Dose Calculation of Rhenium-188 for Radiation Therapy on Preventing Vascular Restenosis

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INTRODUCTION

Recently, a cooperative research program between the Institute of Nuclear Energy Research (INER) and some medical center has been set-up to study the effectiveness of radiation therapy to prevent vascular restenosis after percultaneons transluminal intervention. Several well-known irradiation techniques have been reviewed in details[1-2]. Among those, external beam irradiation techniques and intravascular irradiation techniques including the insertion of permanent beta-emitter stent and the temporary insertion of rhenium-188 solution were considered to be technically practicable for such domestic study. Because beta particles deposit most of their energy in short range, from radiation protection point of view, they have safety advantages for the patient and staff over other irradiation techniques. Rhenium-188 is primarily a beta emitter with maximum beta energy of 2.12MeV. Its half-life is 16.9h, and can be generated through $^{188}W/^{188}Re$ generator in INER[3-6]. Rhenium- 188-perrhenate can be rapidly excreted in the urine if inevitable balloon failure occurred. For the time being, only the rhenium-188-perrhenate solution is adopted in conjunction with balloon angioplasty to irradiate arteries for reducing proliferation of vascular tissue.

Dose for internally deposited beta particles had been well evaluated from other researches[7,8]. Absorbed dose to blood vessels for radionclides in blood was evaluated by Akabani and Poston using Monte Carlo Code EGS4 for various diameter of blood lumen[7]. The dose distribution of ^{90}Y (beta emitter) solution loaded in the balloon of 3 mm diameter was presented by Amoles, Reinstein, and Weinberg[8]. All results of the analytical calculations and measurement agree quite well.

For this study, dose distribution of balloon catheter in various diameter filled with liquid Rhenium-188 solution is calculated using Monte Carlo code MCNP[9].

MODEL

Dose distribution of blood vessel wall around the balloon catheter filled with liquid rhenium-188 is simulated with a homogenous water phantom model represented in cylindrical geometry as shown in Figures 1and 2.

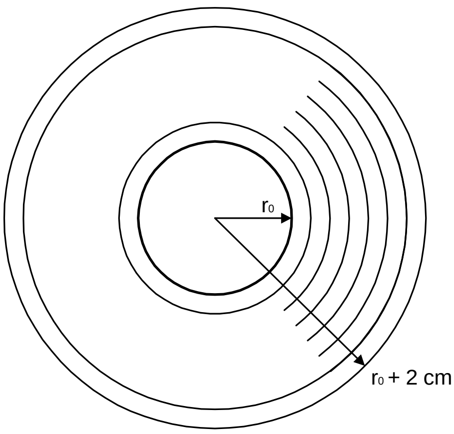

Figure 1. Cross section of cylinder used to simulate a blood vessel. The inner cylinder with radius r_0 represents the source region; the balloon catheter filled liquid rhenium-188. The cylinder away from source region is divided into region with thickness 0.05 mm for the calculations of the spatial absorbed dose throughout the vessel wall.

The central part of inner cylinder of radius r_0 represents the balloon catheter filled with a uniform distribution of rhenium-188 solution. The outer part of inner cylinder represents the lumen containing blood. The outer cylinder between radius r_0 and radius r_0+2 cm represents the range of particle simulation and is subdivided into regions with thickness 0.05 mm. Fifteen different diameters of balloon varying from 0.2 to 20.0 mm, and height of 20 and 40 mm are considered. The results are summarized as the database. For pre-clinical study, it is easy to compute the required source specific activity, irradiation time, the maximum dose to normal tissue, and the minimum dose to malfunction tissue by interpolating suitable values from the database using a prescribed dose.

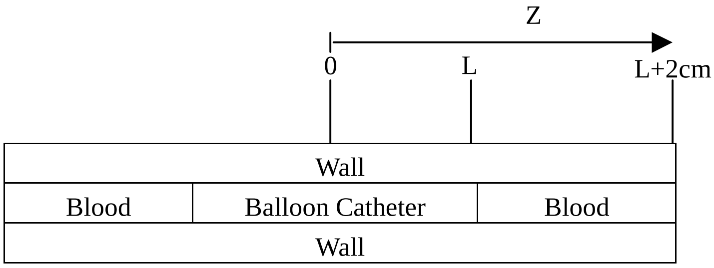

Figure 2. Model of blood vessel used to calculate the absorbed dose profile. The central part of inner cylinder is used to simulated source region in which ^{188}Re solution is uniformly distributed.

In these calculations, particles crossing r_0+2 cm boundary were not traced, since this distance is relatively large than the range of beta particles and therefore contribution of interactions, such as backscatter, would not affect the dose distribution in regions of concern. The MCNP-4B2 Monte Carlo code was used to calculate the absorbed dose profile in the water phantom described as in mentioned figures. The lower cut-off energies are 1keV and 10keV for photons and betas respectively. The spatial absorbed dose calculations require beta spectra, which were created from RSICC DATA LIBRARY DLC-172, NUCDECAY[10]. This database has been designed to address the need in medical, environmental, and occupational radiation protection. The beta spectrum of rhenium-188 used in the calculation is shown in Figure 3. Rhenium-188 is primarily a beta emitter, and is also a gamma emitter. The major gamma ray is with energy 155keV and relative intensity 15%. The dose contribution from those gamma rays was evaluated to be much less than 1% comparing to that from beta ray and was neglected in these calculations. In order to make the standard deviation in each scoring cell within 2%, 4 000 000 particles are simulated for each calculation.

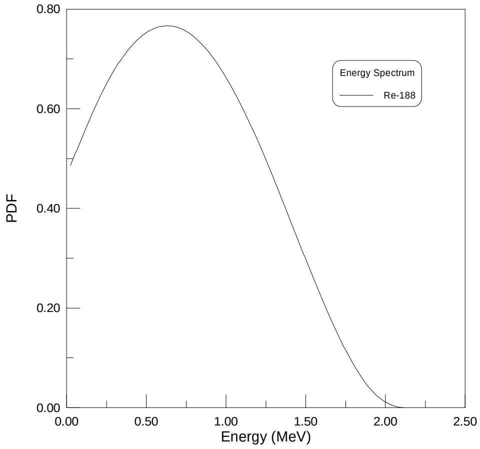

Figure 3. Beta energy spectrum of Re-188

RESULTS AND DISCUSSION

Table 1 gives the absorbed doses to the blood vessel wall for cases of different source diameters. Data in column 2 represent the maximum absorbed doses to blood vessel surface for each case. Data on the third block represent the relative absorbed doses in percentile to the maximum absorbed doses in column 2. The percentile absorbed doses drop rapidly as the distances away from source region increase. It is found that range of beta particle from rhenium-188 solution is around 5 mm; beyond that boundary the absorbed doses drop below 1%.

Figure 4 shows the maximum absorbed doses to the vessel surface for different source diameters, from the data given in column 2 of Table 1. The absorbed dose increases rapidly with the increase of source region size in the beginning, gradually it will come to saturation. If the total activity of rhenium-188 is fixed, it may need to take longer time to deliver the same prescribed dose in the case with larger balloon diameter i.e., case with larger blood lumen diameter. Figure 5 shows an example of the radial distribution of absorbed doses at different axial elevation with source diameter of 3mm. It is also found that the dose curve drop rapidly as beta particles transport away from source regions. The absorbed doses at different elevation of balloon surface are about the same if they are falling into the range bounded by surface of about 4 to 5 mm inside the axial source boundary. And the dose distribution curves varying with the radial distance almost coincide together.

Table 1. Absorbed doses to the blood wall for different source region diameter

Balloon Diameter (mm)	Max. Surface Dose (Gy/sec/Bq/ml)	S+0.5	S+1	S+2	S+3	S+4	S+5	S+6	L-4	L-2	L	L+2	L+4	L+6
0.2	3.02E-12	12.53%	5.81%	2.04%	0.83%	0.34%	0.12%	0.04%	100.09%	99.38%	49.86%	0.68%	0.08%	0.01%
0.5	7.88E-12	23.28%	11.73%	4.26%	1.78%	0.70%	0.25%	0.07%	99.67%	98.35%	49.73%	1.49%	0.19%	0.01%
1	1.51E-11	34.58%	18.85%	7.25%	2.99%	1.17%	0.40%	0.11%	99.60%	96.90%	49.83%	3.05%	0.38%	0.04%
2	2.71E-11	36.52%	26.93%	10.98%	4.48%	1.69%	0.53%	0.14%	99.24%	94.78%	49.74%	5.43%	0.76%	0.08%
3	3.59E-11	51.22%	31.38%	12.88%	5.24%	1.90%	0.59%	0.14%	99.37%	92.84%	49.91%	7.05%	1.11%	0.12%
4	4.24E-11	53.90%	33.67%	13.99%	5.66%	2.01%	0.61%	0.14%	99.03%	91.82%	49.99%	8.12%	1.34%	0.15%
5	4.69E-11	55.70%	34.97%	14.59%	5.79%	2.02%	0.61%	0.14%	98.52%	91.04%	49.74%	8.81%	1.40%	0.14%
6	5.01E-11	56.06%	35.44%	15.16%	5.91%	2.10%	0.64%	0.16%	98.18%	90.48%	49.88%	9.14%	1.58%	0.14%
7	5.21E-11	57.15%	36.31%	15.31%	6.23%	2.15%	0.68%	0.13%	98.25%	90.78%	49.86%	9.37%	1.50%	0.15%
8	5.34E-11	58.19%	36.91%	15.30%	6.33%	2.25%	0.67%	0.17%	99.28%	90.73%	49.89%	9.51%	1.61%	0.19%
9	5.47E-11	57.68%	37.57%	15.75%	6.33%	2.24%	0.65%	0.17%	98.56%	90.05%	49.36%	9.64%	1.65%	0.18%
10	5.52E-11	58.97%	37.87%	16.15%	6.39%	2.23%	0.67%	0.16%	99.10%	90.32%	50.30%	9.78%	1.66%	0.13%
12	5.68E-11	59.09%	38.41%	16.51%	6.79%	2.29%	0.73%	0.14%	97.66%	89.86%	49.30%	9.92%	1.74%	0.17%
15	5.75E-11	59.42%	39.73%	16.91%	6.86%	2.37%	0.72%	0.16%	98.78%	90.33%	50.52%	10.16%	1.62%	0.16%
20	5.90E-11	59.94%	39.85%	17.26%	7.22%	2.50%	0.79%	0.16%	97.65%	89.63%	49.72%	10.35%	1.77%	0.18%

Note: 1. S+a, a=0.5,1,2,3,4,5,6, is the radial distance a mm away from blood vessel surface along Z=0.
2. L+b, b=0,±2, ±4, ±6, is the axial elevation along the vessel surface.

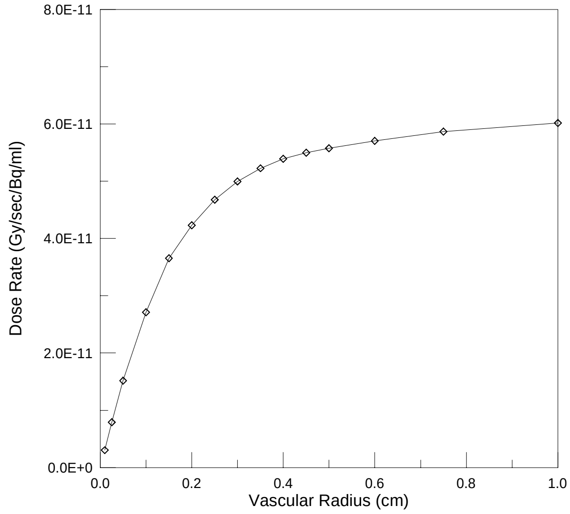

Figure 4. Maximum absorbed doses at vessel surface varied with balloon radius

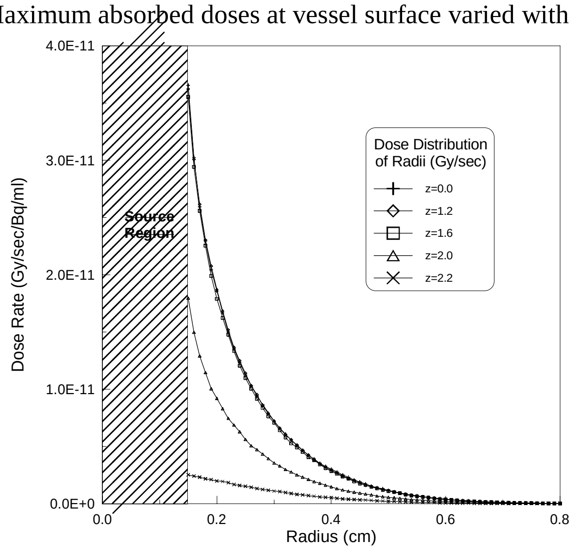

Figure 5. Radial distribution of absorbed doses at different axial elevation for source diameter of 3mm

At the axial edge of balloon catheter the surface absorbed dose is about half of the maximum one since there is no dose contribution from above region. Nevertheless all of them decrease rapidly as radial distance increase. About 0.5 mm away from the balloon surface the absorbed doses drop to about 50%, and as shown in Table 1 the absorbed doses drop to less than 1% at about 5mm away from the balloon surface.

Figure 6 shows an example of the axial distribution of absorbed doses at different radial distance with source diameter of 3 mm. The dose shape keeps flat if it is falling within the surface of about 4 to 5 mm inside the axial source boundary at different radial distance. This might be important to choose suitable balloon length therefore the lesion site of restenosis can be completely covered with adequate dose.

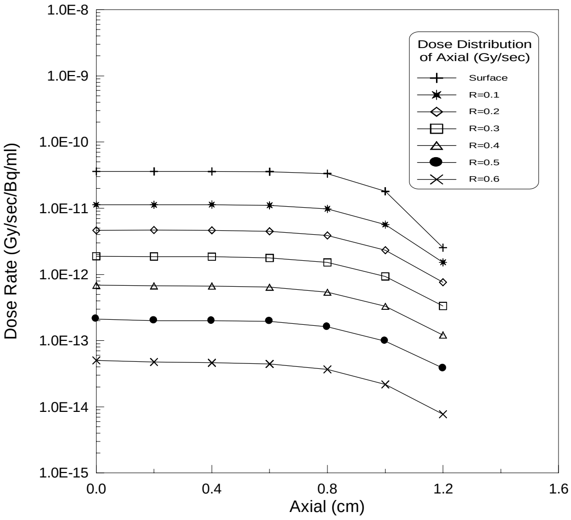

Figure 6. Axial distribution of absorbed doses at different radial distance with source diameter of 3 mm

This preliminary dose calculation is mainly for beta ray application in restenosis preventing study. The calculation is only verified through comparing computing results with the published data. Since the range of beta ray is very limited and the accurate dose to be delivered to the lesion site is crucial for the restenosis preventing effectiveness, it is really important to combine the dose measurement/calibration program altogether with research study in the very beginning. And for future routine practice requirement it is also suggested to establish the dose profile measurement/calibration capability for beta ray irradiation.

REFERENCE

1. R. Waksman and P. Serruys, *Handbook of Vascular Brachytherapy.* Martin Dunitz Ltd., London (1998).
2. R. Waksman, S. B. King, I. Crocker, and R. Mould, *Vascular Brachytherapy.* Nucleatron Corporation (1996).
3. B. T. Hsieh, A. P. Callahan, A. L. Beets, G. Ting, F. F. Knapp, *Ascorbic Acid/Saline Eluent Increase 188Re yields After Wet Storage of W/Re Generators*. APPL. Radiat, Isot.,47(1),23~26 (1996).
4. B. T. Hsieh, C. J. Liu, H. T. Hsieh, Z. T. Tsai, G. Ting, F. F. Knapp, *The Preparation of W-188/Re-188 generator for therapeutic and diagnostic applications*. Nuclear Science Journal, 33(1), 487~499 (1996).
5. F. F. (RUSS) Knapp, Jr. A. P. Callahan, A. L. Beets, S. Mirzadeh, B. T. Hsieh, *Processing of Reactor-Produced Tungsten-188 for Fabrication of Clinical Scale Alumina-Based Tungsten-188/Rhenium-188 Generator.* Applied Radiation and Isotopes, 45(12), 1123~1128 (1994).
6. N. Chen, W. Y. Lin, S. J. Wang, B. T. Hsieh, Z. T. Tsai, G. Ting, *Rhenium-188 Labelling of Lipiodol for Hepatoma Therapy.* European J. Nucl. Med., 22(8), 886 (1995).
7. G. Akabani and J.W. Poston, *Absorbed Dose Calculation to Blood and Blood Vessels for Internally Deposited Radionuclides*, J. Nucl. Med., Vol. 32, No. 5, 830-834 (1991).
8. H. Amoles, L. E. Reinstein and J. Weinberg, *Dosimetry of a Radioactive Coronary Balloon Dilitation Catheter for treatment of Neointimal Hyperplasia*, Med. Phys. 23, 1783-1788 (1996).
9. J.F. Briesmeister, Ed., *MCNP A General Monte Carlo N-Particle Transport Code, Version4B.* . LA-12625-M (1997).
10. K. F. Eckerman, R. J. Westfall, J. C. Ryman, M. Cristy, *NUCDECAY: Nuclear Decay Data for Radiation Dosimetry calculations for ICRP and MIRD*. Radiation Safety Information Computational Center, Oak Ridge National Laboratory, DLC-172 (1995).