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# The fetal dose outside therapeutic radiation beam: Safety distance

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**Background** : *The Radiation Oncology Section, Department of Radiology was presented with a young female patient, who was apt to later become pregnant. The fetal radiation dose was the question.*

**Objective** : *To measure the scattered dose level outside the x-ray beam at fetal in Rando phantom using thermoluminescent dosimeters. To determine the safety distance for a fetus.*

**Setting** : *Department of Radiology, King Chulalongkorn Memorial Hospital*

**Design** : *Experimental study*

**Material** : *A female phantom, thermoluminescent dosimeters and a linear accelerator (Clinac 1800).*

**Methods** : *Measuring the scattered dose from 6 and 10 MV x-rays, beam area 10 x 10 $cm^2$ and 20 x 20 $cm^2$ at fetal position which is 5-50 cm away from the primary beam. Calculate the average fetal doses and the standard deviation.*

**Results** : *The scattered at fetal position depends on the distance and the area of the primary beam rather than the energy. The threshold dose for fetus is 0.1 Gy. When the mother receives 60 Gy, beam area of 10 x 10 $cm^2$ and 20 x 20 $cm^2$, the safety distance for him is at least 22 cm and 28 cm away from beam edges respectively.*

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**Conclusion** : *The dose level outside the useful beam depends on the distance between the point of interest to the fetal position. The results can also be used to determine the safety distance for other sensitive organs.*

**Key words** : *Radiation oncology, Radiation protection, Fetal dose.*

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**เหตุผลการทำวิจัย** : *หน่วยรังสีรักษา ภาควิชารังสีวิทยา ได้รับรักษาผู้ป่วยหญิงวัยเจริญพันธุ์ ซึ่งคาดว่าจะตั้งท้อง ค่าปริมาณรังสีที่ทารกจะได้รับเป็นคำถามที่เกิดขึ้น*

**วัตถุประสงค์** : *วัดระดับปริมาณรังสีสะท้อนนอกลำรังสีเอกซ์ที่ทารกได้รับในหุ่นจำลอง โดยใช้เครื่องวัดปริมาณรังสีชนิดเทอร์โมลูมิเนสเซนส์ และระยะห่างที่ทารกปลอดภัย*

**สถานที่ที่ทำการศึกษา** : *ภาควิชารังสีวิทยา โรงพยาบาลจุฬาลงกรณ์*

**รูปแบบการวิจัย** : *การศึกษาย้อนหลังและการทดลองตรวจวัด*

**วัสดุที่ใช้ในการทดลอง** : *หุ่นจำลองเพศหญิงและ เครื่องวัดปริมาณรังสีชนิดเทอร์โมลูมิเนสเซนส์ และเครื่องเร่งอนุภาค (คลิแนค 1800)*

**วิธีการศึกษาวัดผล** : *วัดปริมาณรังสีสะท้อนที่ตำแหน่งของทารก คำนวนค่าเฉลี่ยและค่าเบี่ยงเบนมาตรฐาน เมื่อมารดาได้รับการฉายรังสีพลังงานสูง 6 และ 10 ล้านโวลต์ที่ระยะห่างจากตำแหน่งของทารกระหว่าง 5-50 ซ.ม. ขนาดของลำรังสี 10 x10 ซ.ม.$^2$ และ 20 x 2 0 ซ.ม$^2$*

**ผลการศึกษา** : *ระดับปริมาณรังสีสะท้อนที่ทารกได้รับขึ้นกับระยะห่าง และขนาดของลำรังสี ค่าปริมาณรังสีที่ปลอดภัยสำหรับทารก 0.1 Gy เมื่อมารดาได้รับรังสี 60 Gy ทารก ควรอยู่ที่ 22 ซ.ม. และ 28 ซ.ม. จากขอบของลำรังสี ขนาด 10 x 10 ซ.ม. $^2$ และ 20 x 20 ซ.ม. $^2$*

**วิจารณ์และสรุป** : *ระดับปริมาณรังสีสะท้อนนอกลำรังสีเอกซ์ขึ้นอยู่กับตำแหน่งที่สนใจ ผลการทดลองสามารถประยุกต์ใช้ได้กับการหาระยะที่ปลอดภัยของอวัยวะอื่น ๆ ที่ไวต่อรังสี*

The Radiation Oncology Section of King Chulalongkorn Memorial Hospital was presented with a 22 year old female patient for treatment of Hodgkin's disease. It was decided to irradiate the lymphatic chains with the mantle field. The absorbed dose outside of the radiation field is clinically important, potentially affecting gonadal function. Fetal development might be abnormal if the patient become pregnant. This outside dose can also be responsible for radiation-induced carcinogenesis in other exposed tissue. Beir III[1] reported that single doses of 10 cGy can produce damage in a fetus and the threshold is 5 cGy. Radiogenic mental deficiency occurs during the gestational age of 8-15 weeks with a decreasing of 7-13 IQ points per Gy.[2] The increase in relative risk for breast cancer[3] in women exposed to ionizing radiation is about 0.5%/ cGy while the threshold is 100 cGy. Dose levels down to 200 cGy had been found to cause cataracts.[4] Sterility in males may be caused by single doses on the order of 300 cGy.[1] The dose level of clinical concern can thus vary from 5 cGy to 300 cGy or 0.08% to 5% relative to a total treatment dose of 60 Gy. A study of the outside dose down to a level of 0.1% of the central ray peak dose is thus necessary.

## Materials and Methods

This study of outside doses was done to evaluate the level of the scattered dose to a fetus, but it can also applied to other sensitive organs. Measurements were made in the position of the fetus in a Rando phantom along a line perpendicular to the beam axis for the 10 x10 $cm^2$ and 20 x20 $cm^2$ beam areas. Measurements were done on a Varian 6 MV and 10 MV linear accelerator (Clinac 1800). A Rando phantom containing a female human skeleton encased in tissue-equivalent material (mass density 0.985 $g/cm^3$, Z=7.3) was chosen for the outside dose evaluation. From the radiograph of the phantom this position was in section number 31 as shown in Fig.1.a. It was decided to study the distribution of scattered doses in this section, which was 2.5 cm thick.

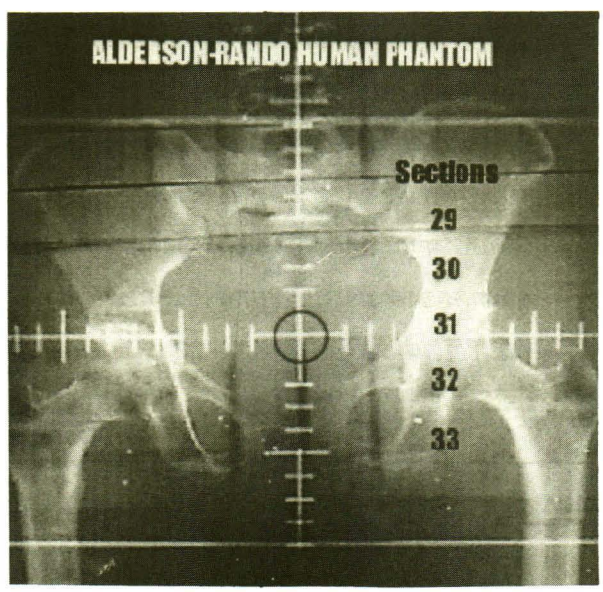


**Figure 1a.** Anterior-posterior view of the female Rando phantom estimated fetal position.

A commercial thermoluminesent dosimeter (TLD) sensitized at low exposure was used in estimating the scattered dose in the phantom. The TLD calibration curve for the estimation of scatter dose measurements was based on irradiation from calibrated $^{137}Cs$ irradiator since 90° Compton scatter for 6 MV and 10 MV x-rays would produce 400 keV and 500 keV photons, respectively. These are values close to the energy of $^{137}Cs$ (662 keV). The dosimeters were read on a Harshaw 5500 TLD reader. The phantom had nine TLD capsules distributed inside the pelvic wall and was kept in the patient treatment position. See the figure 1.b.The trunk was irradiated to a mid plane of 100 cGy through a beam area of 10x10 $cm^2$ parallel opposed fields (AP/PA) technique, 100 cm source-tumor-distance.The experiment was repeated with exposure to a 20x20 $cm^2$ field size. All steps of experiment were done for both 6MV and 10 MV x-rays.

Each of the experiments was repeated three times. Twenty - seven readings of fetal dose were used to calculate for their mean and the standard deviation. Measurements were done along the longitudinal axis at a distance of 5 to 50 cm away from the beam axis as shown in Fig. 2

**Results**

The total scattered dose from 6 MV x-rays are uniform all over the volume of the phantom section and similar to those of 10 MV x-rays . The TLD readings within section no.31were averaged and taken as the whole-body fetal dose or the outside dose level.

The scattered doses obtained from the 10 x10 $cm^2$ and 20 x 20 $cm^2$ field sizes exposed to 6MV and 10 MV x-rays are compared in Table 1. The outside doses corresponding to beam areas at the level of 0.1% is at 35 cm and 45 cm away from the central axis of their beams.

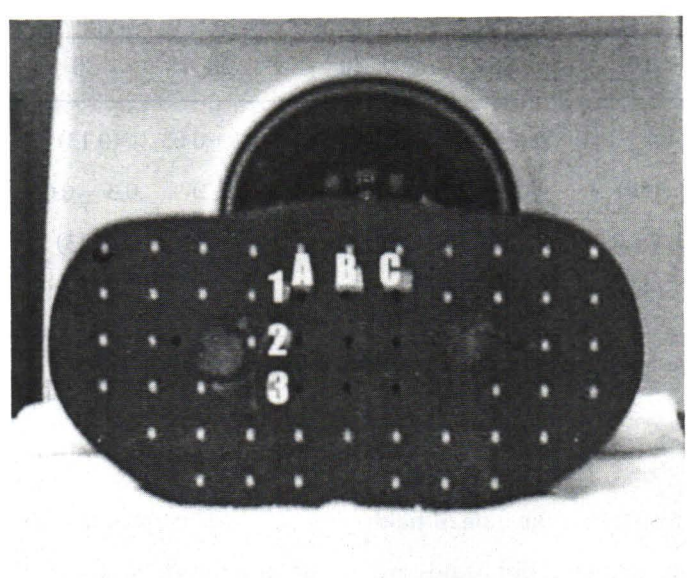


**Figure1b**. The cross-sections of slab no 31 shows the distribution of nine TLD capsules.

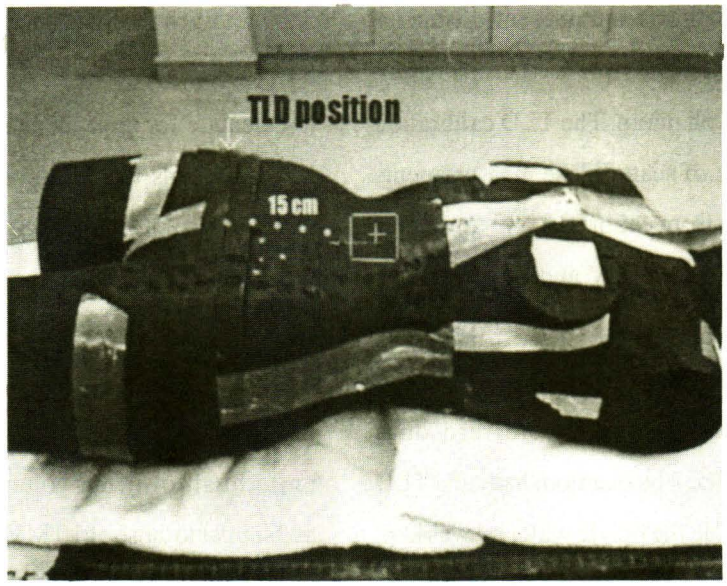


**Figure 2.** The female Rhando phantom was exposed to 100 cGy of 6 MV x-rays, 10 x 10 $cm^2$, 100 cm source tumor distance at 15 cm away from thermolumescent dosemeters in slab number 31.

**Table 1.** Average photon scattered doses at the fetal position in a Rando phantom (percent and standard deviation of peak dose at central axis)

| Energy | Field size | Distance from central axis of x-ray beam (cm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $(cm)^2$ | 5 | 10 | 15 | 20 | 25 | 30 | 45 | 50 |
| 6 MV | 10 x 10 | 50 | 1.4 ± 0.1 | 0.6 ± 0.03 | (0.3) | 0.2 ± 0.03 | (0.13) | 0.04 ± 0.01 | (0.03) |
| | 20 x 20 | 100 | (50) | 4.0 ± 0.18 | 1.2 ± 0.12 | (6.2) | 0.3 ± 0.04 | (0.1) | 0.07 ± 0.01 |
| 10MV | 10 x 10 | 100 | 1.4 ± 0.07 | 0.6 ± 0.03 | (0.3) | 0.2 ± 0.01 | (0.13) | 0.04 ± 0.01 | (0.03) |
| | 20 x 20 | 100 | (50) | 4.0 ± 0.14 | 1.0 ± 0.05 | (6.2) | (0.34) | 0.3 ± 0.02 | 0.07 ± 0.01 |

N.B. Figures in brackets are interpolated from the profile curve in Fig.3.

In considering the results as a function of field size, the radiation levels outside the useful beams are plotted as a function of distance from the nominal beam axis in fig.3. It can be seen that for 6 MV and 10 MV x-rays, their beam profiles are very alike at distances of 10, 15, 20, 25, 30, and 40 cm from the axis of radiation.

This outside dose can induce carcinogenesis or deterministic effects. Table 2 demonstrates the threshold dose[5] for these effects and the safety distance from the beam edge which were calculated from the exposure to 10x10 $cm^2$ and 20x20 $cm^2$ beam areas, 6-10 MV x-rays for 60 Gy.

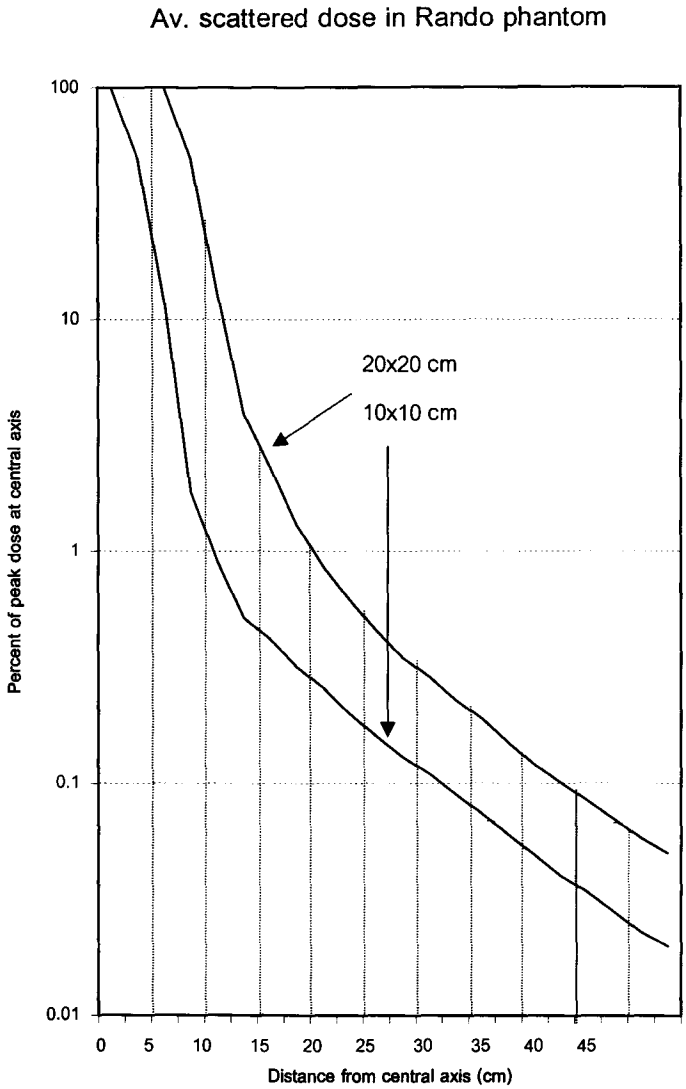


**Figure 3.** Comparison of scatted doses as the percentage of peak dose at the central axis of the square fields of 10 x 10 $cm^2$ and 20 x 20 $cm^2$ from Clinac 1800, 6-10 MV x-rays.

Kelly 1996[6] had investigated the contralateral breast dose scattered from primary breast irradiation to imply the risk of secondary breast malignancy. The result was similar to the present study as shown in fig. 4. The breast brassier is recommended to support the treatment breast and push away the contralateral breast.

## Discussion

Considering fetal doses and organ dose outside of the useful beam, the position of the point of interest is very important. At a distance away from the central axis of the beam the scattered dose rapidly decreases. The present study shows that the total scatter from 6MV and 10 MV depends on the beam area of irradiation. The magnitude of scatter shows agreement with the results of Frass 1983[7], Nair R.P. 1983[8] and Kelly 1996[6] as show in Table 3. It is important to mention about the high scatter adjacent around the beam that measured by the author. This experiment

**Table 2.** Threshold dose and safety distance from beam edges when exposure to 6000 cGy, 6-10 MV x-rays, Clinac 1800.

| Effects | Dose (cGy) | Safety distance from beam edge | |
|---|---|---|---|
| | | area 10 x 10 cm | area 20 x 20 cm |
| Sterility | 300@ | > 3 cm | > 5 cm |
| Cataract | 200 + | > 4 cm | > 6 cm |
| Ca breast | 100 ++ | > 5 cm | > 8 cm |
| Fetus | | | |
| Malforma. | 10 * | > 22 cm | > 28 cm |
| | 5 ** | > 33 cm | > 38 cm |
| IQ (-7pt) | 100 *** | > 5 cm | > 8 cm |

N.B. @ Figures are quoted from ref.1 * Figures are quoted from ref.5
+ Figures are quoted from ref.4 ** Figures are quoted from ref.1
++ Figures are quoted from ref.3 *** Figures are quoted from ref.2

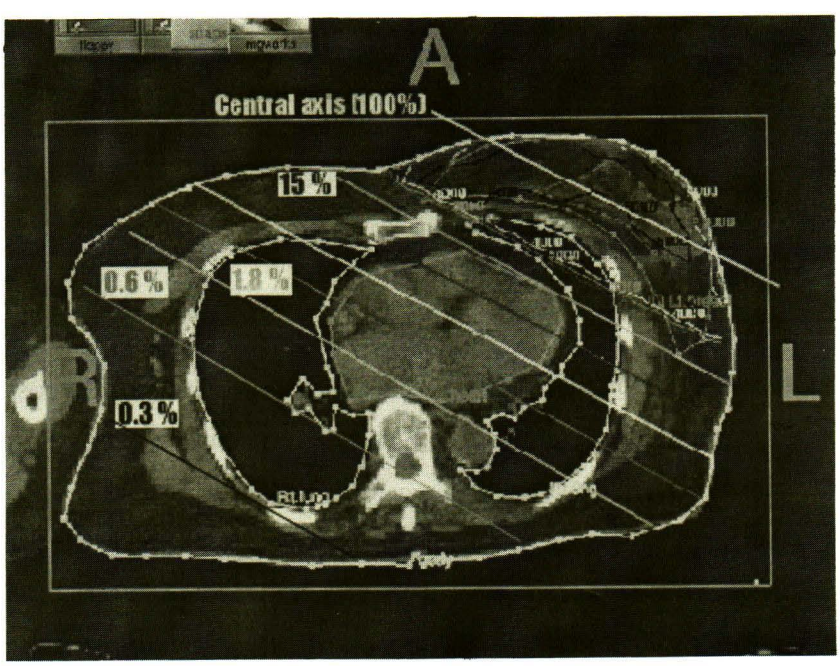


**Figure 4.** Isodose distribution of parallel opposed fields for treatment of carcinoma of breast. The outside dose levels perpedicular to been axes were shown. The contralateral breast doses vary from 0.6 % - 15 % of the treatment dose from medial to lateral aspect of the contra lateral breast.

**Table 3.** Comparison of average photon scattered dose from thermoluminescent dosmeter measutred in Rando phantom by different authors. The scattered dose is recoreded in a percentage of peak dose at central axis).

| Author (Institute) | Energy (Machine) | Field size $(cm)^2$ | Distance from edge of beam to TLD capsules (cm). 2.7 | 5 | 6 | 10 |
|---|---|---|---|---|---|---|
| Pataramontree | 6-10MV | 10 x 10 | 10 % | 2 % | 1.5 % | 0.6 % |
| (U.Chula) | (Clinac 1800) | 20 x 20 | 20 % | 5 % | 3.3 % | 1.2 % |
| Greene | 4 MV | 10 x 10 | 3 % | 2 % | - | 0.7 % |
| (Christie Hosp) | (AEI) | 20 x 20 | 9 % | 4 % | - | 1.1 % |
| | 8 MV | | | | | |
| | (Philips SL75) | 20 x 20 | 10 % | 8 % | - | 4.0 % |
| Kelly (U.Tennessee) | 6 MV | (unknown) | 3.5-4.5 % | 2.2-3.2 % | 2.0-3.0% | 1.0-2.0% |
| | (unknown) | | | | | |
| Nair | 8 MV | 14 x 20 | 3.8 % | 2.7 % | 1.9 % | 1.0 % |
| (King Faisal Hosp.) | (Philips SL75/10) | | | | | |

was perform by the PA/AP irradiation techniques while the other authors reported the percentage of radiation scatter due to AP direction only. The table 3 also shows the dose variation from machine to machine. The scatter should be measured for each machine. The scattered dose due to the technique of lateral parallel pair of beam irradiation is suggested for further study.

Nair (1983)[8] assessed the scattered dose at fetal position under the double folded lead apron. He found that the fetal dose was 96 % of that without the abdominal shield.

Greene (1983)[9] showed that the dose delivered outside the radiation beam is determined mainly by the levels of leakage radiation and scattered radiation in air as well as in a phantom. Therefore the lead apron reduces the dose outside the therapeuti beam for some extents.

## Conclusion

Scattered doses distribute uniformly inside the pelvic wall. For Clinac 1800, the magnitude of scattered dose depends on field sizes but there is no change for 6 and 10 MV x-rays. The safety distances for fetus whose mother receiving 60 Gy are beyond 22, 28 cm for 10 x 10 $cm^2$ and 20 x 20 $cm^2$ respectively.

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