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AN EVALUATION OF RADIATION DOSES RESULTING FROM THE MEDICAL USE OF HIGH-ENERGY BETA-RAY SOURCES

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Abstract - Calculational models to evaluate radiation doses resulting from the medical use of high energy beta-ray sources are presented. The radioactive sources considered are Sr-90/Y-90 used as ophthalmic applicator, Re-188 used for treating restenosis of coronary artery, and Ho-166 used for treating hepatic tumors. Typical therapeutic situations which might induce relatively high radiation doses the medical person involved were considered to compute by using MCNP-4C Monte Carlo code the radiation doses. The calculation results suggest that for all of the cases considered, the evaluated radiation doses are negligible compared to the dose limits. It is also found that the effect of Bremsstrahlung radiations on the total dose is insignificant, and hence the conventional lead gown is also effective in shielding beta-rays.

INTRODUCTION

Radionuclides emitting high energy beta-rays have been widely used for therapeutic applications in nuclear medicine. Since the maximum penetration range into the soft tissue of the high energy beta-rays is about a centimeter, high radiation doses can be effectively delivered to narrow target tissues. Beta particles can destroy the malignant tissue without causing adverse effects on the surrounding normal tissue. A number of radionuclides emitting high energy beta-rays are in practical use or on clinical trials in some domestic medical institutions. Among these are Sr-90/Y-90, Re-188 and Ho-166[1].

Sr-90/Y-90, which emits beta-rays with a maximum energy of 2.27 Mev, has been used as a sealed ophthalmic applicator for the postoperative treatment of recurrent pterygia following surgical resection. Presently, more than 10 hospitals are licensed to use the eye applicator. While use of the Sr-90/Y-90 radiation therapy is gradually declining in eye clinical cases, some hospitals still actively use the conventional therapy.

Re-188, which emits a spectrum of beta rays with a maximum energy of 2.11 Mev, has been on clinical trials, especially in Department of Nuclear Medicine, Seoul National University Hospital(SNUHNM), for the treatment of restenosis following coronary angioplasty. The halflife of Re-188 is 17.0 hours and the maximum range in soft tissue of its beta-rays is 10.8 mm. Re-188 also emits a spectrum of gamma rays[2].

Ho-166 has been also on many clinical trials for internal radiation therapy, especially for treating hepatic tumors in Yonsei University Medical Center. Ho-166 emits 97% of 1.78 and 1.87 Mev beta rays and a small portion(4%) of gamma rays which can be used for gamma camera imaging. Its halflife is 26.9 hours and the maximum range in soft tissue of its beta-rays is 8.7 mm (average 2.1 mm).[1] The favorable physical characteristics described above make both Re-188 and Ho-166 suitable candidates for internal radiation therapy[3].

In spite of the frequent clinical uses of the beta sources, few attempts have been made to evaluate the radiation doses delivered to the therapist during the radiation therapies. This ignorance may be due to the assumption that beta-rays be easily shielded by usual protective measures such as a lead gown, so that they contribute very little doses to the person involved. This assumption may not be valid for the above beta-ray sources since considerable amount of Bremsstrahlung X-rays may be produced in the protective shields. Furthermore, Re-188 and Ho-166 emit some portion of gamma-rays. In this article, we present models used to evaluate radiation doses which can be delivered to a therapist under typical therapeutic situations. We consider therapeutic situations of the Sr-90/Y-90 ophthalmic applicator, Re-188 used for treating coronary restenosis in SNUHNM, and Ho-166 used for the treatment of hepatic tumors in Yonsei University Medical Center. We employ the MCNP-4C Monte Carlo computer code[4] for the analytical calculations. We have conducted computations for various cases for each source, but only present the some of results in this paper.

THERAPEUTIC SITUATIONS

1. Sr-90/Y-90 Ophthalmic Applicator

The ophthalmic applicator is composed of a stainless steel bar with a thin Sr-90/Y-90 disk source attached on one tip of the bar. The other end part of the bar is used as the handle. When not in use the applicator is kept in a locked container. Radiation doses are delivered to the lesion by keeping the active surface just above patient's eye for a predetermined time. The applicator shall always be held in such a manner that it is always pointing away from all persons except the patient. During the treatment, the patient lies on a bed facing upward. The therapist is standing by the bed which is about the height of the therapist's knees while keeping the applicator downward. Thus, in normal therapeutic positions, the therapist receives very little radiation doses since the back surface of the source is thicky shielded by the steel bar. In abnormal circumstances such as dropping of the applicator, however, the active surface may directly point toward the therapist or other attending persons. We consider this situation for the evaluation of radiation doses to the therapist during a Sr-90/Y-90 treatment.

The ophthalmic applicator model considered is an Amersham product which has an source diameter of 9 mm and thickness of 0.008 cm, and a steel cover of 4.6 mg/cm^2 thickness (0.001 cm)[5]. It is assumed that the therapist wears a lead gown which has an effective thickness of 0.05 cm. The therapist is modeled as a cylinder of 34 cm diameter and 170 cm height, filled with soft tissues. The activity of the source is assumed to be 55 mCi and the exposure time is 60 seconds. Fig. 1 shows the geometric model used for the MCNP-4C calculation of this case.

2. Re-188 Source

We consider the therapeutic procedure developed by Department of Nuclear Medicine, Seoul National University Hospital(SNUHNM). Re-188 is eluted in chemical form of $NaReO_4$ in physiological salt solution from a Tungsten-188/ Re-188 generator. A balloon catheter is inserted up to the coronary artery where treatment for the restenosis is intended. The Re-188 solution is loaded into a big syringe, which is then connected to a specially designed injector. The syringe and the injector are contained in a shield box made of acrylic plates. Use of acrylic plates is intended to shield the high energy beta-rays from Re-188 without producing much Bremsstrahlung X-rays. The liquid Re-188 is injected into the balloon catheter by manually pressing the injector piston outside the shield box. The Re-188 solution flows through a long plastic tube which is connected from the injector to the catheter. Relatively high radiation dose is expected to the therapist while the injector is operated.

In this case we evaluate the radiation dose from the loaded syringe in the shield box. Since Re-188 also emits gamma rays, considerable radiation dose may result from the gamma rays. Fig. 2 shows the computation model of this case. It is assumed that medical person in sitting position is represented by a cylinder of 34 cm diameter and 80cm height, and stays 30 cm apart from the shield box. The size of the loaded syringe is 10 cm long and 0.9 cm inner diameter. The size of the acrylic shield box is 30x20x10cm, and thickness of the plates is 1cm. Typical amount of Re-188 radioactivity injection is 100-150 mCi in solution, and hence we take 150 mCi for the loaded source. The exposure time is 30 seconds.

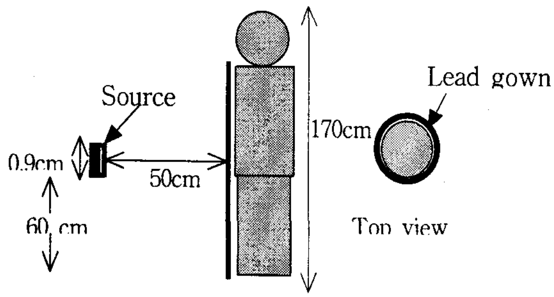

Fig. 1. The geometric model of abnormal therapeutic position of Sr-90/Y-90

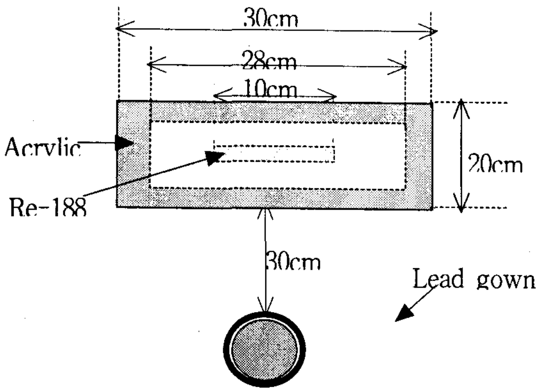

Fig. 2. The geometric model of computing the dose during Re-188 injection

3. Ho-166 Source

We consider the therapeutic procedure followed by Yonsei University Medical Center, where it is used as therapeutic agent for the treatment of hepatic tumors. Ho-166 is produced from Ho-165 by Ho-165(n,γ)Ho-166 reaction at HANAO facility and delivered in the form of $^{166}Ho(No_3)$ solution to the medical institution at the same day it is used. Upon arrival, the radioisotopic solution is mixed with acidic chitosan solution to produce Ho-166 chitosan complex around pH4, or ^{166}Ho-CHICO. While the Ho-166 chitosan complex maintains a sol state under pH4, it becomes gelled as its acidity decreases. This property change can occur when it is injected into a lesion where its acidity is neutralized by body fluid, so that it can be well confined in the lesion destroying the tumoral tissue[6].

In Yonsei Medical Center, the Ho-166 chitosan complex is directly injected under ultrasonic guidance into the tumor center through a long puncture needle. The process is fast and very simple. It is observed that relatively high radiation dose can occur during injection of the agent. Most of the dose is to the hand of the therapist holding the injecting syringe. In order to reduce the radiation doses, the whole prescribed amount of radioactive chitosan is distributed into several syringes with each containing 20-30 mCi. It takes about 5 seconds to finish the injection of a syringe. We considered a tumor size of 3 cm diameter which requires injection of 50 mCi of Ho-166 chitosan complex. For this case, 2 syringes of 25 mCi each are needed, and the total injection time is 10 seconds. In order to evaluate the dose to the therapist's hand, we construct a computation model as shown in Fig. 3. The hand is represented by a center-holed slab disk with a rubber cover. The thickness of the disk is 2 cm and the diameter is 14.4 cm. The thickness of the rubber cover is 0.05 cm. The syringe is modeled as a PVC tube of 7 cm long, 0.4 cm in diameter and 0.1 cm thick. It is plugged into the center hole of the slab disk. It is assumed that only the unplugged part of the syringe is filled with the radioactive Ho-166 source.

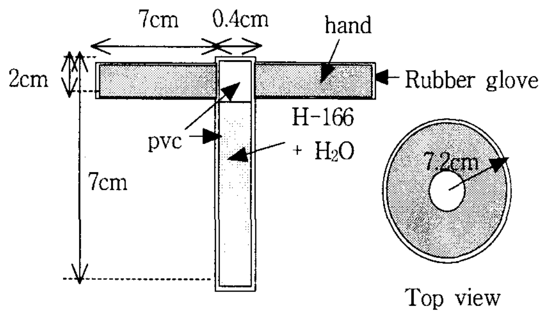

Fig. 3. The geometric model of computing the doses to hand during Ho-166 injection

RADIOLOGICAL DATA

1. Energy Spectra

The maximum-energy spectra of beta-rays emitted from the 3 sources are given in Table 1. For Sr-90/Y-90 source, Sr-90 emits 0.54 Mev and Y-90 emits 2.28 Mev beta particles. Since the two radionuclides are in secular equilibrium both beta rays are emitted at the same frequency. For Ho-166, 1.778 Mev and 1.868 Mev comprises 97.7%. For Re-188, 2.12 Mev and 1.965 Mev comprises 96.7%. Since each beta ray has a continuous energy spectrum below the maximum energy, we used the energy spectra provided by Nuclear Data Lab of KAERI. Re-188 and Ho-166 also emit gamma rays of various energies. Table 2 shows the gamma energy spectra used for this study.

2. Fluence-to-Dose Conversion Factors

MCNP code basically computes the particle fluence (#/cm^2) at target points or volumes. In order to convert the particle fluence into dose rates one needs to specify the fluence-to-dose conversion factors in the input data. We use the fluence-to-dose conversion factors provided in ICRP-74[7].

Table 1. The maximum-energy spectra of beta- ays from Sr-90, Ho-166, Re-188

sources	maximum energy of beta-rays (Mev)	fraction (%)
Sr-90	0.54	100
	2.28	100
Ho-166	0.191 0.394 1.778 1.868	0.307 0.95 47.7 50.0
Re-188	0.658 1.034 1.487 1.965 2.12	0.44 0.63 1.65 25.6 71.1

Table 2. The energy spectra of gamma rays from Re-188 and Ho-166

sources	gamma energy (Mev)	fraction (%)	gamma energy (Mev)	fraction (%)
Ho-166	8.0574E-02	6.71E-02	1.3794E+00	9.30E-03
	1.8440E-01	2.00E-05	1.4476E+00	9.80E-06
	5.2080E-01	3.30E-06	1.5282E+00	2.00E-06
	6.7400E-01	1.94E-04	1.5819E+00	1.87E-03
	7.0530E-01	1.31E-04	1.6625E+00	1.20E-03
	7.8589E-01	1.19E-04	1.7499E+00	2.77E-04
	1.2631E+00	1.40E-05	1.8305E+00	8.50E-05
Re-188	1.5504E-01	1.5137E-01	8.2947E-01	4.1004E-03
	4.7799E-01	1.0200E-02	9.3135E-01	5.5284E-03
	6.3298E-01	1.2730E-02	1.3080E+00	6.4974E-04
	6.3498E-01	1.4749E-03	1.6104E+00	9.7512E-04
	6.7254E-01	1.1128E-03	1.8020E+00	3.6312E-04

COMPUTED RESULTS

1. MCNP-4C Models

MCNP-4C code can compute the transport of electrons and gamma rays simultaneously. We consider photon interactions of Compton scattering, pair production and photoelectric effects. For electron transport, Coulomb interaction, Bremsstrahlung and secondary electron generation are considered. The tracing cutoff energy is set at 10 kev for both photons and electrons. For variance reduction, source biasing(direction and energy) and Bremsstrahlung biasing options are used.

2. Results and Discussions

The radiation doses expected to be received by a therapist who is placed in the therapeutic situations as described above are evaluated as shown in Table 4. For Sr-90/Y-90 ophthalmic applicator, the case considered is when the applicator is accidently pointed toward the therapist. The Re-188 case shows the dose to be received while the therapist is operating the injector piston. The Ho-166 case is the dose to be received by one hand of the therapist while he is injecting the Ho-166 chitosan complex.

Each case shows radiation doses delivered to the whole detector volume by photon and electron including Bremsstrahlung radiations. Since the doses are computed at terminal detector point, it is not possible to distinguish out the contribution of Bremsstrahlung radiations produced in the course of particle transport. The total dose is the product of unit dose rate and therapy time and typical activity, which indicates the whole dose to be received during a specified treatment activity. The relative error is indicates reliability of the computed results. When the value is less than 0.1, the computed result is reliable.

It is found that for the ophthalmic applicator, an accidental wrong placement pointing toward a person wearing a lead gown gives only 0.002 mSv for 1 minute. This implies that the conventional lead gown which is used for gamma ray shielding is also effective in shielding beta-rays, and Bremsstrahlung radiation is not of concern. For the Re-188 case, the contribution of photons is greater than that of electrons. This can be explained by that the gamma rays have penetrated the acrylic shield box more than the beta-rays. The expected dose is about 0.007 mSv for one therapy. If the therapist assumes 100 treatments a year, he would receive a total of 0.7 mSv, which is well below the occupational dose limit of 20 mSv/year. It is even less than the limit of 1 mSv/year pertaining to a general person. For the Ho-166 case, electron dose rate is greater than the photon dose rate. This implies that an ample portion of the beta-rays can penetrate the PVC syringe wall. The radiation dose delivered to one hand of a therapist is 0.11 mSv. If a therapist administers 100 treatments a year, he would receive 11 mSv in his one hand. This value is well below the annual occupational dose limit of 500 mSv to hand.

Table 4. The computed results of radiation doses to the therapist

Cases	unit dose rate(mSv/sec/mCi)			typical therapy time (sec)	typical activity (mCi)	total dose (mSv)	relative error	
	photon	electron	total				photon	electron
Sr-90/ Y-90	1.5E-17	6.9E-7	6.9E-7	60	55	2.2E-3	0.005	0.042
Re-188	1.5E-6	1.1E-8	1.5E-6	30	150	6.8E-3	0.002	0.057
Ho-166	1.1E-5	3.4E-4	3.5E-4	10	30	1.1E-1	0.003	0.007

CONCLUSIONS

We have presented calculational models to evaluate radiation doses resulting from the medical use of high energy beta-ray sources. The radioactive sources considered are Sr-90/Y-90 used as ophthalmic applicator, Re-188 used for treating restenosis of coronary artery, and Ho-166 used for treating hepatic tumors. Typical therapeutic situations which might induce relatively high radiation doses the medical person involved were considered to compute by using MCNP-4C Monte Carlo code the radiation doses. Our calculation results suggest that for all of the cases considered, the evaluated radiation doses are negligible compared to the dose limits. It is also found that the effect of Bremsstrahlung radiations on the total dose is insignificant, and hence the conventional lead gown which is used for gamma ray shielding is also effective in shielding beta-rays.

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