Original Article

Monte Carlo-based dose calculation for ^{32}P patch source for superficial brachytherapy applications

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ABSTRACT

Skin cancer treatment involving ^{32}P source is an easy, less expensive method of treatment limited to small and superficial lesions of approximately 1 mm deep. Bhabha Atomic Research Centre (BARC) has indigenously developed ^{32}P nafion-based patch source (1 cm × 1 cm) for treating skin cancer. For this source, the values of dose per unit activity at different depths including dose profiles in water are calculated using the EGSnrc-based Monte Carlo code system. For an initial activity of 1 Bq distributed in 1 cm^2 surface area of the source, the calculated central axis depth dose values are 3.62×10^{-10} $GyBq^{-1}$ and 8.41×10^{-11} $GyBq^{-1}$ at 0.0125 and 1 mm depths in water, respectively. Hence, the treatment time calculated for delivering therapeutic dose of 30 Gy at 1 mm depth along the central axis of the source involving 37 MBq activity is about 2.7 hrs.

Key words: ^{32}P patch; brachytherapy; dosimetry; nafion; skin cancer

Introduction

Basal cell carcinoma is one of the most common skin cancers, occurs mostly in middle aged people, and is more probable for the fair complexion people.[1] The treatment modalities for skin cancers are surgical excision, radiotherapy and chemotherapy. Each treatment modality has its own advantages and disadvantages. Removing the affected area by surgical excision is usually preferred in many cases, but the recurrence rates after treatment are high. Radiotherapy treatment using external beam therapy is too expensive and it also delivers unnecessary dose to underlying normal tissues. Chemotherapy has its own side effects.

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Mould or superficial brachytherapy is a promising alternative treatment method for such skin cancers, where high-energy beta emitting radio-nuclides such as ^{32}P, $^{90}Sr/^{90}Y$, ^{188}Re are used to overcome the disadvantages of radiotherapy and surgery. In superficial brachytherapy, prescribed dose can be delivered to the affected area without excessive damage to the neighboring normal tissues. This technique is simple, less trauma to patients, and less expensive as compared to external beam therapy.

Lee *et al.*, introduced the treatment of skin cancer and Bowen's disease using beta emitting ^{165}Ho-impregnated patch sources.[2] Successful tumor destruction was observed both in animal and human studies. Mukherjee *et al.*, in their studies evaluated ^{90}Y skin patches and ^{188}Re radioactive bandages for therapy of superficial tumors in mice.[3,4] Treatment of skin cancer using ^{188}Re-labeled paper patches has been reported by Jeong *et al.*[5]

Pandey *et al.*, reported the use of ^{32}P cellulose-based adsorbent paper skin patches to control the tumor regression in C57BL6 mice bearing melanoma.[6] Park *et al.*,[7] studied the use of ^{32}P ophthalmic applicator after pterygium and glaucoma surgeries. They demonstrated that dose distributions obtained using the ^{32}P source is beneficial for reducing the incidence rate of radiation-induced cataract and it can deliver therapeutic doses to the surface of the conjunctiva while sparing the lens better than the $^{90}Sr/^{90}Y$ applicators. Xu *et al.*,[8] investigated the therapeutic effects of the chromic phosphate particle-based ^{32}P source in a rabbit VX 2 lung tumor animal model and found that the tumor volume significantly decreased after implantation of source particle.

Salguerio *et al.*, designed ^{32}P brachytherapy patch source (1 mm in height × 5 mm in dia.) for skin diseases using phosphoric acid and chromic phosphate in combination with natural rubber or silicone and evaluated its therapeutic efficacy.[9,10] They reported arrest of tumor growth and complete regression of tumor in some cases with 40 Gy of single-dose scheme in animal studies. They estimated the dose rate at selected depths (0.0001, 0.01, 4 and 7.5 mm) using the Monte Carlo-based MCNP5 code.[10,11] The activity per unit area considered in their calculations was 10.6 $MBqcm^{-2}$. The surface area of the source was 0.196 cm^2. Hence, the total activity of the source considered in their work was 2.081 MBq. We repeated their study using the DOSRZnrc user-code.[12] The dose rate values showed a good agreement for 0.0001 and 0.01 mm depths. For 4 and 7.5 mm depths, the published values were higher by a factor of about 22 and 3.6×10^4, respectively. We concluded that this large discrepancy in the dose rate values at 4 and 7.5 mm depths published by Salguerio *et al.*,[9] was due to possible systematic error in their Monte Carlo calculations.[13]

^{32}P is a suitable radioisotope for such therapeutic application due to many advantages over other beta emitting radioisotopes. It is a pure beta emitter with maximum energy of 1.71 MeV. Its half-life is 14.2 days. Hence it is less hazardous material from transportation, storage, and waste disposal point of view. The maximum range of ^{32}P beta particle in soft tissue is 8 mm (the average range is 3 mm).[14] Due to its short range, there will be negligible radiation dose to the underlying healthy normal tissues and bone.

Isotope Production and Applications Division, BARC has indigenously developed nafion–zirconium phosphate film-based ^{32}P patch source for superficial brachytherapy applications.[15] A nafion-117 membrane of thickness 100 μm is treated with $ZrOCl_2$ solution, and subsequently dipped in orthophosphoric acid. These radioactive ^{32}P patches are cut in to 1 cm × 1 cm sizes and then subsequently laminated with thermoplastic polyurethane sheets of thickness 40 μm. The above preparation method is robust, inexpensive and reproducible and complies with the safety standard stipulated by Atomic Energy Regulatory Board, India.[16] The detailed preparation of nafion-117 patches is explained by Saxena *et al.*[15]

The present study is aimed at calculating central axis depth dose and dose profiles in water phantom for the indigenously developed ^{32}P-nafion-based patch source. For this purpose, the EGSnrc-based Monte Carlo code system is used.[17] Based on the calculated dose rate data, the treatment time to deliver a therapeutic dose of 30 Gy at reference depth is also calculated, as per the IAEA-tecdoc-1274.[18]

Materials and Methods

Monte Carlo calculations

DOSXYZnrc user-code[19] of the EGSnrc-code system[17] is used to calculate central axis depth doses and dose profiles in the unit density water medium for simulating the 1 cm × 1 cm ^{32}P-nafion-patch source. The 1 cm × 1 cm ^{32}P-nafion-patch source is positioned on 2 × 2 ×2 cm^3 water phantom. The thickness of source is 100 μm. The geometry and co-ordinate system used in the Monte Carlo calculations is shown in Figure 1. The elemental composition and density of phosphorous-loaded zirconium-nafion-117 composite membrane used in the Monte Carlo calculation is given in Table 1.[15]

The ^{32}P beta spectrum [see Figure 2] needed for the Monte Carlo calculation is based on ICRU Report No. 56.[20] In the Monte Carlo calculations, it is considered that the source particles are uniformly distributed in the nafion patch of dimensions 1 cm × 1 cm × 100 μm. The water phantom was divided in to voxels of dimension of 0.25 × 0.25 × 0.25 mm^3 for generating dose profiles. Dose distributions in water are scored in these voxels. Separate simulation is carried out to score central axis depth dose by using bigger voxel dimensions (2 × 2× 0.25 mm^3).

In the Monte Carlo calculations, all secondary particles such as knock on electrons and secondary bremsstrahlung photons produced by primary source electrons are completely followed in the simulation. The PEGS4 dataset needed for EGSnrc calculations is based on the XCOM compilations.[21] The PEGS4 dataset is generated by setting AE = ECUT = 0.521 MeV and AP = PCUT = 0.01 MeV, where the parameters AE and AP are the low energy thresholds for the production of knock-on electrons and secondary bremsstrahlung photons, respectively.

All Monte Carlo simulations utilized the PRESTA-II algorithm. The electron step-size parameter is set at ESTEP = 0.25. To increase the speed of the calculations, electron range rejection technique was used by setting ESAVE = 2 MeV. Auxiliary simulation was also carried without range rejection. The calculations suggest that using the range rejection with ESAVE = 2 MeV, improves

Table 1: Elemental composition of phosphorous-loaded zirconium-nafion-117 composite membrane (density=1620 kgm^{-3})

Element	*C*	*F*	*O*	*S*	*P*	*Zr*
Atom (%)	22.5	67.15	8.1	1.8	0.29	0.16

the efficiency of the calculations by about 40%. In order to know the effect of boundary crossing algorithm on computational time, both PRESTA-I and EXACT boundary crossing algorithms were used in the calculations. The study shows that the using the PRESTA-I option results in improving the efficiency of the calculations by a factor 2 when compared to using the EXACT boundary-crossing algorithm. This observation is consistent with the findings by Walters and Kawrakow in their EGSnrc-based Monte Carlo study involving radiotherapy electron beams.[22]

Results and Discussion

The variation of the dose values per unit activity ($GyBq^{-1}$) as a function of depth (mm) in water for the ^{32}P-nafion-patch source is shown in Figure 3. The dose decreases rapidly with increasing depth in water. Central axis dose at 4 mm depth in water is only 0.08% of the central axis surface dose. Such a rapid decrease in dose will result in better sparing of the normal tissues.

Table 2 compares the values of central axis depth dose per unit activity ($GyBq^{-1}$) of ^{32}P-nafion-patch source with the corresponding values of ^{32}P-silicon-patch[9] for different depths in water. Higher dose rate values are observed in the case of ^{32}P-silicon-patch source, because the radioactivity is distributed in lesser surface area (0.196 cm^2) as compared to ^{32}P-nafion-patch source, where surface area is 1 cm^2.

For treatment time calculation, 1 mm depth from the surface along the central axis of the source is considered as reference depth.[18] The value of dose in water calculated at 1 mm from the source surface is 8.41×10^{-11} $GyBq^{-1}$. Hence, the time required to deliver a therapeutic dose of 30 Gy for a 37 MBq of radioactivity distributed in 1 cm^2 of ^{32}P-nafion-patch source is about 2.7 hours.

Figure 4 presents the dose rate profiles along the x-axis of ^{32}P-nafion-patch source for three different depths z = 0.5, 1 and 2 mm from the source surface. Figure 5 presents normalized dose values along the x-axis at depth 1 mm. The central axis dose value at 1 mm depth is used for normalization. Dose rate value at 3.5 mm away from the central axis is about 91% of the central axis value.

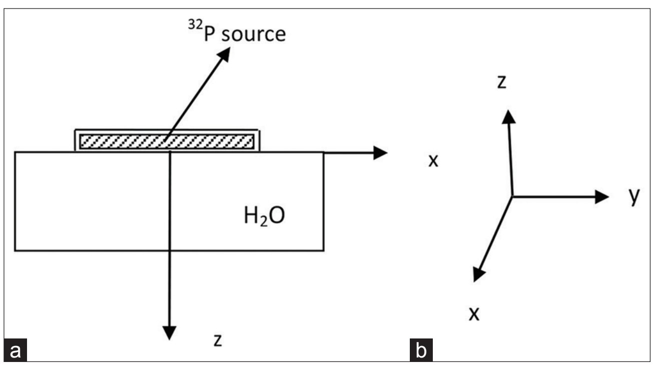

Figure 1: (a) Schematic diagram of the ^{32}P-nafion-patch source and water phantom used in the DOSXYZnrc Monte Carlo simulation. (b) Coordinate system used in the simulation

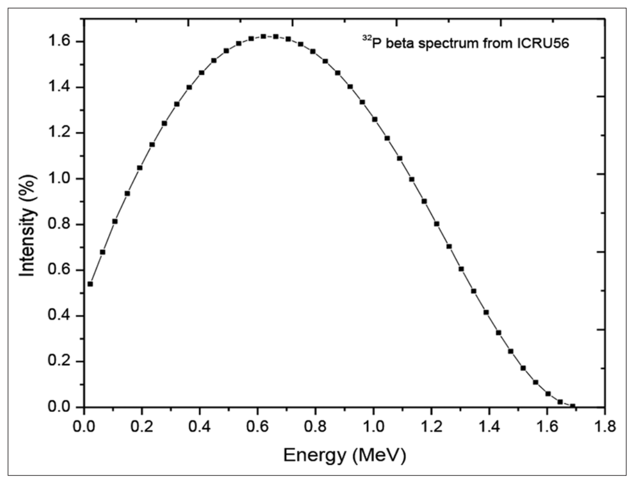

Figure 2: ^{32}P beta spectrum used in the Monte Carlo simulation

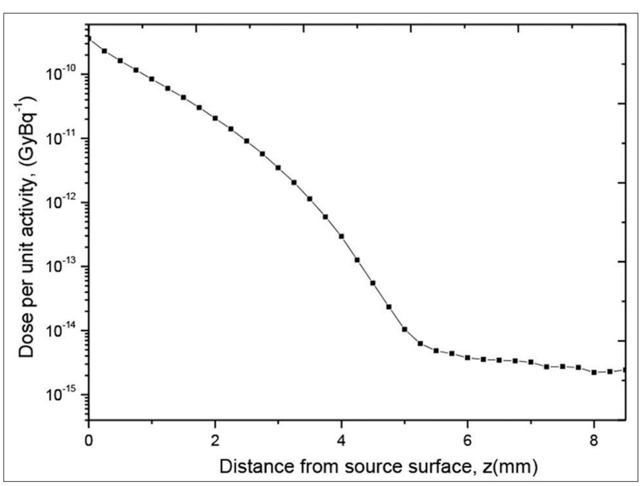

Figure 3: Depth dose distribution of ^{32}P-nafion-patch source along the central axis of the source

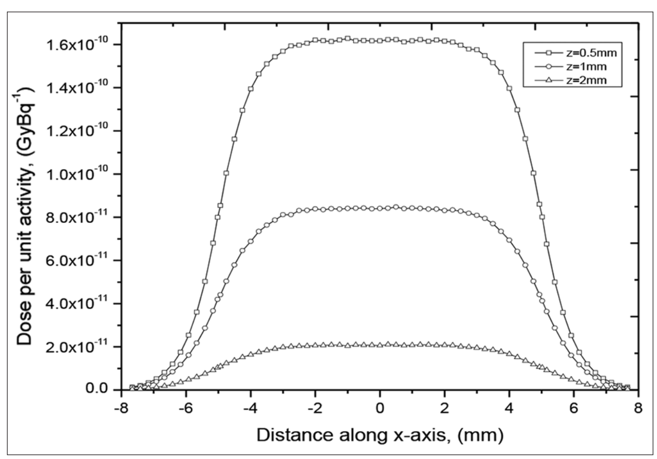

Figure 4: Dose profile along the x-axis of ^{32}P-nafion-patch source for different depths, z = 0.5 mm, z = 1 mm and z = 2 mm

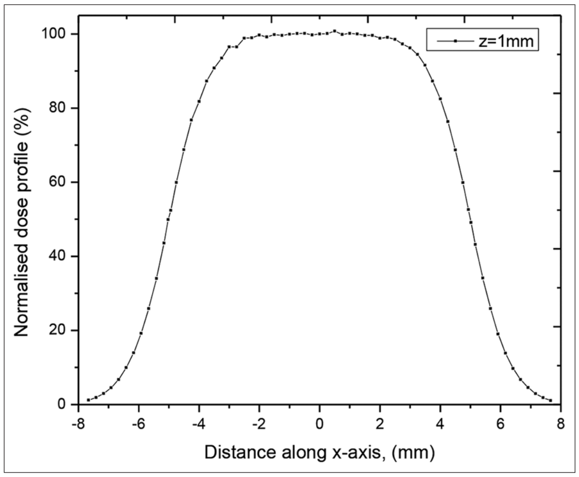

Figure 5: Normalized dose profile along the x-axis of ^{32}P-nafion-patch source for depth z = 1 mm

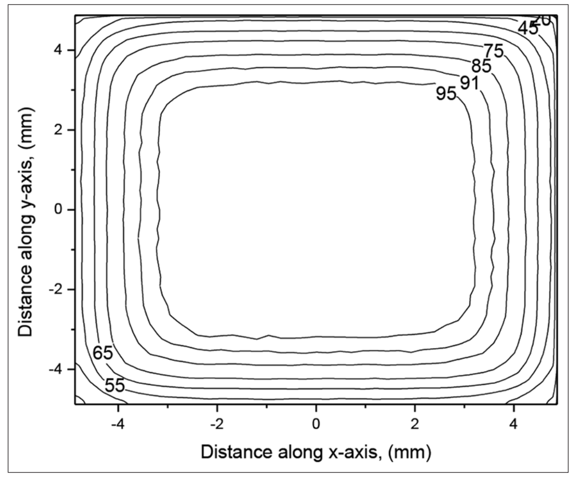

Figure 6: Isodose profiles of the ^{32}P-nafion-patch source on xy-plane at a depth of 0.5 mm

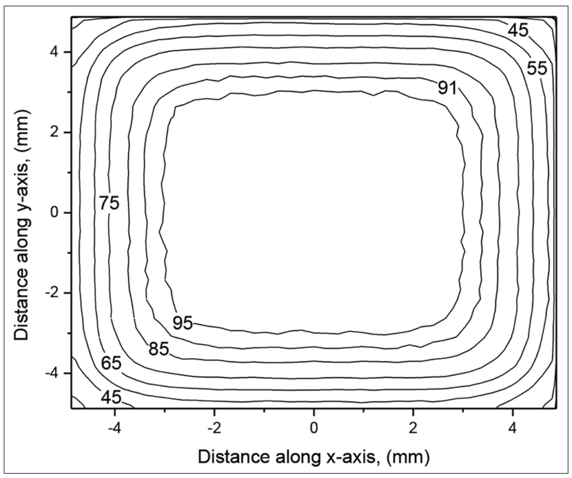

Figure 7: Isodose profiles of the ^{32}P-nafion-patch source on xy-plane at a depth of 1 mm

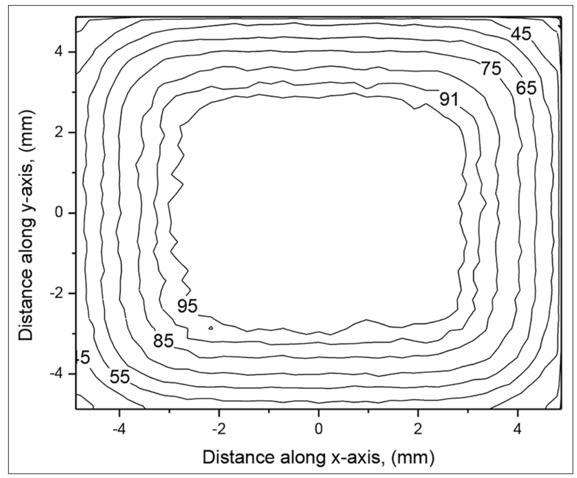

Figure 8: Isodose profiles of the ^{32}P-nafion-patch source on xy-plane at a depth of 2 mm

Table 2: Comparison of dose values per unit activity ($GyBq^{-1}$) presented as a function of depth in water

Depth in water (mm)	*Dose values per unit activity ($GyBq^{-1}$) (%)*	
	^{32}P-nafion-patch source[a] (this work)	*^{32}P-silicone-patch source[b] (Sahoo and Selvam)[13]*
0.0125	3.62×10^{-10} (0.05)	1.51×10^{-9} (0.30)[c]
1	8.41×10^{-11} (0.10)	–
4	2.93×10^{-13} (1.30)	1.41×10^{-11} (0.40)
7.5	2.74×10^{-15} (7.40)	3.50×10^{-15} (24)

The number shown in the parenthesis against the dose values is the percentage error (1 s). [a]Source dimensions: 1 cm×1 cm×100 μm. [b]Source dimensions: 5 mm diameter×1 mm height [c]depth is 0.01 mm

Whereas dose rate at 5 mm away from the central axis is only 50% of the central axis value. Figures 6–8 show isodose profiles of the ^{32}P-nafion-patch source at depths of 0.5, 1, and 2 mm. About 3.25–3.5 mm distance around the central axis is covered by about 90% isodose line for depths of 0.5, 1, and 2 mm. Hence, the ^{32}P-nafion-patch source is effective for treatment of approximately 6.5–7.0 mm diameter lesions.

Conclusions

Dose distributions for the indigenously developed 1 cm × 1 cm ^{32}P-nafion skin patch source are calculated using the Monte Carlo-based EGSnrc code system. The calculated treatment time for delivering therapeutic dose of 30 Gy at 1 mm depth along the central axis of the source involving 37 MBq activity is about 2.7 hrs. This source is effective for treatment of approximately 6.5–7.0 mm diameter lesions.

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References

1. Kopf AW. Computer analysis of 3531 basal cell carcinomas of the skin. J Dermatol 1979;6:267.
2. Lee JD, Park KK, Lee MG, Kim EH, Rhim KJ, Lee JT, *et al*. Radionuclide therapy of skin cancers and Bowen's disease using a specially designed skin patch. J Nucl Med 1997;38:697-702.
3. Mukherjee A, Pandey U, Sarma HD, Pillai MR, Venkatesh M. Preparation and evaluation of ^{90}Y skin patches for therapy of superficial tumors in mice. Nucl Med Commun 2002;23:243-7.
4. Mukherjee A, Pandey U, Sarma HD, Gupta SK, Ingle AD, Pillai MR, *et al*. Bioevaluation of radioactive bandages in a murine model of melanoma. Int J Radiat Biol 2003;79:839-45.
5. Jeong JM, Lee YJ, Kim EH, Chang YS, Kim YJ, Son M, *et al*. Preparation of ^{188}Re labeled paper for treating skin cancer. Appl Radiat Isot 2003;58:551-5.
6. Pandey U, Saxena SK, Sarma HD, Tandon P, Ram R, Samuel G, *et al*. Bioevaluation studies of ^{32}P incorporated mould brachytherapy sources for potential application in treatment of superficial tumors. Nucl Med Commun 2008;29:717-23.
7. Park YK, Ye SJ, Kim IH, Wee WR, Kim MK, Han HS, *et al*. Potential use of ^{32}P ophthalmic applicator: Monte Carlo simulations for design and dosimetry. Med Phys 2008;35:1854-8.
8. Xu YP, Yang M, Pan Dh, Wang Lz, Liu L, Huang P, *et al*. Bioevaluation study of ^{32}P-CP-PLLA particle brachytherapy in a rabbit VX2 lung tumor model. Appl Radiat Isot 2012;70:583-8.
9. Salgueiro MJ, Duran H, Palmieri M, Pirchio R, Nicolini J, Ughetti R, *et al*. Design and bioevaluation of a ^{32}P-patch for brachytherapy of skin diseases. Appl Radiat Isot 2008;66:303-9.
10. Salgueiro MJ, Duran H, Palmieri M, Pirchio R, Medina V, Ughetti R, *et al*. Bioevaluation of ^{32}P patch designed for the treatment of skin diseases. Nucl Med Biol 2008;35:233-7.
11. X-5 Monte Carlo Team. MCNP-A General Monte Carlo N-Particle Transport Code, Version 5. Los Alamos National Laboratory, Los Alamos, NM, USA; 2003.
12. Rogers DWO, Kawrakow I, Seuntjens JP, Walters B, Mainegra-Hing E. NRC user codes for EGSnrc, NRCC Report No. PIRS-702 (rev. B). National Research Council of Canada, Ottawa, Canada; 2010.
13. Sahoo S, Palani Selvam T. Comment on "Design and bioevaluation of a ^{32}P-patch for brachytherapy of skin diseases" [Appl. Radiat. Isot 66, (2008) 303–309]. Appl Radiat Isot 2014;91:62-3.
14. Gao W, Liu L, Liu ZY, Li XD, Li C. Interstitial injection of ^{32}P-chromic phosphate during lung cancer resection to treat occult lymphatic metastasis. Nucl Med Commun 2009;30:420-6.
15. Saxena SK, Kumar Y, Dash A. Nafion-zirconium phosphate composite membrane: A new approach to prepare ^{32}P patches for superficial brachytherapy applications. Cancer Biother Radiopharm 2012;27:276-84.
16. Testing and classification of sealed radioactive sources. AERB Safety Standard No. AERB/SS/3 (Rev. 1); 2001.
17. Kawrakow I, Seuntjens JP, Rogers DW, Tessier F, Walters BR. The EGSnrc code system: Monte Carlo simulation of electron and photon transport, NRCC Report No. PIRS-701. National Research Council of Canada, Ottawa, Canada; 2013.
18. IAEA-Tecdoc-1274. Calibration of photon and beta ray sources used in brachytherapy. March; 2002.
19. Walters B, Kawrakow I, Rogers DWO. DOSXYZnrc users manual, NRCC Report PIRS-794 (rev. B). National Research Council of Canada, Ottawa, Canada; 2009.
20. ICRU Report No. 56. Dosimetry of external beta rays for radiation protection, International Commission on Radiation Units and Measurements, Bethesda, MD; 1997.
21. Berger MJ, Hubbell, JH. XCOM, Photon cross sections on a personal computer, Report no. NBSIR 87-3597. Gaithersburg, MD. NIST; 1987.
22. Walters BR, Kawrakow I. Technical note: Overprediction of dose with default PRESTA-I boundary crossing in DOSXYZnrc and BEAMnrc. Med Phys 2007;34:647-50.

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