Available online at www.scholarsresearchlibrary.com

Scholars Research Library

Archives of Applied Science Research, 2013, 5 (6):164-171
(http://scholarsresearchlibrary.com/archive.html)

ISSN 0975-508X
CODEN (USA) AASRC9

Verification of a treatment planning system using an in-house designed head and neck phantomphantom

Akpochafor M. O., Aweda M. A., Ibitoye A. Z., Adeneye S. O., Iloputaife C. and Omojola A. D.

Department of Radiation Biology, Radiotherapy, Radiodiagnosis and Radiography, College of Medicine, Lagos University Teaching Hospital, Lagos, Nigeria

---

ABSTRACT

To evaluate the accuracy of monitor unit calculated by the treatment planning system (TPS) algorithm using an in-house designed head and neck phantom. The designed in-house phantom was constructed in the shape of a block using a Plexiglas of density 1.16g/cm^3 and diameter 0.3mm. The phantom has provision for five hollow inserts for the ionization chamber and tissue equivalent materialsmimicking different biological tissues such as the bone, Brain, AdiposeandTrachea.The percentage compositions by mass of various chemical components were mixed together to mimic each biological tissues.9.5% of carbon; 87.3% of water to mimic the brain with 3.324e/kg electron density, 37.03g of carbon; 4.83g of hydrogen 35.66g of oxygen; 15.3g of carbon for bone with 3.353e/kg electron density, 68.10g of carbon; 19g of oxygen; 11.02g of hydrogen for adipose with 3.100e/kg electron density, 13.9g of cabon; 71.5g of oxygen; 10.4g of hydrogen for trachea with 3.336e/kg electron density. The phantom was filled with water and scanned with a Hi-Speed CT-scannerand the images were transferred to the ELEKTA-Precise treatment planning system.Several simple treatment plans of multiple beams were made with the designed phantom using the Area Integration Algorithm configured to give 1.0 Gy at the iso-centre. Measurements of Monitor units were conducted using 6 MV photon beams from the ELEKTA-Precise clinical linear accelerator with iso-centric set up. A pre-calibrated NE 2570/1 farmer-type ionization chamber along with its electrometer was used to determine the absorbed dose. Necessary corrections for temperature, pressure, polarization, recombination factor were effected on the ionization chamber response. The result obtained show that the deviation between the monitor unit of the newly designed head and neck phantom and the solid water phantom were within the ±4% accepted limit. The result show that the monitor unit calculated by the treatment planning system algorithm using the in-house designed head and neck phantom is accurate and that the phantom can be used successfully for routine verification exercises.

Key words: Phantom, Plexiglas,Treatment Planning System, Area Integration Algorithm, Ionization chamber.

INTRODUCTION

The radiotherapy treatment planning process is defined to be the process used to determine the number, orientation, type, and characteristics of the radiation beams used to deliver a large dose of radiation to a patient in order to control or cure a cancerous tumor or other problem [11]. During the management of cancer diseases by radiotherapy, the prescribed radiation dosedelivered should be concentrated on the target volume while the doses to normal tissues and organs at risk are minimized.[20].A quality assurance program should ensure that all patients treated with a curative aim receive the prescribed dose within a margin of about ±5%. [2,3,4,10]. Quality assurance program ensures that all the components of the treatment facilities used in radiotherapy are properly checked for accuracy and consistency and that all radiation generating facilities are functioning according to manufacturer's specification [14]. Following the acceptance and commissioning tests of a computerized TPS, a quality assurance program should be established to verify the performance of the system. Several ways of carrying out the quality assurance of TPS has been proposed by various authors [10,15,16,18].Computerized TPS are used in external beam radiotherapyto simulate beam shapes and dose distribution with the intent to maximize tumor control and minimize normal complications [12]. Treatment simulations are used to plan the geometric and radiological aspects of the treatment using radiation transport and optimization principles. TPS facilitate prescribed dose delivery in which a number of parameters of the patient and of the tumor have to be taken into consideration such as the shape, size and depth.There are several algorithms in treatment planning systems that play different roles, however the dose calculation algorithms play the central role of calculating dose distribution within the target volume at any given point [10].Algorithms are a sequence of instructions that operate on a set of input patient and dosimetric data, transforming the information into a set of desired output results [10, 21]. For every algorithm, the precision of the dose calculation depends on the input parameters used.The Presicise PLAN photon beam calculation uses an irregular field algorithm [9,15,19]. The algorithm requires the separation of the dose into primary and scatter components. The concept of this dosimetry of irregular fields using TMRs and SMRs is analogous to the method using TARs and SARs [14].The magnitude of the dose from scattered radiation at some given point can be quantified using the Scatter-Air or Scatter-maximum Ratios (SARs, SMRs). Equation 1 explains this Irregular Field Algorithm which is based on Clarkson Integration.

In Clarkson Integration, the dose is calculated at a point (x, y) in a plane at depth $d$as the sum of primary and scatter dose:

$$D(x, y, d) = \Phi(x, y)\left[TAR(0, d_{eff}) + SAR(x, y, d_{eff})\right] \quad (1)$$

Where:

TAR = Tissue-air ratio
SAR = Scatter-air ratio
d_{eff} = Radiological depth

MATERIALS AND METHODS

The designed in-house phantom was made of Plexiglas of thickness 0.33mm having a density 1.16g/cm^3 [14]. A plastic based hardener (allplast) was used for holding one slab to another to form a cube. The Plexiglas used was purchased from a local plastic shop of dimension 4 by 8 feet, a part of which was cut using a plastic cutter into six slabs each of dimension 20x20 cm. Five holes were drilled on one face. Each drilled hole had a diameter of 2.5cm gummed together using plastic based hardener called 'allplast'. The phantom block was drilled to hold a cylindrical rod (13.5cm) made of plexiglass to accommodate a 0.6 cm^3 graphite ionization chamber (NE2571) and also four holes for the tissue-equivalent mixed chemicals. The centre of the chamber was 10 cm from the end of the block and displaced 7 cm diagonally from the other holes. The anterior block of the phantom, drilled with a 2 cm wide hole, was used to represent an inlet for water. Figure 1 shows the assembly of a head and neck phantom with inserts.

The mass densities of the tissue equivalent materials were derived according to body composition [12]. Mass electron densities were then calculated from the elemental atomic weights, Avogadro`s number (6.022045 x 10^{26} $kmol^{-1}$) .

The percentage compositions by mass of the tissue equivalent materials were mixed together at Pharmaceutical Technology Laboratory LAGOS UNIVERSITY TEACHING HOSPITAL to mimic each biological tissues.9.5% of carbon; 87.3% of water to mimic the brain with 3.324e/kg electron density, 37.03g of carbon; 4.83g of hydrogen 35.66g of oxygen; 15.3g of carbon for bone with 3.353e/kg electron density, 68.10g of carbon; 19g of oxygen; 11.02g of hydrogen for adipose with 3.100e/kg electron density, 13.9g of cabon; 71.5g of oxygen; 10.4g of hydrogen for trachea with 3.336e/kg electron density as shown in table 1 below.

The in-house phantom was filled with water and loaded with the tissue-equivalent materials and scanned under a Hi-Speed CT-scanner. Slices of images were acquired for six different tissue-equivalent materials as shown in figure 3.A second scan was conducted for bone only as shown in figure 2. From the acquired CT images, inhomogeneities were determined using Computed Tomography number calculation algorithm. The scanned images were transferred to the precise PLAN Treatment Planning System for beam application as shown in figure 4, 5 and 6.

A simple experimental protocol for the verification of the algorithm was also performed between the in-house phantom and the solid water phantom with Source to Surface Distance (SSD) of 85cm. According to this study, the precise PLAN photon beam dose calculation uses an Irregular Field Algorithm based on previously published methods [9,15,19] configured to give 1.0 Gy at the iso-centre. The optimal plans were then used with the pre-calibrated Elekta-Precise clinical linear accelerator for measurements.

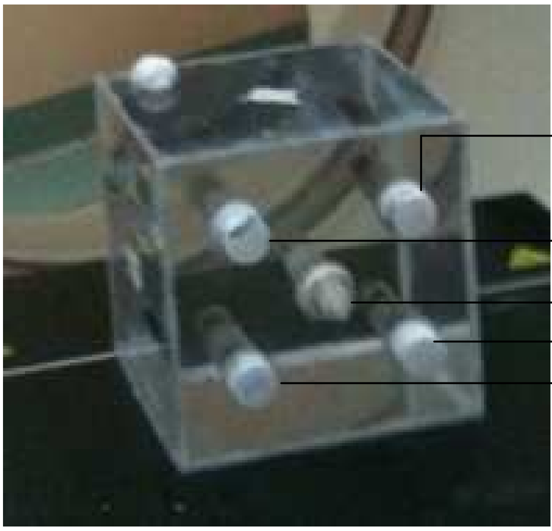

Fig 1: Designed in-house phantom with tissue equivalent materials

Table 1.0: Composition of the mixed chemicals with their densities

TISSUE	CHEMICAL COMPOSTION	DENSITIES MASS (kg/m^3)	ELECTRON DENSITIES(e/kg)
Brain (White matter)	C=9.5; O=76.7; H=10.6	1040	3.324
Bone	C=37.03; H=4.83 O=35.66; Ca=15.3	1920	3.353
Adipose	C=68.10; O=19.1; H=11.02	930	3.100
Trachea	C=13.9; O=71.5; H=10.4	1020	3.336

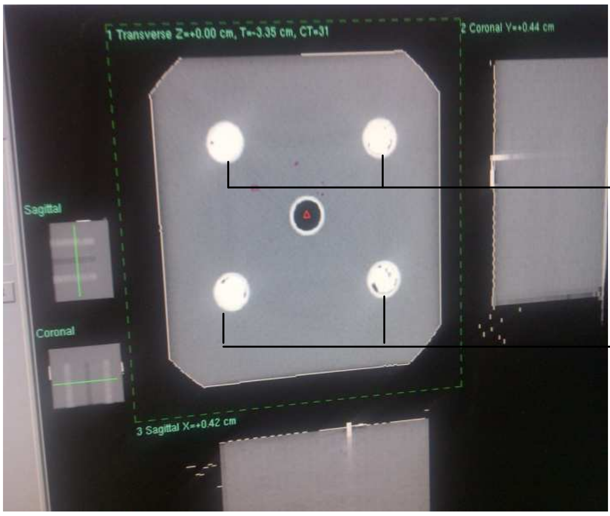

Fig 2: CT scan of the designed in-house phantom (bone insert only)

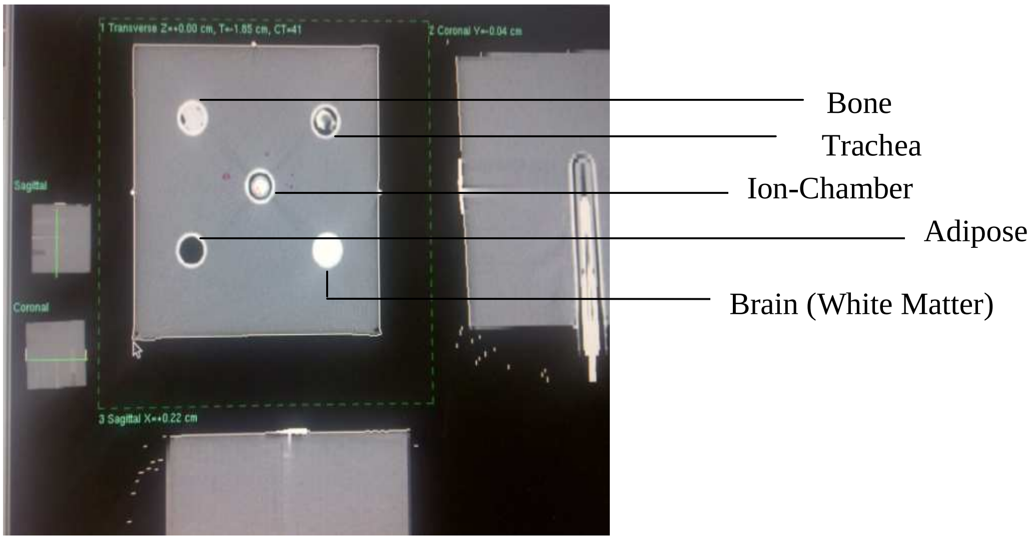

Fig 3: CT scan of the designed in-house phantom (all four inserts)

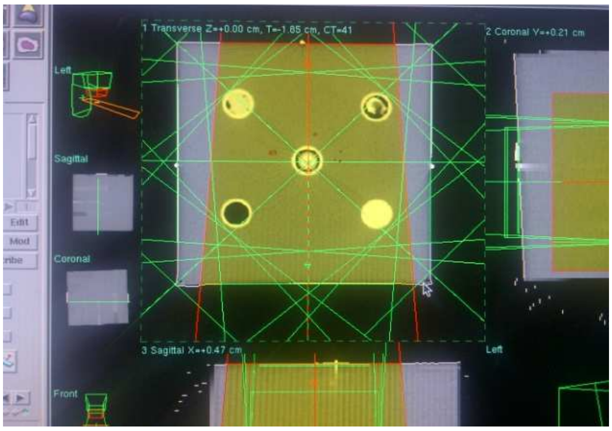

Fig 4: Six beams with large field size (all four inserts)

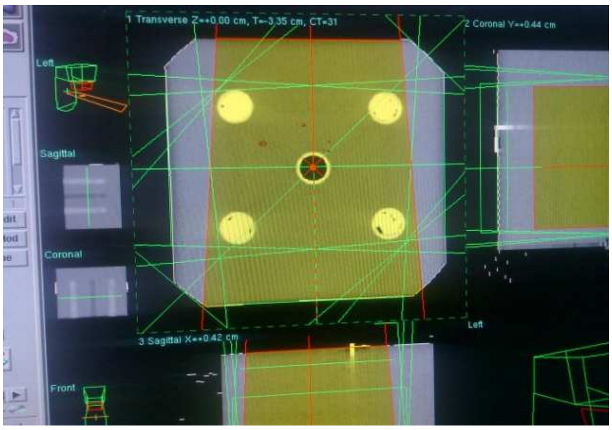

Fig 5: Six beams with large field size (bone insert only)

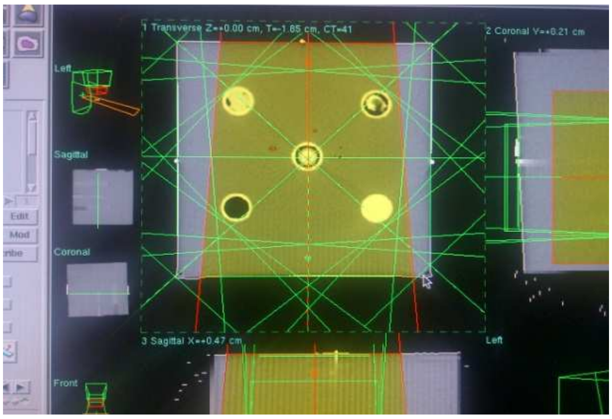

Fig 6: Six beams with 5 x 5 cm^2 Field Size (all four insert)

Measurements were conducted using 6 MeV photon beams from the Elekta-Precise clinical linear accelerator with iso-centric set up. A pre-calibrated NE 2570/1 farmer-type ionization chamber along with its electrometer was used to determine the absorbed dose. Necessary corrections for temperature, pressure, polarization, recombinationwere effected on the ionization chamber response. Five measurements were made in all, four for in-house phantom and one for the solid water phantom. Absorbed dose at reference depth was calculated as follows [1]:

$$D_{W,Q} = M_Q \times N_{D,W} \times K_{Q,Q_0} \qquad (2)$$

Where M_Q is the electrometer reading (charge) corrected for temperature and pressure,N_{DW}inthe chamber calibration factor and K_{Q,Q_0} is the factor which corrects for difference in the response of the dosimeter at the calibration quality Q and at quality $Q_0$of the clinical x-ray beam according to the TRS 398 protocol of the IAEA.

Deviation between expected and measured dose was obtained using equation 3

$$\%\ \text{Deviation} = \frac{D_m - D_c}{D_m} \times 100 \qquad (3)$$

Where:
D_m = Measured dose
D_c = Calculated dose

RESULTS

Table 2 shows the percentage deviation between the solid water phantom and the in-house phantom is 0.3%. Table3 show the results of absorbed dose measured using the head and neck phantom with single to multiple beam plans at 10 x 10 cm^2. Table 4shows that the wedged beam has a 2% percentage deviation compared to the other multiple beam at 10 x 10cm^2. Table 5 show the results of the single to multiple beam plans at 5 x 5 $cm^2$with average percentage deviation of -2.3%. Table 6 shows that the result of bone inserts with single to six beam plans at 10 x 10 cm^2also has a average percentage deviation of -2.3%.Table 7 showed that the percentage deviation of the wedged field for bone is -3% while the results of the percentage deviation of the wedged field for all inserts is 2%.

Table 2: Results of absorbed dose measured using the newly designed phantom and solid water phantom from a standard plan

Solid Water	Designed phantom
0.743	0.746
0.743	0.745
0.744	0.746
0.744	0.746
0.744	0.746
0.743	0.745
Average= 0.744	0.746
%Dev =	0.3

Table 3: Results of absorbed dose measured using the head and neck phantom with single to multiple beam plans at 10 x 10 cm^2 compared using the area integral algorithm

	HEAD AND NECK 10 x 10 cm^2				
	Single Beam	Opposite beams	Three beams	Four beams	Five Beams
	1.000	1.008	1.007	1.012	1.009
	1.000	1.008	1.007	1.011	1.007
	1.000	1.007	1.007	1.012	1.009
	1.000	1.007	1.007	1.012	1.007
	1.000	1.008	1.007	1.011	1.009
	1.000	1.007	1.007	1.012	1.009
Average	1.000	1.008	1.007	1.012	1.008
STD	0	0.0005	0	0.0005	0.0010
% Dev	0	1	1	1	1

Table 4: results of absorbed dose measured using the head and neck phantom with multiple and wedged beam plans at 10 x 10 cm^2 compared using the area integral algorithm

	HEAD AND NECK 10 x 10 cm^2				
	Six Beams	Eight Beams	Ten Beams	Twelve Beams	Wedged Beam
	1.001	1.001	1.009	0.987	1.020
	1.000	1.001	1.009	0.987	1.020
	1.000	1.000	1.009	0.987	1.021
	1.001	1.000	1.009	0.987	1.021
	1.000	1.001	1.009	0.987	1.021
	1.001	1.000	1.009	0.987	1.021
Average	1.001	1.001	1.009	0.987	1.021
STD	0.0005	0.0005	0.0002	0	0.0005
% Dev	0.1	0.1	1	-1	2

Table 5: Results of absorbed dose measured using the head and neck phantom with single to multiple beam plans at 5 x 5 cm^2 compared using the area integral algorithm

	HEAD AND NECK 5 x 5 cm^2					
	Single Beam	Opposite beams	Three beams	Four beams	Five Beams	Six Beams
	0.989	0.992	0.969	0.956	0.987	0.958
	0.989	0.993	0.969	0.956	0.985	0.958
	0.990	0.991	0.969	0.956	0.987	0.958
	0.990	0.992	0.970	0.956	0.986	0.960
	0.989	0.992	0.970	0.956	0.987	0.960
	0.989	0.992	0.969	0.956	0.987	0.958
Average	0.989	0.992	0.970	0.956	0.987	0.960
STD	0.0005	0.0006	0.0005	0	0.0008	0.0010
% Dev	-1	-1	-3	-4	-1	-4
Average % Dev	-2.3					

Table 6: Results of absorbed dose of bone inserts with single to six beam plans at 10 x 10 cm^2 compared using the area integral algorithm

	BONE 10 x 10 cm^2					
	Single Beam	Opposite beams	Three beams	Four beams	Five Beams	Six beams
	0.987	0.980	0.974	0.976	0.974	0.967
	0.987	0.980	0.974	0.976	0.974	0.967
	0.987	0.980	0.974	0.976	0.974	0.967
	0.987	0.981	0.974	0.976	0.974	0.967
	0.987	0.980	0.974	0.976	0.974	0.967
	0.987	0.980	0.974	0.976	0.974	0.967
Average	0.987	0.980	0.974	0.976	0.974	0.967
STD	0	0.0004	0.0004	0	0.0004	0
% Dev	-1	-2	-3	-2	-3	-3
Average % Deviation	-2.3					

Table 7: Results of absorbed dose of bone and all inhomogeneities measured using to wedged beam plan at 10 x 10 cm^2 compared using the area integral algorithm

	BONE INSERTS	ALL INSERTS
	OPPOSED WEDGED	OPPOSED WEDGED
	0.971	1.021
	0.972	1.020
	0.972	1.020
	0.972	1.021
	0.971	1.021
	0.972	1.021
Average	0.972	1.021
STD	0.0005	0.0005
% Dev	-3	2

DISCUSSION AND CONCLUSION

For uniformity in calibration reports for radiation therapy machines, ICRU recommends that the dose per unit time or monitor unit be expressed in terms of dose to water. Table 2 shows the result of the measurement using both the Head and Neck phantom and the solid water phantom in a standard plan. The deviation between the two phantoms was within 0.3%. Table 3 and table 4 shows result of the absorbed dose measured for different field plans with the brain, bone, trachea and adipose inhomogeneity in positions along with the percentage deviation from the reference dose (1.00 Gy) and the standard deviation for the 6 measurements where taken. In tables 3 and 4, results of the single beam plan at 0^0 showed a better accuracy compared to others while the four and six beam plans showed the least accuracy. The percentage deviation is small but with a deviation slightly higher than the deviation of the single beam. This change is as a result of the attenuation offered by the couch and the inhomogeneities while treating from different gantry angle to the centre where the ionization chamber is positioned. There is a good standard deviation between the measurements for all plans. Table 2 shows the result of the absorbed dose measured in solid water along with the percentage deviation from the reference dose (1.00 Gy) and the standard deviation between the 6 measurements taken. The Algorithm was better in table 7 for the wedged opposed beam of all inhomogeneities than the bone inhomogeneities. The average dose of bone inhomogeneity is relatively close to 1. The percentage deviations falls within the range of $-4 \leq 2$vary from beam one to beam six.

The percentage deviation in dose measurement for the 5 x 5cm^2 field is lower when compared with a larger field size of 10 x 10cm^2. This shows that as the field size increase, percentage deviation will as well increase and as field size decreases the percentage deviation also decreases.

Table 6 shows the result of the absorbed dose measured with the bone inhomogeneity in position along with the percentage deviation from the reference dose (1.00 Gy) and the standard deviation between the 6 measurements taken. Larger deviations observed with the 10x10 cm^2 of the bone inhomogeneity could be due to unaccounted scattered radiation contribution from the inhomogeneous material by the Area Integral Algorithm. However, the algorithm appeared good in table 2 where there are no inhomogeneities. There is a general improvement across the tables for the algorithm in the twelve beam plans while poor deviation is noticeable for the wedged field plans across the board. This may be due to the inability of the algorithms to model the fluence calculation for wedges [8]. The

Area integral Algorithm has an increased computation speed for small beam plans compared to other higher beam plans, however the area integral algorithm have good balance of speed versus accuracy in smaller field plans . Other sources of uncertainties such as set-up, phantom and the detector could have as well contributed to the deviations.
There is no significant difference in deviation between the results obtained in tables 2 with the Head and Neck phantom and that of solid water phantom. This shows that the materials used in the design of the Head and Neck phantom, used for testing the Area Integral Algorithm were suitable and that the phantom can be used successfully for verification exercise. Also, the cost of designing the phantom is minimal and it is easier to use compared to other modern verification phantoms such as the Rando Anderson phantom. Smaller radiotherapy centres (especially in Africa) without diode and TLD systems in place can still perform verification exercise using this phantom with their local ionization chamber.

In conclusion, the simplicity and low cost involved with the design of the Head and Neck phantom in this report provides a solution to the inherent problem of neglect of routine QA activities and dosimetry checks. The phantom can be used with different inhomogeneities because of the empty inserts created. The quality and precision obtained in the results with the designed Head and Neck phantom show that it may be used for routine clinical applications.

REFERENCES

[1] IAEA,Absorbed Dose Determination in External Beam Radiotherapy, Technical Reports Series No. 398, Vienna (**2000**).
[2] 2Aweda MA, Akpochafor MO, Moalosi TGC, Mohlapholi MS and Louw M.*Arch. Appl. Sci. Res*.,**2012**, 4 (2):914-922.
[3] A. Brahme. *ActaRadiol.Oncol*.**1984**, 23, 379-391.
[4] A. Brahme. *Radiother.Oncol*.**1988**, 12, 129-140.
[5] AL. Boyer, Y. Zhu, L. Wang, P. Francois. *Med. Phys*. **1989**, 16, 248–253.
[6] BJ. Mijnheer, JJ. Battermann, A. Wambersie. *Radiother.Oncol*.**1987**, 8, 237-252.
[7] BA. Fraass, K. Doppke, M. Hunt, G. Kutcher, G. Starkschall, R. Stern, J. Van Dyk. *Med. Phys.* **1998**, 25, 1773–1829.
[8] BA. Fraass.Palta J, Mackie TR (Eds.). Madison: Advanced Medical Publishing. **1996**, 253–318.
[9] J.RClarkson.,Brit.J.Radiol. **1941**, 14, 265-268.
[10] EB Podgorsak. Radiation Oncology Physics: A handbook for Teachers and Students. Vienna: IAEA publication. **2005**.
[11] Fraass et al.: Quality assurance for clinical radiotherapy treatment planning. Task Group AAPM report 53.Medical Physics, Vol. 25, No. 10, October **1998**
[12] SJFomon, FHaschke,EEZiegler, SENelson.. *Am J ClinNutr* **1982**;35:1169–75.
[13] F.M. Khan, The Physics of Radiation Therapy, Williams and Wilkins, Baltimore, MD., **1984**, p.321, and pp. 182-204 (Chapter 10).
[14] ICRU Reports 24. Determination of absorbed dose in a patient irradiated by beams of X or gamma rays inradiotherapy procedures. Washington DC: ICRU publication. **1976**.
[15] J. Van Dyk, RB. Barnett, JE. Cygler, PC. Shragge.*Int. J. Radiat. Oncol.Biol. Phys.* **1993**, 26,261–273.
[16] J. Van Dyk. “Quality Assurance.”In Treatment Planning in Radiation Oncology.Khan FM, Potish RA (Eds.). (Baltimore, MD: Williams and Wilkins). **1997**, 123–146.
[17] .JE. Shaw. (Ed.) “A Guide to Commissioning and Quality Control of Treatment Planning Systems.”The Institution of Physics and Engineering in Medicine and Biology.**1994**.
[18] P. Nette, H. Svensson. Radiation dosimetry in health care; expanding the reach of global networks.Viena: IAEA bulletin. April **1994**.
[19] Johns, H.E., Cunningham, J.R., The Physics of Radiology, Third Edition, **1971**,pp.362-363.
[20] Khan FM. The Physics of Radiation Therapy, Lippincott, Williams and Wilkins, Baltimore, MD (2003).
[21] Y Poonam, V Ramasubramanian, *Arch.Appl.Sci.Res*.,**2011**,3(3) 436-442.