Master of Science Thesis

# Brachyterapy for cancer of the cervix. 3D Dose distributions for new ring applicator using BrachyVision, for clinical use.

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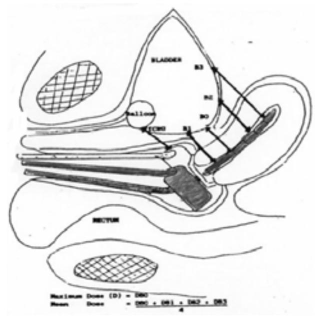
**Summary for the general public in Swedish**

# *Som att gå till skräddaren*

## Brachytherapy för cervix cancer; 3D Dosplanering med nya ring applikatorer och användande av BrachyVision för klinisk användning.

Internationellt gäller att botande strålbehandling av cancer i livmoderhalsen, består av en kombination av extern strålbehandling och brachyterapy (BT). (Brachys är grekiska och betyder nära.) Brachyterapi går ut på att placera en applikator, t.ex en ring applikator i livmoderns nedre del, alldeles intill tumören. Strålkällan förs sedan in i applikatorn (ring och prob) med hjälp av ett datoriserat styrsystem. Strålkällan strålar mot tumören med givna stopp och tider (dosplan) så att cancercellerna skall dö, medan resten av kroppen undviker strålning. Hela behandlingen kan variera från några få minuter upp till ca 15 minuter.



Här till höger kan vi se en ringapplikator placerad mot livmoderhalsens nedre del där proben går upp i livmoderhalsen.

Det nya BrachyVision systemet, som är ett 3D dosplaneringssystem för BT, skall introduceras i klinisk rutin i Lund. Detta system bygger på ett datortomografiskt (CT) underlag där man kan göra en fullständig geometrisk kartläggning av patientens anatomi kring applikatorn. Man ser även var riskorganen (urinblåsa och ändtarm) är belägna i förhållande till tumören. På så sätt kan man skapa en 3D bild av tumören och dess utbredning. Tidigare kunde man bara beskriva tumörens utbredning med ord. Nu har vi en 3D-bild, kan se om dosen till urinblåsa och ändtarm blir för hög och kan korrigera detta omgående. Med tillgång till magnetresonans (MR) bilder kan man förutom riskorganen dessutom se själva tumören.

Utifrån 3D bilder (CT/MR) görs en behandlingsplan medan patienten har applikatorn på plats, dvs. i livmoderns nedre del, utan att ringapplikator eller patientens position ändrats. Detta sker i direkt anslutning till behandlingen. I behandlingsplanen kan man då direkt göra justeringar så att behandlingen blir optimal över tumören samtidigt som riskorganens doser hålls nere. På så sätt får varje enskild patient en skräddarsydd behandlingsplan gjord.
i har nya ringapplikatorer som kan användas vid CT och MR – avbildningar, och de skall tas i kliniskt bruk tillsammans med det nya dosplaneringssystemet.

I denna rapport har vi studerat och utvärderat de nya ringarnas geometri och källans stopp-positioner i applikatorn. Vi har även gjort nya standardplaner som vi använder och anpassar till de bilder vi får från CT och MR. På detta sätt skräddarsyr man en dosplan till patienten. Ringapplikatorerna är nu redo att användas kliniskt.

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## Abstract

Curative radiotherapy for cancer of the cervix consists of a combination of extern beam radiotherapy (EBRT) and brachytherapy (BT). The most important prognostic factors are tumour size, tumour extension and lymph node involvement.

Traditional dose planning for BT of cervix cancer is based on two orthogonal films with the applicators in place in cervix. The dose distribution is related to the applicator geometry.
The target volume consists of the tumour in the cervix, the cervix, part of the vaginal mucosa, part of the corpus and the parimetria. The whole target volume should be inside the specification isodose surface. The critical organs considered are the bladder and the rectum.
The doses to organs-at-risk are calculated at reference points based on the orthogonal films. If the total dose is too high, the BT dose is often lowered the last fraction.

With the new 3D treatment planning system BrachyVision, together with new CT and MR compatible ring applicators, we can use 3D CT- and MR-images as a base for the treatment planning. We can see patient anatomy together with the applicators in the cervix, and thus optimize the BT dose distribution to the actual patient geometry.

The tumour itself can not be defined with CT alone. Thus, with treatment plans based on CT, a predefined standard dose distribution for the applicator used can be adapted to minimize the dose to the organs-at-risk and still cover the target defined above in words.
With accesses to MR images with applicators in place we can define both the tumour, the target and the organ-at-risk and optimize the dose to the target while minimizing the dose to the risk organs.

In this paper we have studied and verified the geometry, for the new ring applicators. We have also evaluated some standard plans, to be used and adapted in CT- and MR- based brachytherapy. The rings are now ready to use in the clinic, starting with the Lund old method, follow by CT-based treatments.

# 1 Introduction

The human papilloma virus plays an important role in the genesis of cervix cancer and is observed in 90% of all women with cervix cancer. Every year 500 women in Sweden get the diagnosis cervix cancer and over 90% of these women can be cured if they come for treatment in an early stage [1]. Today screening is used to diagnose the cancer in an early stage of the disease. The most important prognostic factors are tumour size, tumour extension and lymph node involvement.

Curative radiotherapy for cancer of the cervix consists of a combination of extern beam radiotherapy (EBRT) and brachytherapy (BT). BT gives a high central dose, an essential part of the curative radiotherapy for cervix cancer.

The radiotherapy in Lund consists of EBRT to 46 Gy with 2 Gy/fraction over 5 weeks with box technique to the pelvic lymph nodes (microscopic disease), and a boost to the “cervix volume”. For smaller tumours; EBRT to 50 Gy + 5 fractions BT with 5 Gy/fraction. For larger tumours; EBRT to 60 Gy + 3 fractions BT with 5 Gy/fraction.

The BT-target volume consists of the tumour in the cervix, the cervix itself, the upper part of the vaginal mucosa to a depth of 2 mm, part of the corpus and the parametria. The tumour volume is determined by clinical examination, i.e. inspection and palpation, together with imaging results that are available. The target volume should be inside the specification isodoses surface.

Brachytherapy is a special procedure in therapeutic radiology that utilizes radioactive sources placed inside or at short distance from the target. Intracavitary brachytherapy generates highly non uniform dose distributions. The applicators are placed in body cavities in or near the target with high dose gradients inside and outside the target.

Intracavitary brachytherapy for the cancer of cervix was introduced early, when Radium was the only available radionuclide. Typical dose distributions for cervix cancer, see figure 1. The old Lund Radium technique was based on the classical Stockholm dosimetry system, a low doserate technique. In Lund the last Radium-treatment was given in 1994, when the technique was changed over to high doserate treatments with ring applicators and a $^{192}$Ir source.

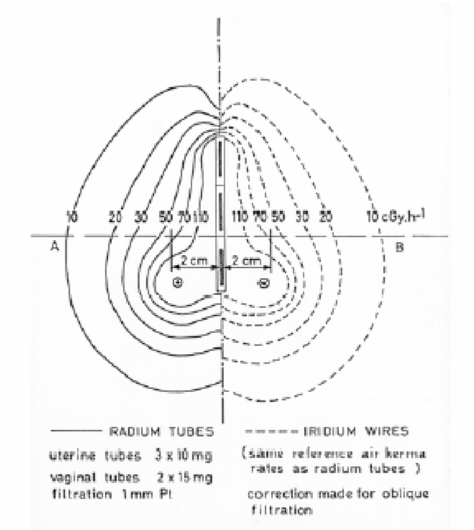


*Figure 1:Typical doserate distributions for cervix cancer. LDR Ra and LDR $^{192}$Ir. From ICRU 38. [2]*

# 2 International recommendations

## *ICRU definitions of target and organ-at-risk [3]*

The success of BT requires the delivery of a high radiation dose directly to the tumour with sparing, to some degree, the surrounding normal tissues.
The target volume must always be described, independently of the dose distribution, in term of the patient's anatomy, topography and tumour volume.

The *gross tumour volume,* GTV, may be evaluated by various diagnostic methods; clinical examination i.e. inspection and palpation, endoscopies, and image techniques such as radiography, CT, MRI, PET, ultrasound, or other techniques, depending on the location and type of pathology.

The *clinical target volume,* CTV, is the volume with contains the gross and subclinical disease. Clinically, it thus contains the GTV and a safety margin around the GTV to take into account (probable) subclinical involvement. The CTV may also include other anatomical areas, e.g., regional lymph nodes or other tissues with suspected (or proven) subclinical involment.

The *planning target volume,* PTV, is a geometrical concept, taking into consideration the net effect all possible geometrical variations.

The *Organ at risk,* OAR, is normal tissues whose radiation sensitivity may significantly influence treatment planning and / or prescribed dose.

For brachytherapy the planning target volume PTV is the same as the clinical target volume, CTV.

### *Dose reporting for cancer of the cervix according to ICRU 38*

Recommendations for reporting brachytherapy for cancer of the cervix are given in ICRU 38 for the old traditional type treatment planning [2].

- The Source
- The applicator
- Total Reference Air Kerma
- Reference Volume
- Description of Dose distribution
- Dose rate and/or treatment time
- Absorbed dose at reference points and the neighboring regional structures, organs-at-risk

Based on clinical experience, three different systems have been proposed for the treatment of cervix carcinoma; Stockholm, Paris and Manchester.
The specification point of the Manchester system, point A, is a point 2 cm lateral to the probe central canal and 2 cm up from the build-up-cap of the lateral fornix in the axis of uterus. [2, 4]
Point A is still often used in reporting, even if the dose is not specified at point A.

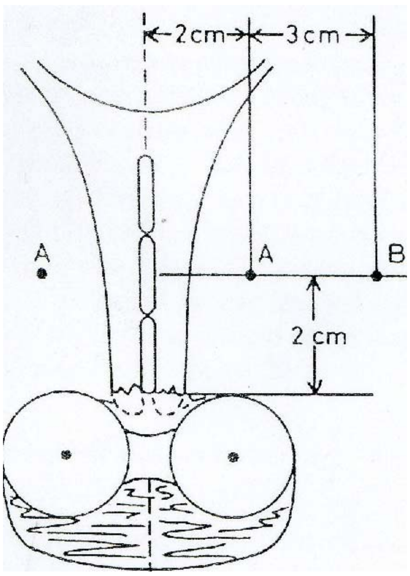


*Figure 2: Manchester system definition finding point A (and B).ICRU 38. [2]*

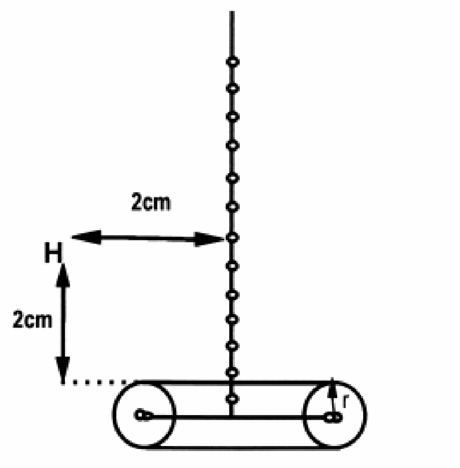


*Figure 3: American Brachytherapy Sociey. The probe and ring, finding point A. [4]*

ICRU 38 has defined reference points related to rectum and bladder.
The catheter in the bladder, with ~7 $cm^3$ contrast in the balloon, is pulled downwards to bring the balloon against the urethra and it will provide an image representing the bladder. Rectum is nominally 0.5 cm below the vaginal wall, see figure 4.

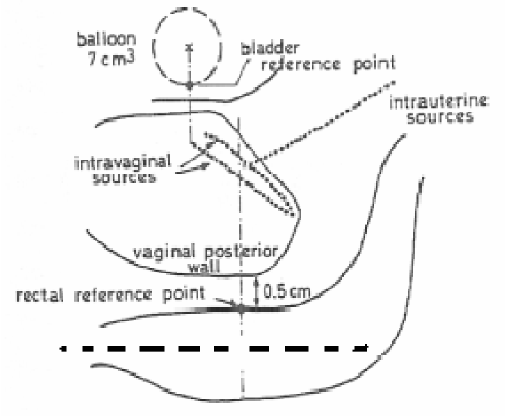


*Figure 4: ICRU 38 Recommendations for Rectum and Bladder reference point. [2]*

### *The new 3D image based method; GEC-ESTRO recommendations.*

The development of 3D image based 3D treatment planning includes a new comprehensive approach to BT for cancer of the cervixin. GTV and topography change significantly during the EBRT, and there is a clear need for a systematic description of GTV and CTV in its specific topographic relation at diagnosis and at time of BT. The BT is usually given at the end of the EBRT. MR imaging is required to define the tumour extention. [5]

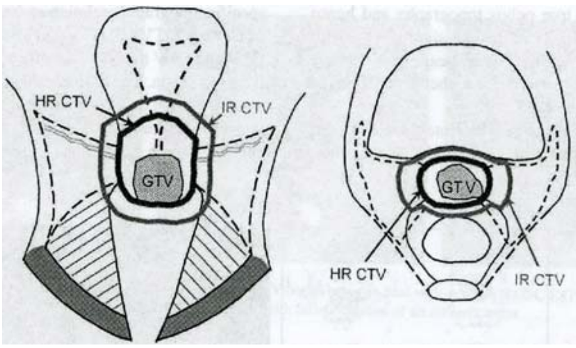


*Figure 5: GEC ESTRO recommendations GTV and CTV, limited disease, coronal and transversal view. [5]*

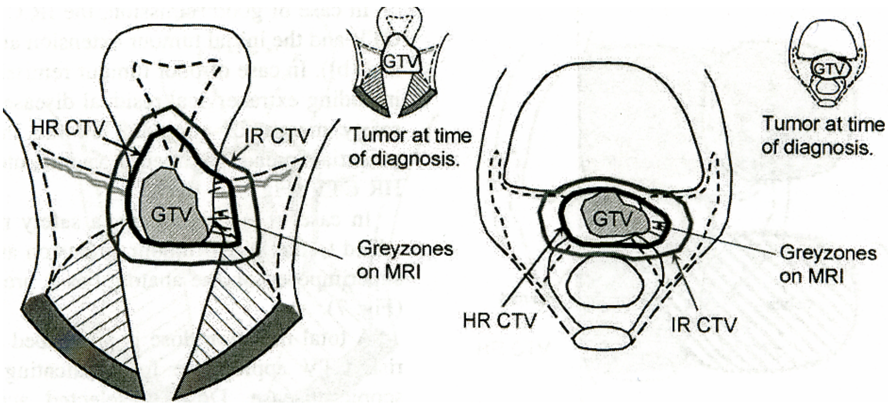


*Figure 6: GEC ESTRO recommendations. GTV and CTV, extensive disease, coronal and transversal view. [5]*

*High risk CTV* (HR CTV), carrying a high tumour load includes GTV at time of BT, always the whole cervix and the presumed extracervical tumour extension at time of BT [5].

The planning target volume PTV, is the same as the clinical target volume CTV. The total dose should be as high as possible and appropriate to eradicate all residual macroscopic tumour. [5]

The GEC – ESTRO recommendations for reporting include parameters for 3D image based dosimetric evaluation of intracavitary BT, for GTV/CTV and OaR.

- Reference Volume
- TRAK
- Prescribed Dose (PD)
- Point A Dose
- $D90_{CTV}$ (Dose in 90% of CTV)
- $D100_{CTV}$ (Minimum Target Dose)
- $D100_{GTV}$ (minimum dos in GTV)
- $V100_{CTV}$ (CTV volume receiving ≥ 100% of PD)
- Dose volume parameters for organs-at risk

# 3 Material/method

### *Treatment unit and Source*

The change in October 2005 from GammaMed 12i to GammaMed plus means changing to a physically smaller source. Both GammaMed 12i and GammaMed plus are remote controlled high dose rate (HDR) afterloading units with 24 channels and one stepping $^{192}$Ir source. (HDR is defined in ICRU 38 as >12Gy/h = 0.2 Gy/min)

The $^{192}Ir$ decay spectrum has a gamma mean value of 0.380 MeV and some low energy beta, mostly captured in the source and source encapsulation. The half life is 73.83 days. The source is changed four times in one year, to keep the treatment times short.

The old treatment unit GammaMed 12i has a source encapsulation 5 mm long with a diameter of 1.1 mm, and an active length of 3.5 mm and diameter 0.6 mm.
The new treatment machine GammaMed plus has a source encapsulation 4.5 mm capsule length and diameter 0.9 mm, with 3.5 mm active length and 0.6 mm diameter.

The afterloader (GammaMed 12i or GammaMed plus) is programmed according to the accepted treatment plan and the applicators are connected to the corresponding channels of the afterloader. The source is computer controlled and travels out into each channel in turn and steps backwards. Both the control software and the treatment planning systems use nominal source strength “10 Ci” and nominal treatment times. The actual treatment times (decay corrections) are calculated in the control software.

At the source exchange, the source strength (apparent activity) is 370 GBq, 10 Ci, or slightly higher.
The Reference air kerma rate, RAKR, for a source is the kerma rate to air, in air, at a referenc distance of 1 m, corrected for air attenuation and scattering. For GammaMed plus the nominal reference air kerma rate is 40.7 mGy/h at 1 m.

## *The new treatment planning system*

BrachyVision is the new 3D dose planning system using 3D patient data from CT/MR/US.

We used CT images to study the new ring applicators in the new dose planning system. There we can set up the dwell time in the stop positions for the standard treatment plans and show the isodoses curves in 3D around the applicator.

If we only have access to CT, we can adapt the dose to the organs-at-risk. But if we have access to MR, we can adapt the dose to both the target and the organs-at-risk. We can moderate the dwell times interactively and see the doses to the target and organs-at-risk, as shown in figure 7. The window up to the right shows the dwell times for the source stop positions. We can adapt the dwell times to have the specification isodose surface covering the target volume and minimizing the risk organ doses.

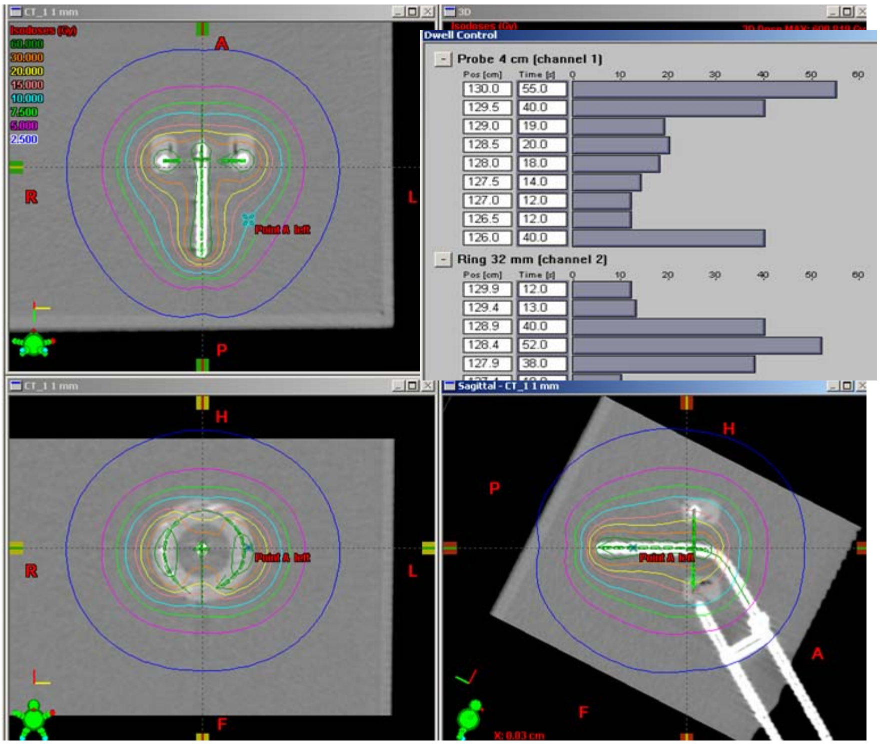


*Figure 7: Isodoses from the BrachyVision system. Ring angle 30$^o$ with 40 mm probe.*

## *Dose distribution around the source*

The dose distribution around a source can be calculated using the AAPM TG-43 formalism for cylindrically symmetric sources [6]. The dose distribution is described using a polar coordinate system with its origin at the source center, with $r$ the distance from the origin to the point-of-interest $P$, and $\theta$ the angle with respect to the long axis of the source, as shown in figure 8. Point $P$ ($r_0,\ \theta_0$) is the reference point that lies on the transverse bisector of the source at a distance of 1 cm from the origin, $r_o$ = 1 cm and $\theta_o = \pi/2$.

The dose rate $\dot{D}\,(r,\ \theta)$ at point $P(r,\ \theta)$ in water, can be written as

$$\dot{D}\,(r,\ \theta) = S_K \Lambda \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta)$$

Where

| | |
|---|---|
| r | is the distance from the origin to the point-of-interest $P$ |
| $\theta$ | is the angle between the direction $r$ and the long axis of the source |
| $S_K$ | is the air-kerma strength of the source |
| $\Lambda$ | is the dose rate constant |
| G($r,\ \theta$) | is the geometry factor |
| g (r) | is the radial dose function |
| F($r,\ \theta$) | is the anisotropy function |

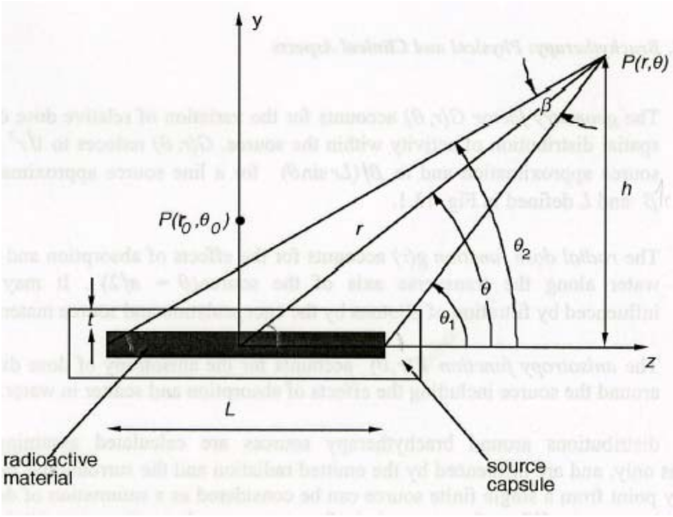


*Figure 8: Geometry used in calculation of dose distribution near a linear source.[6]*

The dose distribution around the source is calculated assuming only photon interactions. BrachyVision uses the AAPM TG-43 formalism. Tables for different sources are published in the literature.

### *Lund Old method – Brachytherapy for cancer of the cervix*

The old ring applicators were not CT/MR compatible, they were made of steel. There were two sizes of the ring: The large ring applicator has a 31 mm stop position diameter and a physical diameter of 41 mm, the small ring a 23 mm stops position diameter and a physical diameter of 34 mm. The intrauterine probes have lengths of 0, 20, 30, 40, 50 and 60 mm. The angles of the rings are $90^{o}$, $60^{o}$ and $45^{o}$, with accompanying probes (see figure 9).

The target volume consists of the tumour in the cervix, the cervix itself, the upper part of the vaginal mucosa to a depth of 2 mm, part of the corpus and the parametria. The tumour volume is determined by clinical examination, i.e. inspection and palpation, together with imaging results that are available.

In the old treatment planning systems, GammaDot and Abacus, we have a catalog of standard dose distributions for the two ring sizes, combined with the different probes. Spacers were specially designed to fit the dose distributions in order to keep the organs-at-risk away from the high dose region “below” the rings.

Inside the specification dose (100%), we should have the target volume. The dose to the organs-at-risk, nominally 5 mm outside the spacer, is 77-80% of the specification dose, which is defined 2 mm outside the spacer, ventrally and dorsally.

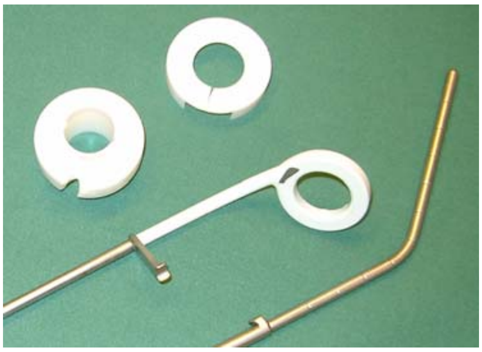

*Figure 9: The old ring applicator, 45$^o$ ring and 6 cm intrauterine probe together with spacer*

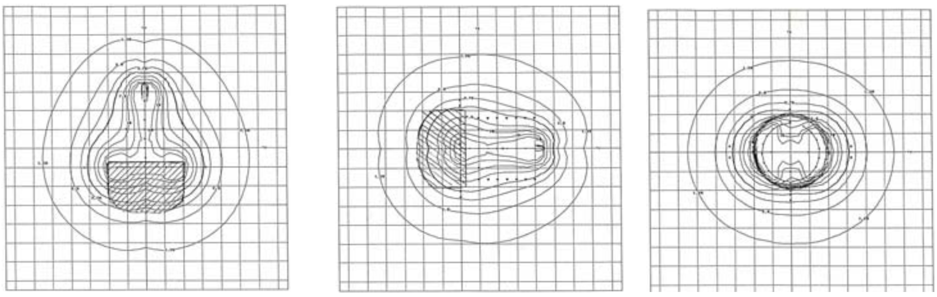

*Figure 10: isodose curves for the large ring and 40 mm probe with spacer indicated.*

To calculate the “actual” dose to the organs-at-risk we used two orthogonal films, one lateral and one anterior as shown in figure 11.

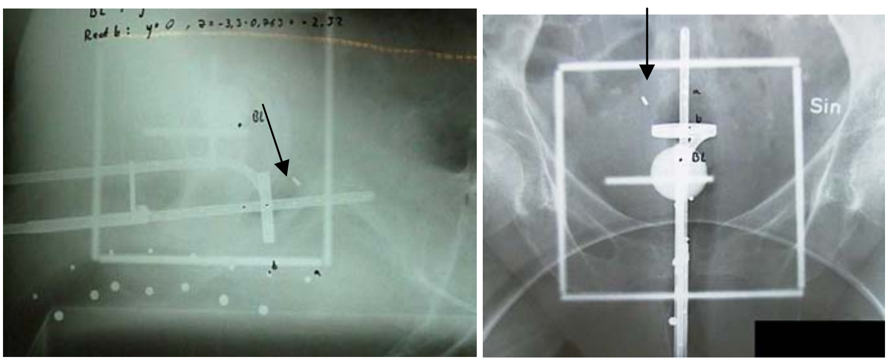


*Figure 11: X-rays films, lateral and anterior views.*

For a brachytherapy application the risk organ points should represent the maximum doses to the organs. They must by easy to identify on both

projection images. Marker wires are helpful in defining the applicator in the orthogonal projection images. ICRU 38 has defined reference point related to rectum and bladder (see figure 4). For the PTV the coverage and the homogeneity of the dose distribution are important factors related to tumour control and damage to late reacting normal tissues inside the PTV.
The bladder is indicated according to the ICRU 38 recommendations, and the rectum is shown using home made indicator with two rows of lead shots.

When the risk organ points are identified and their coordinates calculated in the applicator co-ordinate system, doses are calculated using the treatment planning system GammaDot (or Abacus). Radiobiological effects for organs-at-risk (and target) were calculated for each BT fraction and also for the combined planned EBRT and BT, using the LQ model. The BT doses were adapted to keep the organs-at-risk doses below the agreed limit,
"72-74 Gy in 36-37 fractions".

The old treatment unit GammaMed 12i was upgraded to a GammaMed plus with a physically smaller source in October 2005, as mentioned. We checked the stop positions in the rings for the Gamma Med plus with Gafchromic film and compared that with the old GammaMed 12i. The stop positions were found to be the same and the old applicators and the old standard dose distributions will be used also with the GammaMed plus.

### *Lund new ring applicators*

The new ring applicator is CT/MR compatible for use in field strengths up to 1.5 T. The material is Titanium. The ring applicators have angles of 30$^o$, 45$^o$ and 60$^o$. The probes have lengths of a 20, 40 and 60 mm, see figure 12-15 [7].

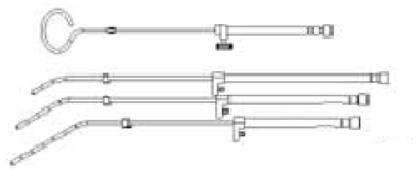

*Figure 12: Angle of 30$^o$*
*Length of probe 20, 40 and 60 mm.*

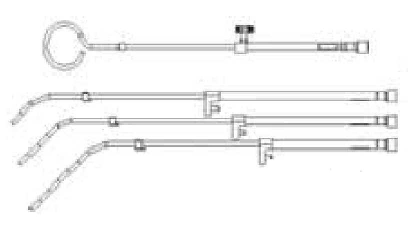

*Figure 13: Angle of 45$^o$*
*Length of probe 20, 40 and 60 mm.*

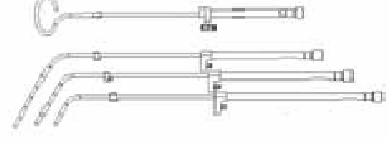

*Figure 14: Angle of 60$^o$*
*Length of probe 20, 40 and 60 mm.*

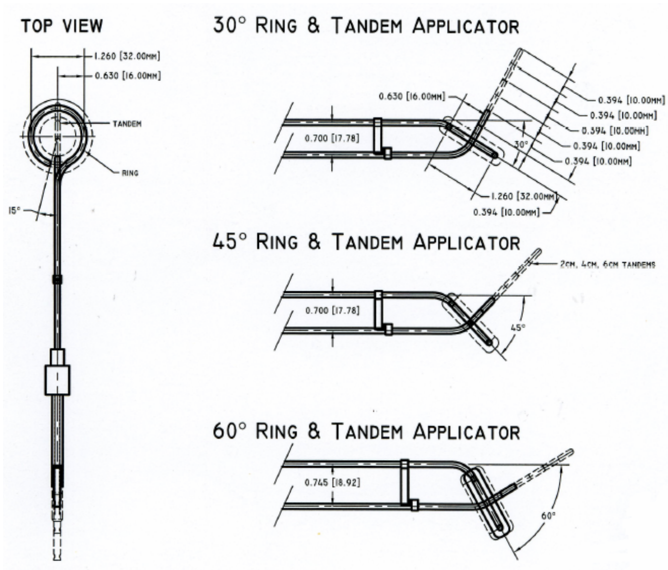


*Figure 15: Top view and 30°, 45°, 60° rings with tandem applicator.*

The ring comes with two different build-up caps,”5 mm and 7.5 mm”.

*Figure 16: Two different thicknesses of build-up caps 5 and 7.5 mm.*

### *Stop positions in the ring and probe*

When the source wire is pushed out into the ring the source wire will follow the outside of the channel wall in the ring. But, when the source wire starts to retract, the wire is first tightened up against the inner channel wall, while the source position remains unchanged in position 1, as shown in figure 17-19.[8]

For a correct treatment delivery this effect can be taken into account either in the treatment planning system, BrachyVision, or in the control software, GammaWin. In BrachyVision we can specify the source position range with an offset to the source position. If we specify 2 mm offset, the wire is

just tightened up in the channel during the first 2 mm of retraction. When the source continues to be retracted, the first and subsequent actual source positions will match the stop positions in the treatment planning system.
In the control software, we can as an alternative "move the origin" 2 mm, with the same effect. Care should be taken not to correct twice!

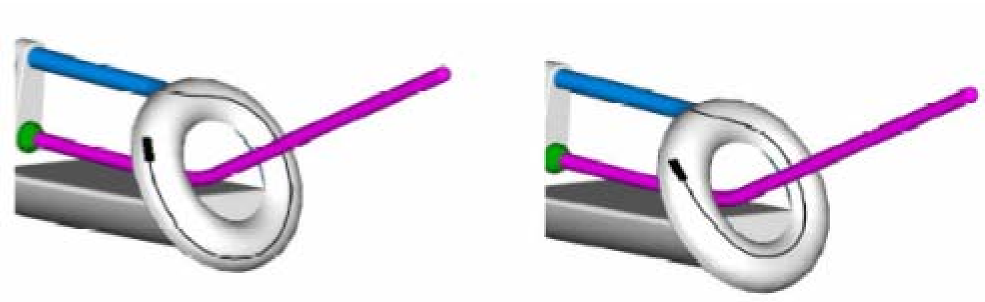

*Figure 17: Source wire extended position and source wire after first retraction in the applicator ring. (Step size 2-3 mm) [7, 8]*

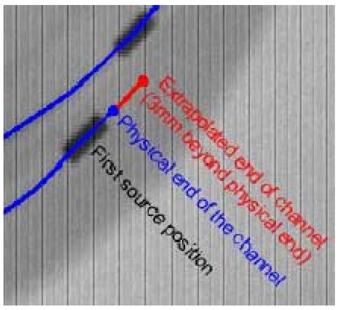


*Figure 18: Extrapolation of the end in the ring channel. [8]*

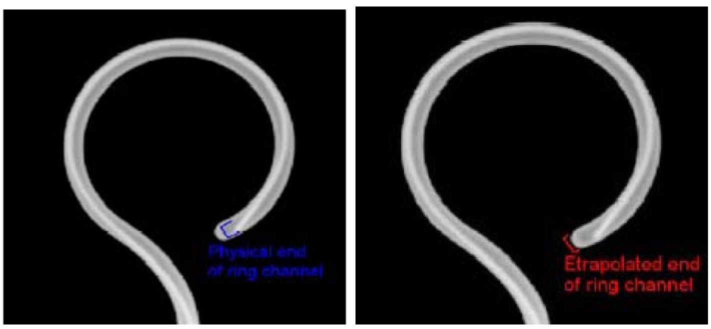


*Figure 19: Physical and Extrapolation end of the ring channel. [8]*

To check the stop positions in the ring and probe we made tests, using Gafchromic film (Gafchromic RTQA, film for QA and commissioning, QA+) as shown in figure 20, 21 for the rings. We placed the ring applicator directly on the film and taped it onto the film to make sure it didn't move.

We ran tests with the GammaMed plus with 10 step size and with 5 mm step size. We also tested moving the origin to verify the number of mm needed to reproduce the correct step movement in the ring.

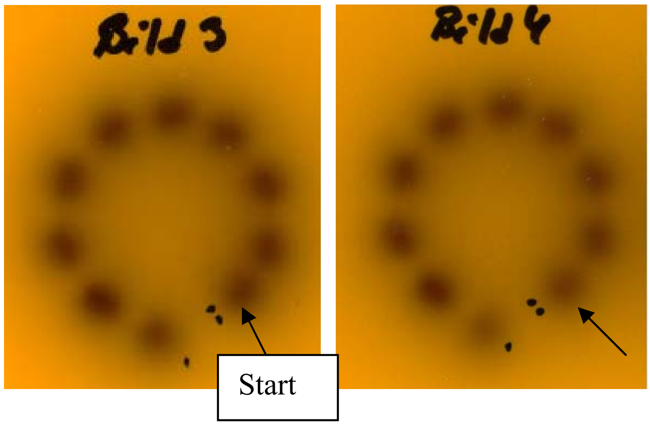


*Figure 20: Gafchromic film test 10 mm step size To the left with origin 0 mm and to the right origin moved 2 mm. All stop positions.*

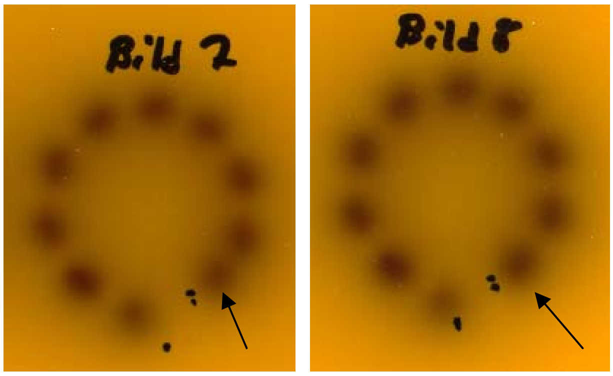


*Figure 21: Gafchromic film test 5 step size To the left with origin 0 mm and to the right origin moved 2 mm. Every other stop position, effectively 10 mm steps.*

To check the ring stop diameter we compared the film stop positions with different ring stop diameters in the Abacus system, see figure 22. The ring stop diameter was determined to be 32 mm.

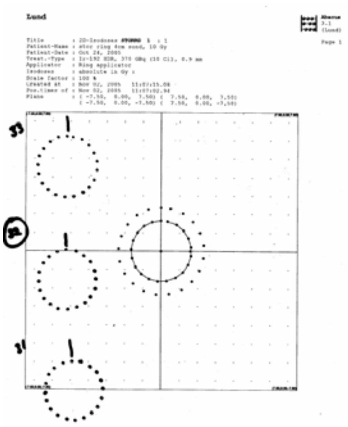

*Figure 22: Comparing ring stop position diameters,
the treatment planning system printout.*

We also checked the probe with the Gafchromic film to verfy the stop positions, as shown in figure 23 for probe length 60 mm.

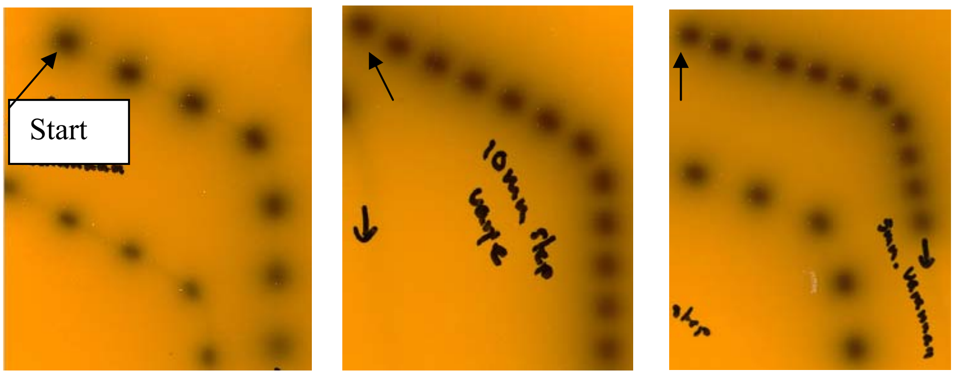


*Figure 23A* *Figure 23B* *Figure 23C*

*Figure 23: Gafchromic film test of the probe. Probe length 60 mm .
A: 10 mm step size. Every other step. B: 10 mm step size. Every step. C:5 mm step size. Every other step. The stop positions start up to the left in the image.*

In another test, we placed the ring applicator and probe with marker wires on an ordinary X-ray film (Kodak, X-Omat V, film for therapy verification) and made an x-ray exposure. We used SSD 100 cm, and 85 kV and (400 + 320 + 320) mAs. After the exposure the marker wires were removed. A GammaMed plus test run was superimposed; 3 s nominal stop time at 5 stop positions with 2 cm intervals in the ring and 4 stop positions with 3 cm intervals in the probe, (see figure 24). The markers on the marker wire are separated with 1 cm intervals. If the source moves correctly there should be 1 and 2 markers respective between every stop position on the film. We can also measure the distances between the stop positions and verify the step size. It is clearly seen that the marker wire follows the outer wall of the ring channel, while the actual stops are in the middle of the channel (stop positiondiameter 32 mm). The distance between the first two stops in the ring is 2 mm too short; we didn't move the origin.

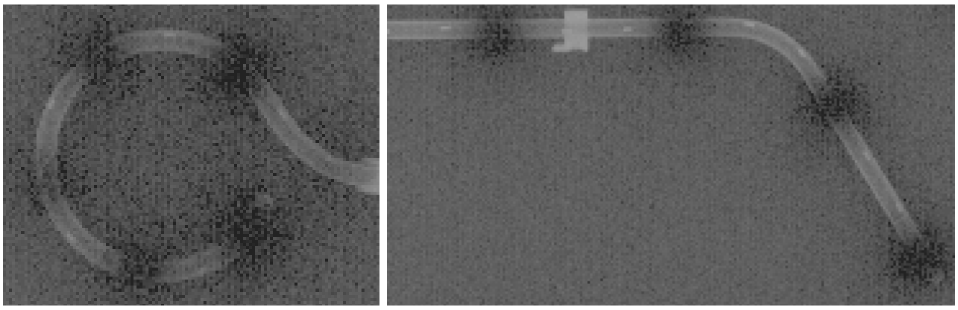

*Figure 24: x-ray exposure. Ring and the 40 mm probe and GammaMed plus test run.*

### CT-test

In the CT-test we used 1 mm slice thickness to study the applicator. We had marker wires in the applicator. All applicators were tested; 30$^o$, 45$^o$, 60$^o$ with the 20 mm, 40 mm, 60 mm probes, and with the two different build-up caps 5 mm and 7.5 mm. The 30$^o$ applicator with the 40 mm probes is used for the illustrations, figure 25. More information is available in the appendix 1.

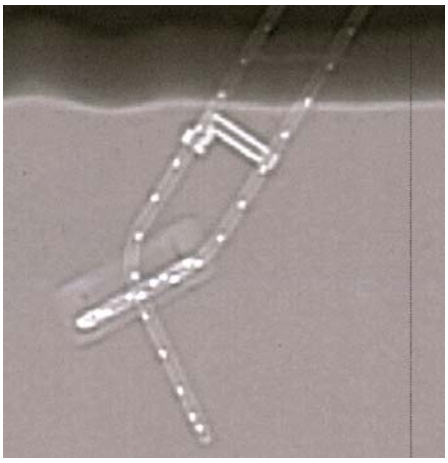

*Figure 25: CT scout view for the applicator 30$^o$and 40 mm probe, 5 mm build-up-cap.*

### Geometry of the assembled ring applicator

It is important that the probe is perpendicular to the ring plane for all ring angles and all probes. This can be verified basically by simple inspection. We have also used X-ray film to study the applicator, as shown in figure 26. CT scans have been used for full 3D verifications of the ring geometry using BrachyVision as shown in figure 27. In appendix 1.1 the geometry of all three rings with their probes is shown using BrachyVision.

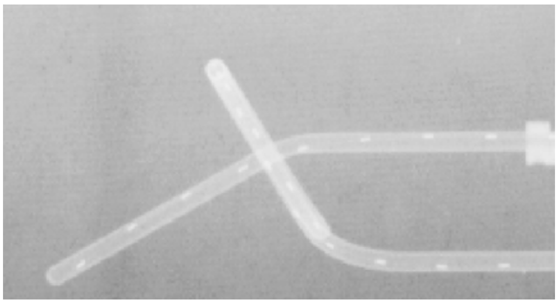

*Figure 26: Perpendicular "lateral" X-ray exposure for ring 60° and 40 mm probe with marker wire.*

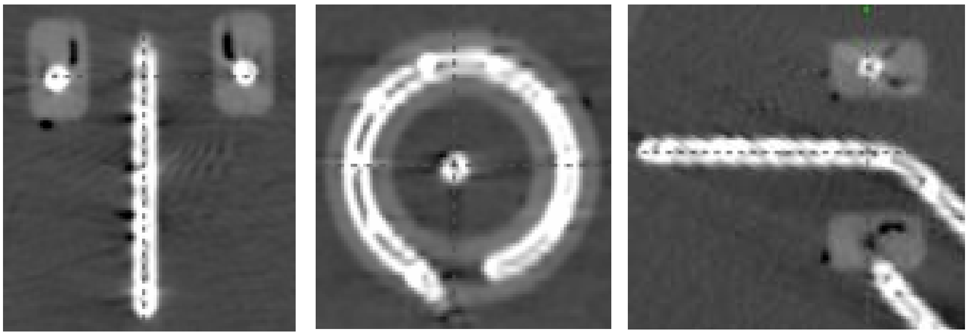

*Figure 27: Geometry for the 45° ring and 40 mm probe, 7.5 mm build-up cap in BrachyVision. "Coronal, transverse and sagittal" sections.*

It is to be noted that if we use 5 mm step size in the applicator, there is no probe stop position in the ring plane, as shown in figure 28.

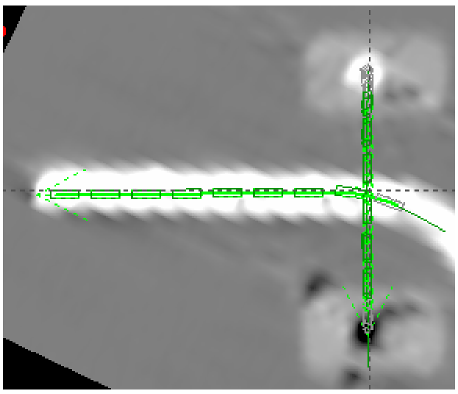

*Figure 28: Stop positions in the 30° ring and the 40 mm probe.*

### *Digitalisation of the ring applicator*

With help of orthogonal X-ray films, as shown in figure 29, we can digitize the applicator using the treatment planning system “Abacus”.

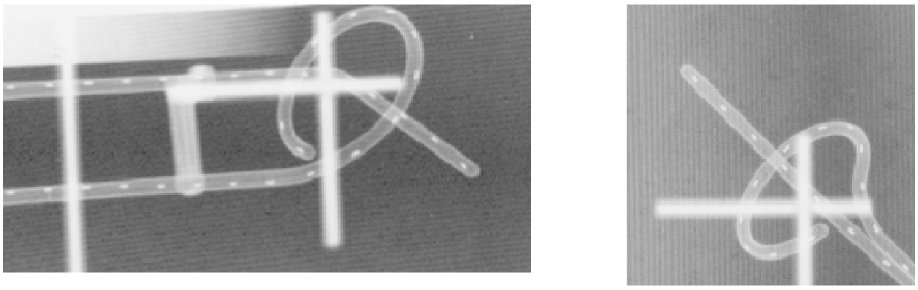

*Figure 29:Orthogonal X-ray films for digitization. Geometry for the 60º ring and 40 mm probe. To the left lateral image and to the right AP.*

The Abacus software allows you to digitize stop positions, as indicated by the marker wires, from orthogonal isocentric films, when the focus-isocenter and the focus-film distances are known.

The result is shown in figure 30. It is clearly seen, that the quality of the reconstruction is not very good, even if the film applicator geometry has been chosen optimally.

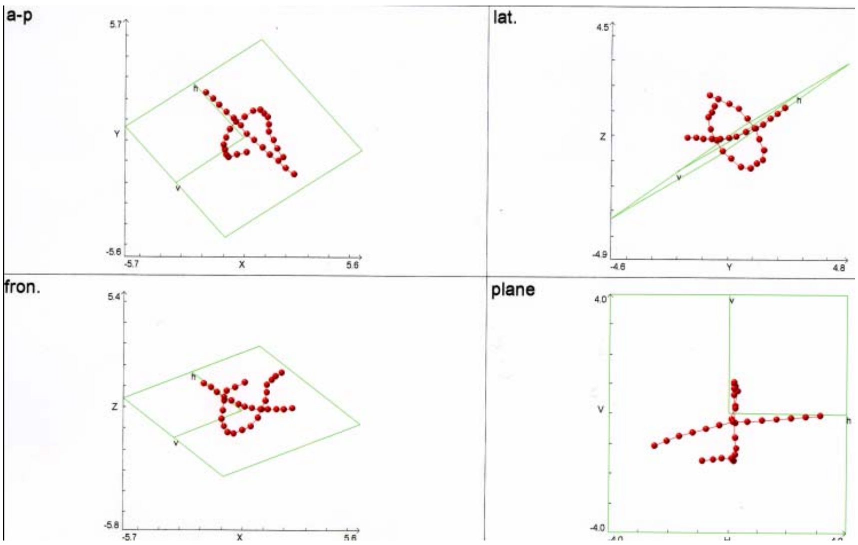


*Figure 30: Digitised pictures. The AP, Front. and Lat. views in the X-Y, Y-Z and X- Z plane and the sagittal H-V-plane.*

Figure 31 shows dose distributions for the three standard orthogonal planes using the standard stops and dwell times for the applicator.

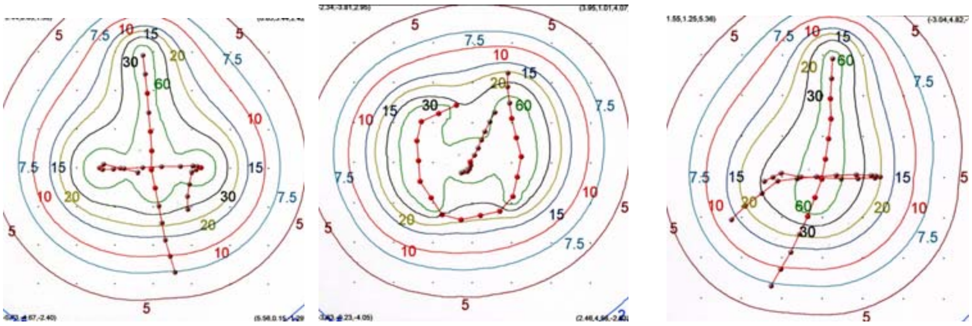

*Figure 31: Isodose in the three orthogonal planes defined for the ring; coronal, transverse and sagittal plane.*

The ring stop position diameter as digitized is ~29 mm, to compare to the 32 mm stop position diameter determined earlier.

In figure 32 the 3D HVO cube with the sagittal ring plane from figure 30 is shown. And in figure 33, we can see the 3D XYZ-cube with the same sagittal ring plane. In appendix 1.2 more digitized images for the ring and probe are presented.

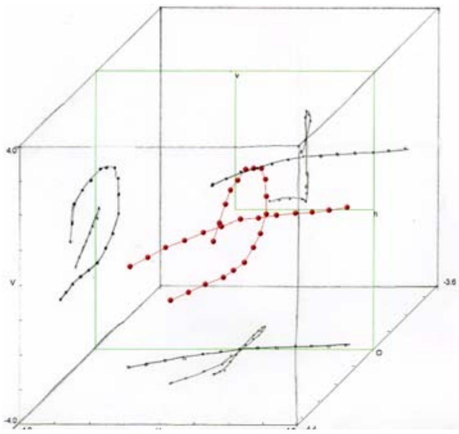

*Figure 32: Applicator in the HVO-cube.*

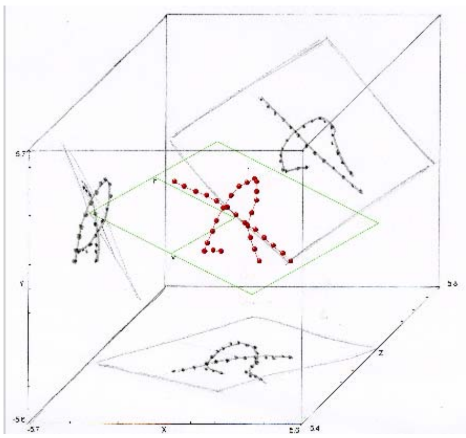

*Figure 33: Applicator in the XY Z-cube.*

### *Standard treatment plans (New rings)*

The standard target volume, expressed in words, is the same as before: the tumour in the cervix, the cervix itself, the upper part of the vaginal mucosa to a depth of 2 mm, part of the corpus and the parametria. The target should be inside the specification dose (100%). The dose to the organs-at-risk, nominally 5 mm outside the spacer, will be 77-80% as the specification isodoses is defined 2 mm outside the spacer. The dose to the organs at risk is "what we get".

The target volume definition leads to a flattened pear shaped dose distribution. A further clinical requirement is that there must be no low dose region in the target volume.
We have many possibilities to produce the required specification isodose shape. Examples are shown in figure 7 and in appendix 1.3.

# 4 Results and discussion

When we change from the old GammaMed 12i with the old ring applicators to GammaMed plus and the new ring applicators, it is important that every thing is checked. We most verify the stop positions, applicator geometry and dose distributions.

The old treatment rings used with the GammaMed 12i and planned with the old treatment planning systems, GammaDot and Abacus, have been checked using the new GammaMed plus and Abacus. The stop positions were found to be the same and the old applicators and the old standard dose distributions will be used also with the GammaMed plus.

In order to verify the new ring applicators we must check the stop positions, applicator geometry, and with the new ring applicators we also need new standard treatment plans. Similar standard treatment plans can be achieved for the new and the old rings, see figure 34.

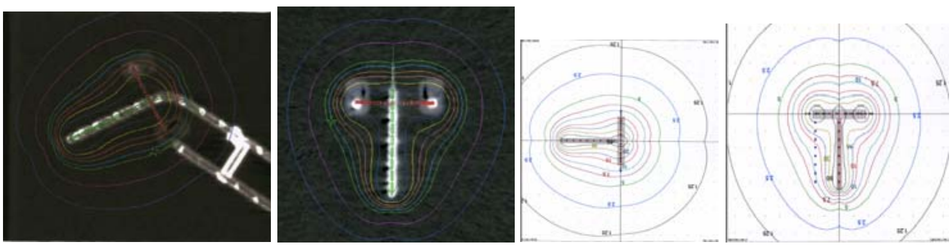

*Figure34: Brachy vision system (new ring) and Abacus system (old ring).*
*30º ring and 40 mm probe*

It is very important that the stop positions are correctly defined in the ring, otherwise the resulting dose distributions will be wrong.

Form the superpositioned x-ray exposure and GammaMed test run, as shown in figure 24, we can see that the marker wire follows the outer wall of the ring channel. The actual source stop positions are seen in the midde of the ring channel. When the marker wire is pushed out into the ring the marker wire will follow the outside of the channel wall in the ring in the same way as the source wire, when it is pushed out into the ring.
When the source wire starts to retract, the wire is first tightened up against the inner channel wall. If we move the origin 2 mm, i.e. tighten up the wire before we start the proper stepping movement, we get the correct distance between the stop positions. With the marker wires we indicate the stop positions. The markers on the marker wire are separated with 1 cm intervals. Figure 24 shows a case where we didn't move the origin the 2 mm required to get the correct stopping movement in the ring.

Checking stop positions in the ring with Gafchromic film shows that the two first stop positions are too close to each other when the source is just retracted. As discussed before, the source wire has to be tightened up against the inner channel wall before the source start to move. In order to have equally spaced stop positions in the whole ring, the source wire must be retracted 2 mm before it start its backwards movement, as shown in figure 20-21.

The ring stop position diameter, 32 mm, was determined by comparing the films with different stop position diameters from the treatment planning system (ABACUS), see figure 20-22.

The stop positions in the probe, as checked using film, are correct, see figure 23-24.

It is important that the probe is perpendicular to the ring plane for all ring / probe combinations. Assembled ring applicators are shown as a CT scout view in figure 25, as a lateral x-ray film in figure 26 and as perpendicular sections in a CT volume in figure 27. The applicator geometry for all rings and probes can be studied in appendix 1.1

When we use 5 mm step size in the applicator, there is no probe stop position in the ring plane, as shown in figure 28.

We also digitized the applicator geometry from films, see figure 29. The treatment planning system "Abacus" software allows you to digitize stop positions as indicated by the marker wires from orthogonal isocentric film, when the focus-isocenter and the focus-film distances are known. It is difficult to digitize the applicator correctly, 7-8 attempts were made, none of them successful, see figure 30.

The result showed a probe, not perpendicular to the ring plane, and incorrect stop positions in the ring, see figure 31. The ring stop position diameter as digitized is ~29 mm, to compare to the 32 mm stop position diameter determined with film. Care should be taken, if films are used to define applicator geometry for treatment planning purposes! Incorrect stop positions will result in incorrect dose distributions.

In appendix 1.2, two set of dose distributions for orthogonal planes are shown, the first with one co-ordinate axis along the probe and the second with one co-ordinate plane through the ring. The stop positions and times used to calculate the dose distributions were taken from plan 4 in
appendix 1.3.

In order to create standard treatment plans, we must know the clinical requirements. The primary clinical requirement is that the target volume should be inside the specification isodose surface. The standard target volume is the tumour in the cervix, the cervix itself, the upper part of the vaginal mucosa to a depth of 2 mm, part of the corpus and the parametria. The dose to the organs-at-risk, nominally 5 mm outside the spacer, will be 77-80% of the specification dose, defined 2 mm outside the spacer. We want to have a flattened pear shape dose distribution, as for the old Lund ring applicators (see figure 10). This shape of isodoses surface is used in many radiotherapy centers, and one of the “Vienna standard plane” is shown in figure 35 as an example.

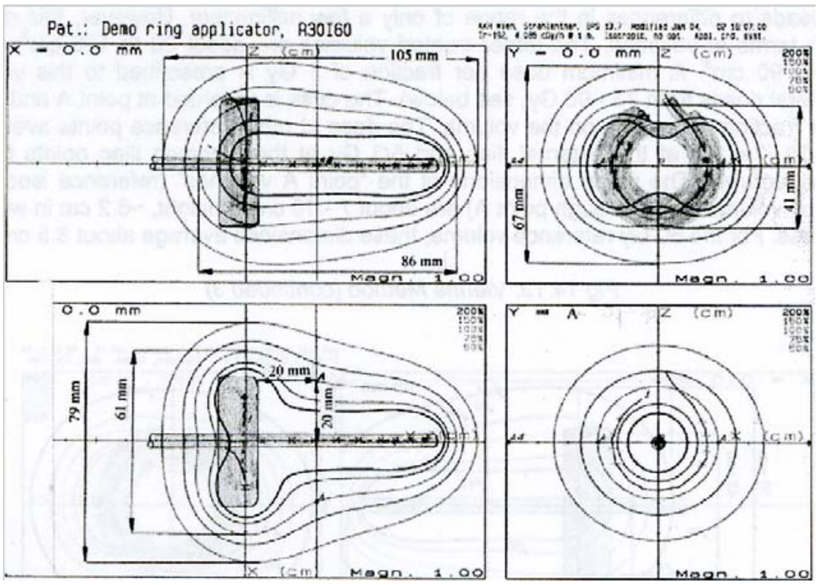


*Figure 35: Vienna Method, Standard ring applicator, medium*. [9]

A further clinical requirement is that there must be no low dose region inside the target.

Many types of treatment plans can be created for the ring applicator,
We can have

- dose around the probe, which is not “uniform” and no flattened pear shape
- dose around the probe, which is “uniform” and no flattened pear shape
- dose around the probe which is “uniform” and no dose laterally
- dose around the probe, which is “uniform” and flattened pear shape etc.

Examples of treatment plans are shown in appendix 1.3.

The plan number 4, shown in figure 36, is most similar to both the standard plans for the old Lund rings and for the Vienna rings (see figure 10 and 35). All ring/probe combinations are perpendicular and have the same stop position geometry, as verified using film and CT. Thus the dose distributions are independent of the ring angle.

The build-up cap pushes tissue away from the ring and the only difference between the two build-up caps is the thickness in front of the ring. If we want to move the tissue, from the high dose region behined the ring, our workshop can make new build-up caps designed after our standard dose distributions.

Standard treatment plans for the standard target volume will constitute the basis for the future image based brachytherapy. The applicators should be inserted into the cervix, imaging preformed, the treatment plan made directly after imaging, followed by the treatment itself without any changes in patient/applicator position. Each treatment plan will be unique for each patient and each reaction.

With CT-imaging, the organs at risk can be defined but not the tumour and thus neither the target volume. MR-imagings is required to define the tumour extent. However, CT-imaging will make it possible to adapt the standard dose distribution to the organs-at-risk without compromising the “classical” target dose.

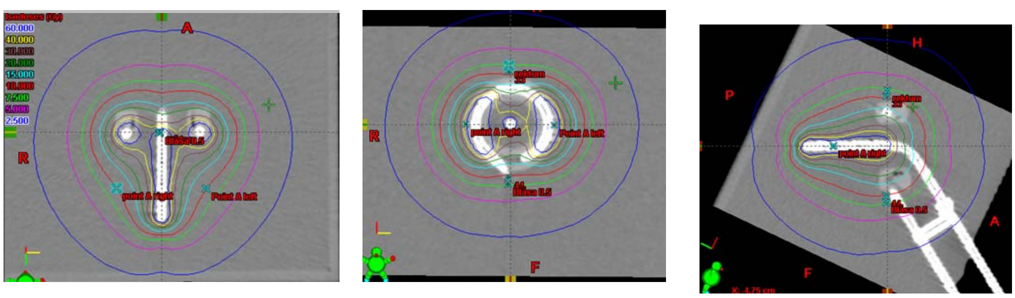

*Figure 36: Plan 4. The dose around the probe is” uniform”. Classic shape. No low dose region in the target volume. This is an acceptable plan.*

With access to MR-imaging we can define the tumour, the target and the organs-at-risk geometrically in 3D and we can optimize the dose to the target and the organs at risk, again starting from the standard dose distributions.

# 5 Conclusion

Curative radiotherapy for cancer of the cervix consists of a combination of extern beam radiotherapy (EBRT) and brachytherapy (BT). BT is used to give a high dose to the tumour itself. The most important prognostic factors are tumour size, tumour extension and lymph node involvement.

With access to MR-imaging, we can define the tumour in the cervix, the target volume, the organs-at-risk and the applicator geometry in 3D. We can truly optimize the dose to the target and minimize the dose to the organs-at risk at the same time. It is recommended [9] to start from well established standard plans defined for a target described in words, and adapt them to the actual 3D geometrically defined structures! With CT-imaging the organ at risk can be defined but not the tumour and the target, making it possible to adapt standard dose distribution to organs-at-risk without compromising the "classical" target dose.

In this paper we have studied and verified the geometry, including stop positions, for a set of new MR/CT compatible ring applicators. We have also evaluated some standard plans, to be used and adapted in CT- and MR-based brachytherapy. The rings are now ready to be used in the clinic, starting with the Lund old method, followed by CT-based treatments.

# 6 Acknowledgement

First of all I would like to thank my supervisor Inger-Lena Lamm for introducing me to the exiting world of brachytherapy.

I would also like to thank

- Inger-Lena Lamm and Per Munck for letting me be their shadow, during the treatments.
- Gun-Maj Aldèn and Jonas Nilsson for assisting me with the X-ray pictures.
- Vilberg Johansson and Sonny La for assisting me with the CT-scans
- Dr Maria Bjurberg for the treatment plan disussions.
- My family for all encouragement and support.

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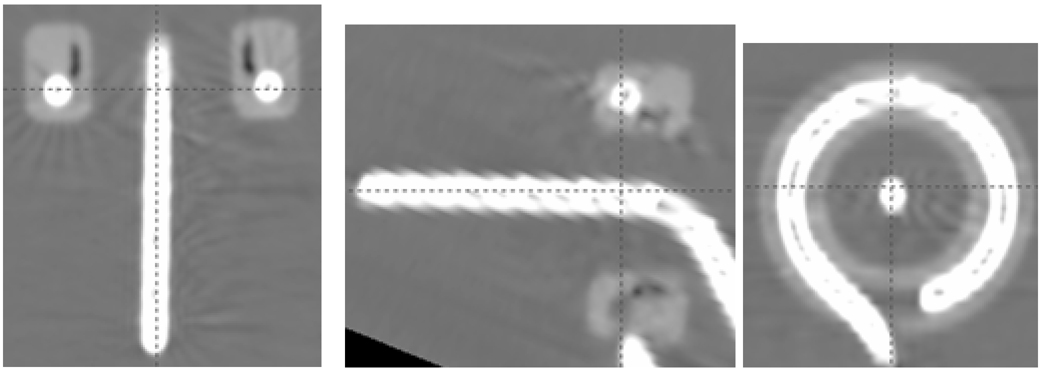
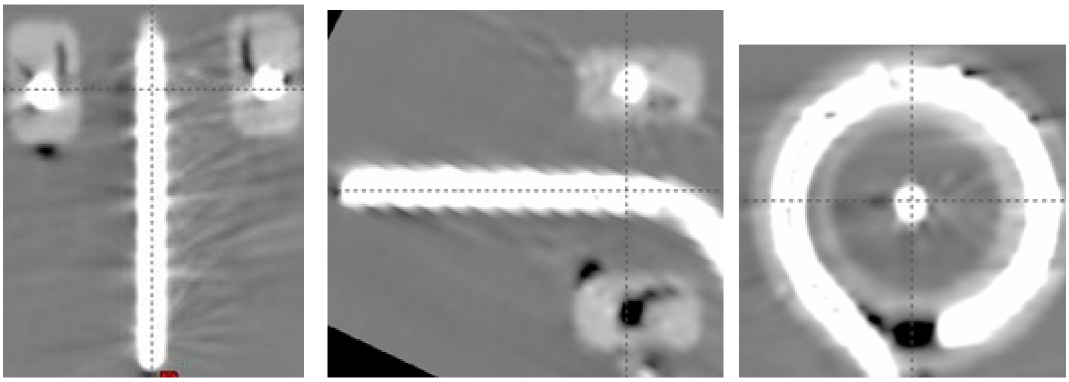
# Appendix 1

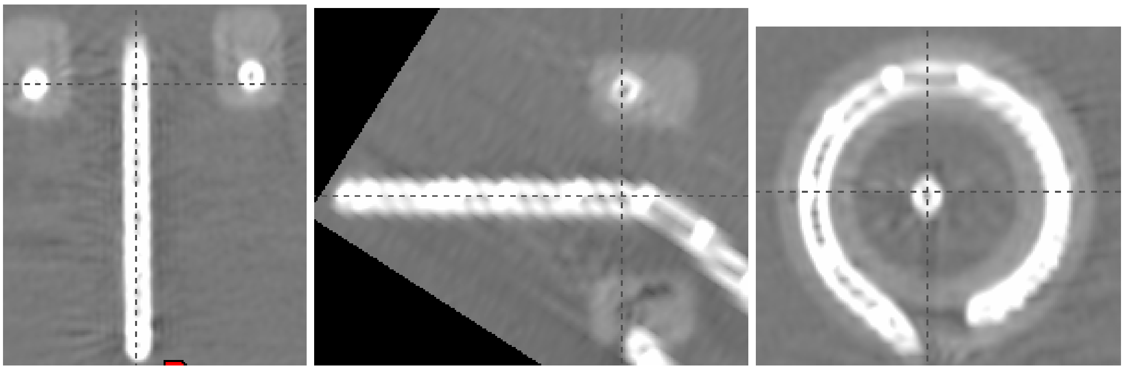
### *1.1 Geometry*



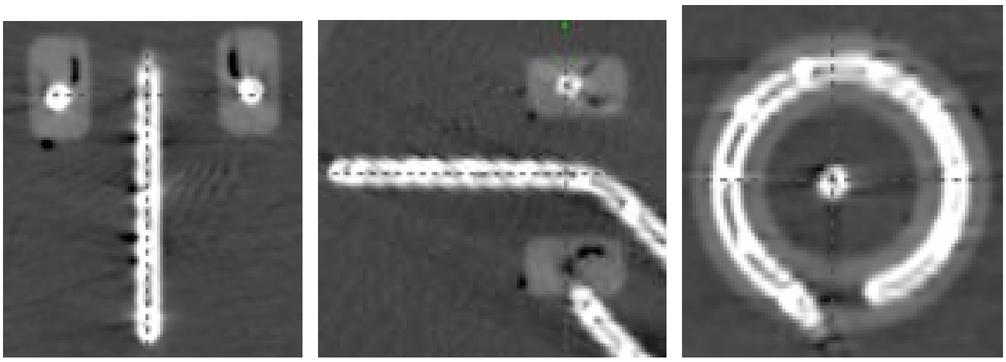
30º ring and 40 mm probe, 5 mm build-up cap



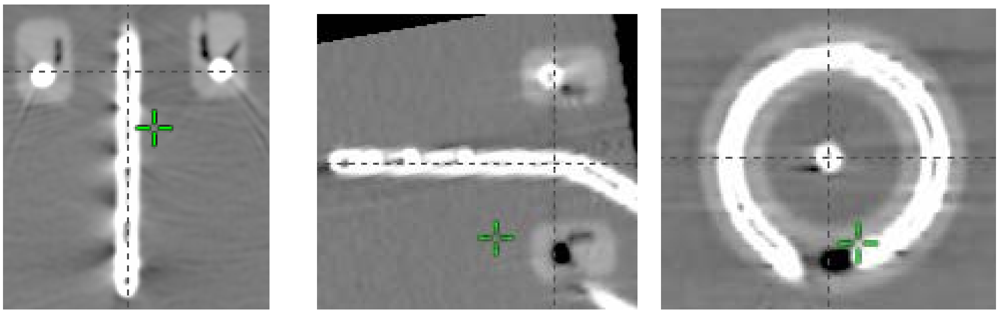
30º ring and 40 mm probe, 7.5 mm build-up cap



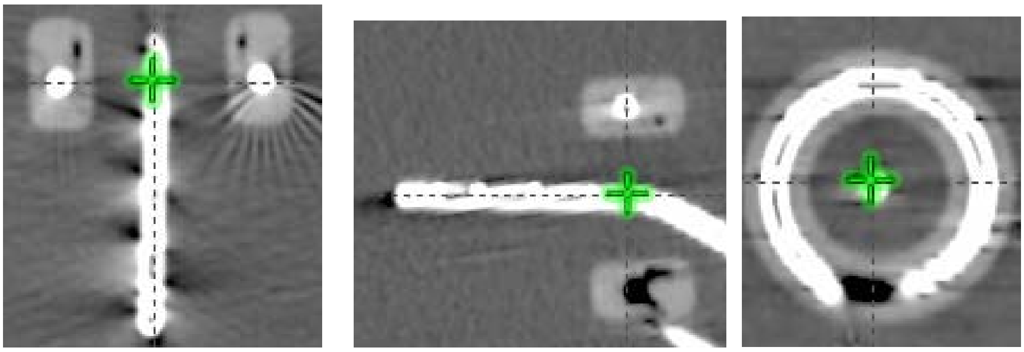
45º ring and 40 mm probe, 5 mm build-up cap.



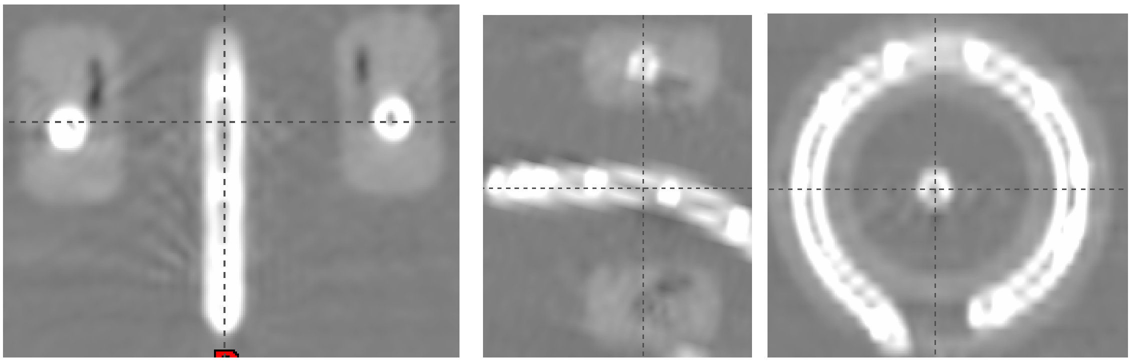
45º ring and 40 mm probe, 7.5 mm build-up cap.



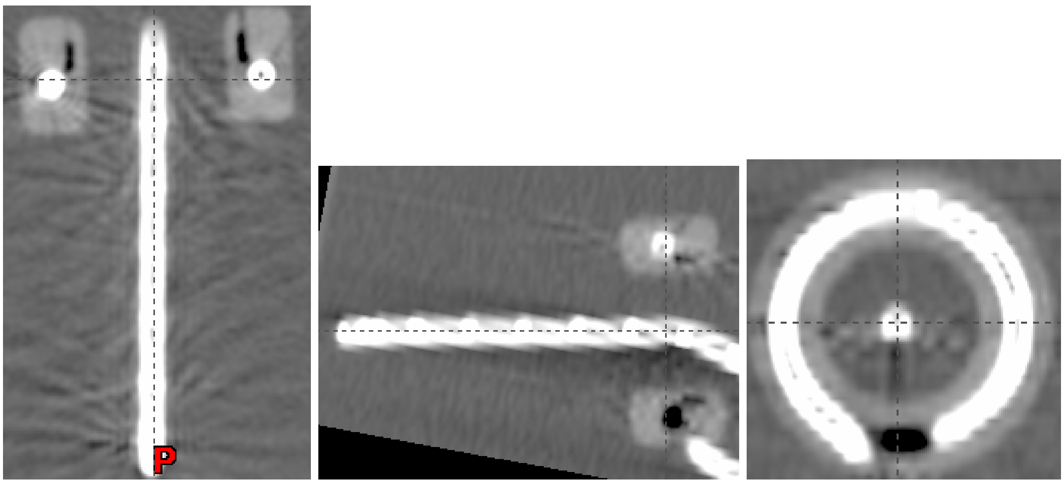
60º ring and 40 mm probe, 5 mm build-up cap



60º ring and 40 mm probe, 7.5 mm build-up cap



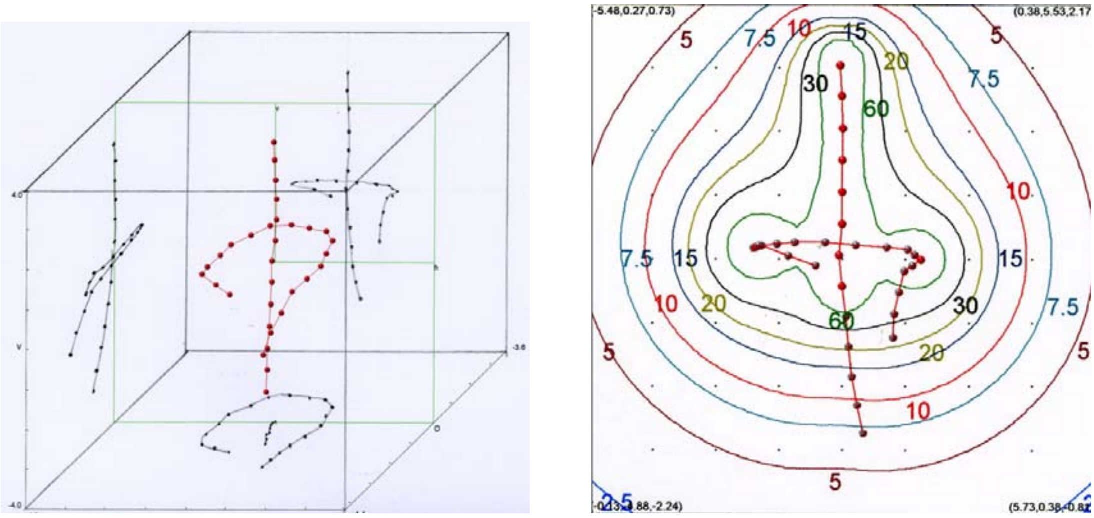
60º ring and 20 mm probe, 7.5 mm build-up cap



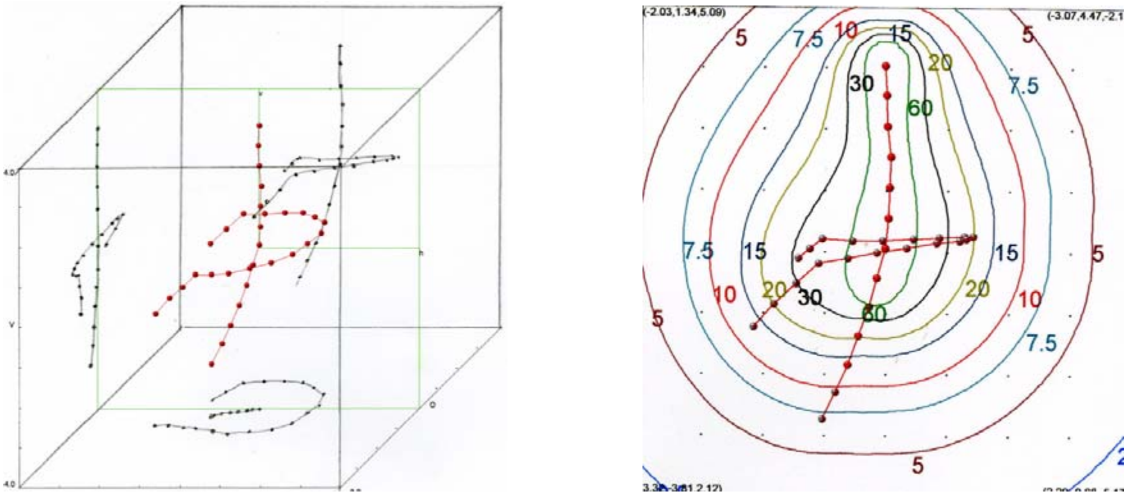
60º ring and 60 mm probe, 7.5 mm build-up cap.

### 1.2 Digitized images, dwell times taken from plan 4

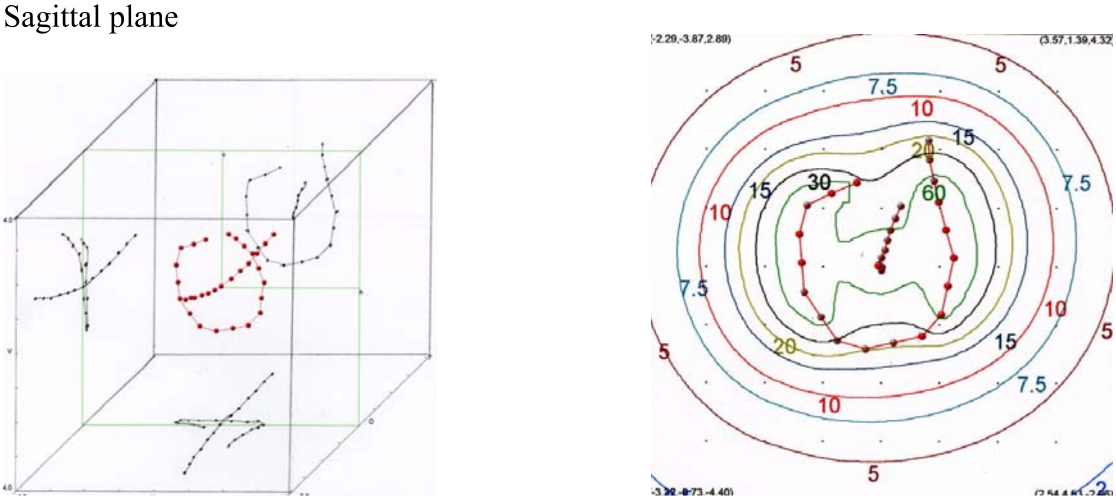
A: One co-ordinate axis along the probe. Three orthogonal planes.




Coronal plane

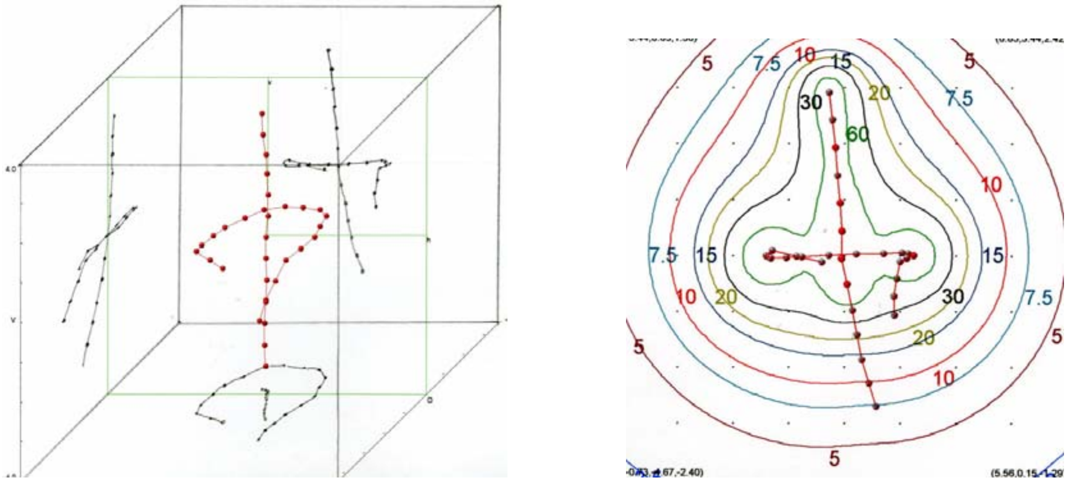



Sagittal plane

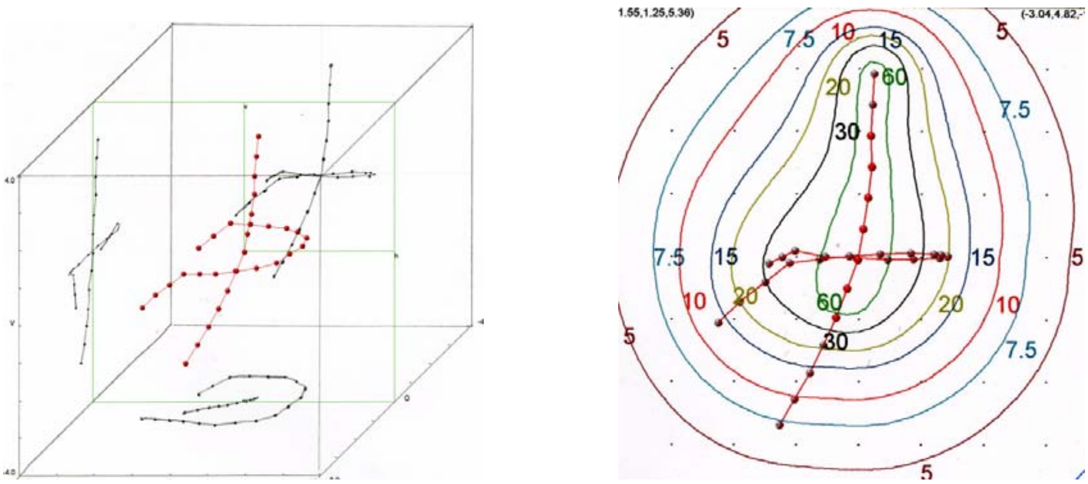



Transversal plane

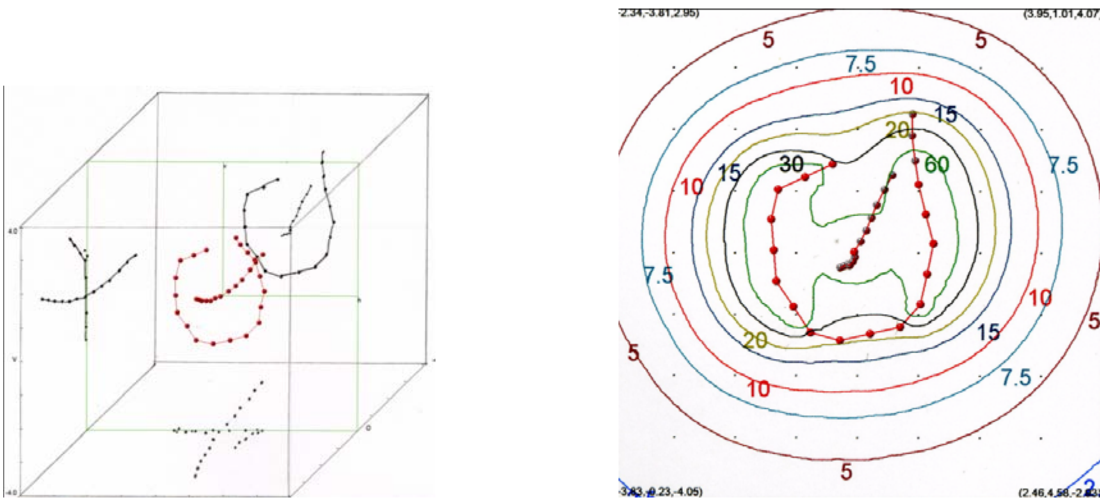
B: One co-ordinate plane defined through the ring plane. Three orthogonal planes.




Coronal plane




Sagittal plane



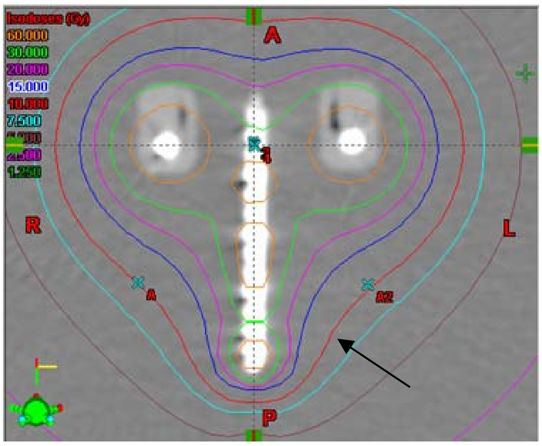

Transversal plane

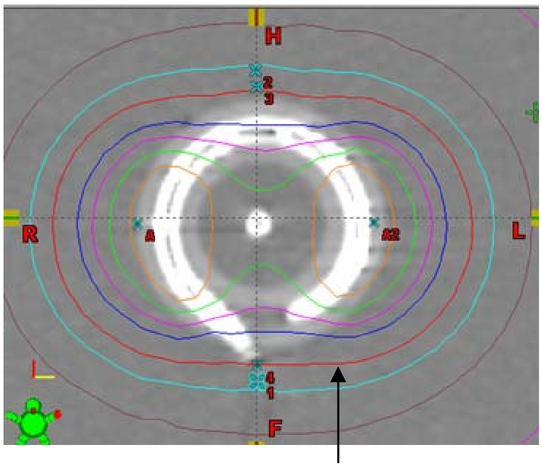
### *1.3 Treatment plans*

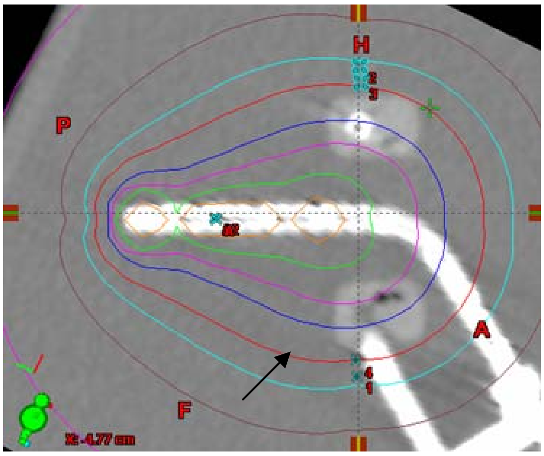
| | Ringangle [degree] | | | probe [mm] | | | Spacer [mm] | | 2 mm spce point | | 5 mm OaR point | | A left | A right | Height | Width | Thickness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dose plan | 30 | 45 | 60 | 20 | 40 | 60 | 5.0 | 7.5 | 12 okl. Gy | 6 okl. Gy | 12okl. Gy | 6 okl. Gy | Gy | Gy | [cm] | [cm] | [cm] |
| 1 | x | | | | x | | x | | 10.455 | 9.229 | 8.053 | 7.631 | 10.426 | 9.978 | 6.70 | 7.15 | 4.80 |
| 2 | x | | | | x | | x | | 9.479 | 9.851 | 7.582 | 7.655 | 10.549 | 9.867 | 6.96 | 6.89 | 4.74 |
| 3 | x | | | | x | | x | | 9.373 | 10.041 | 7.950 | 7.249 | 9.977 | 10.013 | 6.47 | 6.49 | 4.73 |
| 4 | x | | | | x | | x | | 9.823 | 9.281 | 7.646 | 7.260 | 9.943 | 9.672 | 5.77 | 4.88 | 4.83 |
| 5 | | x | | | x | | | x | 9.878 | 9.643 | 8.121 | 7.139 | 10.292 | 10.121 | 6.65 | 6.44 | 4.83 |
| 6 | | | x | | | x | | x | 10.283 | 10.390 | 7.283 | 8.221 | 10.585 | 10.085 | 8.73 | 6.76 | 4.78 |
| 7 | | | x | x | | | | x | 9.537 | 10.313 | 7.418 | 8.233 | 10.259 | 9.520 | 4.91 | 6.79 | 4.65 |
| 8 | x | | | | x | | | x | 10.076 | 9.680 | 8.054 | 7.968 | 9.067 | 8.860 | 6.59 | 6.46 | 4.79 |

Specification dose: 10 Gy (red).
Isodose levels: 1.25, 2.5, 5.0, 7.5, 10.0, 15.0, 20.0, 30.0, 60.0 [Gy].

**Plan 1:** 30° ring and 40 mm probe, 5 mm spacer




The dose around the probe is not "uniform".
Low dose region 3 cm up, in the cervix.
No flattened pear shape.
Not acceptable.

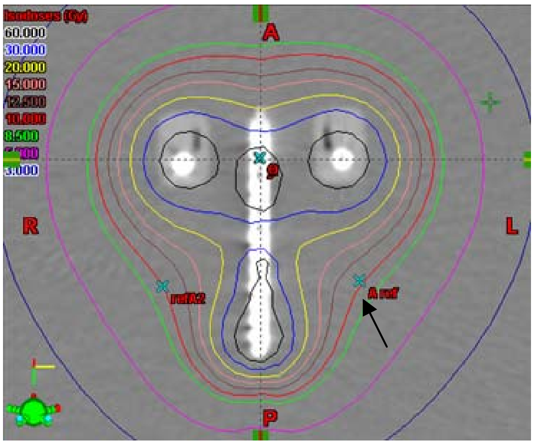
Applicator: Applicator1, Channel: 1, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

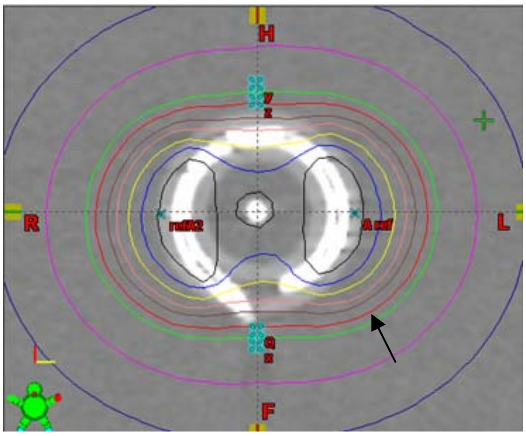
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 130.00 | 129.50 | 129.00 | 128.50 | 128.00 | 127.50 | 127.00 | 126.50 | 126.00 | 125.50 |
| Time [s] | 37.8 | 0.3 | 14.0 | 19.9 | 27.0 | 0.2 | 36.0 | 0.0 | 0.0 | 0.0 |
| Position [cm] | 125.00 | | | | | | | | | |
| Time [s] | 0.0 | | | | | | | | | |

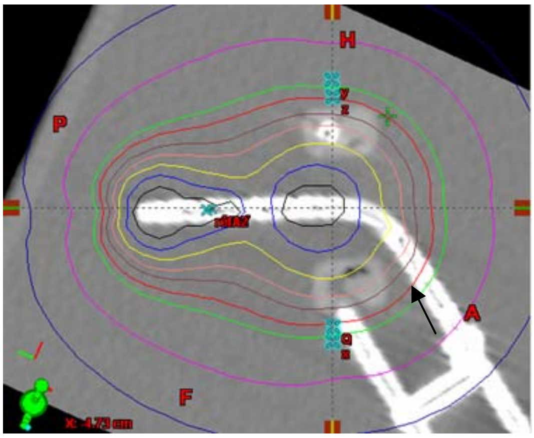
Applicator: Applicator2, Channel: 2, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 129.70 | 129.20 | 128.70 | 128.20 | 127.70 | 127.20 | 126.70 | 126.20 | 125.70 | 125.20 |
| Time [s] | 0.0 | 33.5 | 74.9 | 76.8 | 77.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Position [cm] | 124.70 | 124.20 | 123.70 | 123.20 | 122.70 | 122.20 | 121.70 | 121.20 | | |
| Time [s] | 0.0 | 0.0 | 78.0 | 97.3 | 51.3 | 34.5 | 0.0 | 0.0 | | |

**Plan 2:** 30° ring and 40 mm probe, 5 mm spacer




The dose around the probe is not “uniform”. Cold area around the probe, down in the cervix.
Flattened pear shape.
Not acceptable.

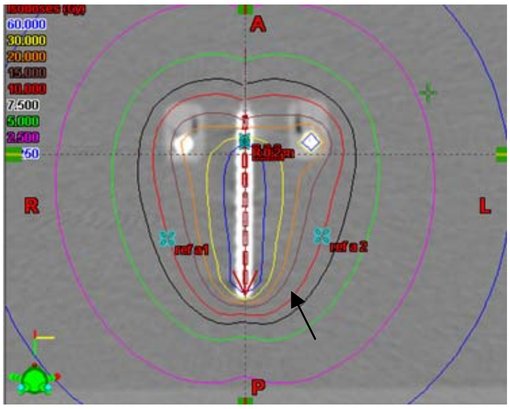
Applicator: prob 4, Channel: 1, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

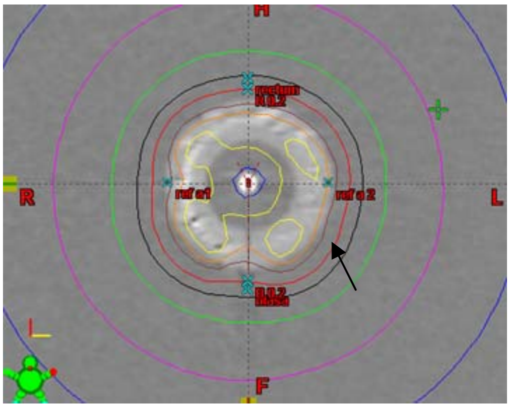
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 130.00 | 129.50 | 129.00 | 128.50 | 128.00 | 127.50 | 127.00 | 126.50 | 126.00 | 125.50 |
| Time [s] | 96.0 | 12.8 | 13.1 | 10.0 | 0.0 | 0.1 | 35.4 | 32.9 | 0.0 | 0.1 |
| Position [cm] | 125.00 | 124.50 | | | | | | | | |
| Time [s] | 0.1 | 0.2 | | | | | | | | |

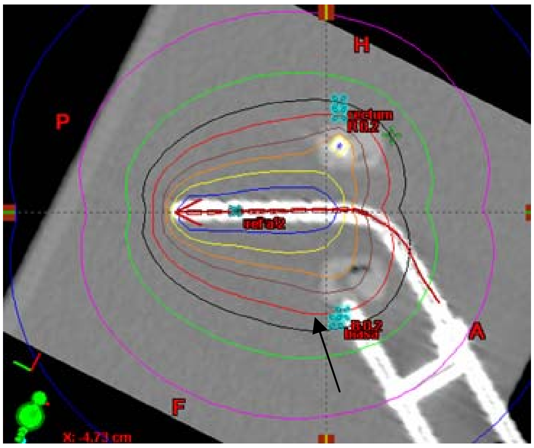
Applicator: ring, Channel: 2, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 129.90 | 129.40 | 128.90 | 128.40 | 127.90 | 127.40 | 126.90 | 126.40 | 125.90 | 125.40 |
| Time [s] | 0.0 | 11.1 | 63.5 | 59.9 | 58.9 | 48.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Position [cm] | 124.90 | 124.40 | 123.90 | 123.40 | 122.90 | 122.40 | 121.90 | | | |
| Time [s] | 0.0 | 0.0 | 40.1 | 47.9 | 66.5 | 50.9 | 18.4 | | | |

**Plan 3:** 30° ring and 40 mm probe, 5 mm spacer




The dose around the probe is "uniform".
No dose laterally.
No flattened pear shape.
Not acceptable

Applicator: sond, Channel: 1, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

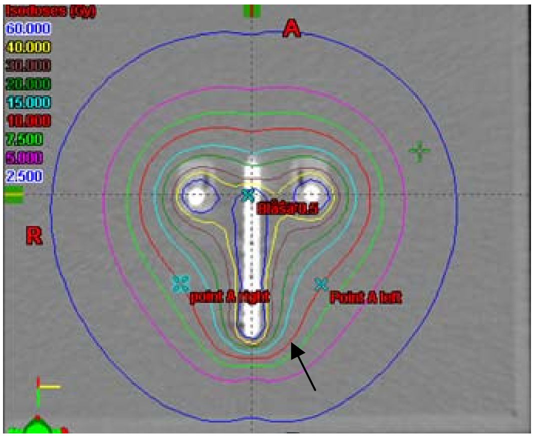
| Position [cm] | 129.90 | 129.40 | 128.90 | 128.40 | 127.90 | 127.40 | 126.90 | 126.40 | 125.90 | 125.40 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time [s] | 41.7 | 34.3 | 37.5 | 44.3 | 48.2 | 49.6 | 51.0 | 0.4 | 0.0 | 0.0 |
| Position [cm] | 124.90 | 124.40 | 123.90 | | | | | | | |
| Time [s] | 0.0 | 0.0 | 0.0 | | | | | | | |

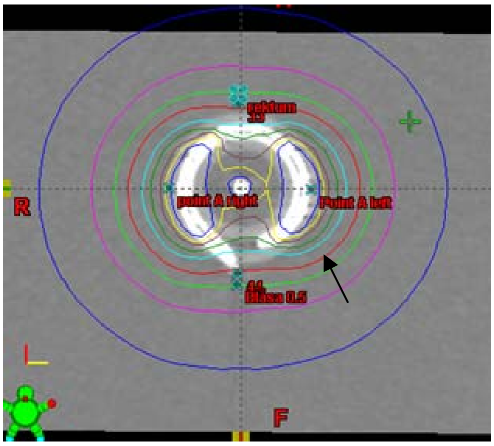
Applicator: ring 30g, Channel: 2, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

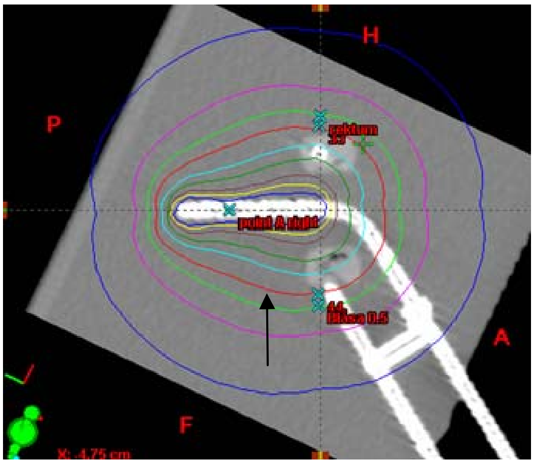
| Position [cm] | 130.00 | 129.50 | 129.00 | 128.50 | 128.00 | 127.50 | 127.00 | 126.50 | 126.00 | 125.50 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time [s] | 27.3 | 11.7 | 5.1 | 3.8 | 9.1 | 11.2 | 11.5 | 4.5 | 5.5 | 4.6 |
| Position [cm] | 125.00 | 124.50 | 124.00 | 123.50 | 123.00 | 122.50 | 122.00 | 121.50 | | |
| Time [s] | 5.4 | 8.9 | 21.2 | 2.4 | 0.3 | 13.8 | 14.9 | 22.9 | | |

*2*

**Plan 4:** $30^{o}$ ring and 40 mm probe, 5 mm spacer




The dose around the probe is "uniform".
Classic shape.
Now low dose region around the probe.
Flattened pear shape.
Looks good.

Cane be used as a standard treatment plan.

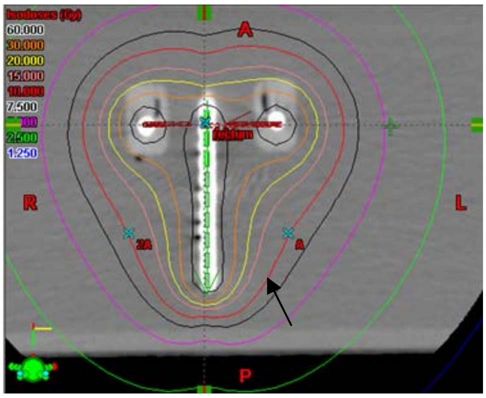
Applicator: Sond 4, Channel: 1, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

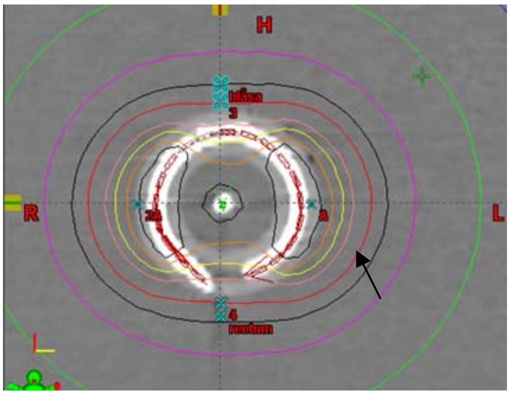
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 130.00 | 129.50 | 129.00 | 128.50 | 128.00 | 127.50 | 127.00 | 126.50 | 126.00 |
| Time [s] | 37.6 | 34.5 | 27.3 | 22.1 | 25.5 | 32.4 | 36.4 | 43.6 | 27.0 |

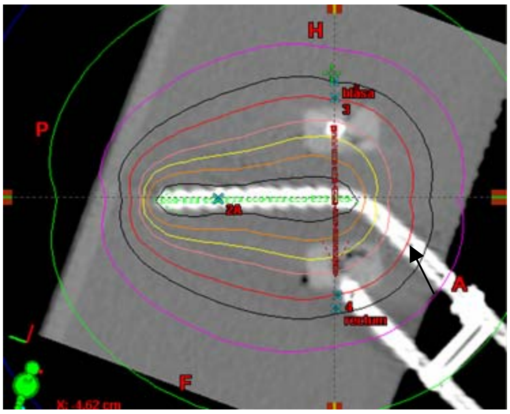
Applicator: ring, Channel: 2, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 130.00 | 129.50 | 129.00 | 128.50 | 128.00 | 127.50 | 127.00 | 126.50 | 126.00 | 125.50 |
| Time [s] | 0.0 | 0.0 | 35.9 | 32.1 | 43.1 | 36.0 | 35.2 | 0.0 | 0.0 | 0.0 |
| Position [cm] | 125.00 | 124.50 | 124.00 | 123.50 | 123.00 | 122.50 | 122.00 | 121.50 | 121.00 | |
| Time [s] | 0.0 | 0.0 | 24.0 | 30.6 | 39.1 | 30.7 | 27.1 | 0.1 | 0.0 | |

**Plan 5:** 45° ring and 40 mm probe, 7.5 mm spacer







The dose around the probe is "uniform".
Classic shape.
Now low dose region around the probe.
Looks good.

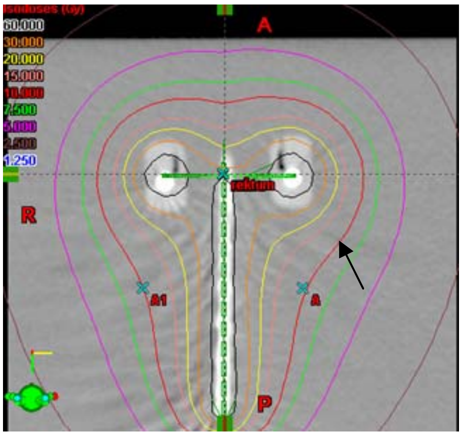
Applicator: Sond 4, Channel: 1, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

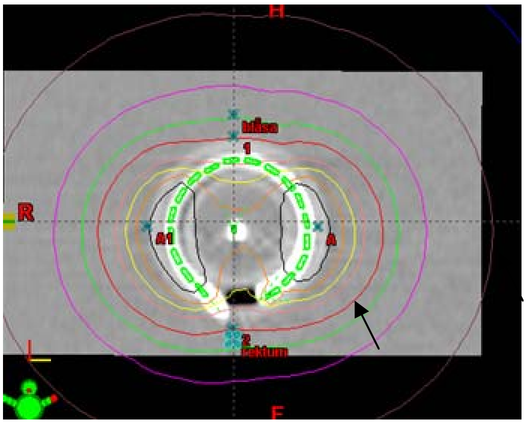
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 130.00 | 129.50 | 129.00 | 128.50 | 128.00 | 127.50 | 127.00 | 126.50 | 126.00 |
| Time [s] | 37.6 | 34.5 | 27.3 | 22.1 | 25.5 | 32.4 | 36.4 | 43.6 | 27.0 |

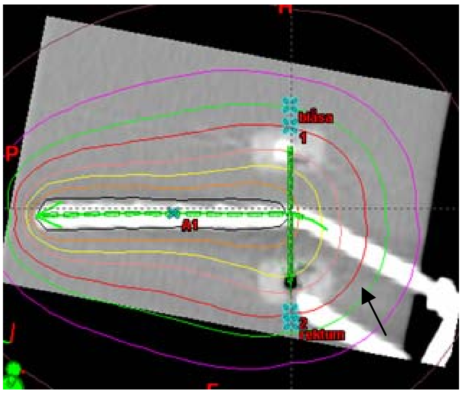
Applicator: ring, Channel: 2, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 130.00 | 129.50 | 129.00 | 128.50 | 128.00 | 127.50 | 127.00 | 126.50 | 126.00 | 125.50 |
| Time [s] | 0.0 | 0.0 | 35.9 | 32.1 | 43.1 | 36.0 | 35.2 | 0.0 | 0.0 | 0.0 |
| Position [cm] | 125.00 | 124.50 | 124.00 | 123.50 | 123.00 | 122.50 | 122.00 | 121.50 | 121.00 | |
| Time [s] | 0.0 | 0.0 | 24.0 | 30.6 | 39.1 | 30.7 | 27.1 | 0.1 | 0.0 | |

**Plan 6:** 60° ring and 60 mm probe, 7.5 mm spacer







The dose around the probe is "uniform".
Classic shape.
Now low dose region around the probe.
Looks good.

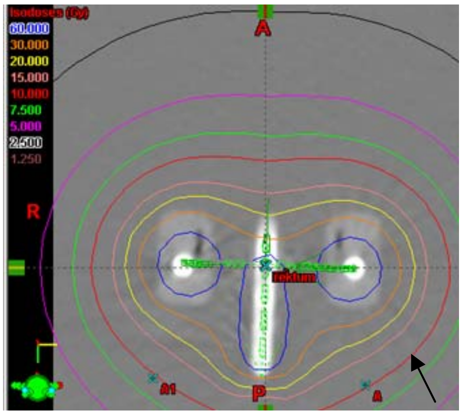
Applicator: sond, Channel: 1, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

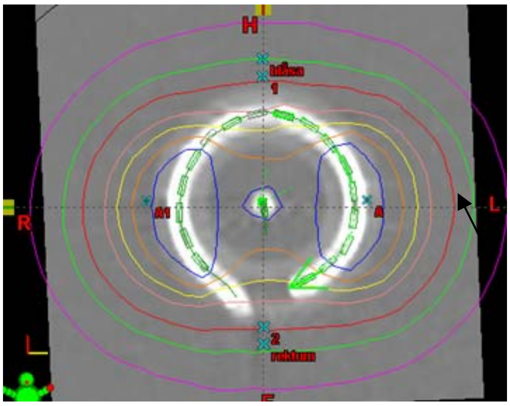
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 130.00 | 129.50 | 129.00 | 128.50 | 128.00 | 127.50 | 127.00 | 126.50 | 126.00 | 125.50 |
| Time [s] | 35.9 | 31.8 | 29.1 | 26.3 | 27.3 | 23.1 | 22.5 | 20.2 | 21.2 | 26.8 |
| Position [cm] | 125.00 | 124.50 | 124.00 | | | | | | | |
| Time [s] | 20.7 | 17.1 | 0.0 | | | | | | | |

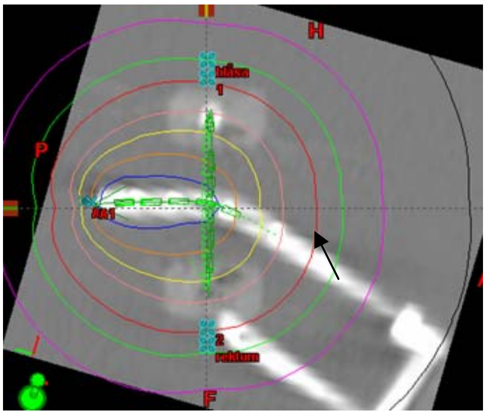
Applicator: ring, Channel: 2, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 130.00 | 129.50 | 129.00 | 128.50 | 128.00 | 127.50 | 127.00 | 126.50 | 126.00 | 125.50 |
| Time [s] | 4.2 | 0.3 | 47.2 | 57.0 | 56.8 | 46.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Position [cm] | 125.00 | 124.50 | 124.00 | 123.50 | 123.00 | 122.50 | 122.00 | 121.50 | | |
| Time [s] | 0.0 | 0.0 | 17.1 | 56.3 | 54.2 | 35.0 | 31.3 | 9.3 | | |

**Plan 7:** 60$^{o}$ ring and 20 mm probe, 7.5 mm spacer




The dose around the probe is uniform.
Dose laterally.
No low dose region in target.
Flattened pear shape.

Applicator: sond, Channel: 1, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

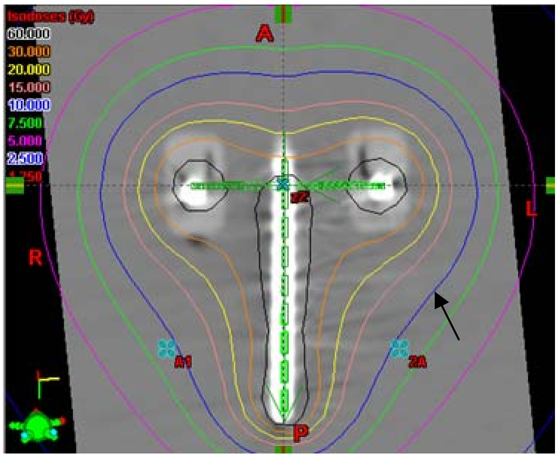
| | | | | | |
|---|---|---|---|---|---|
| Position [cm] | 129.80 | 129.30 | 128.80 | 128.30 | 127.80 |
| Time [s] | 50.3 | 38.1 | 27.4 | 16.8 | 0.0 |

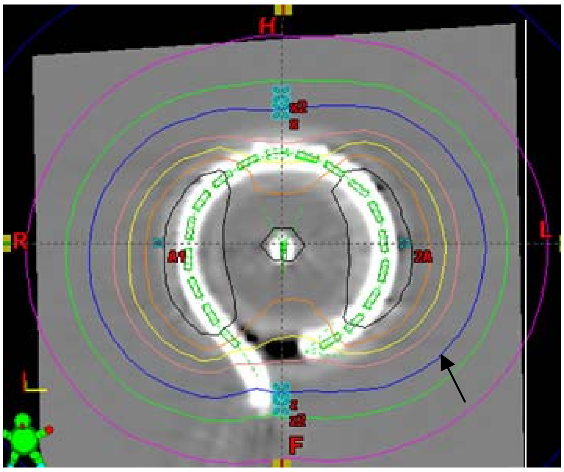
Applicator: ring, Channel: 2, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

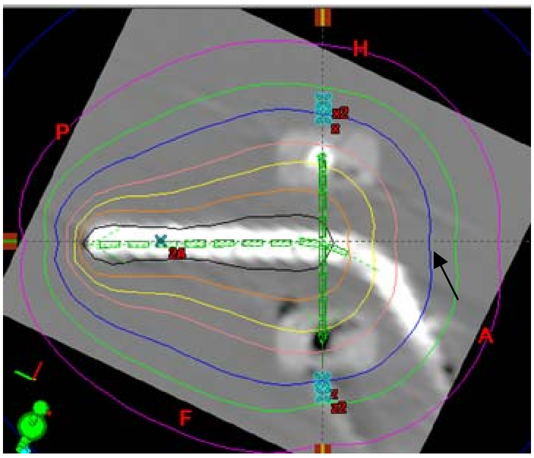
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 130.00 | 129.50 | 129.00 | 128.50 | 128.00 | 127.50 | 127.00 | 126.50 | 126.00 | 125.50 |
| Time [s] | 0.0 | 0.0 | 47.2 | 69.8 | 63.8 | 46.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Position [cm] | 125.00 | 124.50 | 124.00 | 123.50 | 123.00 | 122.50 | 122.00 | | | |
| Time [s] | 0.0 | 0.0 | 13.0 | 57.5 | 68.2 | 55.2 | 16.0 | | | |

**Plan 8:** 30° ring and 40 mm probe, 7.5 mm spacer

10 Gy (blue)




The dose around the probe is uniform.
Classic flatted shape.
No low dose region around the probe.

Same dwell times as plan 4.
Different build-up-cap.
Lower dose in point A!

Applicator: sond, Channel: 1, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 130.00 | 129.50 | 129.00 | 128.50 | 128.00 | 127.50 | 127.00 | 126.50 | 126.00 |
| Time [s] | 42.1 | 24.0 | 16.9 | 18.7 | 24.5 | 32.4 | 30.1 | 42.5 | 0.0 |

Applicator: ring, Channel: 2, Source Model: GMP Ir-192 HDR, Nominal Strength: 40700.00 cGy cm² / h,

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Position [cm] | 129.90 | 129.40 | 128.90 | 128.40 | 127.90 | 127.40 | 126.90 | 126.40 | 125.90 | 125.40 |
| Time [s] | 0.0 | 7.2 | 36.5 | 43.4 | 39.7 | 36.4 | 19.9 | 0.0 | 0.0 | 0.0 |
| Position [cm] | 124.90 | 124.40 | 123.90 | 123.40 | 122.90 | 122.40 | 121.90 | 121.40 | | |
| Time [s] | 0.0 | 7.3 | 26.6 | 35.1 | 38.9 | 40.9 | 44.0 | 0.0 | | |