APPLICATION OF CYCLOTRONS IN BRACHYTHERAPY

P.Saidi, Islamic Azad University (PPRC) Science and Research Branch, Tehran, Iran
M.Sadeghi, Agricultural, Medical & Industrial Research School, Tehran, Iran
A.Shirazi, Tehran University Faculty of Medicine Department of Biophysics, Tehran, Iran

Abstract

Cyclotrons are particle accelerator machines which have many applications in industry, technology and medicine. Cyclotrons play an important role in medicine and about 50% of the all particle accelerators running in the world are used in medicine for radiation therapy, medical radioisotopes production, and biomedical research. In this short review the use of cyclotrons for a radiation therapy method, brachytherapy, is discussed.

Brachytherapy is a form of radiotherapy where a radioactive source placed on or in the tissue to be irradiated. For a long period the production of radioactive isotopes for medical applications was essentially done in nuclear reactors but due to some advantages of radioisotopes production with cyclotron over a nuclear reactor, in the last two decades several types of cyclotrons have been developed to meet the specific demands of radionuclide production.

This talk will briefly explain the technical design, beam transfer and beam delivery systems of cyclotron for brachytherapy radioisotope production; and also will shortly describe some detail of 103Pd production in the following: production, targetry, radiochemical separation and seed fabrication.

INTRODUCTION

Brachytherapy is a special form of radiotherapy where a radioactive source is carefully placed on or inside the area to be treated. Brachytherapy sources are usually encapsulated; they can be used within the body cavities close to the tumor, placed in a lumen of organs, implanted in to the tumor or placed over the tissue to be treated. Depending on the dose rate of the sources at the dose specification point, brachytherapy treatment classified in three categories: high dose rate sources (HDR) >12 Gy/h, high energy photon emitters s like ^{137}Cs, 60Co, ^{192}Ir, ^{198}Au are used, medium dose rate (MDR) 2-12 Gy/h, is not common use; and low dose rate sources (LDR), less than 2 Gy/h with low energy photon emitters such as ^{125}I and ^{103}Pd. The use of radioactive sources for treatment of cancerous tumours started shortly after the discovery of radium (^{226}Ra) in 1898 by Madame Curie. Quantities and forms of radioactivity useful for brachytherapy were not available until 1940s, when civilian applications of nuclear reactors were encouraged, and also after for a long period the production of radioactive isotopes for medical applications was mainly based on neutron induced nuclear reactions. This was essentially done in nuclear reactors but their availability is slowly decreasing so that the accelerators based production facilities are growing up. The development of particle accelerators started in the past century and various radio-isotopes which are suitable for medical applications, produced.

In this study the accelerator production method for ^{103}Pd, is investigated. The production of 103Pd is carried out via the ^{103}Rh(p,n)^{103}Pd reaction which is well suited to low-energy cyclotrons. The irradiation of the electroplated Rh target was performed in a cyclotron (Cyclone-30, IBA) at 18 MeV energy [1-2] of proton and a beam current intensity of 200 μA at the Agricultural, Medical and Industrial Research School (AMIRS) [3].

The main problem in the 103Pd radiochemical separation stage is dissolution of target material due to extremely low chemical reactivity of rhodium metal. The other problem is the high quantity of rhodium in solution. Well known palladium extractor is dimethylglyoxime, but to prevent the decrease of extraction yield, the α-furyldioxime is used [5]. Pure obtained 103Pd is then absorbed in to resin; the active resins are encapsulated inside the titanium brachytherapy seed.

MATERIALS AND METHODS

According to Sadeghi et al. [4] manuscript, to prepare copper backing for proton bombardment, $RhCl_3.3H2O$ was dissolved in water. sulfamic acid (stress reducing agent) was added to this solution followed by filtration to remove any solid particles. The resultant solution was transferred to the plating vessel, heated up to 40 °C and then a DC current was applied to the electrodes. The plating continued for 24 hours to complete Rh depletion. The copper carriers of electroplated ^{103}Rh targets were dissolved in concentrated nitric acid. A mixture of alcoholic solution which contains dimethylglyoxime (DMG) and chloroform as the organic phases were added to the Rh/^{103}Pd/HCl solution. The mixture was vigorously stirred for 10 minutes. The separated organic phase was washed with HCl. After complete degradation of organic compounds, in order to remove the residue oxidizing agent and form 103Pd chloride, the residue evaporated in hydrochloric acid, this process repeated for two times. The final product was dissolved in hydrochloric acid with desired concentration. ^{103}Pd radioactivity was measured by HPGe detector coupled with a CanberraTM multi-channel analyzer and the extraction process was repeated several times in the same conditions. Produced paladium-103 is then absorbed in (20-50 mesh) IRA-93 resin beads to encapsulate inside the titanium brachytherapy seed. Generally brachytherapy are packed inside a titanium cylinder of 4.8 mm length, 0.7 and 0.8 mm internal and external diameter respectively, in different format like resin beads or loaded on silver or copper rods. Because low energy photon emitting sources, such as ^{103}Pd, are sensitive to specifications and fabricating practices, according to American Association of Physicists

in Medicine (AAPM) TG-43U1 recommendation, the dosimetric characteristics of the source must be determined to provide reliable data for clinical use. Few different brachytherapy seed models have been developed the Agricultural, Medical and Industrial Research School. All the dosimetric parameters following the TG43-U1, determined (experimental and theoretical) [7-10]. Table 1 show a comparison between the dose rate constant of the seeds with other commercial brachytherapy seeds, which are in acceptable range. Figure 1 depicts radial dose function, of developed seeds at AMIRS with commercial sources.

Table 1: Monte Carlo calculated dose rate constant, Λ, of the IRA1-103Pd, IR01-103Pd and IR08-103Pd seeds in compare with the measured and calculated values of model MED3633 and Theragenics200 and best double-wall sources.

Source type	Method	Medium	Λ (cGy h^{-1} U^{-1})
IR01-^{103}Pd	MC simulation[8]	Liquid water	0.69±0.05
	TLD dosimetry[8]	Perspex	0.83±0.05
IRA1-^{103}Pd	MC simulation[7]	Perspex	0.669±0.001
IR08-^{103}Pd	MC simulation[9]	Liquid water	0.695±0.021
Theragenics 200	MC simulation[11]	Liquid water	0.686±0.03
	TLD dosimetry[12]	Solid water	0.650±0.08
MED3633	MC simulation[13]	Liquid water	0.677±0.02
	TLD dosimetry[14]	Liquid water	0.680±0.05
Best® double-wall	TLD dosimetry[15]	Solid water	0.69±0.08
	Monte Carlo simulation[15]	Liquid water	0.67±0.02

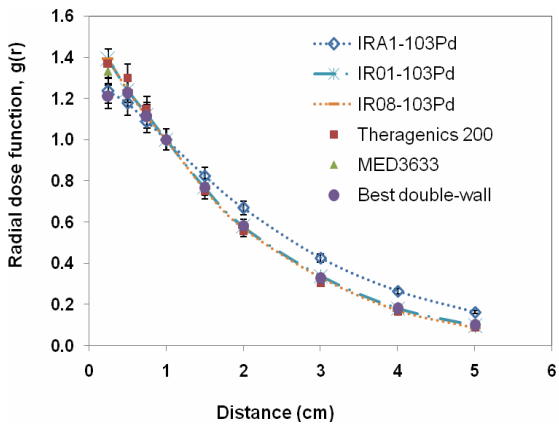

Figure 1: Comparison of the Monte Carlo calculation radial dose function of IRA1-103Pd [7], IR01-^{103}Pd [8], and IR08-^{103}Pd [9] seeds with the three model commercial sources [6].

RESULTS

The rhodium target for production of 103Pd can be prepared by an electro-deposition technique. Produced palladium is loaded on resin or absorbed on silver of copper core for use in brachytherapy seeds. Three new models brachytherapy seeds developed and fabricated at

AMIRS, the dosimetric parameters of them compared with three commercial sources [6]. The dose rate constant values of the seeds are in good agreement with other sources. Comparison between the radial dose rate function values show a good agreement with the exception for IRA1-103Pd model due to different internal component in compare with others.

REFERENCES

[1] A. Hermanne, M. Sonck, S. Takacs, F. Tárkányi, FY.Shubin,"Study on alternative production of 103Pd and characterisation of contaminant sin the deuteron irradiation of 103Rh up to 21 MeV", Nucl Instrum Methods B 187:3–14, (2002).

[2] S. Sudar, F. Cserpak, SM. Qaim, "Measurements and nuclear model calculations on proton-induced reactions on Rh-103 up to 40-MeV-evaluation of the excitation function of the Rh-103(p,n)Pd-103 reaction relevant to the production of the therapeutic radionuclide Pd-103", Appl Radiat Isot 56:821–831, (2002).

[3] M. Sadeghi, B. Shirazi, "Extraction separation of no-carrier-added 103Pd from irradiated Rh target, Cu and Zn using α-furyldioxime, dimethylglyoxime and α-benzildioxime", Appl Radiat Isot 66:1810–1813, (2008).

[4] M. Sadeghi , P. Van den Winkel , H. Afarideh, M. Haji-Saeid , "A thick rhodium electrodeposition on copper backing as the target for production of palladium-103", J. Radioanal Nucl Chem 262:665–672, (2004).

[5] M. Sadeghi, B. Shirazi, N. Shadanpour, "Solvent extraction of no-carrier-added 103Pd from irradiated rhodium target with α-furyldioxime", J Radioanal Nucl Chem 269:223−225, (2006).
[6] M. J. Rivard, B. M. Coursey, L. A. DeWerd, W. F. Hanson, M. S. Huq, G. S. Ibbott, M. G. Mitch, R. Nath, and J. F. Williamson, "Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations," Med. Phys. 31, 633-674 (2004).
[7] M. Sadeghi, GH. Raisali, S. H. Hosseini, A. Shahvar, "Monte Carlo calculations and experimental measurements of dosimetric parameters of the IRA-103Pd brachytherapy source" Med. Phys. 35, 1288-1294 (2008).
[8]Gh. Raisali, MG.Ghonchehnazi, P. Shokrani, M. Sadeghi, "Monte Carlo and experimental characterization of the first AMIRS 103Pd brachytherapy source", Appl. Radiat. Iso. 66: 1856-1860, (2008).
[9] P. Saidi, M. Sadeghi, A. Shirazi, C. Tenreiro, "Monte Carlo calculation of dosimetry parameters for the IR08-103Pd brachytherapy source", Med. Phys. 37: 2509-2515, (2010).
[10] M. Sadeghi, SH. Hosseini, Gh. Raisali, "Experimental measurements and Monte Carlo calculations of dosimetric parameters of the IRA1-103Pd brachytherapy source." Appl. Radiat. Isot. 66, 10,1431–1437, (2008).
[11] JF. Williamson "Monte Carlo modelling of the transverse-axis dose distribution of the model 200 103Pd interstitial brachytherapy source", Med. Phys 2000; 27: 643-654.
[12] R. Nath, N. Yue, K. Shahnazi, and P. J. Bongiorni, "Measurement of dose-rate constant for 103Pd seeds with air kerma strength calibration based upon a primary national standard," Med. Phys. 27, 655-658 (2000).
[13] Z. Li, JR. Palta, JJ Fan, "Monte Carlo calculations and experimental measurements of dosimetry parameters of a new 103Pd source." Med. Phys. 27: 1108-1112, (2000).
[14] RE. Wallace, JJ. Fan, "Dosimetric characterization of a new design 103palladium brachytherapy source." Med. Phys. 26: 2465-2470, (1999).
[15] AS. Meigooni, Z. Bharucha , W. Yoe-Sein M, et al. "Dosimetric characteristic of the best double –wall 103Pd brachytherapy source". Med. Phys. 28: 2568-2575 (2001).