Journal of Nature, Life and Applied Sciences
Volume (5), Issue (4): 30 Dec 2021
P: 131 - 141

ISSN: 2522-3356

مجلة العلوم الطبيعية والحياتية والتطبيقية
المجلد (5)، العدد (4): 30 ديسمبر 2021م
ص: 131 - 141

Radiation therapy with neutrons and hydrons of the liver region using the MCNP code

Lara Kamal Jarouj

Anis Bilal

College of Science || Al-Baath university || Syria

Nikola Abo Issa

Faculty of Mechanical and Electrical Engineering || University of Damascus || Syria

Abstract: CT images were read and a 3D model of the tumor was created in the liver area, Then the values of the radiation dose in terms of the depth resulting from (photons, neutrons and protons) were estimated and studied using the code (MCNP) after entering the data into it.

The value of the radiation dose in terms of depth and curvature in photons, neutrons and protons radiation therapy was studied, from our findings in the research we note that protons are the best option for radiation therapy for high-depth liver cancer of photons and neutrons due to the lower dose at entry compared to the dose absorbed in the tumor area and its ability to deliver a greater amount of dose of neutrons and photons to the tumor area.

We note that the values reached are acceptable for the treatment of tumors at a depth close to the surface. As for a large-depth tumor, it is necessary to increase high-energy radiation doses deep in the tumor area by accelerating proton therapy to protect natural organs from high-energy radiation doses.

Keywords: The MCNP code – Matlab – accelerators – liver phantom – DICOM.

المعالجة الاشعاعية بالنترونات والهدرونات لمنطقة الكبد باستخدام الكود MCNP

لارا كمال جروج

أنيس بلال

كلية العلوم || جامعة البعث || سورية

نقولا أبو عيسى

كلية الهندسة الميكانيكية والكهربائية || جامعة دمشق || سورية

المستخلص: تمت قراءة صور التصوير المقطعي (CT) وتم إنشاء نموذج ثلاثي الأبعاد للورم في منطقة الكبد، ثم تم تقدير ودراسة قيم الجرعة الإشعاعية بدلالة العمق الناتجة عن الفوتونات والنيوترونات والبروتونات باستخدام الكود (MCNP) بعد إدخال البيانات إليه.

تمت دراسة قيمة الجرعة الإشعاعية من حيث العمق والانحناء عند العلاج الإشعاعي بالفوتونات والنيوترونات والبروتونات، من النتائج التي توصلنا اليها في البحث لاحظنا أن البروتونات هي أفضل خيار للعلاج الإشعاعي لسرطان الكبد ذي العمق الكبير من العلاج بالفوتونات والنيوترونات بسبب انخفاض الجرعة عند الدخول مقارنة بالجرعة الممتصة في منطقة الورم وقدرتها على إيصال كمية أكبر من الجرعة من النيوترونات والفوتونات إلى منطقة الورم.

نشير إلى أن القيم التي تم التوصل إليها مقبولة لعلاج الأورام على عمق قريب من السطح. أما بالنسبة للورم ذي العمق الكبير، فمن الضروري زيادة الجرعات الإشعاعية ذات الطاقة العالية على عمق منطقة الورم عن طريق العلاج بالبروتونات المسرعة لحماية الأعضاء الطبيعية من الجرعات الإشعاعية العالية الطاقة.

الكلمات المفتاحية: الكود MCNP – برنامج الماتلاب – المسرعات – فانتوم الكبد – DICOM.

1. Introduction.

Cancer is a disease that affects the cells of the body, which is the main mass in the construction of the body and liver cancer is one of the most common tumors in the world, and is classified as the third most common type of tumor, and chronic liver infection due to hepatitis C viruses, advanced liver waxing and other hepatic infections are the most important factors in causing liver cancer.

Radiation therapy is one of the treatment methods used in the treatment of different types of cancer, where radiotherapy employs the different applications of ionizing radiation to destroy the structure of cancer cells and treat tumors, which is either external radiation therapy using X-rays and gamma rays, or internal radiotherapy that is given to the patient through Radioactive materials, or systemic radiotherapy, this treatment uses a radioactive substance given orally or intravenously, such as radioactive iodine [1, 2].

The widespread use of ionizing radiation applications has contributed to treating cancers and increasing cure rates. The interaction of ionizing radiation with matter is one of the basics of studying and understanding the behavior of ionizing radiation, radiation doses, and prevention. these concepts sought to design and build many radiological devices such as nuclear detectors and radiation dosimeters, as well as contributed to the development of many applications of ionizing radiation in several areas, the most important of which is the medical field, with its diagnostic and therapeutic branches, and the interaction of radiation with matter is classified according to the type pf particles, to:

- The interaction of photons with matter
- The interaction of neutrons with matter
- The interaction of protons with matter

As for the physical quantities used to express exposure to ionizing radiation, they have been set by international organizations concerned with radiation protection matters such as; the international committee of radiation protection and the international committee of radiation units which including,. [3, 4]:

Radiation dose: it includes the total amount of radiation absorbed by the material or living tissues.

Absorbed dose (D):which represented by the relationship:

$$D = \frac{E}{M}(Gy)$$

The equivalent dose (H): which represented by the relationship: $H = D \times W_R$

Where W_R is the coefficient of radiation.

Effective dose (E): $E = \sum W_T H_T$

$$E = \sum W_T \sum D_R W_R$$

The relationship between the probability of occurrence of random effects of radiation damage such as cancer and between the equivalent dose depends on the type of organ or tissue exposed to radiation. so a quantity associated with the type of organ Wτ and its values vary depending on the type of organ affected by radiation and take the values:

Element type	Genital gland	Bone marrow Colon stomach	Bladder Chest Thyroid gland	Skin and bones	Whole body
W_T	0.2	0.12	0.05	0.01	**1**

2. Material and Methods.

The material: Laptop – MCNP code- CT images

The methods: The Monte Carlo method represented by the MCNP code was adopted in this research in order to:

- modeling the medical linear accelerator channel, i.e. modeling the electronic beam selector used from the electronic beam composed of lead and aluminum to produce a radial square with dimensions $(10 \times 10)cm^2$ at distance $ssd = 100\ cm$
- modeling a tungsten target in front of the accelerator channel and calculating the dose deposited in the liver resulting from the interaction of the accelerated electrons with the target used

for the primary energy of electrons (6-9 MeV) used a Gaussian distribution which is expressed by relationship, ref. [5]:

$$p(E) = C * \exp\left[-\left(\frac{E-b}{a}\right)^2\right] \quad .....(1)$$

A: the width of the beam in (MeV) and it took value (FWHM=0.01 MeV)

B: medium energy (MeV)

As for the section energy: $E_{cut} = 0.512 MeV$

This data had entered into MCNP code for processing.

The studied case: the study was carried out on a patient after imaging the liver area to examine the condition. The 50-year-old patient was photographed using a Toship Asteion MEC with a thickness of 7mm at a voltage of 120KVP and a current 200 Ma,

Figure 1 shows a three-dimensional model of the liver area for the studied case, which was built using the Matlab program.

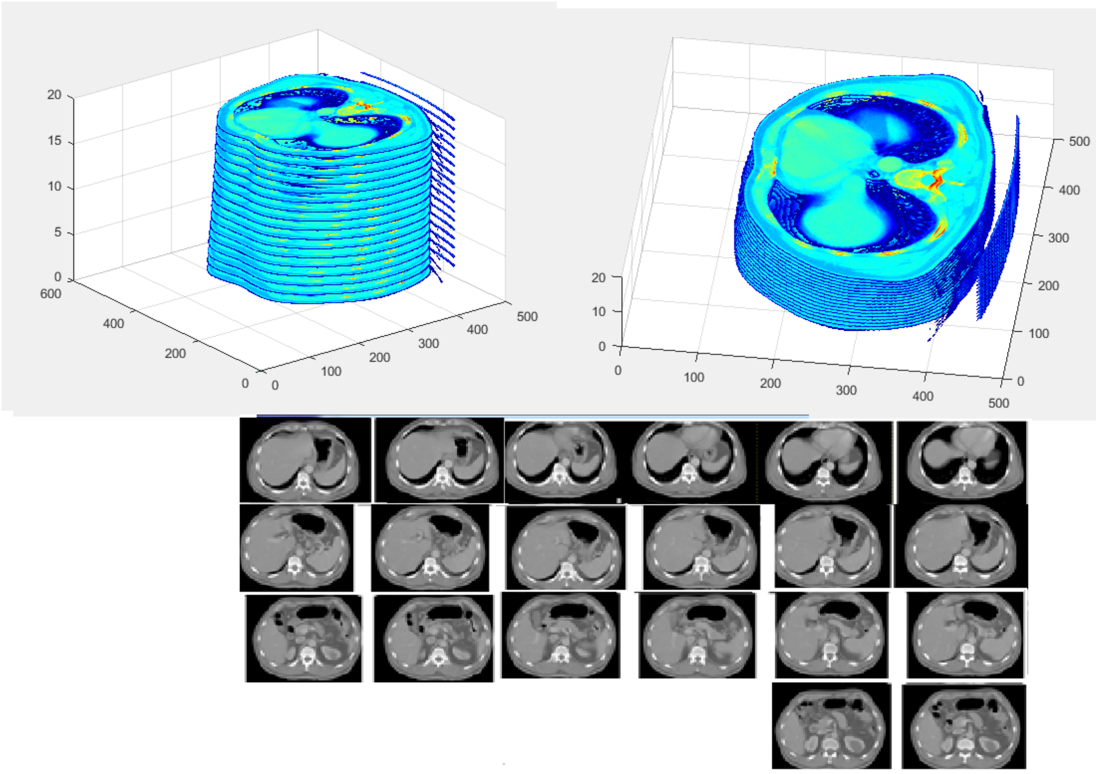

Figure (1) shows a three-dimensional model of the liver area for the studied case

After that the images were read using Matlab program to extract the values of imaging numbers from each cross-sectional image with dimensions (512*512) and spatial accuracy up to (1.0244pixel/mm), the imaging number values for each pixel in each image were then converted to a special component number, using the component number, each material is identified in the code input file, up to the filling of this material in the size element corresponding to a voxel per pixel.

Work' algorithm:

1- scan the patient using a CT device
2- reading CT images in Matlab using the instruction DICONINFO, DICOMREAD
3- Storing the values of the color levels of each image within a square matrix (512*512)
4- using repetition loops (FOR) and comparison relationships (IF) to replace the values of the imaging number corresponding to specific field with the component number (universe number)
5- store the resulting matrix of component number values (512*512) to be filled later in the corresponding layer in the 3d model
6- reducing the image to the dimensions of (325*171) to be read using the code MCNP
7- Create a three-dimensional model in the form of a rectangular prism divided into a number of small elemental volumes, each of which has a volume (0.2*0.2*1 cm^3) using the code MCNP, the length

and width of this model (on the X, Y axes)is determined by the dimensions of the medical image, While the height of this model (on the Z axis) is determined by the number of clips of the studied area.

8- write a working algorithm using Matlab to fill each volumetric element in the 3d model in the code input file with the value of the special component number stored previously in step 5

Figure 2 shows an example of one of the sections after processing and exporting to the code input file MCNP where it gives the accumulation of sections according to the dimension Z model three-dimensional of the studied area.

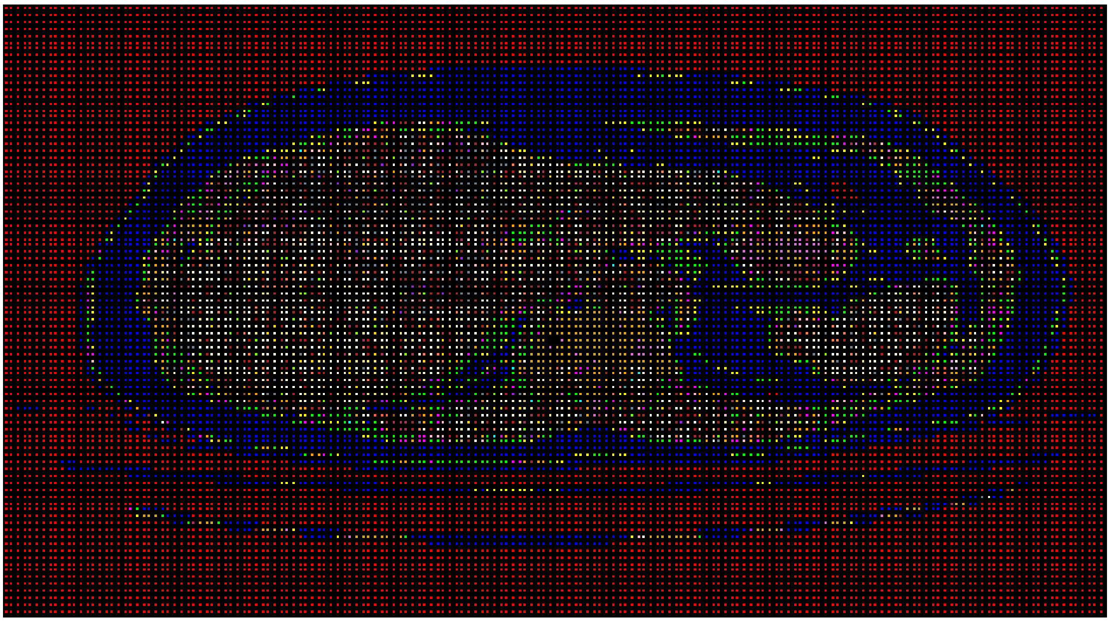

Figure (2) one of the sections after processing and exporting to the code input file MCNP

3. Results and calculations:

the amount of radiation dose deposited in the liver area (the tumor area) was estimated for the model that was built based on CT DICOM images for different radiation beams:

- a beam of photons with a diameter of 1cm resulting from accelerating electrons to energy 9MeV on a target of tungsten
- neutrons resulting from the automatic fission source cf-252 that emits a continuous spectrum of neutrons with an activity of (2.3*$10^{12} per/g$) with an average energy 2.3MeV And half-life 2.638y [6], in this simulation, a capsule of californium with a radius of 0.19558cm was used.
- protons accelerated to the energies are 30, 50, 100, 120, 130, 150 MeV resulting from a cyclone accelerator channel with a diameter of 0.2cm [6]

As for in figure 3 shows the changes in the absorbed dose of the photons relative to each source particle (GY/Particle) as a function of the depth within the tissue.

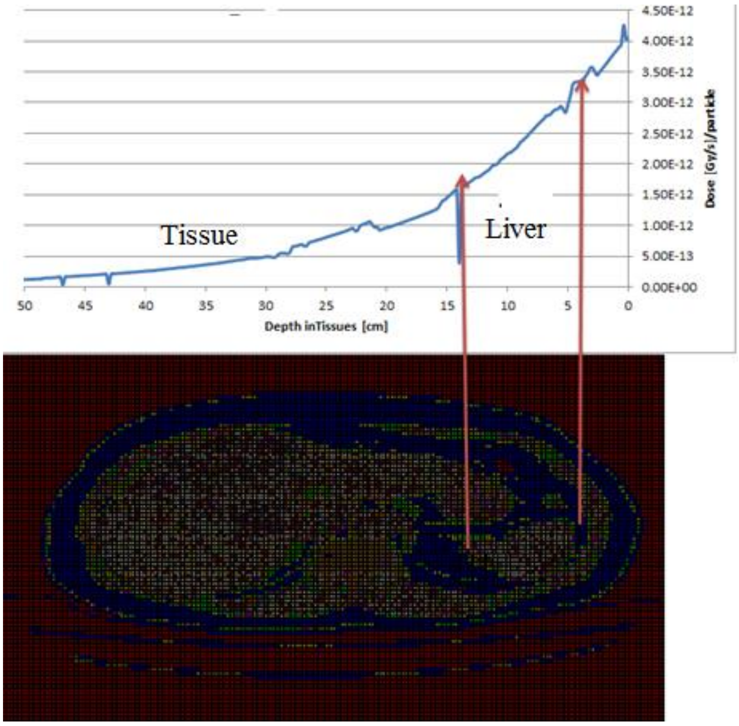

Figure (3) changes in the absorbed dose in tissues for photons (GY/Particle)

While the figure 4 shows changes for absorbed dose for neutrons resulting from CF-252 source relative to each particle source (GY/Particle) in terms of depth within the fabric.

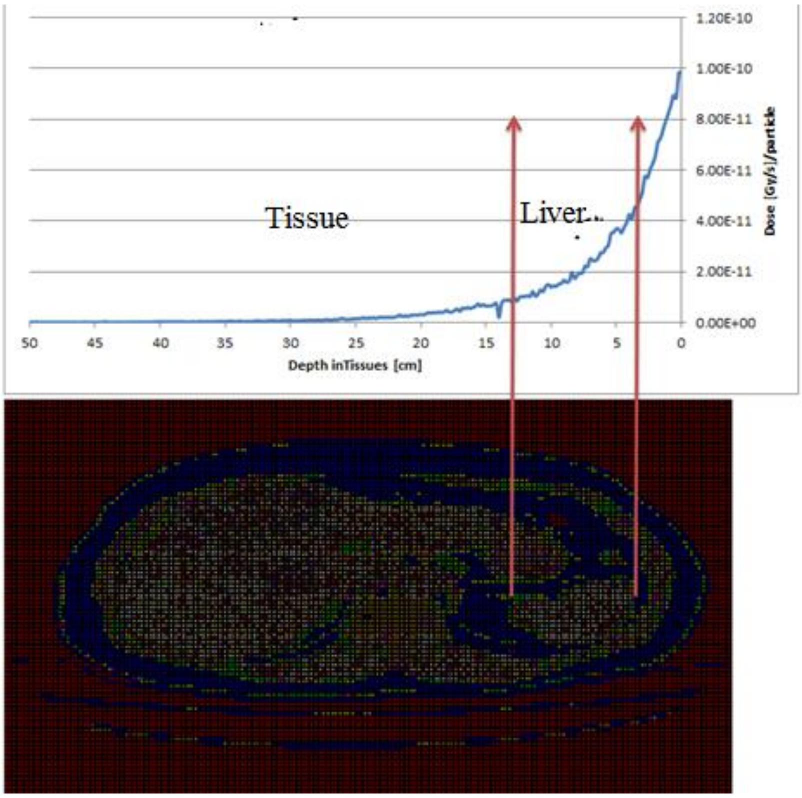

Figure (4) changes in the absorbed dose of the neutrons relative to each particle source (GY/Particle) in terms of depth within the fabric

While the figure 5 shows changes for absorbed dose for protons accelerated to energies (30, 50, 100, 120, 130, 150) MeV relative to each particle source (GY/Particle) in terms of depth within the fabric

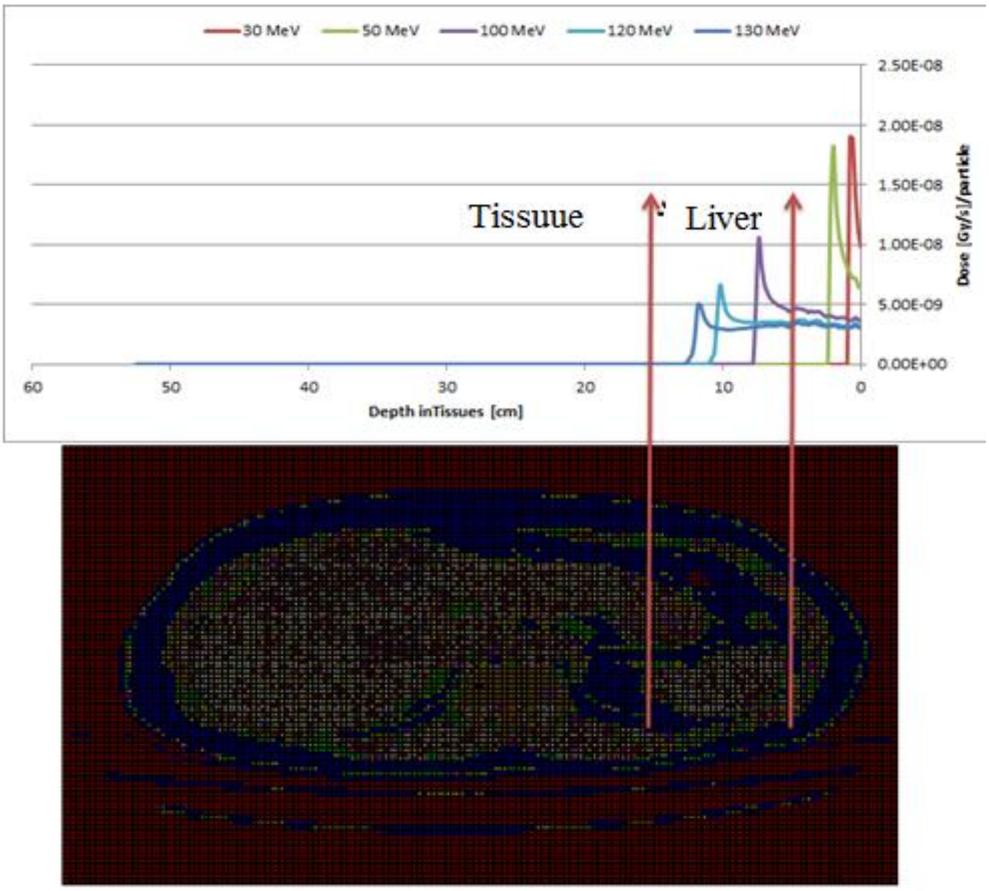

Figure (5) changes in the absorbed dose of the protons accelerated to energies (30, 50, 100, 120, 130, 150) MeV relative to each particle source (GY/Particle) in terms of depth within the fabric

From figure 3 for photons we not that the dose decreases exponentially when it crosses the tissue and it deposit the largest dose value at the beginning of the tissue (the entry point) where its (4*$10^{-12}Gy/p$) , Then it enters the liver area after a distance 4cm from entering the tissue and the dose for entering the liver region is equal (3.4*$10^{-12}Gy/p$), for the photons, an average absorbed dose is (2* $10^{-12}Gy/p$) at the liver region.

As for the neutrons we note from figure 4 that the amount of entry dose for neutrons at the beginning of healthy tissue is (1*$10^{-12}Gy/p$) then they enter the liver region after distance 4cm from entering the tissue and the dose of entry into the liver area is equal (4*$10^{-11}Gy/p$) to deposited an average absorbed dose (3* $10^{-12}Gy/p$) , As for the protons, unlike both photons and neutrons, protons deposit their energy locally within the tissue through the formation of the so-called Prague summit, where the proton enters the tissue and after crossing a certain distance (range), the positive proton picks up a negative electron and is electrically neutral to reduce its energy suddenly after it deposits its all energy at a specific point at the end of the path, forming what is called the Prague summit

We note from figure 5 that in order to deliver a dose via protons to the liver area, its necessary to accelerate the protons to an energy exceeding 90MeV, from figure 5 we note that at 30MeV energy, the proton path in this case dose not exceed a 1cm distance inside the tissue and reaches the range to about 8cm for 100MeV protons and 10 cm for `120MeV protons and 12cm for 130MeV protons, on the other hand, the amount of energy deposited (the absorbed dose) at the end of the proton path, i.e. the Prague peak decreases with the increase in the energy of the accelerating protons, i.e. decreases as the depth increased so that for protons of 100MeV energy, the value of the maximum absorbed dose reaches to (1*$10^{-8} Gy/p$)

And degreases at 120MeV energy for protons to the value(7*$10^{-9} Gy/p$)

While for 130MeV protons it reaches the value 5* $10^{-9}\ Gy/p$.

static errors:

The MCNP code provides the possibility of calculating the relative static errors, the variance of the variance (vov) and the figure of merit (FOM), as shown below, the relative error, variance, vov, slope, mean number of particles, and figure of merit (FOM) In terms of the number of events per second (NPS), for photons in table (1), and neutrons in table (2).

Table (1) Error, difference variance, slop, mean number of particles calculated, and figure of merit in terms of number of histories (NPS) for photons.

nps	mean	error	vov	slope	FOM
32000	6.99E-07	9.72%	0.0108	0	29
64000	7.04E-07	6.91%	0.0054	0	29
96000	7.44E-07	5.48%	0.0034	0	31
128000	7.52E-07	4.71%	0.0025	0	31
160000	7.39E-07	4.25%	0.0021	10	31
192000	7.36E-07	3.89%	0.0017	10	31
224000	7.35E-07	3.60%	0.0015	10	31
256000	7.17E-07	3.41%	0.0013	10	30
288000	7.26E-07	3.20%	0.0012	10	30
320000	7.19E-07	3.05%	0.0011	10	30
352000	7.21E-07	2.91%	0.001	10	30
384000	7.19E-07	2.79%	0.0009	10	30
416000	7.26E-07	2.66%	0.0008	10	30
448000	7.30E-07	2.56%	0.0008	10	31
480000	7.36E-07	2.46%	0.0007	10	31
512000	7.35E-07	2.39%	0.0007	10	31
532264	7.37E-07	2.34%	0.0006	10	31

Table (2) error, difference variance, slop, mean number of particles calculated, and figure of merit in terms of number of histories (NPS) for neutrons.

nps	mean	error	vov	slope	FOM
32000	1.03E-07	36.10%	0.1434	0	3.70
64000	9.36E-08	26.30%	0.0757	0	3.50
96000	9.01E-08	21.64%	0.0506	0	3.40
128000	1.07E-07	17.58%	0.0412	0	3.90
160000	1.08E-07	15.47%	0.0313	0	4.00
192000	1.02E-07	14.72%	0.0289	0	3.70
224000	1.01E-07	13.72%	0.0243	0	3.60
256000	9.39E-08	13.24%	0.0224	0	3.40
288000	9.54E-08	12.44%	0.0196	0	3.40
320000	9.24E-08	11.99%	0.018	0	3.30
352000	8.64E-08	11.83%	0.0174	0	3.10
384000	8.61E-08	11.36%	0.016	0	3.10
416000	8.76E-08	10.95%	0.015	0	3.20
448000	8.89E-08	10.60%	0.015	0	3.20
480000	9.31E-08	10.18%	0.0154	0	3.30
512000	9.32E-08	9.80%	0.0142	0	3.30
519572	9.33E-08	9.71%	0.0139	0	3.30

Conclusion.

Protons are the best choice for using it for radiation treatment to liver cancer than photons and neutrons and that is because of the amount of low entry dose comparing with the absorbed dose at tumor area and its ability to deliver a higher dose than both photons and neutrons to tumor area, but it's necessary to work to reduce the intake dose to the lowest possible value while maintaining the delivery of a quantity of the dose to the tumor area commensurate with the extent of the tumor and this is done by using the appropriate design of the proton therapy system.

From table(1) we found that the relative error was less than 5% which is acceptable, but in table(2) the relative error was relative high due that the MCNP code uses the physics models, which depends on mathematical relations, in case of charged particles calculations at high energies rather than cross section tables.

MCNPX offers options based on three physics packages [7]; the Bertini and ISABEL models taken from the LAHET Code System, and the CEM package, which has been specially adapted by the author for the MCNPX work. Table3 gives the working range of validity for each.

Table (3) Summary of Physics in Intermediate Energy Models [7].

Physics Process	Bertini	ISABEL	CEM
Method	INC + EQ or INC + PE + EQ	INC + EQ or INC + PE + EQ	INC + PE + EQ
Intranuclear Cascade Model	Bertini INC	ISABEL INC	Improved Dubna INC
Monte Carlo Technique	"spacelike"	"timelike"	"spacelike"
Nuclear Density Distribution	$\rho(r)=\rho_0\{exp[(r-c)/a]+1\}$ $c=1.07A^{1/3}$ fm $a=0.545$ fm $\rho(r) = \alpha_i\rho(0)$; i - 1,...,3 $\alpha_1=0.9$, $\alpha_2=0.2$ $\alpha_3=0.01$	$\rho(r)=\rho_0\{exp[(r-c)/a]+1\}$ $c=1.07A^{1/3}$ fm $a=0.545$ fm $\rho(r) = \alpha_i\rho(0)$; i - 1,...,16	$\rho(r)=\rho_0\{exp[(r-c)/a]+1\}$ $c=1.07A^{1/3}$ fm $a=0.545$ fm $\rho_n(r)/\rho_p(r) = N/Z$ $\rho(r)=\alpha_i\rho(0)$; i=1,...,7 $\alpha_1=0.95$, $\alpha_2=0.8$ $\alpha_3=0.5$ $\alpha_4=0.2$ $\alpha_5=0.1$ $\alpha_6=0.05$ $\alpha_7=0.01$
Nucleon Potential	$V_N = T_F + B_N$	Nucleon kinetic energy (T_N) dependent potential $V_N=V_i(1-T_n/T_{max})$	$V_N = T_F + B_N$
Pion Potential	$V\pi = V_N$	$V\pi = 0$	$V\pi = 25$ MeV
Mean Nucleon Binding Energy	$B_N \sim 7$ MeV	Initial B_N from mass table; the same value is used throughout the calculation	$B_N \sim 7$ MeV
Elementary Cross Sections	standard BERTINI INC (old)	standard ISABEL (old)	new CEM97, last update March 1999
A + A Interactions	not considered	allowed	not considered
γA Interactions	not considered	not considered	may be considered
Condition for passing from the INC stage	cutoff energy ~ 7 MeV	different cutoff energies for p and n, as in VEGAS code	$P=\|(W_{mod}-W_{exp})/W_{exp}\|$ $P = 0.3$
Nuclear density depletion	not considered	considered	not considered
Pre-equilibrium stage	MPM (LAHET) model	MPM (LAHET) model	Improved MEM (CEM97)
Equilibrium stage	Dresner model for n, p, d, t, ^{3}He, ^{4}He emission (+ fission) (+ γ)	Dresner model for n, p, d, t, ^{3}He, ^{4}He emission (+ fission) (+ γ)	CEM97 model for n, p, d, t, ^{3}He ^{4}He emission (+ fission) (+γ)
Level density	3 LAHET models for a = a(Z, N, E*)	3 LAHET models for a = a(Z, N, E*)	CEM97 models for a = a(Z, N, E*)
Multifragmentation of light nuclei	Fermi breakup as in LAHET	Fermi breakup as in LAHET	Fermi breakup as in LAHET
Fission models	ORNL or RAL models	ORNL or RAL models	CEM model for σ_f, RAL fission fragmentation

References:

[1] Marie-Louise Olsson; Monte Carlo simulations of the Elekta SLi Plus electron applicator system – A base for a new applicator design to reduce radiation leakage; Department of Radiation Physics, Lund University Hospital, Lund, Sweden; LUJI-RADFYS-EX-3/2003.

[2] DONGYOUL LEE .December 2011.simulation and analysis of human phantoms exposed to heavy charged particle irradiations using the particle and heavy ion transport system (phits): in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE .Texas A&M University ،December 2011

[3] Shaheen Azim Dewji. 2009. assessing internal contamination after a radiological dispersion device event using a 2x2-inch sodium-iodide detector: in partial fulfillment of the requirements for the degree master of science in the school of nuclear and radiological engineering .georgia institute of technology

[4] James E. Martin: A Handbook. Physics for Radiation Protection: Copyright _ 2006 ISBN: 3-527- 40611-5

[5] X-5 Monte Carlo Team: MCNP —– A General Monte Carlo
N-Particle Transport Code, Version 5; Los Alamos National Laboratory Controlled Publication (April 24, 2003)

[6] Alexis L. Reed .2007 medical physics calculations with mcnp: a primer.los alamos national laboratory, x-3 mcc, Texas A&M University, Dept. of Nuclear Engineering،2007 .LA-UR-07-4133.

[7] Laurie S. Waters. MCNPX User's Manual Version 2.3.0, LA-UR-02-2607 (April 2002)