Master of Science Thesis

Build-down and Build-up of Absorbed Dose at Interfaces between Air and Tissue: A Comparative Study between Monte Carlo Simulations and the Helax-TMS Treatment Planning System

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Abstract

Purpose: To study the build-down and build up of the absorbed dose at the interface between air and tissue in the head and neck region. Monte Carlo simulations are compared to a treatment planning system that is used at the University Hospital in Lund.

Materials and methods

A virtual phantom was constructed to resemble an air cavity in the head and neck region. The phantom consisted of a water cylinder with an air cylinder place at the centre. Irradiation with three different field sizes and four different energies were included.

The Monte Carlo simulations were done with the EGSnrc user code DOSRZnrc and the treatment planning system was Helax-TMS. In Helax-TMS the dose calculation algorithms Pencil Beam and Collapsed cone were included.

Results: The results from the Monte Carlo simulations and the treatment planning system were presented as depth dose curves and dose profiles.

The build-up effect is most evident for the smallest field sizes and especially for the field size that has a smaller radius than the air cavity radius. The Pencil Beam algorithm was overestimating the dose compared to the Monte Carlo simulations. The curves for Collapsed Cone and Monte Carlo simulation have a good agreement.

Conclusion: Pencil Beam overestimates the dose at the interface between air and water when an air cavity is present. The recommended accuracy limits are not met for this algorithm. Collapsed Cone on the other hand gives a better estimation of the actual absorbed dose in this region and is a better tool to calculate the dose in regions with air cavities. Collapsed cone is however a very time consuming algorithm.

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1. Introduction

This study was carried out at the University Hospital in Lund. It has been performed as a Master of Science thesis for a degree in Medical Physics at Lund University.

The head and neck region contains many air volumes, for example trachea, paranasal sinus and the mouth cavity. When a patient receives photon radiation therapy in this region the incident beam may pass through these cavities. This work was looking on what happens with the absorbed dose in the regions around these cavities when they are irradiated with photon beams and how well a treatment planning system is modelling the dose in heterogenic lesions.

The dose calculations were done with Monte Carlo simulations where the code system EGSnrc was used [1]. EGSnrc is a general-purpose package for Monte Carlo simulation (EGS is an acronym for Electron Gamma Shower). Monte Carlo simulations are considered as one of the most accurate methods to calculate the absorbed dose to a media. A number of studies has shown the agreement of absorbed dose between Monte Carlo simulation and physical measurements in heterogeneous media [2,3,4,5,7,8]. Thus the Monte Carlo simulations in this work were assumed to give the correct dose and no physical measurements were done.

The Treatment Planning System (TPS) compared to the Monte Carlo simulations was Helax-TMS, which is one of two TPS that is available at the University hospital in Lund. Helax-TMS includes the algorithms Pencil Beam (PB) and Collapsed Cone (CC).

2. Materials and methods

2.1 Geometry

The geometry used in this report should resemble an air cavity in the head and neck region. This was done with a simplified geometry that consisted of a water cylinder where a small air cylinder was placed at its centre. The water cylinder had a length of 12.0 cm and a radius of 7.5 cm. The air cylinder had a length of 3.0 cm and a radius of 1.5 cm (fig. 1).

Similar size of the air cavity is also used in other publications [2,4,5].

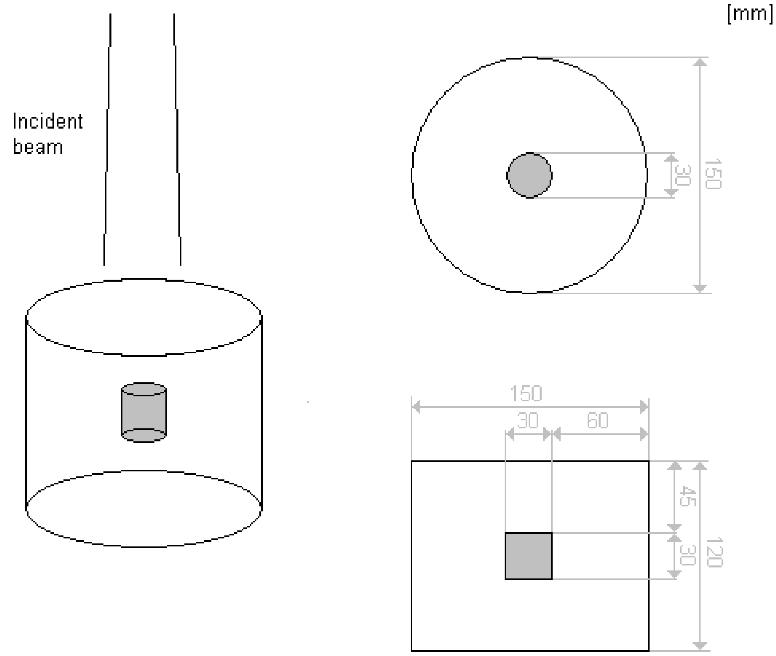

Figure 1. The geometry used in this report. The large cylinder consists of water and the small cylinder consists of air.

2.2 Energies and field sizes

The beam of photons was incident along the central axis of the cylinder and the cavity was placed so that the depth of dose maximum (d_{max}) was achieved well ahead of the cavity. The source to surface distance (SSD) was set to 100 cm.

The energies used in treatment of head and neck cancer are often 4 MV or 6 MV [6]. The energies used in this work range from 4, 6, 10 and 18 MV. The energy-spectrums used in the Monte Carlo simulations and in the Helax-TMS treatment planning system were spectrum taken from accelerators (appendix 1), present at the University Hospital in Lund.

The field sizes used in clinical head and neck treatment vary somewhere between 5x5cm^2-15x20cm^2 (for conventional therapy), and for IMRT field sizes down to 1x1cm^2 can be used. In this report circular fields were used. The reason for circular fields are mainly because of that DOSRZnrc uses circular fields. Three different field sizes were used in this report: 1, 2.5 and 5 cm (radius).

2.3 Treatment planning system

At USiL there are two different treatment planning systems (TPS) available: Oncentra Masterplan and Helax-TMS (Both from Nucletron B.V. , Netherlands). These two TPS use the same algorithms to calculate the absorbed dose. This report will use Helax-TMS to do the dose calculations since it was not possible to create a water phantom in Masterplan with an air cavity.

The phantom for TMS-Collapsed Cone and TMS-Pencil Beam has dimensions equal to those in the geometry section. It consists of 120 slabs each with a thickness of 0.1 cm (fig. 2).

Source to surface distance (SSD) was 100 cm. Gantry angle was 90 degrees and the table was turned 90 degrees so that the incident beam entered along the cylinders central axis. To get a circular field in the Helax-TMS a square 10x10 cm^2 field was collimated with an external block into three different circular field sizes with radius of 1.0, 2.5 and 5.0 cm, respectively.

The dose was collected with the function Linedose. In this study the dose along the central axis of the cylinder and the dose along a line positioned at a depth of 6 cm, at the centre of the air cavity, were scored.

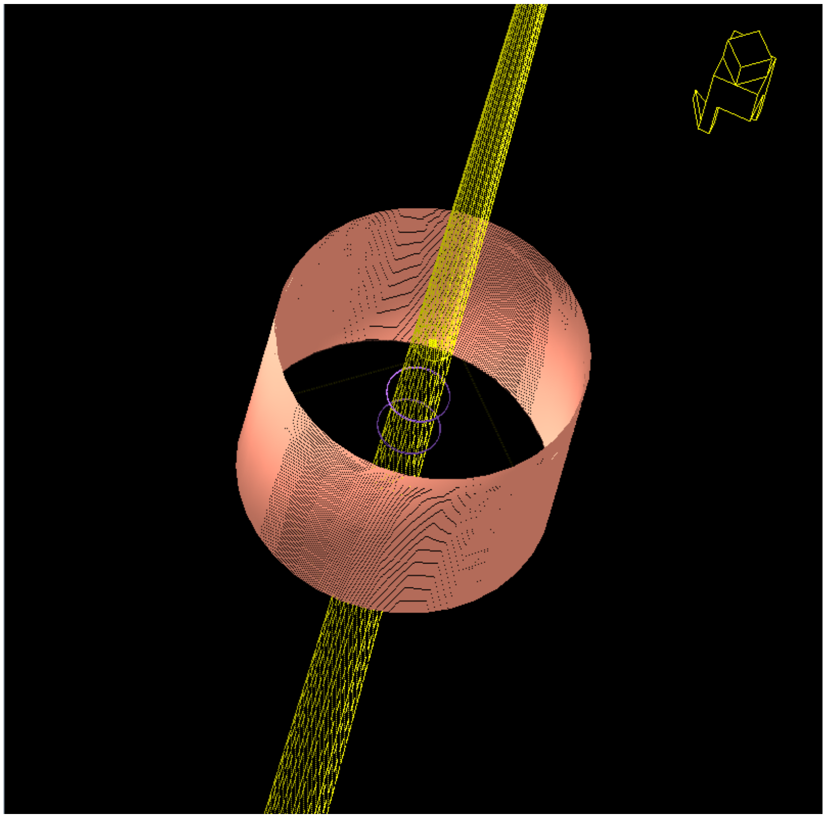

Figure 2. Helax-TMS phantom. 120 slabs with 0.1 cm thickness. SSD=100 cm and the field radius is 1 cm at the surface. The large cylinder consists of water and the small cylinder consists of water.

2.3.1 Pencil Beam

Pencil beam calculates the dose distribution around an infinitely small beam in water using a convolution technique. The convolution is performed between polyenergetic pencil beams and the planar photon energy fluence distribution (**figure 3**). To calculate the dose the following equation is used: $D(\bar{r}) = \iint_{field} \Psi(x', y') \frac{P}{\rho}(x - x', y - y', z) dx'y'$ [9]

Where Ψ is the impinging planar photon energy fluence distribution and P/ρ is the dose distribution of a pencil beam in water.

The Pencil beam algorithm does not take the changes of lateral scattering effects into consideration.

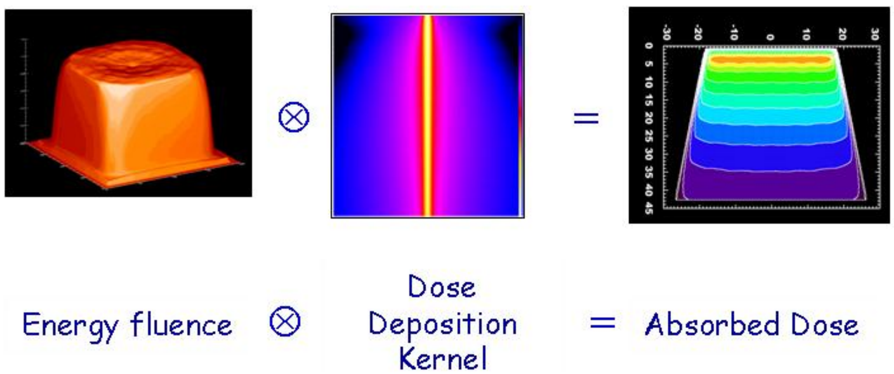

Figure 3. Dose equation for Pencil beam. A convolution between the energy fluence,ψ (left), and the dose distribution of a pencil beam in water (middle), which results in the dose distribution (right).

2.3.2 Collapsed Cone

Collapsed cone uses a convolution technique between TERMA and a dose deposition kernel. The algorithm uses an approximation where all energy inside a specified solid angle will be transported along a line[9].

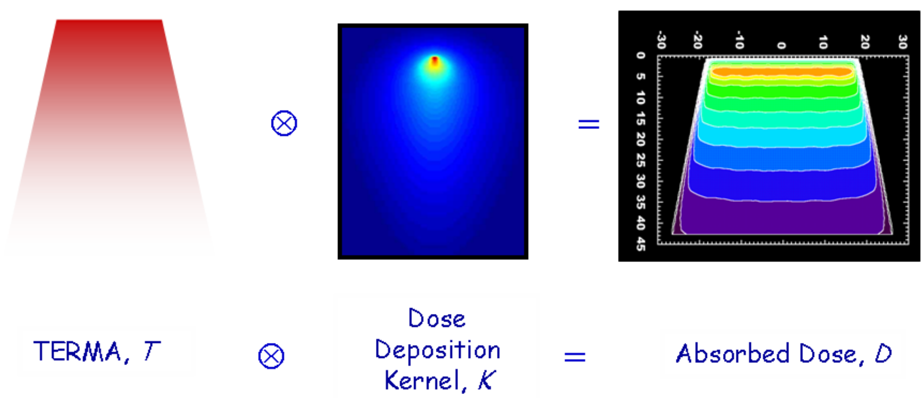

Figure 4. Dose equation for Collapsed Cone is a Convolution between TERMA (left) and the dose deposition kernel (middle) which gives the dose distribution (right).

2.4 Monte Carlo simulation

Monte Carlo simulation is a way to calculate the average behaviour of a system. This is done by performing statistical sampling experiments for physical event responsible for the behaviour. The trials are made on a computer where a random number generator is used. The Monte Carlo simulations in this work were done by a program called DOSRZnrc.

2.4.1 DOSRZnrc

The DOSRZnrc [1] module is a program included in the EGSnrc-package and thus uses EGSnrc (acronym for Electron Gamma Shower) as a transport engine. The reason that DOSRZnrc was used was that it has a simple geometric variance reduction technique performing the simulations in cylindrical geometry. Thus the simulations will relatively fast reach a low statistical uncertainty compared to performing the calculations in a three-dimensional voxel geometry. DOSRZnrc uses a cylindrical geometry where the user can control a number of parameters:

- How many, and the size of, cylindrical regions (r or radius) and planar regions (Z or slabs) the total cylinder will consists of (figure 5).
- The content of the regions in the geometry model also have to be set.
- In which regions the dose should be scored
- How the output should be presented
- How the source is constructed (energy, point or parallel etc.)
- Transport parameters that will be used e.g. particle energy cutoffs.
- Number of histories (or trials) has to be defined were a time limit or a statistical limit can be defined.

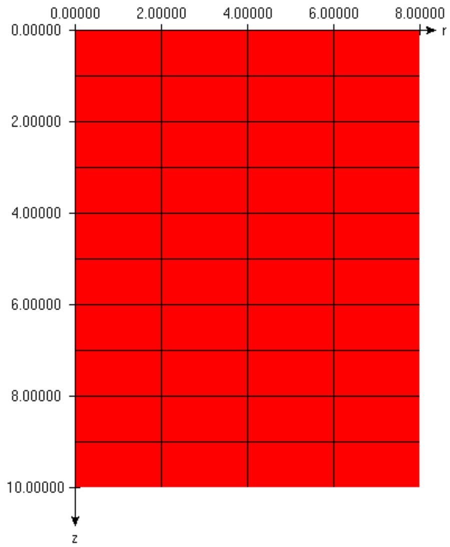

Figure 5. An example of a DOSRZnrc geometry definition for a homogeneous cylinder with radius 8 cm and a length of 10 cm. The Phantom consists of 10 slabs (z) with a thickness of 1cm and 4 cylinder each with a thickness of 2 cm.

2.4.2 Parameters and phantoms for Monte Carlo simulation

The cross section data file (PEGS4) used is 521icru.pegs4dat. The transport parameters were set to: PCUT[1] = 0.001MeV, ECUT[1] = 0.521MeV, ESTEPE[2] = 0.25, xlmax[3] =0.25, SMAX[4] = 1e10, skin depth for BCA[5] =3. The source that was used in this report is "point source on axis incident from front". SSD was set to 100 cm

Two different phantoms were used in Monte Carlo simulation, one for depth dose and one for dose profiles. This was done to save time because more voxels result in longer simulation time (when the number of histories is constant).

To get depth dose the geometry in fig 6 (a), were used. Totally 240 slabs (z-direction) are used each with a thickness of 0.05 cm and the dose is scored in the cylinder. The dose scoring region is preferable as large as possible, but inside the dose scoring region the dose should not vary more than a few percent. The depth dose given by the smallest field size will have the biggest difference of the dose. The region was chosen to 0.4 cm, where the standard deviation is about 1.5% (fig. 7).

To get the dose profiles the geometry in fig 6 (b) were used. The dose was scored at a depth of 6 cm i.e. in the middle of the air-cavity perpendicular to the beam direction. The amount of histories that were used in this work depends on phantom and field size (tab. 1).

Table 1. Histories used for simulation of depth dose and dose profiles. The number of histories is in millions

field size [mm]	histories
Depth dose	
10	40
25	200
50	500
Dose profiles	
10	40
25	100
50	200

[1] PCUT and ECUT is photon respectively electron transport cutoff energy. This means that when a particle's energy falls below this threshold (cutoff), its history is terminated and the remaining energy is deposited at the site.

[2] ESTEPE is maximum fractional energy loss per step. Default is 0.25 (25%)

[3] Xlmax is maximum first elastic scattering moment per step. Default is 0.5

[4] SMAX is Maximum step-size restriction for electron transport (in cm).

[5] Skin depth for BCA determines the distance from a boundary at which the algorithm will go into single scattering mode or switch off lateral correlations.

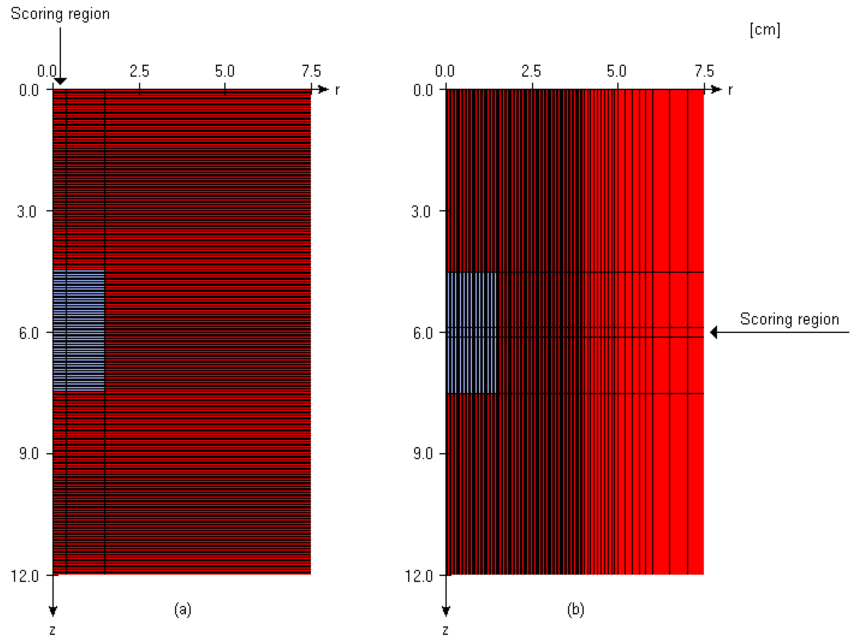

Figure 6. Phantom used in Monte Carlo simulations. (a) Depth dose. 240 slabs with a thickness of 0.05cm and cylinders 0.4, 1.5 and 7.5 cm. (b) Dose profiles. 5 slabs (4.5, 1.375, 0.25, 1.375, 4.5 cm) and 98 cylinders (spacing between cylinders:1-80 = 0.05cm, 81-90 = 0.1cm, 91-96 = 0.2, 96-98 = 0.5cm). The colours represents water (red) and air (grey).

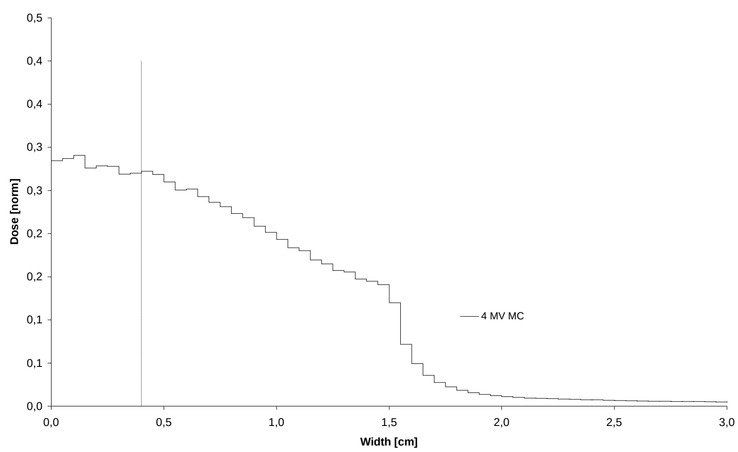

Figure 7. Dose profile at 6 cm depth through the air cavity for the smallest field size, 10mm. The dotted line is at 4mm which is the size of the chosen dose scoring region for depth doses.

2.4.3 Statistics and histories for Monte Carlo simulation

The statistics in each voxel depends on the number of incident histories (*N*), field size (A_{beam}), voxel size (V_{voxel}) and the effective energy absorption coefficient (μ_{en}^{eff}) [10].

$N = \frac{1}{\sigma^2 \cdot \mu_{en}^{eff}} \cdot \frac{A_{beam}}{V_{voxel}} \rightarrow \sigma = \sqrt{\frac{1}{N \cdot \mu_{en}^{eff}} \cdot \frac{A_{beam}}{V_{voxel}}}$ and if A_{beam}, V_{voxel} and μ_{en}^{eff} are constant then we can write $\sigma \propto \sqrt{\frac{1}{N}}$. This means that to halve the statistics you have to increase the number of histories four times.

The statistics used in this work lies mainly around a standard deviation of 1%.

2.5 Normalization for depth doses and dose profiles

Monte Carlo simulation gives the absorbed dose in gray per incident fluence while Helax-TMS gives the absorbed dose in gray per Monitor Units. Therefore a common normalization was required.

The depth dose curves and the dose profiles were normalized to the dose at the depth of 5 cm for a phantom without an air cavity. The depth dose curves for phantom without an air cavity will in this report be referred to as a *normalization curve*. Each depth dose curve and dose profiles will be normalized to a normalization curve that has been generated with the same field size, energy and calculation method.

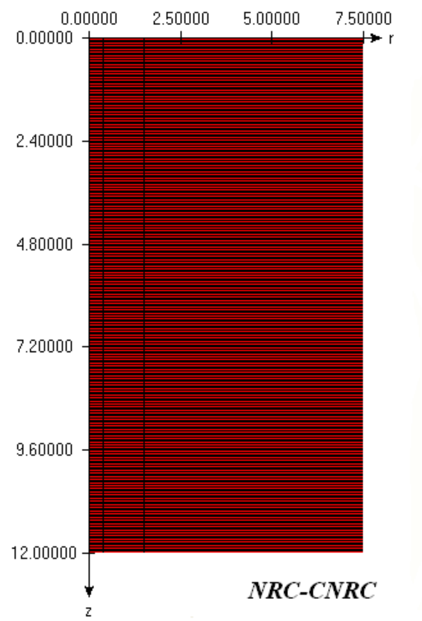

Figure 8. Phantom used for normalization. The same phantom as used for depth dose curves but without an air cavity

3. Results and discussion

Results from the simulations and the calculations were presented as depth dose curves and dose profiles. The Monte Carlo simulations were compared with data taken from the dose planning system Helax-TMS for the algorithms pencil beam and collapsed cone. The four different energies used in this report were compared to each other. The Monte Carlo simulations (black) and collapsed cone (red) were presented as histograms. The reason for this was that the results gave the dose as the average within the whole voxel. While in the case of pencil beam (blue) the result is calculated to a point that is specified.

The results for depth dose are presented in diagrams where the normalized dose is on the y-axis and the depth (in cm) is on the x-axis. Figure 9 shows an example of a normalization curve for 6 MV and 1 cm field radius.

Figure 10 is depth dose curves with air cavities for 6 MV where the field size was altered. The depth dose curves for the other energies can be seen in appendix 2 and 3

The results for the dose profiles are presented in diagrams where the normalized dose is on the y-axis and the width (in cm) is on the x-axis. Dose profiles for 6 MV for the three different field sizes can be seen in figure 11. Dose profiles for the other energies can be seen in appendix 4.

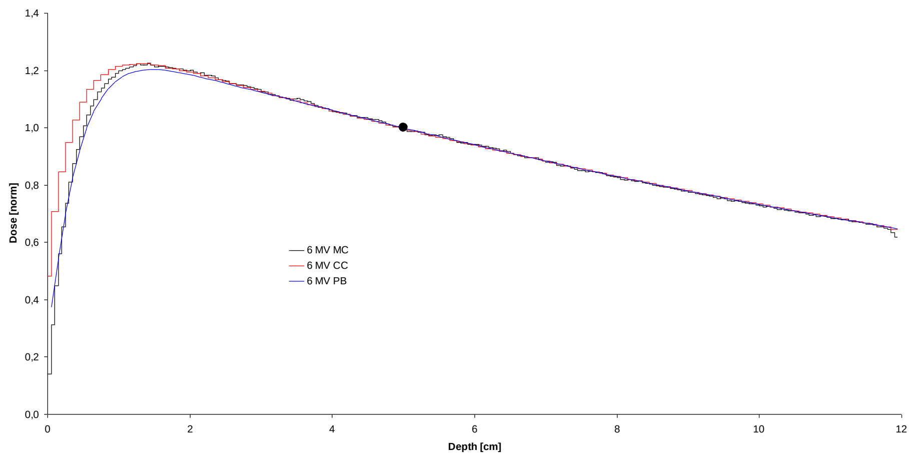

Figure 9. Curve for normalization. Depth dose for the cylinder without an air-cavity for Monte Carlo simulation (MC), TMS Collapsed cone (CC) and TMS pencil beam (PB). A 6 MV energy spectrum is used and field size of 1cm radius.

3.1 Normalization curves

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An excellent agreement between the normalization curves (figure 9) is found between the three different models except for the build-up region where contaminant electrons from the treatment head contribute to the dose. This latter component is not considered in the Monte Carlo calculations. One may also note a difference for this component between the two TPS algorithms in this region.

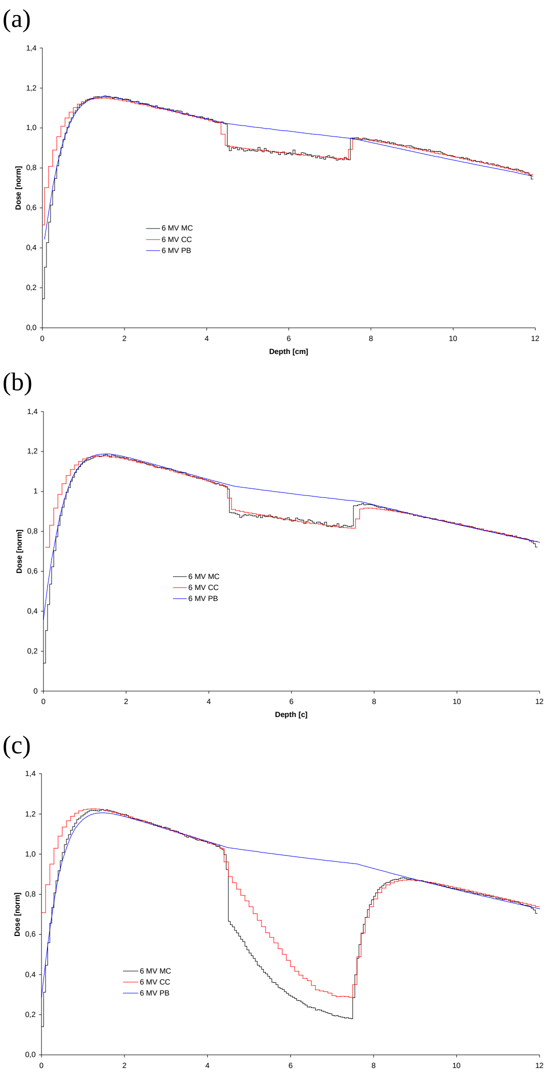

Figure 10. Depth dose for cylinder with an air cavity for 6 MV. For field radius 5 cm (a), 2.5 (b) and 1 cm (c).

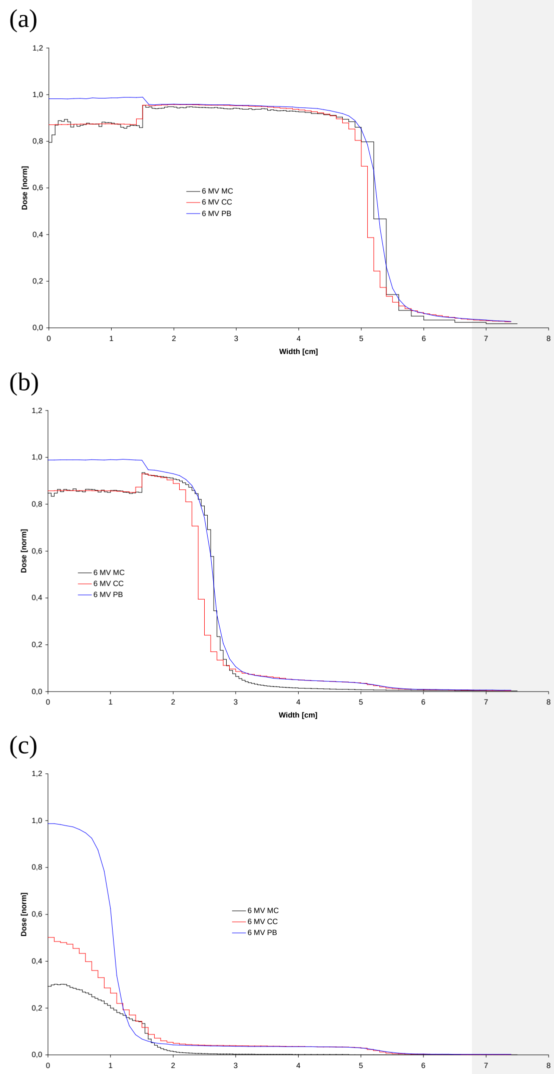

Figure 11. Dose profiles in the middle of the air cavity (at 6.0 cm) for 5 cm field radius (a), 2.5 cm field radius (b) and 1 cm field radius (c). 6 MV spektrum

3.2 Depth doses and dose profiles for phantom with an air cavity

For Depth dose curves created with 5 cm field radius (figure 10 a) a good agreement between Monte Carlo and Collapsed cone where seen in the cavity region, while the pencil beam algorithm overestimates in the cavity region. All three curves have a relatively good agreement outside the air cavity region. The dose profile for 5cm field radius (figure 11 a) the pencil beam algorithm overestimates in the air cavity region.

Collapsed cone and Monte Carlo have a good agreement. Outside the air cavity region the three curves have a good agreement apart from that collapsed cone which looks to have a smaller field size width. This is something that has to be investigated further prior to clinical use of the model.

A slight increase in build-down and build-up compared to 5 cm field radius can be noticed when the field is decreased to 2.5 cm (figure 10 b). Pencil beam still overestimates and Collapsed cone and Monte Carlo have a quite good agreement. Also here a good agreement outside the air cavity region is present. Dose profiles for 2.5 cm (figure 11 b) field radius agree with the results for 5 cm field size. Also here a discrepancy in the field size width is seen between collapsed cone and the other two calculation models.

For 1 cm field radius (figure 10 c) there is a deviation between collapsed cone and Monte Carlo simulation in the air cavity region that is not seen for the two larger field sizes. The build-down and build-up is also much larger for 1 cm field size than for the other two. It should be noted here that the field size of 1 cm is smaller than the air cavity radius. The dose profile for 1 cm field radius (figure 11 c) all three curves differ in the air cavity region. Pencil beam overestimates much in the air cavity region. Collapsed cone and Monte Carlo does not have the good agreement that is seen for the other field sizes and collapsed cone can be seen to overestimates for 1 cm field size.

The appearance of the Monte Carlo depth dose curves for 5cm and 2.5cm field radius, i.e. the reason that the dose will be reduced in a low density medium (build-down and build-up), depend on that the mass energy absorption coefficient is smaller for air than it is for water. In and around the air cavity there is electron equilibrium (for 5cm and 2.5cm field radius). This means that, when there is charge particle equilibrium, the dose to the medium can be written as: $D = K_c = \psi \cdot \left(\frac{\mu_{en}}{\rho}\right)$

And hence to dose quota between air and water can be written as:

$D_{air}^{water} = \frac{K_{c,water}}{K_{c,air}} = \frac{\psi_{water}\left(\frac{\mu_{en}}{\rho}\right)_{water}}{\psi_{air}\left(\frac{\mu_{en}}{\rho}\right)_{air}}$ and if $\psi_{air} = \psi_{water}$ than $D_{air}^{water} = \left(\frac{\mu_{en}}{\rho}\right)_{air}^{water} \approx 1.1$. The dose quota between Monte Carlo with and without an air cavity at a depth of 6cm (in the middle of the air cavity (figure 12)) is also somewhere around 1.1. This shows that the dose difference between the two curves probably only depends on the difference between mass energy-absorption coefficients.

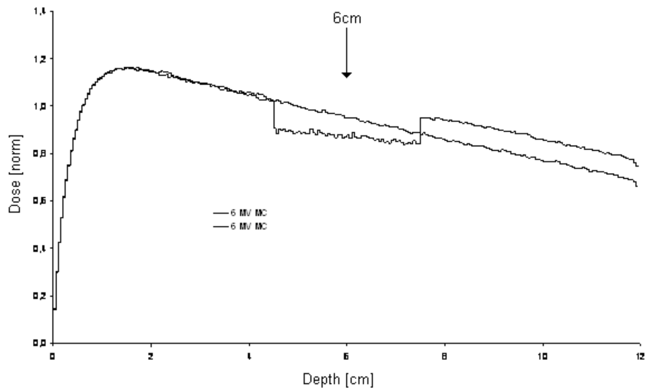

Figure 12. Depth dose curves for Monte Carlo simulation for phantom with and without an air cavity. The Simulation is made with 6 MV and a field radius of 5cm.

When 1cm field radius is used the difference between mass absorption coefficients can not alone explain the large build-down and build-up of the Monte Carlo depth dose curve (figure 10.c). For 1cm field radius there is also a lack of electron equilibrium which contributes to the dose reduction. More electrons, and hence the dose, will “disappear” laterally which can be seen in the dose profile (figure 11.c).

The reason that pencil beam overestimates (for all field sizes) in the air cavity region depends on that the algorithm uses the mass energy absorption coefficient (μ_{en}/ρ) for water instead of air (the electron equilibrium is kept). This is in analogy with the Monte Carlo simulations for phantom with and without air cavity i.e. $\left(\frac{\mu_{en}}{\rho}\right)_{water}^{air} \neq 1$. The reason that the Pencil beam depth dose curve level out in the air cavity region depends on the algorithm considers the effective depth (d_{eff}), i.e. inhomogeniety corrections, in the dose calculation.

The collapsed cone algorithm and the Monte Carlo simulation, as was seen earlier, agree well in the air cavity region. This depends on that the Collapsed cone algorithm calculates the primary and the scatter dose separately and the algorithm calculates the dose to the actual media (not to water as pencil beam). This makes Collapsed cone a good algorithm to calculate dose in a heterogeneous media.

The reason that Collapsed cone overestimates in comparing to Monte Carlo in the air cavity region for 1 cm field radius could be of the appearance of the algorithm. The collapsed cone algorithm uses an approximation method where all energy inside a solid angle is travelled along a line. This could lead to an incorrect modulation of the dose in lateral direction in a low density media when the field size is smaller than the cavity. This is however just a theory why the collapsed cone and Monte Carlo simulation differs for 1 cm field radius.

The uncertainty for the Monte Carlo simulation is largest in the air cavity region. This is due to the low density of the air which will result in few interactions and, as was seen in chapter *2.4.3*, the statistics depend of $\sigma = \sqrt{\frac{1}{N \cdot \mu_{en}^{eff}} \cdot \frac{A_{beam}}{V_{voxel}}} \Rightarrow \sigma \propto \sqrt{\frac{1}{\mu_{en}^{eff}}}$ if A_{beam}, V_{voxel} and N are constant.

Depth dose data and dose profiles for the 4, 10 and 18 MV x-rays are presented in the appendix. As can be seen in appendix 3 the build-down and build-up increases with increasing energy and it decreases with increasing field size. The dose profiles are quite similar and no mayor difference between them can be seen.

Table 2. Build-up. Depth dose at 0.5 and 1 mm below the cavity. The depth dose is presented as percentage of the normalization dose. The dose for Monte Carlo simulation is compared to the dose for TMS-collapsed cone and TMS-pencil beam.

Energy	$dd_{0.5mm}$ MC	$dd_{0.5mm}$ TMS CC	$dd_{0.5mm}$ TMS PB	dd_{1mm} MC	dd_{1mm} TMS CC	dd_{1mm} TMS PB
			field radius 1 cm			
4 MV	42	51	95	54	31	95
6 MV	33	46	95	42	32	95
10 MV	30	43	96	36	35	95
18 MV	32	43	96	37	39	96
			field radius 2.5 cm			
4 MV	88	80	95	93	85	95
6 MV	89	81	95	93	86	95
10 MV	90	86	95	93	90	95
18 MV	86	83	95	90	87	95
			field radius 5 cm			
4 MV	91	89	94	95	94	94
6 MV	91	90	95	95	94	94
10 MV	92	90	95	95	94	95
18 MV	93	90	95	96	94	95

In table 2 the extracted absorbed dose 0.05 and 0.1 cm below the air cavity are summarised. The build-up effect is shown for the different field sizes and different energies. The build-up effect increases with increasing energy and decreasing with increasing field size. The pencil beam algorithm overestimates the dose up to 250% in the air cavity region. Collapsed cone overestimates only for 1 cm field radius and then with 30% at most, otherwise Monte Carlo and Collapsed cone agree very well.

Table 3. The absorbed dose at a depth of 4.5 cm , i.e. the dose at the beginning of the cavity just before the beam enters the cavity. The dose is presented as percentage of normalization dose. The three columns to the left is with cavity and the column to the right is without cavity for MC.

	With cavity			Without cavity
Energy	$dd_{4.5mm}$ MC	$dd_{4.5mm}$ TMS CC	$dd_{4.5mm}$ TMS PB	$dd_{4.5mm}$ MC
	1.0 cm field radius			
4 MV	95	99	104	104
6 MV	94	99	103	103
10 MV	94	99	103	103
18 MV	95	99	102	102
	2.5 cm field radius			
4 MV	102	103	103	104
6 MV	101	102	103	103
10 MV	101	102	102	102
18 MV	98	102	101	101
	5.0 cm field radius			
4 MV	102	102	103	103
6 MV	102	102	102	103
10 MV	102	102	102	102
18 MV	101	101	102	101

The build-down effect (table 3) in front of the cavity is not as evident as the build-up effect. Pencil beam and collapsed cone only overestimates for 1 cm field radius. Otherwise the curves have a good agreement. The build down effect increases with increasing energy and decreases with increasing field size.

4. Conclusion

The build-down and build-up effect as was seen in this report increases with increasing energy and decreases with increasing field size. Other studies also suggest that the build-down and build-up depends on the size of the cavity and the placement of the cavity [11].

The Pencil Beam algorithm overestimates much in a heterogeneous media. The reason the Pencil beam overestimates depends on the algorithm do not take changes of lateral scattering effects into consideration. Collapsed cone performs better but is to slow to use in clinical treatment in its current appearance. Collapsed cone should be preferable in a heterogeneous medium.

According to ICRU it is recommended that inside a target volume the homogeneity of the absorbed dose should be kept between 95-107% of the prescribed absorbed dose [12]. The accuracy of dose planning algorithms should according to IPEM aim at a discrepancy of 2% or 2 mm [13]. Some studies also say that an accuracy improvement of 1% will result in a 2% increase of cure [14]. This shows that it is important to have a good algorithm that calculates the dose well.

4.1 Solve the problem

What can be done to solve the problem of underdosage in a heterogeneous media? A better dose calculation algorithm is of course wanted. For example a faster collapsed cone. A future goal could be to use Monte Carlo simulations for all individual cases. This does not however solve the problem its just models underdosage better.

To really solve the problem some studies have suggested a method where longitudinal external magnetic fields are applied [15, 16, 17]. This will take away the loss of electron equilibrium by reducing the penumbra effects i.e. reduce the lateral electron transport in low density media. The electrons will travel along a spiral about the field lines caused by the longitudinal magnetic field.

5. References

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6. Appendices

6.1 Appendix 1. Energy and spectrum

Table 4. Spectrum used in Helax-TMS- and Monte Carlo-simulation

Energy	Spektrum
4 MV	CL4 MAR02, Varian clinac 600c
6 MV	L25 MAR02, Philips SL25
10 MV	L03 MAR03, Elekta precise
18 MV	L25 MAR02, Philips SL25

6.2 Appendix 2. Normalization curves

Normalization curves i.e. depth dose curves for a phantom without an air cavity.

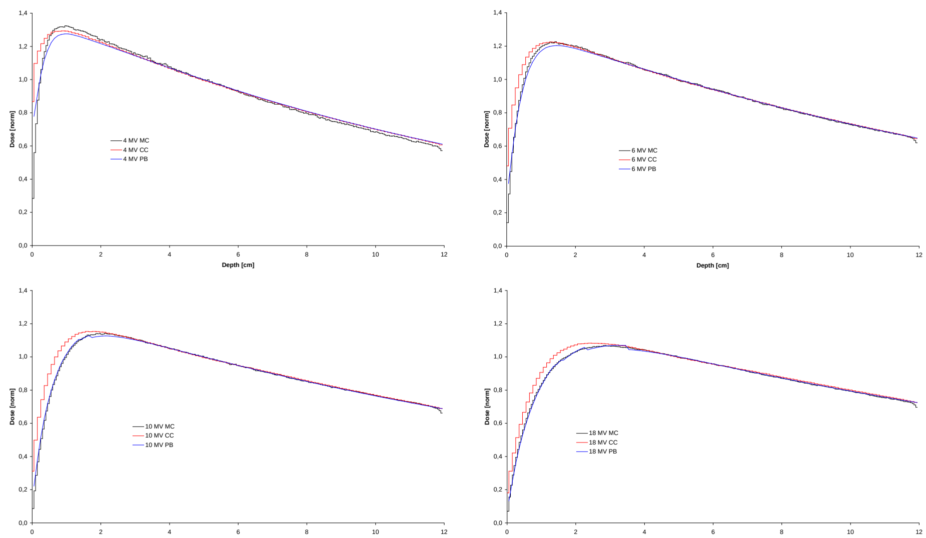

Figure 13. 10mm field size without a cavity. 4 MV (up left), 6 MV (up right), 10 MV (down left) and 18 MV (down right)

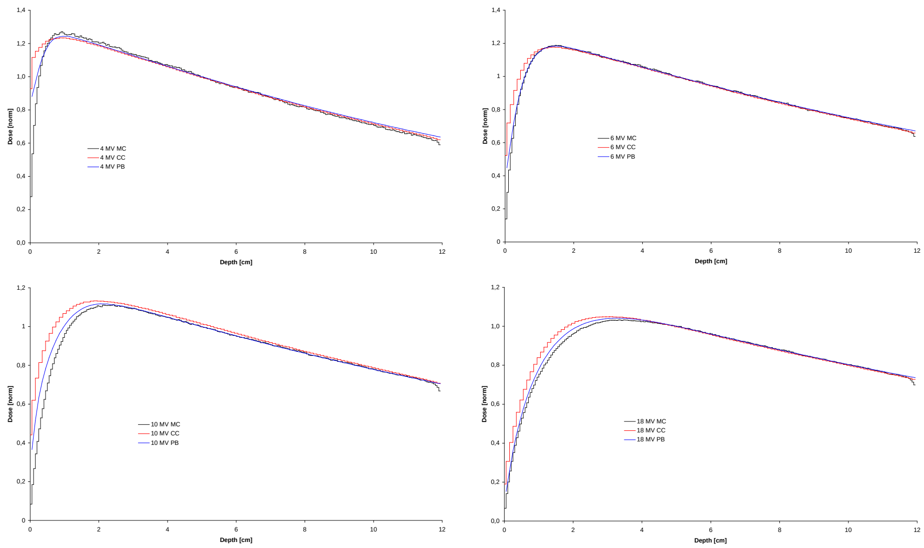

Figure 14. 25 mm field size without a cavity. 4 MV (up left), 6 MV (up right), 10 MV (down left) and 18 MV (down right)

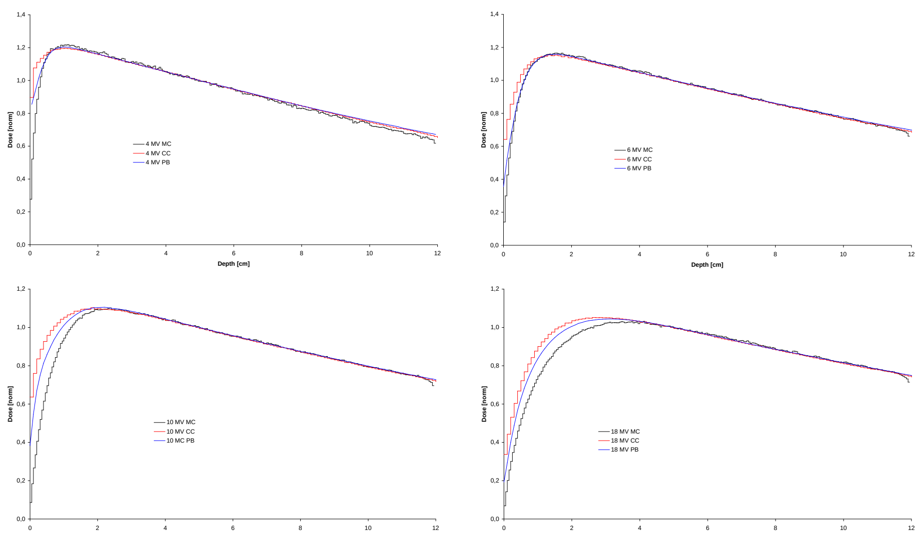

Figure 15. 50 mm field size without a cavity. 4 MV (up left), 6 MV (up right), 10 MV (down left) and 18 MV (down right)

Table 5. Normalization for different field sizes and energies. The dose at 5 cm depth for a phantom without an air-cavity

Energy	MC	PB	CC
	50 mm field size		
4 MV	4,211E-12	1,307586	1,310102
6 MV	6,612E-12	1,275279	1,275882
10 MV	9,017E-12	1,242084	1,241978
18 MV	1,090E-12	1,219372	1,218255
	25 mm field size		
4 MV	3,996E-12	1,239991	1,245543
6 MV	6,409E-12	1,219961	1,221987
10 MV	8,813E-12	1,195972	1,19452
18 MV	1,069E-11	1,177256	1,174707
	10 mm field size		
4 MV	3,745E-12	1,17058	1,139228
6 MV	6,04E-12	1,155088	1,109623
10 MV	8,09E-12	1,094987	1,046928
18 MV	9,27E-12	1,036388	0,989844

6.3 Appendix 3. Depth doses for phantom with a cylindrical air-cavity.

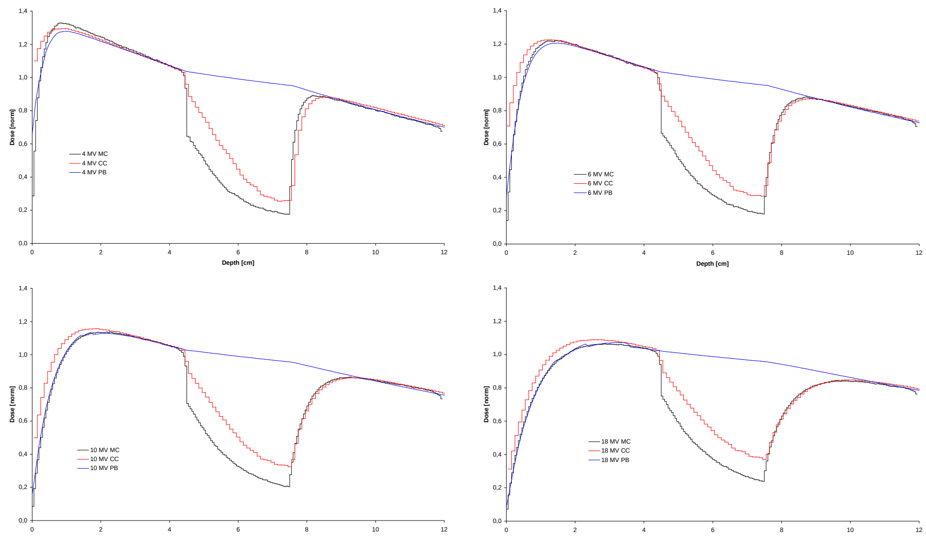

Figure 16. 10 mm field size with an air cavity. 4 MV (up left), 6 MV (up right), 10 MV (down left) and 18 MV (down right)

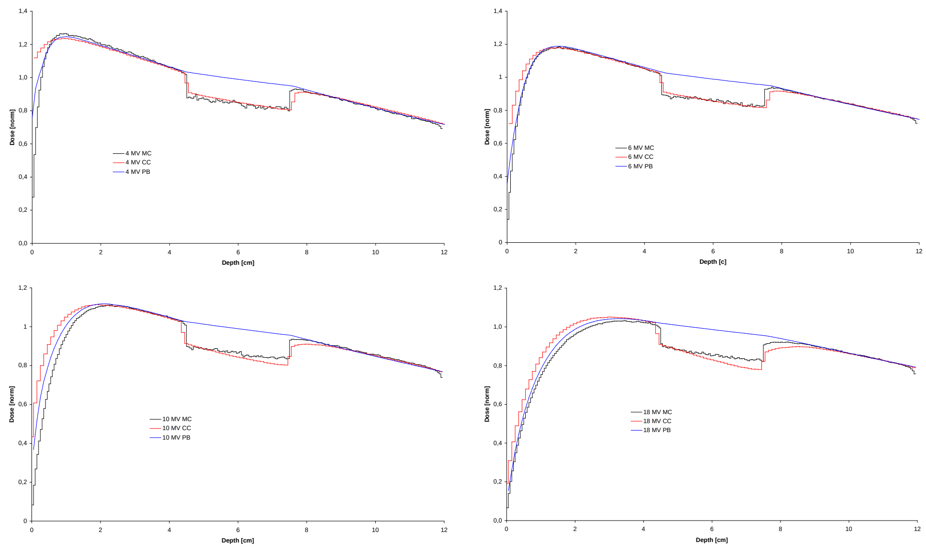

Figure 17. 25 mm field size with an air cavity. 4 MV (up left), 6 MV (up right), 10 MV (down left) and 18 MV (down right)

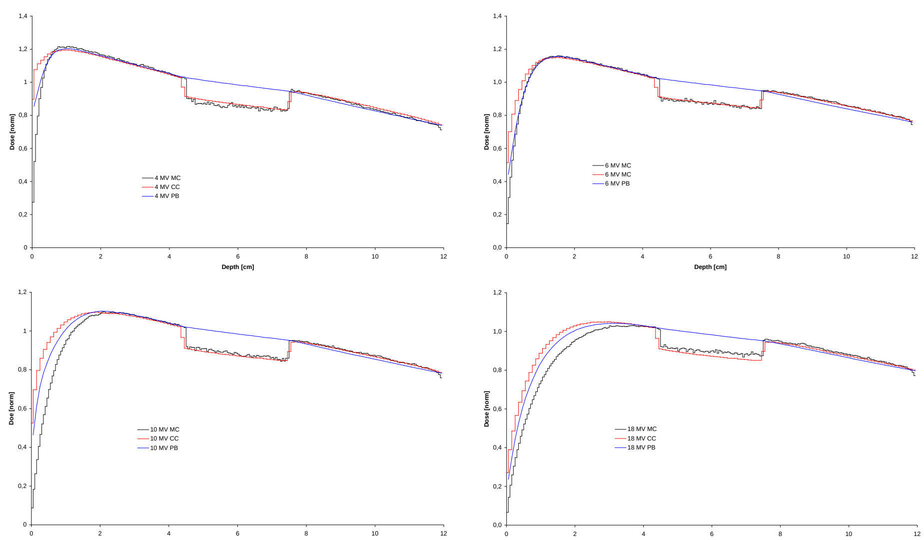

Figure 18. 50 mm field size with an air cavity. 4 MV (up left), 6 MV (up right), 10 MV (down left) and 18 MV (down right)

6.4 Appendix 4. Profile of the dose in the air-cavity

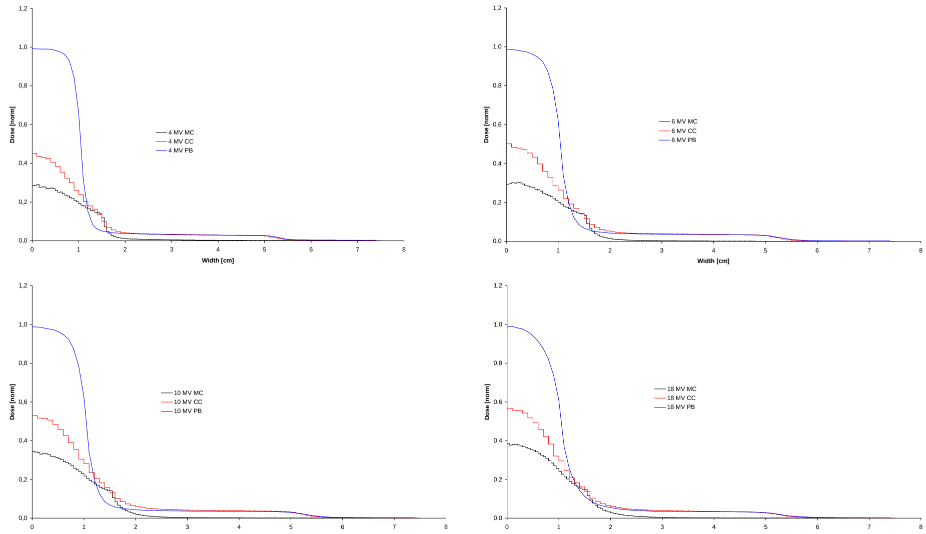

Figure 19. Profile of the dose for 10 mm field size with an air cavity at 6 cm depth. 4 MV (up left), 6 MV (up right), 10 MV (down left) and 18 MV (down right)

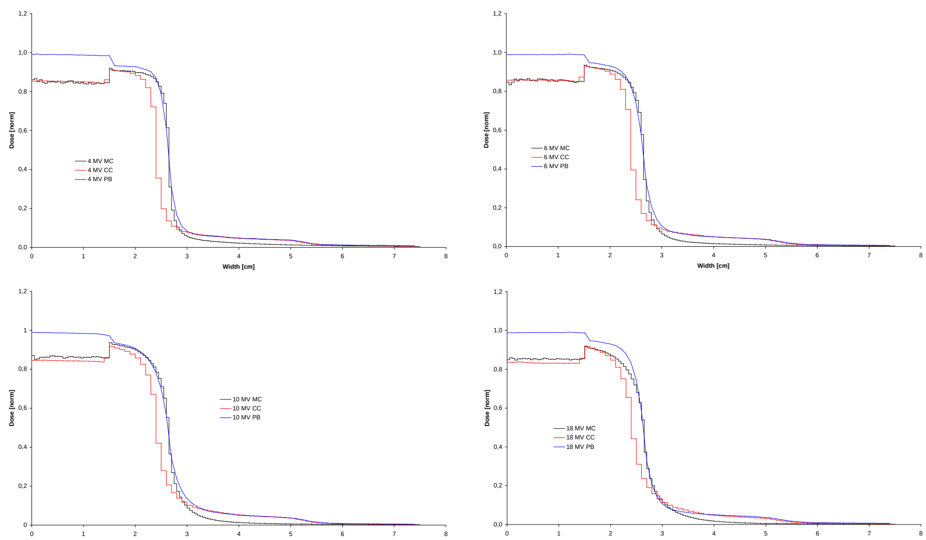

Figure 20. Profile of the dose at 6 cm depth for 25 mm field size with an air cavity. 4 MV (up left), 6 MV (up right), 10 MV (down left) and 18 MV (down right)

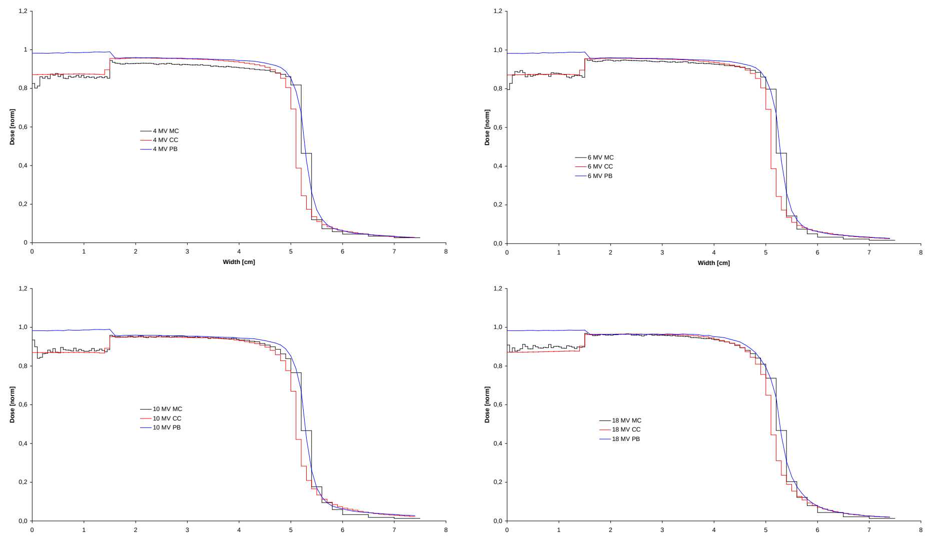

Figure 21. Profile of the dose at 6 cm depth for 50 mm field size with an air cavity. 4 MV (up left), 6 MV (up right), 10 MV (down left) and 18 MV (down right)

7. Summary for the general public in Swedish

7.1 Dosens upp- och nedbyggnad i gränsskiktet mellan mjukvävnad och luft vid strålbehandling i hals- och huvudregionen

Hals- och Huvudregionen innehåller många luftkaviteter t.ex. luftstrupe, bihålor och munhåla. Detta arbete undersökte vad som händer i vävnaden kring dessa luftkaviteter när de blir bestrålade med fotoner och hur bra ett dosplaneringssystem för strålbehandling modellerar den absorberade dosen till ett heterogent media.

Dosberäkningarna gjordes med hjälp av ett Monte Carlo-simuleringsprogram som heter DOSRZnrc. Monte Carlo simulering använder en slumpgenerator och är en av de mest precisa metoderna för att beräkna den absorberade dosen till ett medium. Dosplaneringssystemet som jämfördes med Monte Carlo simuleringarna heter Helax-TMS. Helax-TMS innehåller två olika beräkningsalgoritmer: Collapsed Cone och Pencil Beam. Collapsed cone används idag inte på universitetssjukhuset i Lund. Anledningen till detta beror på att algoritmen är långsam i beräkningen.

Geometrin som användes skulle efterlikna en luftkavitet som befinner sig i hals och huvudregionen. Detta gjordes med en förenklad geometri som endast bestod av en vattencylinder med en liten luftcylinder placerad i dess centrum. Vattencylinder var 12 cm lång och med en radie på 7.5 cm. Luftcylindern var 3 cm lång och med en radie på 1.5 cm. Fotonstrålning skickades in längs med cylinderns centralaxel med energierna 4, 6, 10 och 18 MV. 4 och 6 MV används vanligtvis vid behandling i hals- och huvudregionen. Tre olika storlekar på strålfältet användes: 1, 2.5 och 5 cm.

Den absorberade dosen samlades in längs cylinderns centralaxel, dvs. djupdosen. Dosen samlades också in på ett djup av 6 cm längs hela cylinderns tvärsnitt, dvs. dosprofilen. Resultatet presenterades som djupdos- och dosprofilkurvor för de fyra energier och de tre olika fältstorlekarna.

När den infallande strålningen når till luftkaviteten kommer den absorberade dosen att minska. Detta sker gradvis och kallas för build-down. På samma sätt blir det när den infallande strålningen har passerat kaviteten och når vävnaden kommer mer dos att absorberas. Detta kallas för build-up. Build-up och build-down visade sig att öka med ökande energi och minskade med ökande fältstorlek. Andra studier har även visat att build-down och build-up även beror på placeringen av luftkaviteten och storleken på kaviteten. Dosplanneringssystemets algoritm Pencil beam visade sig överskatta dosen med upp till 250 % medan den andra algoritmen, collapsed cone, endast överskattade med som mest 20 %. Men collapsed cone är i nuläget för långsam för att användas till alla behandlingar. Ett alternativ skulle vara att endast använda collapsed cone i de fall där man har luftkaviteter närvarande.