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Technical note

Using matrix summation method for three dimensional dose calculation in brachytherapy

Mahmoud Zibandeh-Gorji[a], *Ali Asghar Mowlavi*[b,c,*], *Saeed Mohammadi*[d]

[a] *Physics Department of Payamnor University of Tehran, Tehran, Iran*
[b] *Physics Department of Sabsevar Tarbiat Moallem University, Sabzevar, Iran*
[c] *TRIL, ICTP, Trieste, Italy*
[d] *Physics Department of Payamnor University of Mashhad, Mashhad, Iran*

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ABSTRACT

Aim: The purpose of this study is to calculate radiation dose around a brachytherapy source in a water phantom for different seed locations or rotation the sources by the matrix summation method.
Background: Monte Carlo based codes like MCNP are widely used for performing radiation transport calculations and dose evaluation in brachytherapy. But for complicated situations, like using more than one source, moving or rotating the source, the routine Monte Carlo method for dose calculation needs a long time running.
Materials and methods: The MCNPX code has been used to calculate radiation dose around a ^{192}Ir brachytherapy source and saved in a 3D matrix. Then, we used this matrix to evaluate the absorbed dose in any point due to some sources or a source which shifted or rotated in some places by the matrix summation method.
Results: Three dimensional (3D) dose results and isodose curves were presented for ^{192}Ir source in a water cube phantom shifted for 10 steps and rotated for 45 and 90° based on the matrix summation method. Also, we applied this method for some arrays of sources.
Conclusion: The matrix summation method can be used for 3D dose calculations for any brachytherapy source which has moved or rotated. This simple method is very fast compared to routine Monte Carlo based methods. In addition, it can be applied for dose optimization study.

1. Background

Recently, the application of radioisotopes for diagnostic and therapy has been developed very fast year by year.[1–5] Brachytherapy is an advanced cancer treatment modality where radioactive seeds or sources are placed in or near the tumor itself, giving a high radiation dose to the tumor while reducing the radiation exposure in the surrounding healthy tissues.[6] ^{192}Ir source is used widely in brachytherapy to treat

* *Corresponding author at*: Physics Department of Sabsevar Tarbiat Moallem University, PO Box 397, Sabzevar, Iran. Tel.: +98 571 4003159; fax: +98 571 4411161.
E-mail addresses: aa_mowlavi@yahoo.com, amowlavi@sttu.ac.ir (A.A. Mowlavi).
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localized tumors near the body site.[7–9] Mowlavi et al. have calculated and reported Monte Carlo and experimental relative dose determination for a microselectron HDR ^{192}Ir source in a water phantom.[7]

Recently, Bahreyni Toossi et al. have published an article related to a matrix shift based technique for dose calculation of GZP6 ^{60}Co as a stepping source for brachytherapy.[10] They employed the pedep mesh tally (Type 1) of MCNPX code to calculate absorbed dose in each mesh cell.[10,11]

2. Materials and methods

The dose distribution has been calculated around the ^{192}Ir located in the center of 30 cm × 30 cm × 30 cm water phantom cube by using tally *F8:p of MCNPX code with less than 5% relative error.[11] We used MCNX code to calculate relative dose as percentage deep dose (PDD) for a microselectron HDR ^{192}Ir, which is described in reference article 6, in a water phantom as arrays of main matrix dose.

Tally *F8 was evaluated in a sphere with 0.1 mm diameter cell for 960 in each z = 0, 0.1,. . ., 14 mm planes. Reference point was selected as PDD = 100 in: x = 0.21 mm, y = 0.57 mm and z = 0 mm when the source is placed in the origin. According to the symmetry of the phantom and source geometry, we saved the dose data in several 50 × 50 matrixes.

3. Results and discussion

Usually, in a brachytherapy treatment plan we want to expose an area inside the tumor to give a high radiation specific dose while reducing radiation exposure in the surrounding healthy tissues.[12–19] Treatments may be delivered at a high dose rate (HDR) or a low dose rate (LDR) sources. To achieve this aim; the source location and time of exposure were varied in HRD like ^{192}Ir and ^{137}Cs sources.[16,17] For LDR sources like ^{125}I, ^{103}Pd, the seeds may be put inside the tumor for ever in different places with different activity.[18,19] The physician may also insert the radioactive material manually through a delivery device and remove the material and delivery device when the treatment is done. For more than one source or seed, dose calculation by the Monte Carlo method needs a long time. Therefore, using the matrix summation method is a fast and easy way to obtain dose results from many sources or seeds.

Fig. 1 shows the 3D PPD variation in z = 0 mm plane. Shifting of the main matrix can be done by 0.21 mm step in the x-axis direction and 0.20 mm step in the y-axis direction and 0.1 mm step in the z direction. According to the activity or time of exposure and location of sources, each matrix was generated by shifting of the origin matrix. Fig. 2 shows the 2 units shift of the matrix in the x and y directions. We considered adding more arrays for the shifted matrix to be zero (the first and the second columns and rows in Fig. 2). We must mention that the values of these arrays are small because they are far from the source and out of the tumor region. Therefore, we plan to find them by extrapolation in further development of the method.

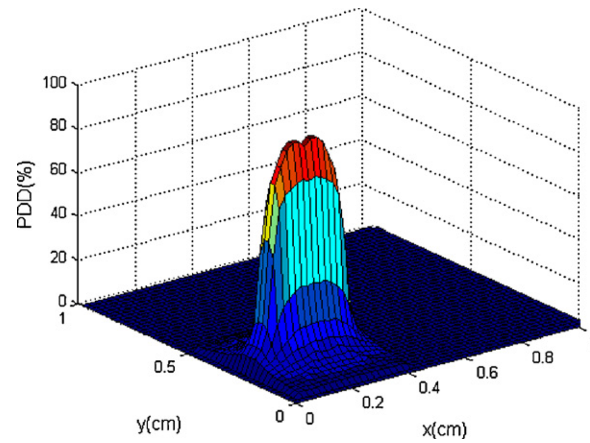


Fig. 1 – The 3D of PPD variation in z = 0 mm plane (the ^{192}Ir source was located in the center of the water phantom).

The PPD result of 10 matrixes summation is shown in Fig. 3-a; where each matrix was shifted one step (0.21 mm) relative to the previous matrix in the x direction axis in z = 0 mm plane. The isodose curve for different PDD corresponding to the data of Fig. 3-a is presented in Fig. 3-b. This situation is like moving the source with a constant speed in the tumor.

Furthermore, we considered the matrix rotation role for the sources with different angles. Fig. 4 shows the PDD variation in the xy plane and its isodose curves, when two sources located in two different directions with angle of 45°. The same result is presented in Fig. 5 where the sources make a 90° angle. It can be seen that by shifting and rotating of the main matrix and summation method, we can obtain any isodose plan.

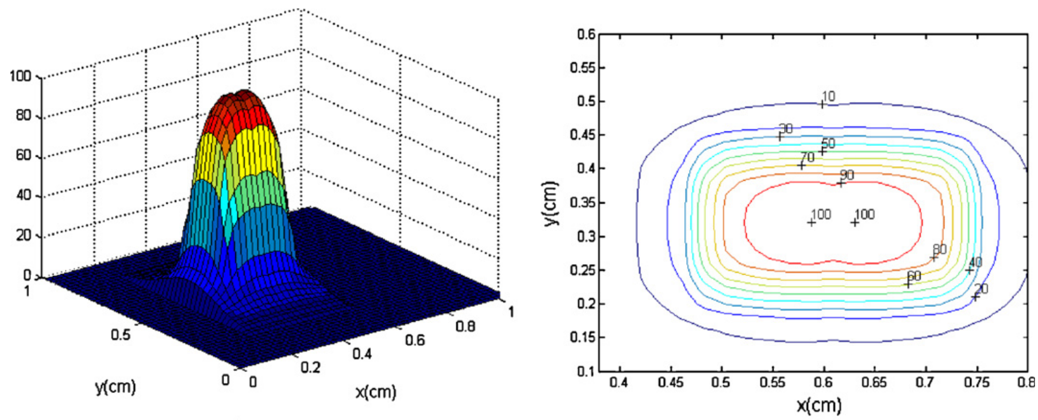
We applied the matrix summation technique for different arrays of sources. Figs. 6–8 show the 3-D PPD variation and the isodose curves for square, triangle and circle arrays of sources, respectively. The method can be used easily for any array of sources with different activity or time of exposure.

1.37575E-14	1.36329E-14	1.61457E-14	1.77855E-14	2.26942E-14
1.51655E-14	1.5896E-14	1.68479E-14	1.94135E-14	2.53796E-14
1.28354E-14	1.80138E-14	2.0596E-14	2.1597E-14	2.51043E-14
1.4574E-14	1.56737E-14	2.49275E-14	2.5795E-14	2.80844E-14
1.49041E-14	1.84723E-14	1.95284E-14	3.4632E-14	3.3161E-14

0	0	0	0	0	0
0	0	0	0	0	0
0	0	1.37575E-14	1.36329E-14	1.61457E-14	1.77855E-14
0	0	1.51655E-14	1.5896E-14	1.68479E-14	1.94135E-14
0	0	1.28354E-14	1.80138E-14	2.0596E-14	2.1597E-14

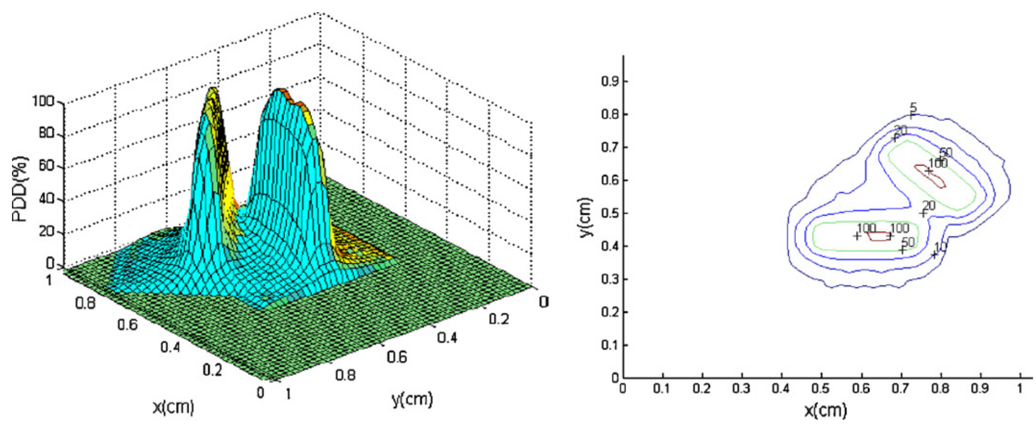
$$D_{ij} = D_{i+2\ \ j+2}$$

Fig. 2 – The shift of matrix 2 units in the x and y directions.



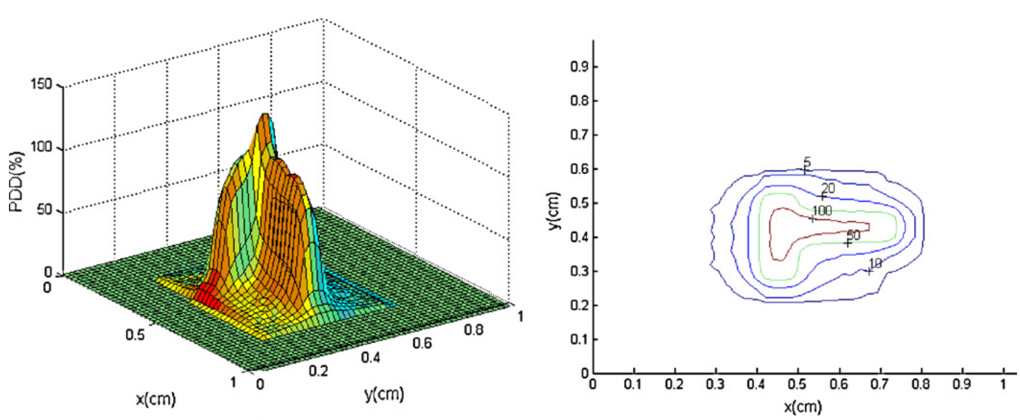
(a) (b)

Fig. 3 – (a) The summation of 10 matrixes in z = 0 mm plane, each matrix was shifted one step (0.21 mm) relative to the previous matrix in the x direction axis; (b) the isodose curve for different PDD.



(a) (b)

Fig. 4 – (a) The summation of two sources with 45° angle and (b) the isodose curve for different PDD.



(a) (b)

Fig. 5 – (a) The summation of two sources perpendicular to each other and (b) the corresponding isodose curve for different PDD.

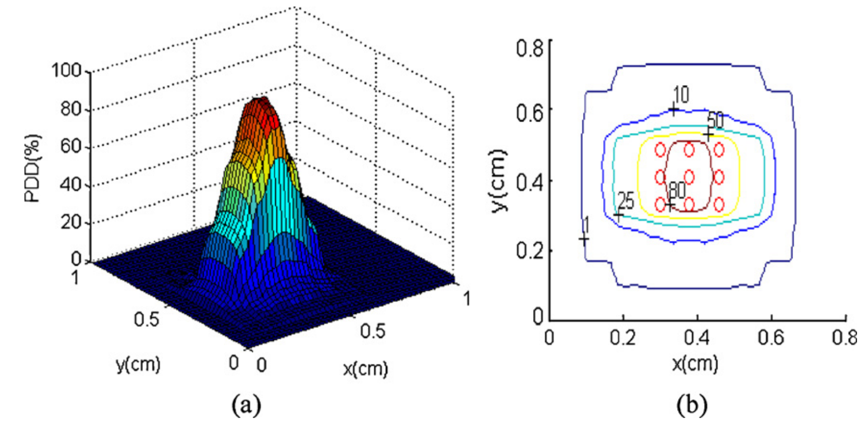


Fig. 6 – (a) The 3-D PDD variation for a square array of sources and (b) the isodose curves (the red cycles show the positions of 9 sources).

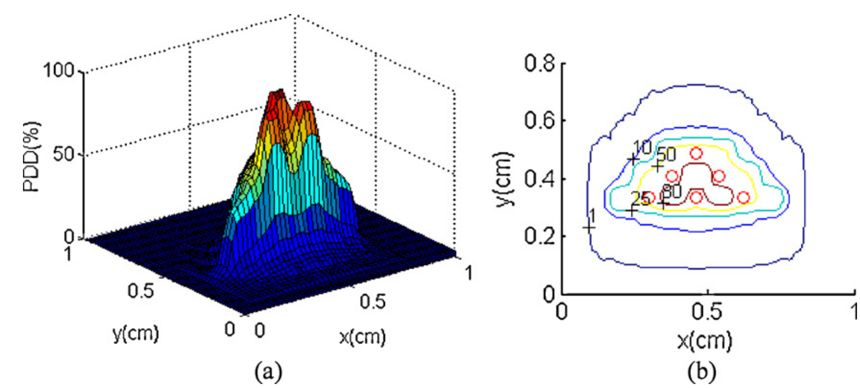


Fig. 7 – (a) The 3-D PDD variation for a triangle array of sources and (b) the isodose curves (the red cycles show the positions of 6 sources).

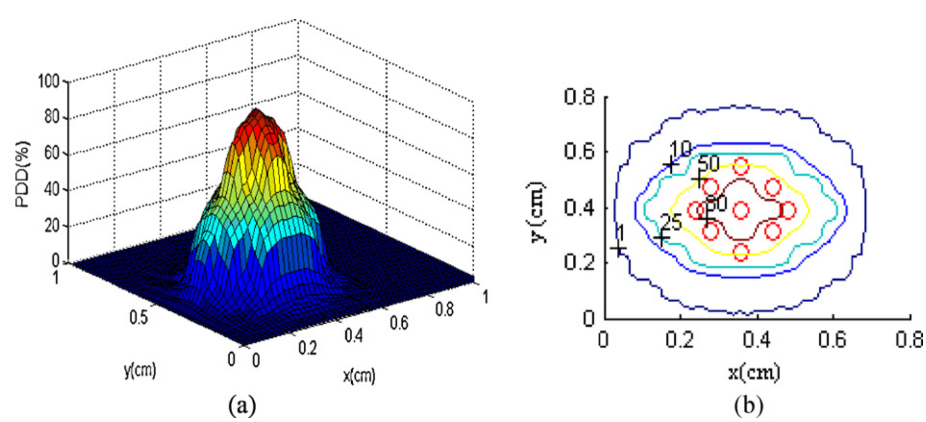


Fig. 8 – (a) The 3-D PDD variation for a circle array of sources and (b) the isodose curves (the red cycles show the positions of 9 sources).

4. Conclusion

The Monte Carlo method is used to provide accurate radiation dose estimates in brachytherapy. While this method is more accurate than commonly used analytical dose calculations, it is computationally intense. Therefore, by applying the matrix summation method to dose result of Monte Carlo calculation, we reduced the time of computing and increased the accuracy of the result for dose calculation from the same sources. We can consider the shifting and rotating of the source or both of them in the matrix summation method and evaluate the dose summation in a simple way. This method can be applied for any HDR and LDR brachytherapy sources. In addition, it can be applied for dose optimizations study.

Conflict of interest

We have not any conflict of interest with *Payamnor University of Tehran, Sabsevar Tarbiat Moallem University, ICTP and Payamnor University of Mashhad*. This work was partially supported by the Training and Research in Italian Laboratories Programme (TRIL) of the Abdus Salam International Centre of Theoretical Physics (ICTP). Authors would like to thank Prof. D. Treleani head of TRIL program at ICTP, Trieste, Italy.

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