방사선방어학회지
제6권 제1호 1981

고 에너지 방사선 치료실의 차폐계산과 누출선량의 측정

연세대학교 의과대학 방사선과학교실

추 성 실 · 박 창 윤

Measurement of Leakage and Design for the Protective Barrier of the High Energy Radiation Therapy Room

Sung Sil Chu, Ph. D., Chang Yun Park, M.D., D.M.Sc.

Department of Radiology & Nuclear Medicine Yonsei University College of Medicine. Seoul, Korea.

국 문 요 약

방사선 치료를 위한 의료용 13 MeV 선형가속기를 설치 사용함에 따라 종사자에 대한 피폭방어를 비롯한 제반 설비구조의 설계가 중요하므로 저자들은 방사선 차폐벽과 시설구조를 법에 정해진 최대 허용선량을 초과하지 않도록 계산하여 건축했으며 고에너지 선형가속기를 가동한 이후 실재 누출선량과 종사자의 피폭량을 측정하여 상호 검토하였다.

1) 방어벽의 계산은 NCRP #34 (1970)을 기초로 하였으며 이것이 가장 간단한 방법이고 경제적이었다.
2) 가속기 가동이후의 차폐벽으로부터 누출된 선량측정치는 계산에 의해 계획된 누출선량치의 약 $\frac{1}{5}$ 로 줄었으며 이는 치료환자의 수와 가장 안전한 수치를 사용했기 때문이었다.
3) 가속기에 의하여 방사선을 발생시키고 있는 동안 출입문 밖과 조종실 내에서의 누출선량율은 2—10mR/hr이었다.
4) 장시간 방사선을 발생시키거나 공기 조절장치의 성능이 약해졌을때 치료실내의 오존냄새가 예측 의외로 심하였다.

Abstract

The logical development of an optimum structural shielding design and the computation of protective barriers for high energy radiation therapy room, Toshiba 13 MeV. are presented.

We obtained following results by comparison in between the precalculating values and actual survey after complete installation of radiogenerating units.

1. The calculating formula for the protective barrier written in NCRP report #34(1970) was the most ideal and economic calculating methods for the construction of barrier and to determine thickness for the meeting requirements of the number of patients of 80—100 in daily treatment.
2. The precalculating values of protective barrier are 5 times more protective than that of

actual measurement.

It is depending on radiation workload and utilization the datas most sequrely.

3. The dose rate during exposure are 2—10 mR/hr at out of the door and the controll room.
4. The foul smelling and ozone gas production from long exposure of cancer patients cannot be eliminated when the room is ill ventilated.

I. INTRODUCTION

The linear accelerator for radiotherapy was installed in Yonsei Cancer Center at first in Korea in 1974, and then it was contributed to treate the tumors of cancer patients, otherwise, it was threatened for radiotherapist, technician, and other occupationally persons.

Authors designed the therapy room to protecte the exposure doses from high energy linear accelerator and measured the leakage doses through the tube housing after completely installation.

The primary protective barriers must be provide for those portions of the walls, floor and ceiling at which the radiation beam can be directed.

The barriers including the maze must provide adequate protection from scattered radiation and radiation leaking through the tube housing.

In addition, the high energy radiation has possible to nuclear reaction by collison with matters and tissue, and then, the induced radiation cannot be regreted for persons to radiation exposure (Fig. 1).

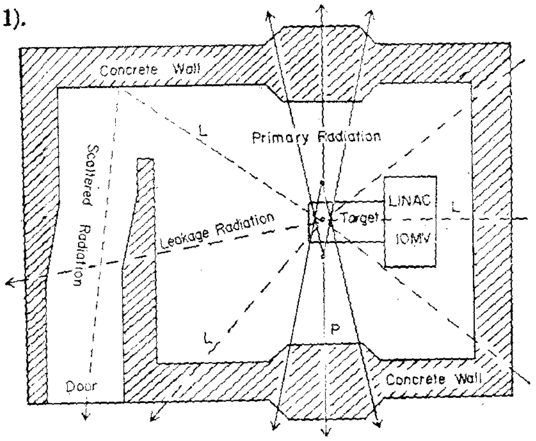

Fig. 1. Protection from high energy radiation
—— Primary beam — — Leakage beam
……Scattered beam

Also the high energy radiation produce the ozone and nitrogen oxides through air ionization to hazards resulting for persons.

Therefore, the design of high energy therapy room considered carefully for protective barriers.

II. PRINCIPLE OF PROTECTION

1. Maxinum Permissible dose

The degree of protection aimed as such as to maintain the total occupational exposure of monitored staff at less than 100mR/week and that of unmonitored staff at less than 10 mR/week

2. Energy and output of linear accerator

Rotation gantry mounted 13 MeV Linear accelerator, Toshiba LMR-13, Produced 10MV X-Ray and 8, 10, 13 MeV electron beam. The out put dose rate at 1m from the target is 200—400rads/min for the electron beam.

3. The workload

The workload is total irradiated doses at 1m from target during a week.

If daily dose irradiated individualy patients is 300 rads and number of daily treated patients are 80, the treatment days are 6 in a week, and the multiple factor for large field long distance irradiation is one and a half, then the total workload in week with linear accelerator are 2.16×10^5 rads/wk.

4. Use factor and occupancy factors for primary protective barriers.

The use factor of rotating machine for the therapy installation is following.

1) floor : 1
2) walls : 1/4

3) ceiling : 1/4

The occupation factor in areas adjacent to the radiation room is following

1) full occupancy : 1

work areas such as offices, laboratories, shops, warde and occupied space in nearby buildings

2) Partial occupancy : 1/4

restroom, corridors, elevators using operators

3) Occasional occupancy : 1/16

waiting room, toilets, stairways.

Ⅲ. COMPUTATION OF BARRIER REQUIREMENTS

1. Barrier against primary radiation

The weekly exposure E_p from the primary radiation at the point of interest, which is at a distanc d_p from the target is related to workload the exposure dose per week at one meter from target, by following equation

$$E_p = \frac{WUT}{d^2_p} \qquad (1)$$

Where U is the use factor irrediated fraction of the total beam on time of the equipments at the point of interest and T is the fraction of the total beam on-time in the anticipated occupancy of the point of interest.

If E_p is greater than the permissible weekly exposure, P, a primary barrier of sufficient thickness to give a transmission factor of F_p, must be

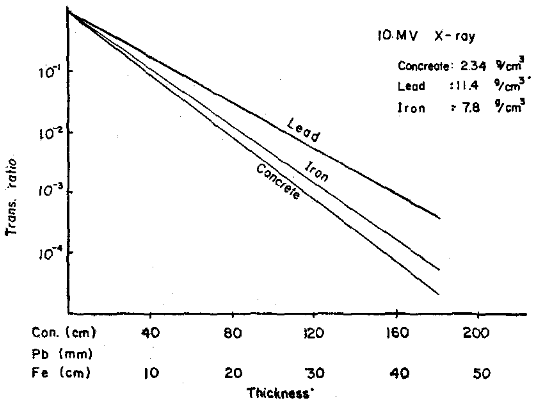

Fig. 2. Transmission factor for thickness of concrete, iron and lead.

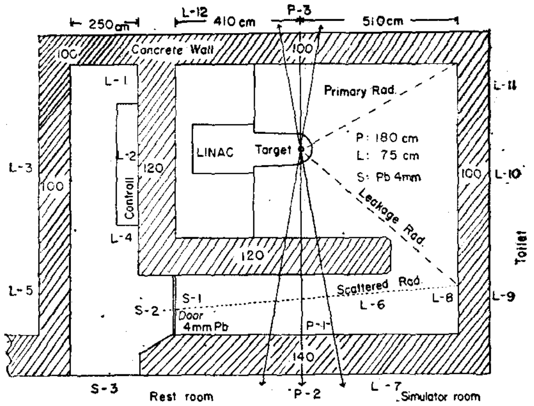

Fig. 3. Plan view of treatment room showing protective barriers and interesting points.

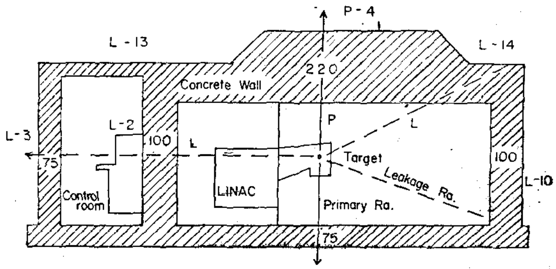

Fig. 4. Vertical section of treatment room showing protective barriers and interesting points.

inserted into the beam between the source and the point of interest, then

$$F_p = \frac{WUT}{d^2_p} \qquad (2)$$

The figure 2 is the curve showing the relation between F_p and the required barrier thickness.

The barrier thickness by primary radiation is calculated as 180cm concrete shown in Fig. 3, 4.

2. Barrier against leakage radiation

The therapeutic type protective tube housing for high energy X-ray therapy equipment have in their design a limitation on the amount of leakage radiation as 0.1 percent of the useful beam dose rate at one meter from the source, thus, the weekly leakage exposure at the point of interest, which is at a distance d_p from the source of radiation, would be

$$E_l = \frac{0.001\ WUT}{d^2_s} \qquad (3)$$

Table 1. Scattering Ratio For 10 MV X-Ray

Scattered Angle	Ratio
10	1.1×10^{-2}
30	7.8×10^{-3}
45	1.9×10^{-3}
60	1.2×10^{-3}
90	7.3×10^{-4}
135	5.1×10^{-4}

Table 2. Estimation of Protective Barrier

Radiation	Interesting point	Distance m	Concrete Thickness cm	Estimated Leakage Dose mR/W
Primary	P—1	4.0	120	1.3×10^{3}
	P—2	8.0	260	9.0×10^{-1}
	P—3	4.0	100	1.0×10^{3}
	P—4	5.3	210	1.4×10^{2}
Leakage	L—1	6.0	135	1.5×10
	L—2	5.2	120	6.5×10
	L—3	8.5	220	1.5×10^{-2}
	L—4	6.0	140	1.4×10
	L—5	10.0	250	5.2×10^{-2}
	L—6	6.0	170	4.3×10^{3}
	L—7	8.0	280	1.1×10^{-1}
	L—8	4.5		1.2×10^{4}
	L—9	8.0	130	1.7×10
	L—10	6.2	100	1.4×10^{2}
	L—11	6.6	110	1.2×10^{2}
	L—12	5.0	120	7.0×10
	L—13	6.0	150	9.8×10^{-1}
	L—14	6.5	150	7.3×10^{-1}
Scattered	S—1	6.0	165	3.5×10^{2}
	S—2	7.0	165	6.9×10
	S—3	10.0	Pb 4mm	2.1×10

Where W is the workload in rads/week at one meter from target.

At the point of interest, the barrier having a transmission factor F_1 is required to reduce the permissible weekly exposure top, thus

$$F_1=\frac{1000P\ D^2_s}{WT} \qquad (4)$$

Since U is equal to unity for leakge radiation The barrier thickness by leakage radiation is calculated as 75cm concrete shown in table 1

3. Barrier against scattered radiation

Radiation scattered from an irradiated object has a much lower exposure rate than that of the incident radiation and usually is lower energy.

The ratio, A, of the scattered to incident exposure is a function of energy and scattering angle, The numerical values are given in table 2.

Since the exposure dose rate E_s of scattered radiation. measured at one meter from the scatterer is propertional to S, irradiating field size, and S', total field size faced on interesting points.

The exposure dose from the scatterer, E_s, at the interesting points which is at the distance of d_s from the scatterer, is related to the workload, by following equation

$$E_s=\frac{SW+S'W'}{d^2_p\ d^2_s}AU \qquad (5)$$

The transmission factor, F_s needed to calculate the thickness of protective barrier for scattered radiation from high energy radiation is given by

$$F_s=\frac{P\ d^2_p\ d^2_s}{A(SW+S'W')} \qquad (6)$$

Ⅳ. ACTUAL MEASUREMENT OF LEAKAGE DOSE

1. The methods of measurement

We used following equipment for exposure dose and low dose rate

thermoluminescent dosimeter
Photoluminescent dosimeter
survey meter
scintillation counter
pocket dosimeter
monitering dosimeter
tissue equivalent phantom

There were installed on the point of interest and measured the integral dose and exposure rate during beam irradiation. Figure 5 is the picture to measure the air exposure on interesting points by 10MV X-ray openfield

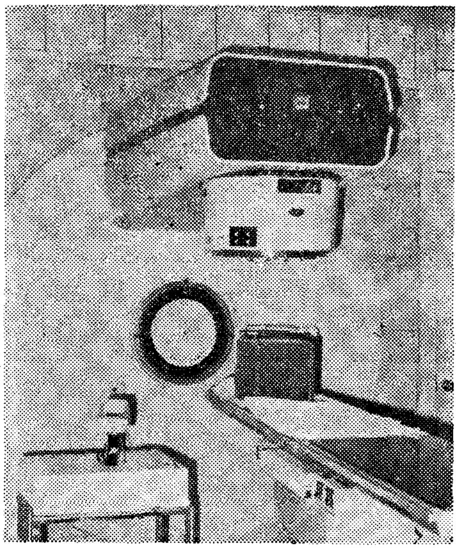

Fig. 5. The view of measuring of exposure dose from target in treatment room

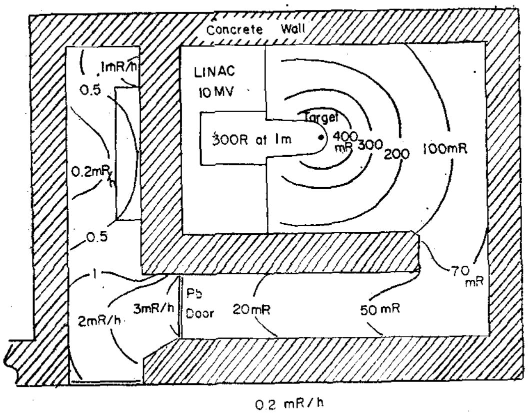

Fig. 6. Air exposure in treatment room when irradiating 300 R at 1m from target.

2. Exposure dose in radiation therapy room

For measuring of scattering and leakage dose in therapy room, the radiodetectors; TLD, pocket dosimeter, PLD, survey meter etc., is installed at the interesting points at 120cm from floor and measured the exposure dose during operation about 300 rads, field size 30×30cm, at 1m from 10MV X-ray target.

Exposure dose distribution of therapy room is shown in figure 6.

3. Radio-activation measurement.

The induced radiation from tangsten target by 10 MV X-ray beam is measured with scintillation counter and was recorded 0.4mR/hr after 2000 rads irradiated at 1m from target and it's decay curve is shown in figure 7 and the half life are concidered as 4 minute and 24 hours

4. Actual survey of leakage dose on the points of interest.

The exposure dose in week and dose rate on operating for the interesting points are measured with film badge. TLD, PLD ect., and as shown in Table 3

The values of actal measuring are less than computation by NCRP #34 about one fifth.

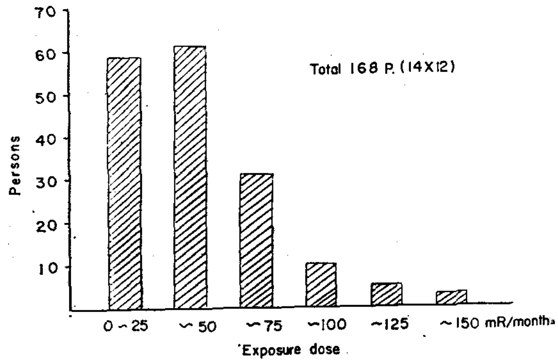

Fig. 7. Decay curve by induced radiation from target.

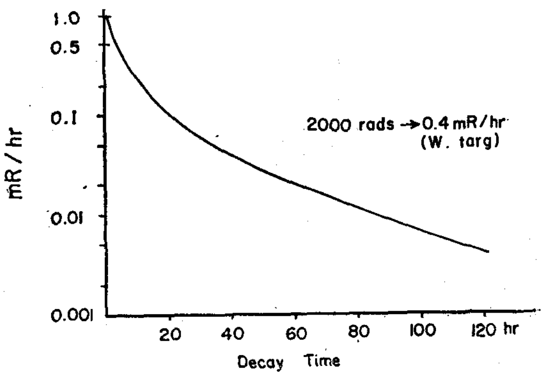

Fig. 8. The exposure dose for occupationally persons.

Table 3. Actual Measurement of Leakage Doses

Radiation	Interesting Point	Leakage Doses mR/w	Leakage Dose Rate on Operation mR/hr	Occupation
Primary	P— 2	0.7	0.2	Rest Room
Leakage	L— 1	4.0	0.8	Control Room
	L— 2	2.9	0.5	Control Room
	L— 4	3.8	0.7	Control Room
	L— 9	2.3	0.4	Simulating Room
	L—10	4.7	1.0	Toilet
Scattered	S— 2	12.6	2.5	Door
Leakage	S— 3	6.5	1.2	Outside Door

$F = \frac{\text{Measuring Doses}}{\text{Calculating Doses}} = 1/5$

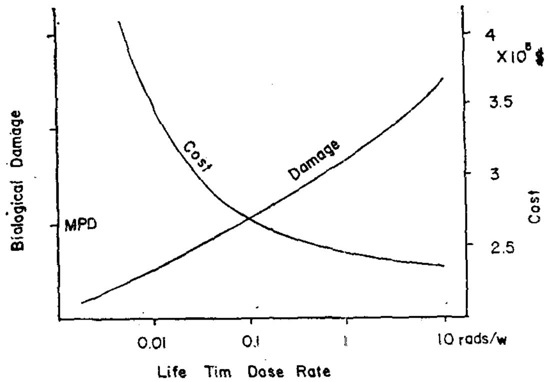

Fig. 9. The generating of ozone gas by high energy radiation

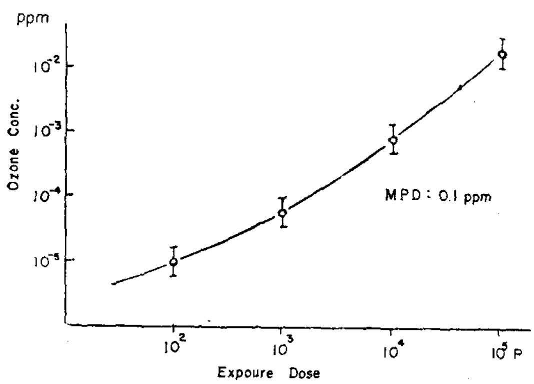

Fig. 10. Comparison of exposure dose and installed cost of barriers.

5. Exposur dose for occupationally persons

The average exposure dose in every month is 10—50 mR/month and the persons who are exposure about 50—120 mR/month are few as shown in Fig. 8 but it's values are very small than maximum permisible dose

6. Measurement of ozone gas

When the exposure dose was large and prolonged, the noxious and smelling gases were generated and the ozone gas could be measured as shown in figure 9.

The concentration of noxious gases within the treatment room are effected by the beam current, duration of exposure, distance from extraction point to far wall, volume of air in treatment room.

7. Comparison leakage doses and installing cost for protective barrier

It is not possible to complete protection of radiion but the protective barriers must be designed to decrease under maximum permissible dose.

The barrier thickness of 10 MV X-ray are calculated as 70—80cm concrete wall, that is corresponded to 250,000$. If the leakage dose is reduced as one fifth, the cost of installation need more than 50,000$. The relation of installed cost and leakage dose is shown in figure 10.

V. CONCLUTION

The protection of leakage exposure dose from high energy radiation are very important, to installed in the radiation therapy room.

The transmitting power of high energy radiation is very strong, and then the leakage and scattered doses are comparative large. Therfore occupationally persons in therapy section must be worked under maximum permissible dose and the authors designed the therapy room and computation of protective barriers for linear accelerator, Toshiba LMR-13.

The comparison and discussion for the protective barrier between precalculation and actual measurement through a few year after installation.

1. The transmitted radiation by actual measurements was about 5 times less than that of calculating by NCRP #34 for the protective barriers
2. Design of protective door is difficult, than the leakage dose rates during exposure are 2—10mR/hr at out of door.
3. Induced radiation from target is contaminated at collimeter immediately after exposure, about 0.2—0.5mR/hr.
4. Radiation exposures are prolonged, it may be necessary to provide for very high ventilation to remove ozone concentration.

REFERENCES

1. National Committee on Radiation Protection and Measurements, Protection against radiations from sealed gamma source. NCRP Report No. **24**, 1960.
2. National Committee on Radiation Protection and Measurements, Medical X-ray protection up to three million volts. NCRP Report No. **26**, 1961.
3. National Council on Radiation protection and Measurements, Medical X-ray and ga mma ray protection for energies up to 10 MeV, structural shielding design and evaluation. NCRP Report **34**, 1970.
4. International Commission on Radiation Units and Measurements. Radiation Quantities and Units. ICRU Report **11**, 1968.
5. C.J. Karzmark and T. Capone. Measurements of 6MV X-ray, Part I. Primary radiation absorption in Lead, Steel, and Concrete. *Brit. J. Radiology* **41**, 33, 1968.
6. W. Miller and R.J. Kennedy. Attenuation of 86 and 176 MeV synchrotron X-rays in Concrete and Lead. Radiation Research **4**, 360, 1956.
7. W.W. Evans, R.C. Granke, K.A. Wright and J.G. Trump. Absorption of 2 MeV constant potential roentgen rays by Lead and Concrete. Radiology **58**, 560, 1952.
8. D. Greene and S.K. Stephenson. The design of a treatment room to house a gantry mounted 4 MeV Linear accelerator. *Brit. J. Radiology* **36**, 640, 1961.
9. K.R. Kase. Radioactive gas production at 100 MeV electron LINAC facility. *Health Physics* **13**, 869, 1967.
10. P.A. Roys. Penetration of 6 MeV gamma rays in water. *Phy. Rev.* **95**, 911, 195.
11. P.E. Asard. Radiation protection measurements for a 17 MeV betatron. *ACTA Radiologica* **7**. 59, 1968.
12. L.V. Spencer. Theory of electron penetration. *Phy. Rev.* **98**, 1597, 1955.
13. H.H. Seliger. Transmission of positron and electrons. *Phy. Rev.* **100**, 1029, 1955.
14. F.L. Herford and C.P. Swann. The maximum range of high energy electrons in aluminium and copper *Phy. Rev.* **78**, 727, 1950.
15. R. Wilson. The range and straggling of high energy electrons. *Phy. Rev.* **84**, 100, 1951.