CHAPTER 4

COMPUTATION OF RELATIVE DOSE DISTRIBUTION
AND EFFECTIVE TRANSMISSION AROUND A SHIELDED
VAGINAL CYLINDER WITH mHDR Ir-192 SOURCE

4.1 BACKGROUND OF THE STUDY

Cancer of the cervix begins in the lining of the cervix, growth of which is a process not a sudden one. Normal cervical cells gradually develop pre-cancerous changes that turn into cancer. Doctors use several terms to describe these pre-cancerous changes, including cervical intraepithelial neoplasia (CIN), squamous intraepithelial lesion (SIL), and dysplasia. There are two main types of cervical cancers such as squamous cell carcinoma and adenocarcinoma. Cervical cancers and cervical precancers are classified by their appearance under a microscope. About 80% to 90% of cervical cancers are squamous cell carcinomas, which are composed of cells that resemble the flat, thin cells called squamous cells that cover the surface of the endocervix. Squamous cell carcinoma most often begins where the ectocervix joins with the endocervix. The remaining 10 to 20% of cervical cancers are adenocarcinomas. Adenocarcinomas are becoming more common in women in the last 20 to 30 years. Cervical adenocarcinoma develops from the mucus-producing gland cells of the endocervix. Less commonly, cervical cancers have features of both squamous cell carcinomas and adenocarcinomas. These are called adenosquamous carcinomas or mixed carcinomas. Carcinoma of the uterine cervix is the most common cancer in South Indian women and...
occupies the top rank among cancers in women in most developing countries, constituting 34% of all women’s cancers. To an estimated annual global incidence of 500,000 cervical cancers, India contributes 100,000, i.e. 1/5 of the world burden. The magnitude of the problem is thus more than evident. The world pattern of cervical cancer, together with the age adjusted rate and ranking, clearly indicate that cervical cancer is predominantly a problem of poorer socio-economic societies. The risk factors for cervical cancer in India are socio-economic, viz. they relate to education and income, personal lifestyle, religion, multiple partners and sexual exposure prior to the age of 18 (IARC Scientific Publication No. 143, 1997).

HDR Ir-192 source is most commonly used for intracavitary treatment of vaginal and cervical malignancies. Vaginal cylinders are often used to deliver dose to the vaginal apex, upper vagina and/or to the entire vaginal surface for the management of post-operative endometrial cancer or cervical cancer (Nguyen et al 1995). Since the bladder and rectum are relatively radiosensitive, severe complication of rectal bleeding may occur due to excess dose delivery during HDR intracavitary brachytherapy (Chen et al 2000). In the case of bladder, complications like bowel obstruction and ulcers may be expected due to excess dose delivery. To limit the complications to the small bowels, rectum and bladder, a commercial shielded vaginal cylinder (Applicator Model 084.320, Nucletron Corporation, Netherlands) is used to reduce the excess dose to the rectum and bladder. The introduction of this high-density cylindrical shield will perturb the dose distribution in the shadow region. Commercially available brachytherapy TPSs, do not accurately calculate the dose distributions under realistic clinical conditions (Waterman and Holcomb 1994). In this regard, it was recommended that the effect of heterogeneities and shielding materials should be incorporated in the treatment planning during clinical practice (Venselaar
Based on these, Waterman and Holcomb measured the planer dose distribution using a 0.147 cm$^3$ ionization chamber around an Ir-192 source with a tungsten shielded vaginal cylinder (Applicator 084.320). Chen et al calculated the 3D spatial dose distribution around a shielded vaginal cylinder with Ir-192 sources calculated by using EGS4 Monte Carlo code. They observed that some discrepancy close to the source axis due to the negligence of the heterogeneity effect, such as the encapsulated material of source and the guide tube in the existing TPS (Chen et al 2000). Recently, Lymperopoulou et al compared the relative dose distribution of two different shielding materials (stainless steel with tungsten alloy). They reported that the shielding material stainless steel is ineffective compared to tungsten alloy (Lymperopoulou et al 2004). In the present chapter, an attempt was made to verify the inhomogeneity effect with tungsten shielded vaginal cylinder using the Monte Carlo code, MCNP4B. Further, attempts were also made to evaluate the dose distribution both in the shielded and unshielded region as a function of different thickness of tungsten and different shielding materials such as gold and lead. The computed values were also compared with the experimental data reported by Waterman and Holcomb (1994) in order to validate our computed values.

4.2 SHIELDING MATERIALS

Dose distributions were evaluated in the presence of different shielding materials such as tungsten ($\rho=19.3$ g/cm$^3$), lead ($\rho=11.34$ g/cm$^3$) and gold ($\rho=19.3$ g/cm$^3$). Owing to the commercial availability, tungsten was taken as shielding material. Lead was also considered, as it is used in LDR brachytherapy applications (Ron Sloboda and Reqing Wang 1998), and gold was taken into consideration as it has the same density with that of tungsten.
4.3 DESCRIPTION OF CALCULATION GEOMETRY

A typical commercially available shielded vaginal cylinder is shown in Figure 4.1. The internal construction and dimensions of the shielded vaginal cylinder for 180° shielding was modelled using MCNP4B and it is shown in Figure 4.2. The applicator consists of a 15 cm long cylindrical plastic shell having an outer diameter of 2.5 cm. It is centered on a thin-wall stainless steel tube of 0.4 cm outer diameter, which serves as a conduit for the Ir-192 source. There is an air gap between the steel tube and the inner wall of the cylinder in the absence of shielding material inside the cylinder. Generally, this gap can be filled with 0.8 cm thick tungsten with 90°, 180° or 270° angular shields. The shield is supported by the steel tube at the axis, the inner wall of the cylinder, and by a “leg” which fits through a hole in the end plate. All of these components are held in place by the end cap, which is screwed onto the cylinder.

The mHDR Ir-192 source was located approximately 4.5 cm from the tip of the cylinder. Readings were computed at 1.35 cm from the centre of the cylinder. The computed values were, normalized to 1000 cGy at 1.65 cm in order to compare the Monte Carlo computed results with that of the experimental data reported by Waterman and Holcomb (1994). Readings were also computed sequentially from 0° to 180° at every 5° interval. The dose distribution between 180° and 360° were duplicated from that of 0° and 180°. All dose distributions are pertaining to the lateral plane. When a shield is inserted into the cylinder, the user must specify its effective transmission, which is defined as the ratio of the dose at a point in the shadow of the shield, with that of the same in the absence of shield. This includes the effects of both transmission and scatter. The effective transmission and shield thickness define an effective linear attenuation coefficient, which, together with the geometric path length through the shield, is used to attenuate the dose from each dwell position to a point behind the shield.
Figure 4.1  A typical commercially available shielded vaginal cylinder
(Courtesy of Nucletron)

Figure 4.2  Geometric model of the shielded vaginal cylinder modelled
using MCNP4B code
4.4 DOSE DISTRIBUTION OF THE UNSHIELDED VAGINAL CYLINDER

After confirming the validity of our code in the evaluation of dose distribution of Ir-192 HDR source, the dose distribution around the unshielded vaginal cylinder as a function of radial distance was computed. In this computation, 1 million photon histories yield a statistical uncertainty of one standard deviation. It has the dependence on distance. In this application, it is found that there is less than 3% uncertainty for distances up to 5 cm and the uncertainty is between 3-5% for distances above 5 cm. The computed values were also compared with the experimental data of Waterman & Holcomb under identical conditions. Figure 4.3 shows the relative normalized dose distribution around the unshielded vaginal cylinder. For comparison, the experimental data of Waterman & Holcomb are interpolated using DigXY software (Thunderhead Engineering, 1006 Poyntz Ave, Manhattan, KS 66502-5459, USA) and plotted. In order to compare the MCNP computed values with experimentally measured values, the ratio of relative dose obtained from this work is divided by the result of Waterman & Holcomb work is evaluated and plotted as a function of radial distance and which is shown as an insert in Figure 4.3. The insert clearly indicates that the relative dose computed by MCNP4B is in good agreement with the experimental data with an average deviation of 6%. This variation may be due to the repositioning of the ion chamber after each scan and error caused by random background noise. The error caused by random background noise may increase an amount of 0.2% at the surface of the cylinder and more than 5% at greater distances (Waterman and Holcomb 1994).
Figure 4.3 Comparison of relative dose from the unshielded vaginal cylinder between MCNP4B computed and ionization chamber measured values

4.5 DOSE DISTRIBUTION FOR VARIOUS ANGULAR TUNGSTEN SHIELDING

Figures 4.4 (a-d), represents the MCNP computed dose distribution in the absence and presence of shielding of 90°, 180° and 270°. The isodose lines were plotted from 10 cGy to 1500 cGy using Systat 11.2.1 software (Systat Software Asia Pacific Ltd, Bangalore, India). This computed data were also normalized to 1000 cGy. 100 cGy isodose lines were taken here for explanation. In the unshielded case, the 100 cGy line crosses the positive X- axis at 6.12 cm and the same is also seen in the negative X- axis. In the case of 90° shielding, the 100 cGy line crosses the positive X- axis at 6.03 cm and the negative X- axis at 1.18 cm.
Figure 4.4a  Relative dose distribution around an unshielded vaginal cylinder of diameter 2.5 cm using MCNP4B code

Figure 4.4b  Relative dose distribution around a 2.5 cm diameter vaginal cylinder with a 90° tungsten shielding using MCNP4B code
Figure 4.4c  Relative dose distribution around a 2.5 cm diameter vaginal cylinder with a 180° tungsten shielding using MCNP4B code

Figure 4.4d  Relative dose distribution around a 2.5 cm diameter vaginal cylinder with a 270° tungsten shielding using MCNP4B code
For 180° shielding, the 100 cGy line crosses the positive X-axis at 5.88 cm and the negative X-axis at 0.75 cm. For 270° shielding, the 100 cGy line crosses positive X-axis at 5.58 cm and the negative X-axis at 0.58 cm. This observation clearly indicates that the dose to the unshielded region is reduced due to the shielding. This reduction increases with increase of angular shielding. This may be due to the decrease in the scatter from the shielded volume (Waterman and Holcomb 1994).

The relative dose, which is defined as the ratio between the dose measured at any point in the presence and in the absence of shielding material on the unshielded (tumor) region, was computed for various angular shielding. Similarly, the effective transmission is defined as the ratio of the dose measured at any point in the presence and absence of shielding material on the shielded (normal tissue) region, was also computed for 90°, 180° and 270° shielding. Figures 4.5 (a & b) show the relative dose on the unshielded region and the effective transmission on the shielded region for 90°, 180° and 270° angular shielding respectively. From the Figure 4.5a, it is observed that the relative dose for 90°, 180° and 270° shielding is reduced from 1.0 to 0.96, 0.91 and 0.80 respectively. From the Figure 4.5b, it is observed that the effective transmission for 90°, 180° and 270° shielding is increased from 0.10 to 0.27, 0.15 and 0.11 respectively. Table 4.1 shows the variation in relative dose/effective transmission for various angular shielding by tungsten as a function of radial distance. Highest percentage of reduction in relative dose to the unshielded side of the cylinder was observed for 270° shielding, which is three times higher than that of 90° shielding, whereas the increase in effective transmission is more for 90° shielding and it is almost same for both 180° and 270° shielding. It is also observed that the increase in effective transmission increases with distance and it is highest for 90° shielding. This is due to the larger unshielded volume available to contribute scattered radiation. It is reported that the scattered radiation accounts for a significant fraction of the dose, any condition that reduces the scatter will affect the dose. Such
conditions exist when there is insufficient tissue surrounding the source for full scatter, or when a high-density heterogeneity is introduced into the scattering volume (Waterman and Holcomb 1994).

Figure 4.5a The relative dose in the presence of 90°, 180° and 270° shielding with 0.8 cm thickness tungsten in respect to radial distance along the X direction.

Figure 4.5b The effective transmission in the presence of 90°, 180° and 270° shielding with 0.8 cm thickness tungsten in respect to radial distance along the X direction.
Table 4.1 The variation in relative dose and effective transmission for various angular shielding by tungsten as a function of radial distance

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>90° Reduction in relative dose (%)</th>
<th>180° Reduction in relative dose (%)</th>
<th>270° Reduction in relative dose (%)</th>
<th>90° Increase in effective transmission (%)</th>
<th>180° Increase in effective transmission (%)</th>
<th>270° Increase in effective transmission (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.35-5</td>
<td>0-2</td>
<td>0-5</td>
<td>0-10</td>
<td>10-19</td>
<td>10-12</td>
<td>9-9.5</td>
</tr>
<tr>
<td>5-10</td>
<td>2-4</td>
<td>5-9</td>
<td>10-20</td>
<td>19-27</td>
<td>12-15</td>
<td>9.5-10</td>
</tr>
</tbody>
</table>

4.6 DOSE DISTRIBUTION FOR VARIOUS THICKNESSES OF TUNGSTEN SHIELDING

As dose calculations by currently available brachytherapy TPSs are based on the radiation around an encapsulated bare source, and do not take applicator attenuation into account and they also do not account for scattered dose. This results in an undesirable dose reduction to the tumor volume. To incorporate such applicator attenuation into TPSs, it is suggested for attenuation corrected radial dose function and anisotropy function in a form parallel to the AAPM TG-43 formalism (Nath et al 1995 and Anctil et al 1998). In this context, it is also aimed to find whether there is any considerable change in the dose distribution due to the applicator attenuation as a function of thickness of the shielding material. Based on this, comparison of doses of the unshielded vaginal cylinder, with that of the 0.8 cm, 180° tungsten shielded vaginal cylinder were made. In the unshielded case, the 331.18, 81.95 cGy lines cross the both positive and negative X- axis at 3 and 6 cm radial distances respectively. However, in the case of 180° with 0.8 cm thickness tungsten shielding, the 320.17, 76.97 cGy lines cross the positive X- direction and 33.14, 10.91 cGy lines cross the negative X- direction at 3 and 6 cm radial distances respectively. This shows that there is a decrease in
dose on the unshielded side of the shielded cylinder, which could lead to under dosage to the tumor volume.

In order to find whether there is any clinical significance exists in varying the shielding thickness, the dose distribution for various shielding thickness of tungsten were also computed and compared the same with 0.8 cm tungsten shielding. In the case of 0.5 cm thickness of tungsten, the 323.17, 76.87 cGy lines crosses the positive X- direction and 71.33, 17.80 cGy lines crosses the negative X- direction at 3 and 6 cm radial distances. For 0.6 cm thickness of tungsten, the 322.67, 76.76 cGy lines crosses the positive X- direction and 55.98, 15.73 cGy lines crosses the negative X- direction at 3 and 6 cm radial distances. For 0.7 cm thickness of tungsten, the 321.57, 76.53 cGy lines crosses the positive X- direction and 45.00, 13.30 cGy lines crosses the negative X- direction at 3 and 6 cm radial distances. This observation clearly indicates that even at lesser thicknesses of shielding, the dose to the unshielded region is found to be almost same. However, the dose to the shielded region depends not only on angular shielding but also on the shielding thickness. The dose is increasing with decrease of shielding thickness.

The relative dose and effective transmission variation for other shielding thickness such as 0.5, 0.6, 0.7 and 0.8 cm with respect to radial distances were also computed. From this, it is observed that there is no considerable variation in relative dose between various thicknesses and also it is observed that for 0.5, 0.6, 0.7 and 0.8 cm thick tungsten shielding, the effective transmission is increased from 0.20 to 0.26, 0.16 to 0.21, 0.12 to 0.18 and 0.1 to 0.17 respectively. Table 4.2 shows the variation in relative dose/effective transmission for various thicknesses of tungsten for 180º angular shielding by tungsten as a function of radial distance. From this table, it is observed that as the thickness of the shielding decreases, the percentage of reduction in relative dose to the unshielded side of the shielded
vaginal cylinder is decreased for all the distances. It is also observed that as the thickness of shielding decreases the percentage of increase in effective transmission is also increases for all the distances.

Table 4.2  The variation in relative dose and effective transmission for various thickness of tungsten at 180° shielding angle as a function of radial distance

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>0.8 cm</th>
<th>0.7 cm</th>
<th>0.6 cm</th>
<th>0.5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reduction in relative dose (%)</td>
<td>Increase in effective transmission (%)</td>
<td>Reduction in relative dose (%)</td>
<td>Increase in effective transmission (%)</td>
</tr>
<tr>
<td>1.35-5</td>
<td>0-5</td>
<td>10-12</td>
<td>0-4</td>
<td>12-14</td>
</tr>
<tr>
<td>5-10</td>
<td>5-9</td>
<td>12-15</td>
<td>5-9</td>
<td>15-18</td>
</tr>
</tbody>
</table>

4.7 DOSE DISTRIBUTION FOR VARIOUS SHIELDING MATERIALS

In order to compare the effectiveness of shielding on the dose distribution for other materials similar calculations were performed under identical conditions for 0.8 cm lead and 0.8 cm gold for 180° shielding and their results are given in Table 4.3. The dose distributions for tungsten, lead and gold for 180° shielding were also compared. For tungsten, the 100 cGy line crosses the positive X- axis at 5.88 cm and the negative X- axis at 0.75 cm. For lead, the 100 cGy lines cross the positive X- axis at 5.92 cm and the negative X- axis at 1.08 cm. For gold, the 100 cGy line crosses the positive X- axis at 5.82 cm and the negative X- axis at 0.64 cm. This
observation clearly indicates that lead is having more doses in the shielded region than gold and tungsten because of its lesser mass density than tungsten and gold. The relative dose and effective transmission variation with respect to radial distance for various shielding materials were also computed. From this, it is observed that there is no considerable variation in relative dose between various shielding materials and also it is observed that the effective transmission for tungsten, lead and gold is increased from 0.09 to 0.10, 0.16 to 0.21 and 0.07 to 0.14 respectively. The percentages of relative dose/effective transmission for various shielding materials as a function of radial distance are given in Table 4.3. From this table, it is observed that the reduction in percentage of relative dose to the unshielded side of the cylinder for gold is higher than tungsten and lead or in other words lead is having very low percentage of dose reduction in the unshielded side of the shielded vaginal cylinder than tungsten and gold. It is also observed that the increase in percentage of effective transmission for gold is lower than tungsten and lead whereas lead is having very high percentage of transmission in the shielded side of the shielded vaginal cylinder than tungsten and gold.

Table 4.3  The variation in relative dose and effective transmission for various shielding materials for 180° angular shielding as a function of radial distance.

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>Tungsten</th>
<th>Lead</th>
<th>Gold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in relative dose (%)</td>
<td>Increase in effective transmission (%)</td>
<td>Reduction in relative dose (%)</td>
<td>Increase in effective transmission (%)</td>
</tr>
<tr>
<td>1.35-5</td>
<td>0-5</td>
<td>10-12</td>
<td>0-4</td>
</tr>
<tr>
<td>5-10</td>
<td>5-9</td>
<td>12-15</td>
<td>5-8</td>
</tr>
</tbody>
</table>
4.8 CONCLUSION

In conclusion, in this chapter, the relative dose distribution from a commercially available vaginal cylinder of 0.8 cm thickness tungsten with 90°, 180° and 270° angular shielding were computed. In addition, the relative dose distribution for various shielding thicknesses of tungsten and various other shielding materials were also computed and compared. Further, the MCNP4B computed relative dose distribution values for unshielded vaginal cylinder were also compared with the experimental values obtained by Waterman and Holcomb (1994). The simulated results are in good agreement with the experimental data with a maximum deviation of 10%. This deviation may be due to the contribution of the scatter factor, strong photoelectric absorption and it may also be due to the difference in the scoring volume. To confirm the exact reason, further experimental studies are to be carried out. Studies show that 0.8 cm thickness shielding contribute tolerable dose in order to protect critical organs. It is also observed that the higher the shielding angles, more the protection of surrounding tissues. Among the three shielding materials, gold is giving highest attenuation or lowest transmission against protection of shielded region. However, one could also use lead enclosed in a suitable applicator, if in need of more doses to the unshielded region.

Dependence of the dose distribution upon the shielding angle and thickness can be predicted using Monte Carlo methods. Among the three materials studied, gold is having the highest shielding, however one should think about the cost effectiveness. In order to deliver higher dose to the unshielded region, lead may be preferred as shielding material, also it is more economic when compared to that of tungsten and gold. In this regard, it is worth to look for some alloys to compromise the dose at both shielded and unshielded regions in order to improve dose delivery to the target.