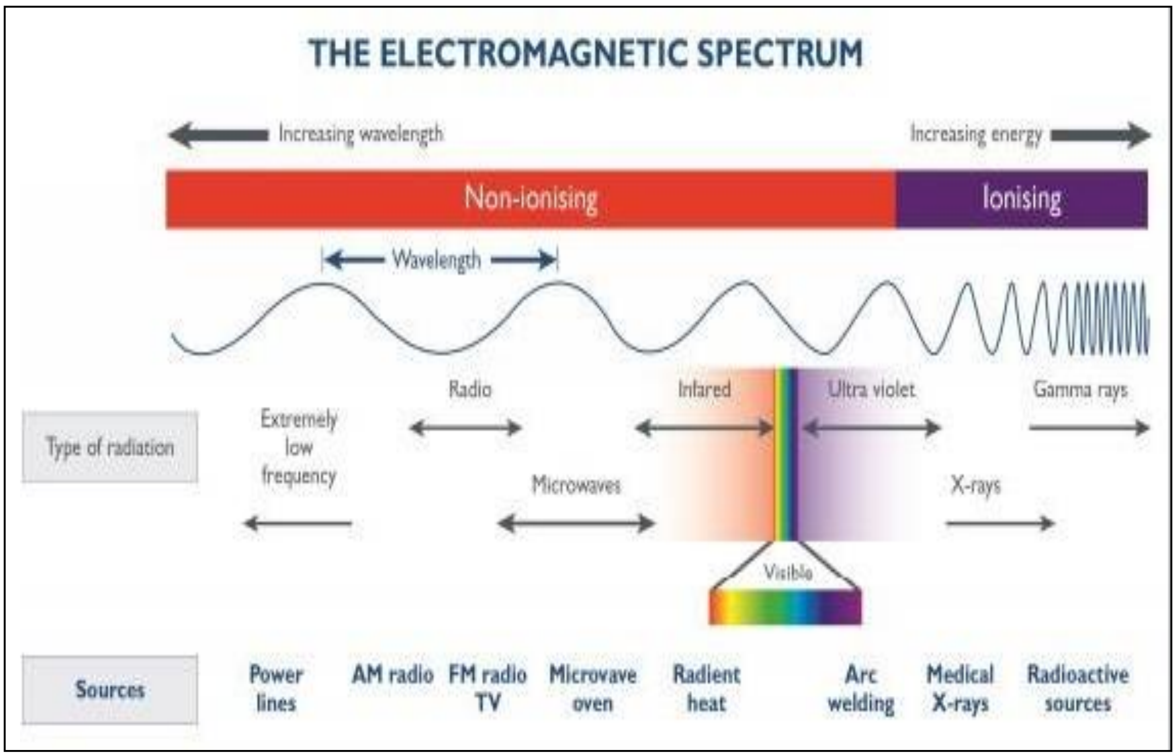

Figure (2): The Electromagnetic Spectrum

1.3 X-Ray Properties

X-rays are electromagnetic radiation of exactly the same nature as light but of very much shorter wavelength. X-rays ionize atoms. The energy required for ionization varies with the material (e.g., 34 eV in air, 25 eV in tissue) but is generally in the range of several eV. A 100 keV X-ray can potentially create thousands of ions [9].

X-Ray Production

X-rays are produced when accelerated electrons collide with the target. The loss of energy of the electrons due to impact is manifested as x-rays. X- ray radiation is produced in an x-ray tube. Most of the kinetic energy of the electrons striking the target is converted into heat, less than 1% being transformed into x-rays [10].

$$Ek = eV = 1/2\ mv^2$$

e – electron charge ($1.6x10^{-19}$ C)

EK – kinetic energy, V – applied voltage, m – mass of the electron ($9.11x10^{-31}$ kg), v – electron velocity (m/sec)

There are three major components of tube: The cathode which is negatively charged, the Anode which is positively charged and the glass envelope which supports the anode and cathode structures. X-rays are generated by an x-ray tube. In this device, a metal filament is heated until energetic electrons escape from the cathode surface into a vacuum. These electrons are then accelerated by an electric field, gaining kinetic energy while being attracted to a positive anode target [11].

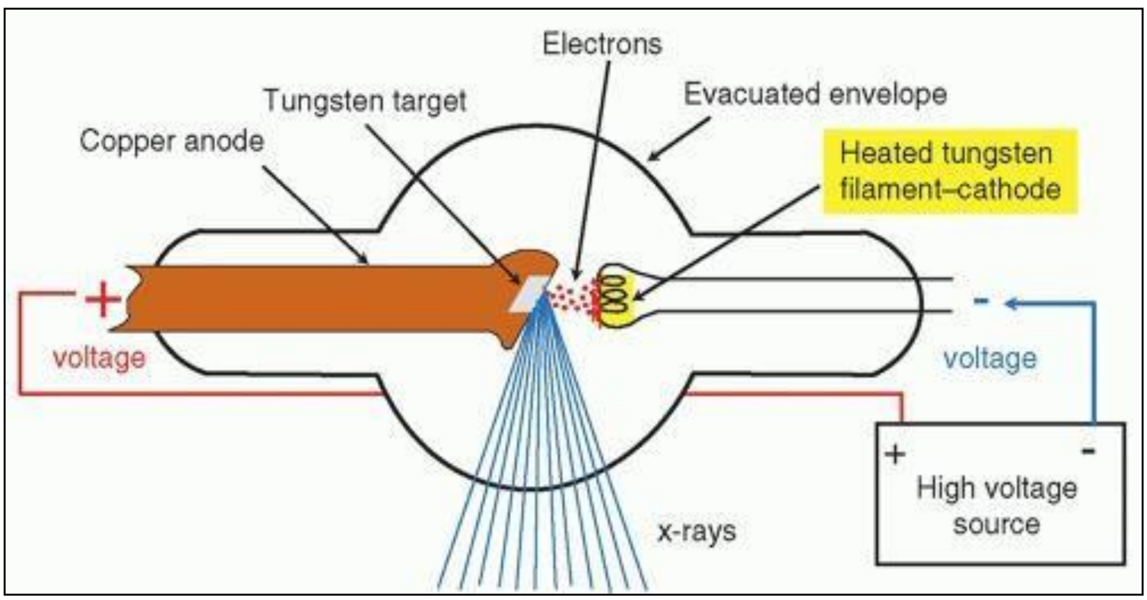

Figure (3): X ray tube components

The total amount of energy acquired by the electron in the accelerating electric field is equal to the product of the potential (peak kilo voltage kVp) multiplying by the unit of electrical charge, possessing units of electron volts (kilo electron volts, keV). The amount of charge generated by the x-ray tube per unit time has units of electrical current (mill amperes, mA), and the product of voltage and current is the amount of power (watts) delivered by the tube [12].

X- Ray Types

Continuous X-ray Spectrum

When electrons hit the anode, they decelerate or brake and emit Bremsstrahlung (meaning braking radiation in German). Bremsstrahlung is produced most effectively when small charged particles interact with large atoms, such as when electrons hit a tungsten anode. However, Bremsstrahlung can be produced with any charged particles and any target. It is also called polychromatic, continuous or white radiation. Some electrons lose all the energy in a single collision with a target atom [13].

• Properties of the Continuous Spectrum

1. Smooth, monotonic function of intensity vs wavelength.

2. The intensity is zero up to a certain wavelength – short wavelength limit (λSWL). The electrons transfer all their energy into photon energy.

3. The total x-ray energy emitted per second depends on the atomic number Z of the target material and on the x-ray tube current [12].

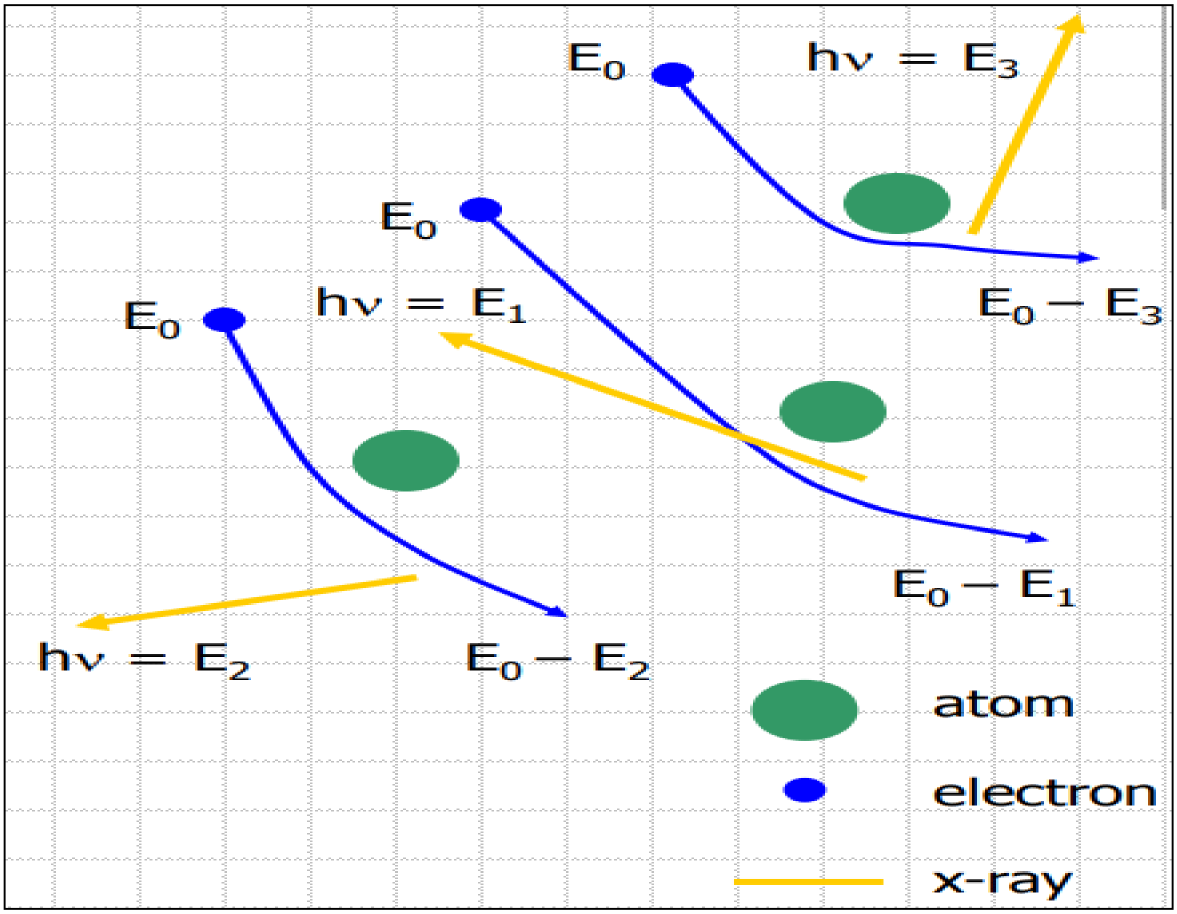

Figure (4): Continuous X-ray Spectrum production

Characteristic X-ray Spectrum

Characteristic x-rays are emitted from heavy elements when their electrons make transitions between the lower atomic energy levels. The characteristic x-ray emission which is shown as two sharp peaks in the illustration at left occur when vacancies are produced in the n=1 or K-shell of the atom and electrons drop down from above to fill the gap. The x-rays produced by transitions from the n=2 to n=1 levels are called K-alpha x-rays, and those for the n=3→1 transition are called K-beta x-rays [13].

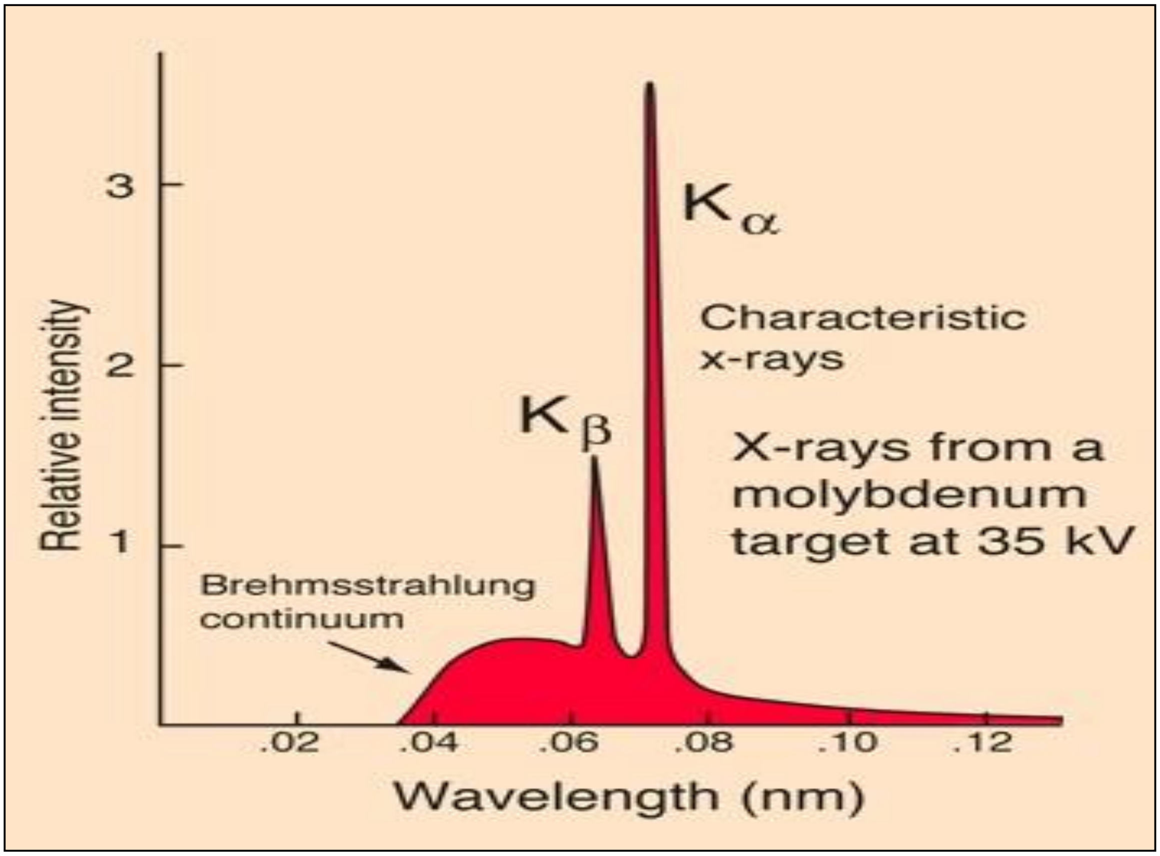

Figure (5): Bremsstrahlung and Characteristic X-ray Spectrum

X-ray production typically involves bombarding a metal target in an x- ray tube with high speed electrons which have been accelerated by tens to hundreds of kilovolts of potential. The bombarding electrons can eject electrons from the inner shells of the atoms of the metal target. Those vacancies will be quickly filled by electrons dropping down from higher levels, emitting x-rays with sharply defined frequencies associated with the difference between the atomic energy levels of the target atoms [13].

Characteristic x-rays are used for the investigation of crystal structure by x-ray diffraction. Crystal lattice dimensions may be determined with the use of Bragg's law in a Bragg [12].

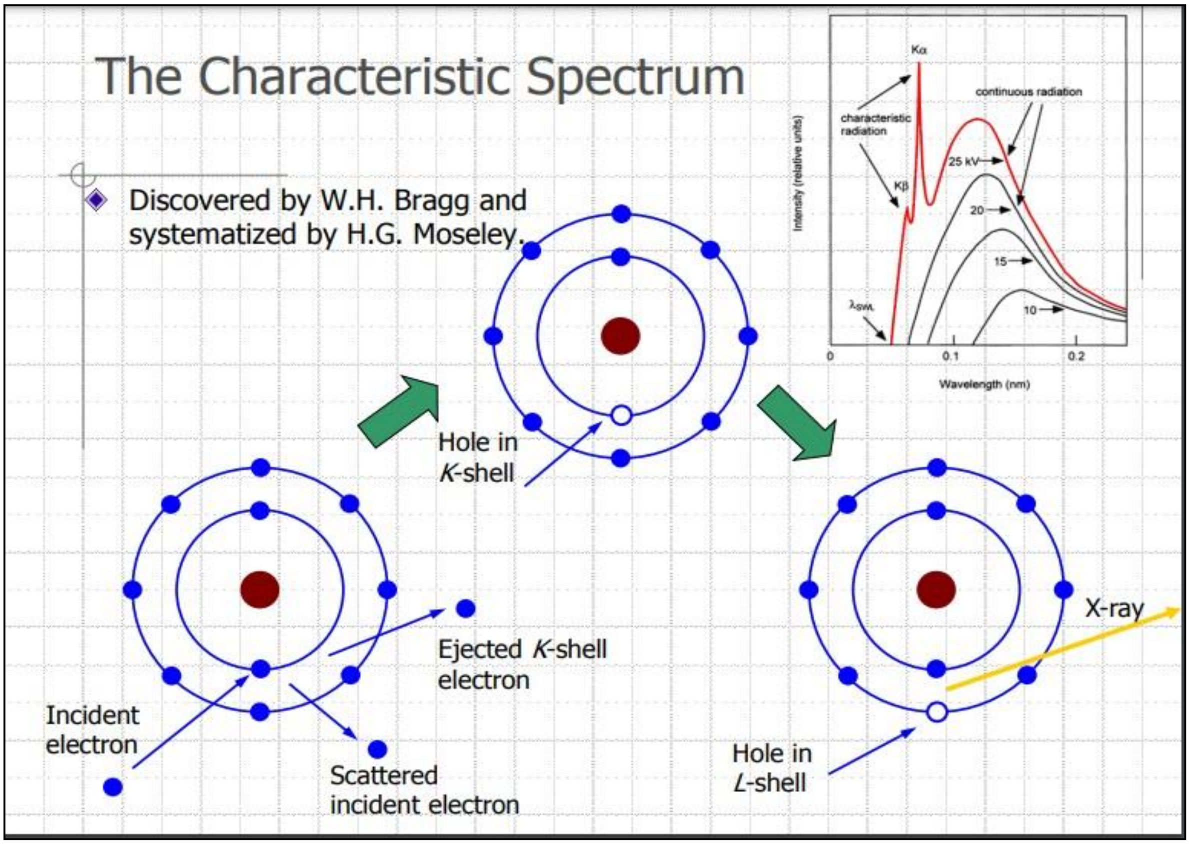

Figure (6): Characteristic X-ray production

- Properties of the Characteristic Spectrum

1. The intensity of any characteristic line depends both on the tube current I and the amount of applied voltage V

2. Characteristic lines are also very narrow, most of them less than 0.001 Å wide (Full Width at Half Maximum) [13].

Radiation- Tissues Risks

Tissue damage occurs through the change in chemical properties of molecules in the tissue following exposure to radiation. The major contributor to damage from radiation is through radiation changing a water molecule into a new form called a “free radical”. Free radicals are chemically highly active and as such can have reactions with genetic molecules of the cell (i.e., the DNA). This can cause damage to the DNA most of which is readily repaired by the cell. If it is not, it can result in cell death. Alternatively, if the DNA damage is repaired erroneously, it can result in an alteration of the genetic encoding leading to hereditary changes or cancer induction most comes from diagnostic medical exposures, and smaller amounts that comes from medical therapy, occupational exposures, and from radioactive pollutants [14].

Tissue effects of ionizing radiation can be observed in virtually all tissues. One prominent attribute of ‘deterministic’ effects is that they only occur if a certain, albeit – for some symptoms – small, threshold dose is reached. With regard to their time course, early effects are seen within the first weeks after an acute radiation exposure, while chronic, late radiation sequelae manifest after months to many years. In some instances, the extent, i.e. severity and/or duration, of the early effects has an impact on the risk for the manifestation of late symptoms in the same tissue or organ (consequential late effects). A number of factors have been identified with regard to the exposure characteristics that significantly influence the radiation tolerance of normal tissues such as [15]:

- The dose rate.
- The energy and type of radiation.
- The time of the exposure.
- Biological species, sex and age.
- The portion of the body tissues exposed.
- repair mechanisms.

Pathobiological Principles of Tissue Effects

Based on their time, early reactions in tissues are defined as those observed within weeks after the (onset of) radiation exposure, e.g. within the first 90 days after the start of radiotherapy. Any symptom that is first diagnosed at a later time is considered a late response, with typical latent times of months to many years and sometimes decades for very late effects [16].

It must be emphasized that tissue effects in many instances are not based on the consequences of radiation exposure of an individual organ, but on the interaction of radiation effects in physiologically 'connected' organs, such as the lung and the heart after thoracic exposure, or the systemic contribution of the immune system to individual organ effects [17].

1. Deterministic effects

These effects depend on time of exposure, doses, type of Radiation. It has a threshold of doses below which the effect does not occur the threshold may be varying from person to person. Deterministic effects are those responses which increase in severity with increased dose if the dose increases the severity of an effect increases. All early effect and most tissue late effect is deterministic. deterministic effect includes Acute Radiation Sickness and chronic radiation Sickness [17].

2. stochastic Effect

Is those effect which occur when a person receives a high dose of radiation.

These effects have an increase probability of occurrence with increase dose. There is no threshold dose below which is a stochastic effect cannot occur. Severity does not depend on magnitude of absorbed doses these effects occur by chance. Stochastic effect is of two types (somatic stochastic effect and Genetic effect) [17].

The processes that lead to the cells destroyed by radiation can be divided into four stages [18]:

Physical Stage (10-13 sec) Chemical Stage (10-13 to 1 sec)

Biochemical Stage (1 sec to 10 days) Biological Stage (11 days to 32 years)

Radiation-eyes risks

Exposure to ionizing radiation could affect the human brain and eyes leading to both cognitive and visual impairments. the most frequent ionizing radiation-induced ophthalmic effects include cataracts, glaucoma, optic neuropathy, retinopathy and angiopathy, sometimes associated with specific neurocognitive deficits. According to available information that eye alterations may induce or may be associated with brain dysfunctions and vice versa [19].

It is well recognized that the human brain and eyes are radiosensitive and radiovulnerable organs. The eye lens is one of the most radiosensitive human tissues, and the retina is at risk for suffering from severe consequences induced by ionizing radiation, such as angiopathy and angiosclerosis [19].

Interests concerning the effects of IR on eye structures are progressively increasing, given the evidence that they are easily accessible, and particularly the retina, which is part of the brain, may represent a reliable indicator of the actual conditions of the central nervous system (CNS) [20].

in 2012 did the International Commission on Radiological Protection (ICRP) note how "special attention should be paid to the radiation effects in the lens of the eye and the cardiovascular system". In addition, taking into account new epidemiological data, the ICRP underlined that some tissue reactions were due to threshold or lower doses than the previous ones [21]. with the threshold considered to be 0.5 Gy, irrespective of the rate of dose delivery [22].

Ionizing radiation-induced ophthalmic effects includecataract, glaucoma, optic neuropathy, retinal angiopathy and dry-eye syndrome [23].

Radiation Measuring units

Radiation Activity

The rate of disintegration per unit time is measured in curies and based on the following standard [24]:

Unit	Quantity
1 curie (Ci)	3.7 X 10^{10} dps (disintegrations per second)
1 millicurie (mCi)	3.7 X 10^{7} dps = 1 X 10^{-3} Ci
1 microcurie (µCi)	3.7 X 10^{4} dps = 1 X 10^{-6} Ci
1 nanocurie (nCi)	37 dps = 1 X 10^{-9} Ci
1 picocurie (pCi)	3.7 X 10^{-2} dps = 1 X 10^{-12} Ci
1 becquerel (Bq)	1 disintegration per second

Radiation Exposure

The measurement of radiation exposure in air as ionizations per unit mass of air due to x-ray or gamma radiation [25]:

Unit	Quantity
1 Roentgen (R)	2.58 X 10^{-4} Coulomb/Kg air
1 milliroentgen	2.58 X 10^{-7} Coulomb/Kg air = 1 X 10-3 R

Absorbed Dose

The measurement of radiation absorbed dose (rad) represents the amount of energy deposited per unit mass of absorbing material [26]:

Unit	Quantity
1 rad	100 ergs/gram
1 rad	1 X 10^{-2} Joule/kg
1 millirad (mrad)	1 X 10^{-5} Joule/kg = 1 X 10-3 rad

Dose Equivalent

The measurement of biological effect of radiation requires a third unit called a quality factor (QF). The quality factor takes into account the different degrees of biological damage produced by equal doses of different types of radiation. 1 rem (Roentgen equivalent man) is the product of the amount of energy absorbed (rad) times the efficiency of radiation in producing damage (QF) [27]:

1 rem = 1 rad x QF

The S.I. system

is widely used in Europe and is gradually being adopted in the United States [27]:

Current Unit	S.I. Units	Conversion
Curie (Ci)	Becquerel (Bq)	1 Ci= 3.7 x 10^{10} Bq
rad	Gray (Gy)	1 rad= 1 X 10^{-2} Gy
rem	Sievert(Sv)	1 rem=1 X 10^{-2} Sv

Radiation hazards and Standard limits of eyes exposure

As a result of the great use of ionizing radiation, especially in the field of diagnosis and medical examination, in addition to what humans are exposed to from natural radiation emanating from sources in its surroundings such as uranium, thorium and others that are found in the rocks of the earth's crust, where the rate of radiation dose is estimated at a height of one meter above limestone rocks in About 20 mrem per year [28].

The elements can also be found inside the human body by inhaling them with air contaminated with radioactive gases or entering them with food and drink, where they become a permanent source of radiation inside the body. As the number of nuclear reactors increased after World War II and the residues of fission of radioactive elements increased, and as a result, attention must be paid to radiation protection because of the serious dangers it poses to life. Therefore, several international institutions worked on this subject in order to reduce and prevent exposure to harmful radiation. The Roentgen Association that founded in 1916, and the (ICRU) International Commission On Radiological Units that founded in 1928, International Atomic Energy Agency (IAEA), National council on radiation protection (NCRP), United nation scientific committee on the effects of the atomic radiation (UNSCEAR), National institute of environmental health sciences (NIEHS), and International Commission on Radiological Protection (ICRP) [28].

The organization (ICRP) identified the organs of the body sensitive to radiation and named as (Critical Organs), which are the bone marrow, the reproductive organs and the lens of the eye. In 1956, the International Agency for Radiation Protection (ICRP) proposed an equivalent dose rate for radiation workers to be 3rem during 13 weeks, in addition to formulating the relationship of equivalent dose (DE) in REM with the age of workers (N) in years [29].

$DE(rem) = 5(N-18)$

Radiation emitted from Television

Electromagnetic radiation covers a wide range of radiation emitted by display devices and can be divided into: ionizing radiation such as X-rays, and non-ionizing radiation, which includes frequencies of ultraviolet and infrared radiation, visible rays, and low frequencies of electric and magnetic fields, so it can be said that electromagnetic radiation, Therefore, the display screens emit a group of radiation as follows [30]:

1. Low-energy X-rays, which consist of a CRT cathode ray tube, when electrons hit the glass (screen) that forms the surface of the display device. The glass cover of the display device contains large amounts of lead, which absorbs the x-rays efficiently and tries to prevent them from leaking out.

2. Ultraviolet in the near area (UV-A) can be detected by some display devices.

3. Infrared radiation (IR) is emitted by all hot objects, and since all projector surfaces are at or slightly above room temperature, infrared radiation can be detected, although its level is much lower than the level of concern.

4. Electric and magnetic fields, detected in the low-frequency and high- frequency fields. The dominant sources in this regard are power supplies at frequencies 50-85KHz and 15-35KHz. In comparison with fields emitted by industry or homes, the electric and magnetic fields around the display devices can be considered not associated with high exposure doses.

5. Stable electric fields near display devices may be the reason for the appearance of some abnormal marks in the skin of workers on these devices.

6. Ultrasound waves are usually formed as a result of mechanical vibrations generated in the transducers core of display devices [31].

X ray radiation emitted from Television

Television emits in addition to visible light, a low percentage of radiation that the human eye cannot see, the most dangerous is X-rays, because they have energy can penetrate the human body for distances that other radiations emitted from the same device cannot reach [31].

10,000V of the voltage supplied to the CRT tube and 40.000V that is used in color TV are produce X-rays when the fast and accelerating electrons hit the inner surface of the tube. These operating voltages are considered relatively low when compared to the operating voltages in medical instruments, so the x-rays generated by the television are less than the x-rays designated for medical purposes [32].

Experimental works

X- Ray films and densitometer

Small doses of X-ray leaked from television were measured and analyzed using radiographic film, which is used in dental medical diagnosis, due to its sensitivity to low energy X-ray leakage.

The film is usually coated with a layer that is very sensitive to radiation (silver bromide crystals are usually used), as these crystals are affected by radiation, forming dark and transparent areas called (latent images), Then the image is shown on the film, the parts exposed to radiation appear dark, and the parts not exposed to radiation are transparent. The optical density on the film at any point represents a measure of the degree of blackening at that point, which is used to find exposure in units (mR) of films used and exposed to radiation emitted by television.

In order to measure the optical density using a (Densitometer) which consists of (the base) and (the photometer unit), the film is placed in the way of a light beam and the intensity of the transmitted light is measured by a photocell containing a photo diode that converts the light into electrical pulses (Signals) to be amplified by the amplifier, and sent to the digital panel mater in the form of numbers that express the optical density.

$D=Log_{10} I_o/I_t$

I_o- The intensity of visible light falling on a small area of the film. I_t - the intensity of light absorbed by that area.

The amount of radiation exposure for x-ray film can be found by measuring its optical density using a densitometer and finding the exposure unit using sensitometric curve [33]:

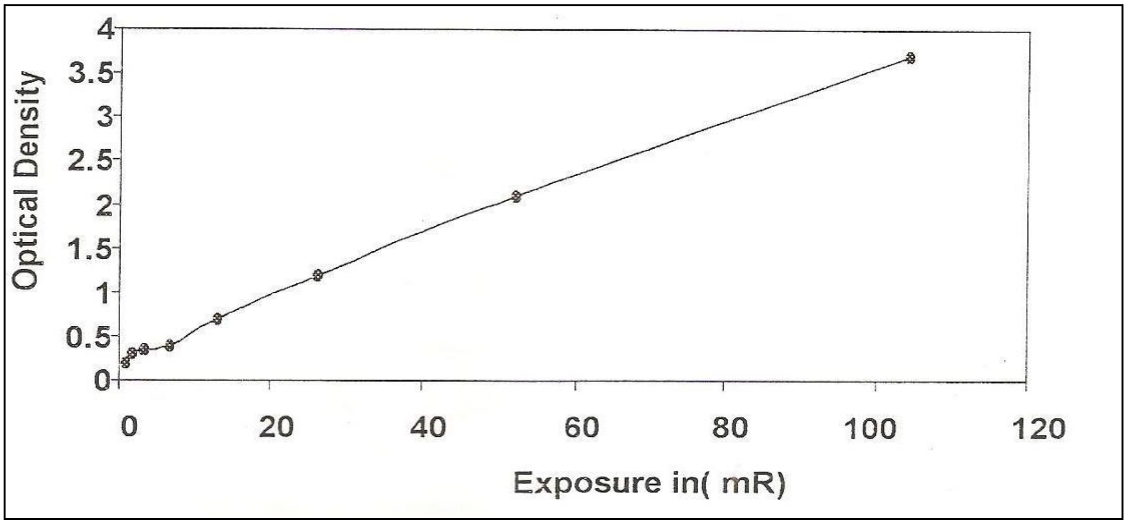

Figure (7): Sensitometric curve of optical density and exposure in Gray and mR

X-Ray measurement at a distance of (0.5, 1, 1.5, 2) meters from the TV screen

Three films were installed on a piece of cork, the first one parallel to the center of the screen and the other to the right of the screen, while the third film was fixed to the left of the screen for an exposure period of ten hours per day in a dark room and at a distance of 0.5m, and the other films were installed in the same way at distances of 1m, 1.5m, 2m. The (Optical Density) is measured by a densitometer, and the optical densities are converted to the exposure unit mR using the curve in Figure (7).

The result of the measurements that were obtained for distances (0.5, 1, 1.5, 2) m from the TV screen for a period of ten hours of exposure per day, was used for each distance of three films: film (1) parallel to the center of the screen, film (2) left of the screen, film (3) the right of the screen, and the results were as follows:

Table (1): Film (1) parallel to the center of the screen, the exposure time (ten) hours and the distances (0.5, 1, 1.5, 2) m:

Film(1)		
Distance(m)	**Reading optical density**	**Exposure(mR)**
0.5	1.89 ± 0.1	6.8 ± 0.14
1	1.81 ± 0.1	6.6 ± 0.14
1.5	1.78 ± 0.1	6.4 ± 0.14
2	1.66 ± 0.1	6.2 ± 0.14

Table (2): Film (2) parallel to the left of the screen, the exposure time (ten) hours and the distances (0.5, 1, 1.5, 2) m:

Film(2)		
Distance(m)	**Reading optical density**	**Exposure(mR)**
0.5	1.62 ± 0.1	6.9 ± 0.14
1	1.54 ± 0.1	6.5 ± 0.14
1.5	1.48 ± 0.1	6.3 ± 0.14
2	1.39 ± 0.1	6.1 ± 0.14

It is noted from figure () there is a clear decrease in the dose with distances, if we assume that the viewer is at the farthest calculated distance (2m) from the center of the screen for ten hours, the absorbed dose per year can be calculated as follows:

6.2 mR/yr x 365 = 2263 mR/yr

2263 mR/yr /100 R/sv = 22.63 msv/yr

To compare this dose with the allowed dose determined by the (ICRP) for the eye as one of the sensitive and critical organs for radiation, the maximum eye dose equal to (15.6msev) per year [34].

22.63 msv/yr /15.6 msv/yr =1.45

Where this value is higher than the allowed limit by about 1.45

Conclusions

Sitting in front of TV at a rate of 10 hours per day at close distances is exposed to dose higher than the permissible dose per year. The calculated doses are directly affected by time, so the longer the exposure time, the higher dose and vice versa. Also, reducing the distance between the source and the viewer leads to an increase in the absorbed dose and vice versa. It was observed that the readings of the right of the screen differ from the readings of the left of the screen, which is slightly higher, and this is due to the fact that the transducer inside the TV set is on the right side, as well as other parts that can generate X-rays. Therefore, it is preferable for the viewer to sit on the left of the screen as much as possible.

References

1. Khaledi N, Arbabi A, and Dabaghi M, “X-ray dose estimation from cathode ray tube monitors by monte carlo calculation”, Health Physics, 108(4), (2015).
2. Kyrnin M. CRT vs. LCD monitors. 2012. Available at http:// compreviews.about.com/od/multimedia/a/CRTvsLCD.htm. Accessed 8 May 2013.
3. Mortazavi SM, Ahmadi J, Shariati M. Prevalence of subjective poor health symptoms associated with exposure to electromagnetic fields among university students. Bioelectromagn 28:326–330; 2007. DOI 10.1002/bem.20305.

4. Holms A, De Cuir CA. A technical research report: the cathode ray tube. Santa Barbara, CA: University of California, College of Engineering; 2005.
5. Eliyahu I., Luria R., Hareuveny R., Margaliot M., Meiran N., and Shani G.. “Effects of radiofrequency radiation emitted by cellular telephones on the cognitive functions of humans”. Bioelectromagnetics (2006) 27:119–126.
6. Ferreri F., Curcio G., Pasqualetti P., De Gennaro L., Fini R., and Rossini
7. P.M. Mobile phone emissions and human brain excit-ability. Ann. Neurol.
8.)2006(, 60:188–196.
9. Ng KH. “Non-ionizing radiation – sources, biological effects, emissions and exposures”. In Proceedings of the International Conference on Non-Ionizing Radiation at UNITEN. (2003).
10. Grasty R.L. and LaMarre J.R., "The Annual effective dose from natural sources of ionizing radiation in Canada". Radiation Protection Dosimetry”. 2004(,108: 215-226.
11. Behling, R. 2016. Modern Diagnostic X-Ray Sources. Boca Raton, FL: CRC Press/Taylor & Francis.
12. Gall, B., S. D. Kovaleski, J. A. VanGordon, P. Norgard, A. Benwell, B. H. Kim, J. W. Kwon, and G. E. Dale. 2013. Investigation of the piezoelectric effect as a means to generate X-rays. IEEE Transactions in Plasma Science 41:106–11.
13. Krestel, E., ed. 1990. Imaging Systems for Medical Diagnosis. Munich, Germany: Siemens Aktiengesellschaft.
14. Rizk, F. A. M. 2014. High Voltage Engineering. Boca Raton, FL: CRC Press.
15. Rossi, R. P., P. J. P. Lin, P. L. Rauch, and K. J. Strauss. 1985. Performance Specifications and Acceptance Testing for X-Ray Generators and Automatic Exposure Control. Published for the American Association of Physics in Medicine. AAPM Report no. 14. New York, NY: American Institute of Physics.
16. Do¨rr, W., 2009a. Time factors in normal tissue responses to irradiation. In: Joiner, M., Van der Kogel, A. (Eds.), Basic Clinical Radiobiology. 4th edn. Hodder Arnold, London, pp. 149–157.
17. Do¨rr, W., 2009b. Pathogenesis of normal tissue side effects. In: Joiner, M., Van der Kogel, A. (Eds.), Basic Clinical Radiobiology. 4th edn. Hodder Arnold, London, pp. 169–190.
18. Do¨rr, W., 2009c. Biological response modifiers: normal tissues. In: Joiner, M., Van der Kogel, A. (Eds.), Basic Clinical Radiobiology. 4th edn. Hodder Arnold, London, pp. 301–315.
19. Do¨rr, W., Stewart, F.A., 2009. Retreatment tolerance of normal tissues. In: Joiner, M., Van der Kogel, A. (Eds.), Basic Clinical Radiobiology. 4th Hodder Arnold, London, pp. 259–270.
20. Do¨rr, W., Van der Kogel, A.J., 2009. The volume effect in radiotherapy. In: Joiner, M., Van der Kogel, A. (Eds.), Basic Clinical Radiobiology. 4th edn. Hodder Arnold, London, pp. 191–206.
21. Tang, F.R.; Loganovsky, K. Low dose or low dose rate ionizing radiation- induced health effect in the human. J. Environ. Radioact. 2018, 192, 32–47.
22. Ciarmatori, A.; Nocetti, L.; Mistretta, G.; Zambelli, G.; Costi, T. Reducing absorbed dose to eye lenses in head CT examinations: The effect of bismuth shielding. Phys. Eng. Sci. Med. 2016, 39, 583–589.
23. Gaddini, L.; Balduzzi, M.; Campa, A.; Esposito, G.; Malchiodi-Albedi, F.; Patrono, C.; Matteucci, A. Exposing primary rat retina cell cultures to γ- rays: An in vitro model for evaluating radiation responses. Exp. Eye Res. 2018, 166, 21–28.
24. Stewart, F.A.; Akleyev, A.V.; Hauer-Jensen, M.; Hendry, J.H.; Kleiman, N.J.; Macvittie, T.J.; Aleman, B.M.; Edgar, A.B.; Mabuchi, K.; Muirhead, C.R.; et al. ICRP publication 118: ICRP statement on tissue reactions and early and late effects of radiation in normal tissues and organs—Threshold doses for tissue reactions in a radiation protection context. Ann. ICRP 2012, 41, 1–322.

25. K. N. Loganovsky et al., “Radiation-Induced Cerebro-Ophthalmic Effects in Humans,” pp. 1–17, 2020.
26. Datz H, Ben-Shlomo A, Bader D, Sadetzki S, Juster-Reicher A, Marks K, et al. The additional dose to radiosensitive organs caused by using under- collimated X-ray beams in neonatal intensive care radiography. Radiat Prot Dosimetry. 2008;130(4):518–24. doi: 10.1093/rpd/ncn090.
27. Smans K, Struelens L, Smet M, Bosmans H, Vanhavere F. Patient dose in neonatal units. Radiat Prot Dosimetry. 2008;131(1):143–7. doi: 10.1093/rpd/ncn237.
28. Faghihi R, Mehdizadeh S, Sina S, Alizadeh FN, Zeinali B, Kamyab GR, et al. Radiation Dose to Neonates Undergoing X-ray Imaging in special Care Baby Units in Iran. Radiat Prot Dosi. 2011;150(1):1–5.
29. Brindhaban A, Al-Khalifah K. Radiation dose to premature infants in neonatal intensive care units in Kuwait. Radiat Prot Dosimetry. 2004;111(3):275–81. doi: 10.1093/rpd/nch338.
30. Ploussi, A.; Stathopoulos, I.; Syrgiamiotis, V.; Makri, T.; Hatzigiorgi, C.; Platoni, K.; Carinou, E.; Efstathopoulos, E.P. Direct measurements of skin, eye lens and thyroid dose during pediatric brain CT examinations. Radiat. Prot. Dosim. 2018, 179, 199–205.
31. Reighard.H.L,2005 :" Radiation Health Hazard and Protection", New York Times, Medical Science section.
32. Kurppa K, Holmberg PC, Rantala K, Nurminen T, Saxen L,1985 : Birth Defects and Exposure to Video Display Terminals - a Finnish Case- Referent Study. Scandinavian Journal of Work Environment and Health.
33. Yng - Shlang . W, 1975: Measurement of Ionizing Radiation from Colour Television Receivers by Thermoluminescent Dosimeters. , Health physics Journal , Vol. 28 .
34. Lachenbruck.L,1967: "What You Should Know About X-Ray Radiation in TV Sets, Radio-Electronics " Int J Epidemiol .
35. Bouffler S., Ainsbury E., Gilvin P., Harrison J. Radiation-induced cataracts: The Health Protection Agency's response to the ICRP statement on tissue reactions and recommendation on the dose limit for the eye lens. J. Radiol. Prot. 2012;32:479–488. doi: 10.1088/0952-4746/32/4/479.
36. The 2007 Recommendations of the International Commission on Radiological protection. ICRP Publication 103. Ann. ICRP. 2007;37:1–332.