Calculation of the Sputtering for Havar and Bronze Alloys Irradiated by (60-250) MeV protons in Proton Therapy Technology

Buthainah Abdulmunem Ibrahim

Department of physics -Science College - Diyala University - Baquba - Iraq

buth_oubaidi2@yahoo.com

Received: 19 November 2017 **Accepted: 3 October 2018**

Abstract

The theoretical study of ion ranges and stopping powers of (60-250) MeV protons from medical cyclotron on Havar and Bronze alloys have been carried out by SRIM Computer Code. It is shown that the results are nearly the same for both alloys. The sputtering of Havar and Bronze alloys bombarded by (60-250) MeV protons was also calculated by Anderson Model. The results show that the sputtering yield from Bronze alloy is larger than that of Havar alloy, which indicates that the survival treating time for Havar alloy is greater than that of Bronze alloy. From this study, we concluded that Havar alloy is preferred alloy for manufacturing the nozzle system, in addition to the physical properties of Havar alloy that has high melting point and high modulus of elasticity, which allows easy formation of nozzle system in various forms and different volumes according to required usage treatment, in contrary to Bronze alloy.

This study is the tool to indicate the preferable alloy used in manufacturing the treating nozzle system for proton therapy which lasts longer in use and saves effort and money.

Keywords: Sputtering yield, Ion ranges, Stopping power, Proton therapy, Havar, Bronze.

DIYALA JOURNAL FOR PURE SCIENCES

Calculation of the Sputtering for Havar and Bronze Alloys Irradiated by (60-250) MeV protons in Proton Therapy Technology

Buthainah Abdulmunem Ibrahim

حساب الترذذ لسبيكتي الهفار والبرونز المشععة بالبروتونات بطاقة (60-250) م.أ.ف في تقنية العلاج البروتوني

بثينة عبد المنعم إبراهيم

كلية العلوم- قسم الفيزياء - جامعة ديالى – بعقوبة - العراق

الخلاصة

اجريت دراسة نظرية حول المديات الايونية وقدرات الايقاف للبروتونات بطاقة (60-250) م. أ. ف. الناتجة من معجل السايكلوترون الطبي لسبائك الهافار والبرونز، وقد تم حسابها باستخدام برنامج SRIM، أظهرت الحسابات بان النتائج هي نفسها تقريبا للسبيكتين.

كما تم دراسة الترذذ لسبيكتي الهافار والبرونز التي تم قصفهما بالبروتونات بطاقة (60-250) م. أ. ف.، حيث حسبت باستخدام نموذج اندرسون، وبينت النتائج ان الترذذ الناتج من سبيكة البرونز هو اكبر مما عليه من سبيكة الهافار، مما يشير الى ان فترة بقاء الجهاز المصنع من سبيكة الهافارالمستخدم للعلاج اكبر مما عليه من سبيكة البرونز.

وقد استنتجنا من هذه الدراسة أن سبيكة الهافار هي السبيكة المفضلة لتصنيع فوهة النظام في العلاج البروتوني، فضلا" عن الخصائص الفيزيائية لسبيكة الهافار التي لها نقطة انصهار عالية ومعامل مرونة عالي التي تسمح بسهولة تشكيل فوهة النظام بأحجام مختلفة و أشكال متعددة وفقا لنوع الاستخدام المطلوب، على عكس سبيكة البرونز.

تعتبر هذه الدراسة أداة تشير إلى ماهية السبيكة المفضلة في تصنيع فوهة نظام العلاج البروتوني الذي يستمر لفترة أطول في الاستخدام ويوفرالجهد والمال.

الكلمات المفتاحية: ناتج الترذذ، المدى الايوني، قدرة الايقاف، العلاج البروتوني، سبيكتا الهفار والبرونز.

Introduction

Proton Beam Therapy is developed cancer treatment based on the smart physics of the proton [1]. Protons deposit extreme active energy in exactly controlled range directly into tumor and saving healthy tissues. Proton therapy is progressively considered as one of the most advanced and objective cancer treatments due to, its maximum distribution dose and few side effects.

The beam imparted through the nozzle (transport system) to the treatment rooms is comparatively narrow and it has definite energy value. The main design of this nozzle system is passive spread of the beam or active scanning.

Because of protons are charged particles, a pencil protons beam can be precisely guided towards the tumor. As protons are heavy particles so they penetrate with minimal spread and they slow down relatively fast when entering biological tissues [2]. Moreover, protons beam offers the advantage of exact dose localization and convenient dose-depth distribution [3], compared with the photon radiotherapy in which adjoining healthy tissues to tumor might receive the same dose that causes the destruction [4].

The nozzle is a relatively complicated system, (the nozzles design defines the beam delivery techniques) [1]. The preferred property of proton is that it acts only at certain depth and in narrow range (Bragg peak) [5]. However, the tumor has definite area and an irregular shape so the beam must be extended laterally and distally to cover it [6].

The continuous collisions of proton with nozzle system may form cracks and cause radiation leakage to the outside affecting patients and workers [7], so Havar or Bronze alloys may be used for the manufacture of some parts of the nozzle system.

Theoretical Methods

A. Stopping power

The ion is slowed down by outer electrons of atoms of the physical medium at high energy, and it moves nearly in a straight path. When the ion is slowed, the collision with the nucleus would be more probable. Finally, the nuclear stopping power dominates in the slowing down process [8].

Total stopping power is the ratio of energy loss (E) and length of the path (x) as shown in the following equation [8]:

$$S(E) = -N_t \frac{dE}{dx}$$

$\frac{dE}{dx}$ – Loss of Energy.

N_t - Atomic density (atom.cm^{-3})

If the target is composed of more than one element, it is presumed that each component contributes to stopping power, for compound $A_q\ B_r$, where q + r =1, then the stopping power is given by the following equation:

$$S_{AB} = qS_A + rS_B$$

Where,

S_A , S_B - Stopping powers of atoms, A and B, respectively.

B. Ion ranges

Ion range, (R) of projectile with energy E_o is determined by the rate of loss of energy along ion path until stopping (E_o =0) [8].

$$R = \int_{E_o}^{0} \frac{dE}{dE/dx} = \int_{E_o}^{0} \frac{dE}{NS(E)}$$

Sputtering Yield

The sputtering process includes complex series of collisions, angular deflections and transferring of the energy among many atoms in solid.

According to "Anderson Model" the energy deposited on a matter surface is given in the following equation [9, 10]:

$$\mathbf{Y = \Lambda\ F_D\ (E_O)} \qquad (1)$$

Λ is the material factor which is represented by:

$$\mathbf{\Lambda = 4.2\ /N\ U_0 \quad nm.eV^{-1}} \qquad (2)$$

N - The atomic density (atom. nm^{-3}), U_0- binding energy of the surface (eV.$atom^{-1}$).

F_D (E_o): deposited energy per unit length due to nuclear processes at surface, depends on type, direction and energy of incident ion with atomic number (Z1) and the target composition atomic number (Z2), mass number (M2), and atomic density (N) [11, 12].

$$\mathbf{F_D\ (E_O) = \alpha\ N\ S_n\ (E_0)} \qquad (3)$$

Where,

(α) - constant and depends on (M_2/M_1) [13].

S_n (E_0) - the nuclear stopping power which may be represented by:

$$N\,S_n(E_0) = dE/dx\,\big|_n \qquad \textbf{(4)}$$

$dE/dx\,|_n$ - nuclear energy loss.

Substitute the equations (2- 4) into equation (1) we get:

$$Y = 4.2\,\alpha\, dE/dx\,\big|_n / (N\,U_0) \qquad \textbf{(5)}$$

Equation (5) represents sputtering yield in (atom.ion^{-1}) units.

Properties of Havar and Bronze alloys

The chemical composition of Havar and Bronze alloys are shown in tables (1, 2) [8].

Table1: Chemical compositions of Havar (ICRU-470)

elements	Atomic No.	Mass(amu)	%
Carbon, C	6	12.011	0.2
Chromium, Cr	24	51.996	20.01
Manganese, Mn	25	54.938	1.6
Iron, Fe	26	55.847	17.47
Cobalt, Co	27	58.933	42.52
Nickel, Ni	28	58.69	13
Molybdenum,Mo	42	95.94	2.4
Tungsten, W	74	183.85	2.79

Table 2: Chemical compositions of Bronze

elements	Atomic No.	Mass(amu)	%
Copper, Cu	29	63.546	84.94
Zinc, Zn	30	65.59	8.84
Lead, Pb	82	207.19	6.22

The physical properties for these alloys are shown in table (3).

Table 3: Physical properties of Havar and Bronze alloys

Properties	Havar	Bronze
Density	at/cm^3 8.6304×10^{22}	at/cm^3 7.9769×10^{22}
Melting point	1480 °C	1035 °C
Modulus of elasticity	190-210 GPa	115 GPa
Tensile strength	1158 MPa	600-760 MPa
Elongation A5 (%)	15	5-15
Hardness	335	170-220
Thermal conductivity	42.7 W/m.K	37.7 W/m. K

Results and Discussion

Nuclear stopping powers and ion ranges are calculated by "SRIM Computer Code" as shown in figure (1) and figure (2) respectively which showed the same results for Havar and Bronze alloys. The sputtering yields are calculated for Havar and Bronze alloys, which showed that the sputtering yield of Bronze alloy is larger than that of Havar alloy as shown in figure (3). This means that the nozzle system manufactured from Havar alloy lasts longer in use than Bronze alloy.

The sputtering yield is produced from continuous collisions of protons with nozzle system, cracks may be formed causing radiation leakage and putting patients and workers at risk.

It is seen from physical properties of Havar alloy that has high melting point and high modulus of elasticity larger than those for Bronze alloy as shown in table (3). These physical properties allow easy formation of nozzle parts in various forms and different volumes according to required usage treatment.

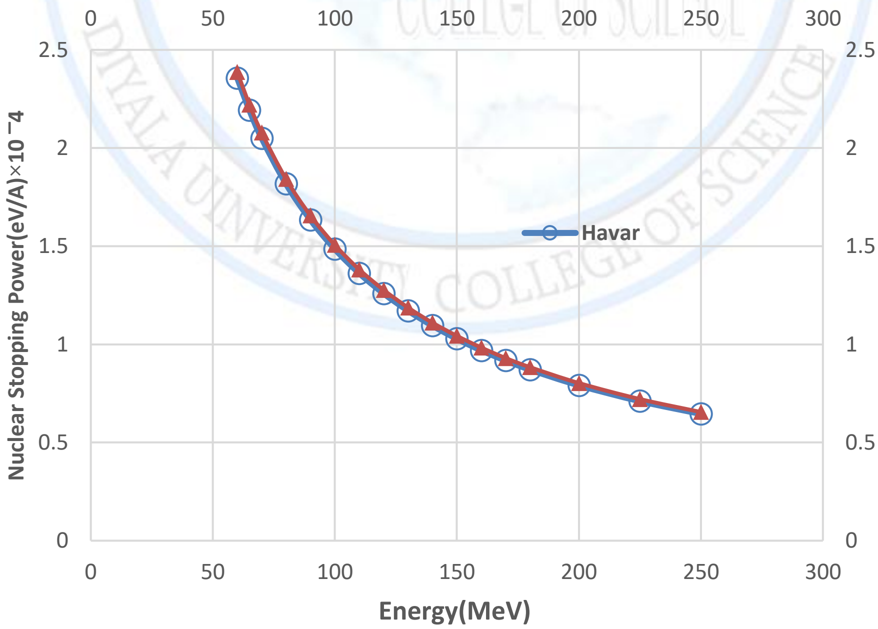

Figure 1: Nuclear stopping power versus proton energy

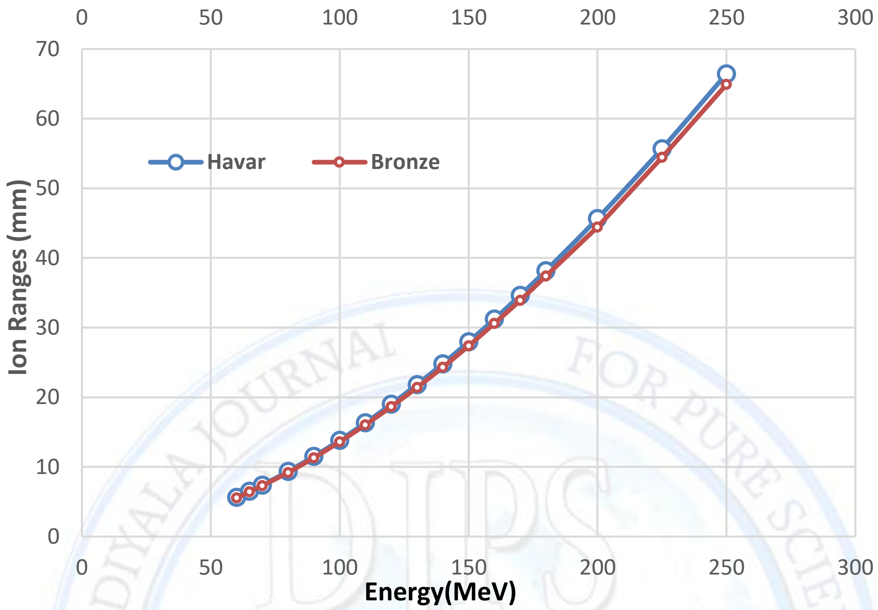

Figure 2: Ion ranges versus proton energy

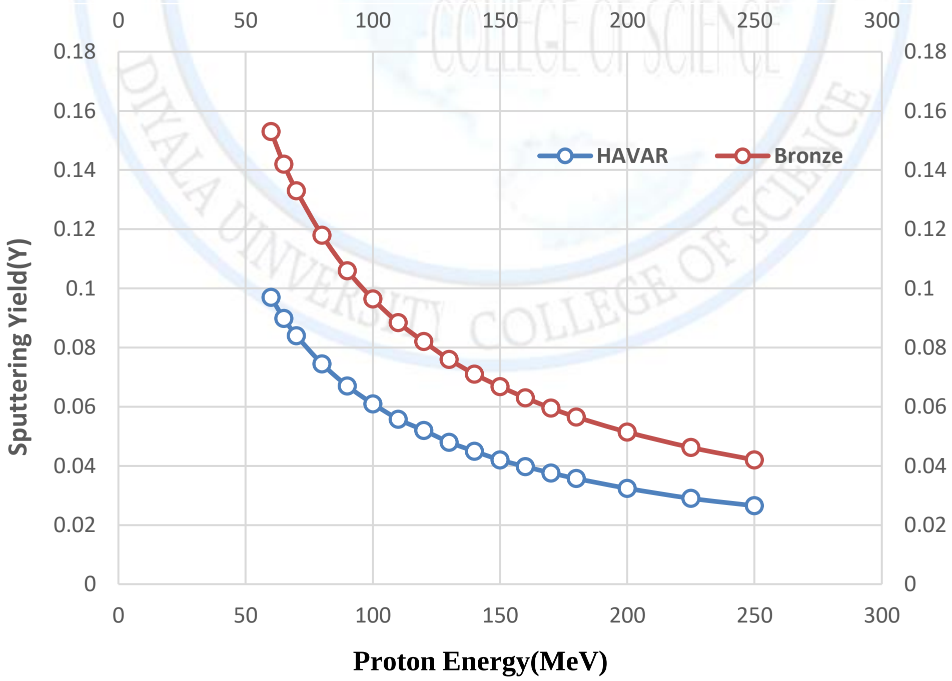

Figure 3: Sputtering yield versus proton energy

Conclusions

Nozzle rupture is one of the major emergencies which puts the workers and patients at risk during proton therapy. This study evaluates the importance of the selection of preferable alloy which lasts longer in use for manufacturing of treating nozzle parts. Theoretical procedure for calculating the sputtering yield for Havar and Bronze alloys of (60 – 250) MeV protons for proton therapy showed that the sputtering yield of bronze is larger than that of Havar alloy. This indicates that cracks are produced faster for Bronze alloy. On the other hand, the physical properties of Havar alloy make it easily formed in different shapes and volumes according to the required treatments.

In conclusion, Havar alloy is proven to be more efficient than Bronze alloy, as it is more affordable and lasts longer.

References

1. Giap, H.; Giap, B. *Transl. Cancer Res*. 2012, 1**,** 127.
2. Delaney, T. F.; Smith, AR.; Lomax, A.; Adams, J.; Loeffler, J. S. Cancer Principles & Practice of Oncology 2003, 1, 17.
3. Weber, D. C.; Trofimov, A. V.; Delaney, T. F.; Bortfeld, T. International Journal of Radiation, Oncology, Biology, Physics 2004, 58, 1596.
4. Clair, W. H.; Adams, J. A.; Bues M.; Fullerton, B. C.; Sean, L. S.; Kooy, H. M.; Loeffler, J. S.; Tarbell N. J. International Journal of Radiation Oncology Biology Physics 2004, 58, 727.
5. Schlegel W.; Thomas B.; Grosu A-L. New Technologies in Radiation Oncology; Springer: Berlin Heidelberg, 2006, 345.
6. Pedroni, E. Latest developments in proton therapy in Proceedings of EPAC 2000, pp 240-244.
7. Shaiju V. S.; Sharma, S. D.; Kumar, R.; Sarin, B. J. Med. Physics 2009, 34, 161.

8. Ziegler J. F.; Biersack, J. P.; Littmark, U. The stopping and range of ions in matter; Pergamon Press: New York, 1985.

9. Andersen, H. H. Appl. Physics 1979, 18, 131.

10. Nordlund, K.; Runeberg, N.; Sundholm, D. Nuclear instruments & methods in physics research 1997, 132, pp 45-54.

11. Nastasi, M. J.; Mayer, W.; Hirvonen, J. K. Ion – Solid Interaction: Fundamentals and Applications, Cambridge University Press, 2003.

12. Sigmund, P. Mat Fys Medd Dan Vid Selsk 1993, 43, 1.

13. Sigmund, P. Phys. Rev. 1969, 184, 383.