PROSTATE BRACHYTHERAPY DOSIMETRY USING VOXEL PHANTOMS

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Outline

- **Introduction**
  - Prostate brachytherapy
  - Parameters that influence dose to the prostate

- **Experimental**
  - MCNPX validation
  - Real treatment planning

- **Simulations**
 - Golem voxel phantom and comparison with a real treatment

Motivation

- **Study the effects of several paramenters in prostate brachytherapy treatments**
  - Prostate volume variation
  - Interseed effect
  - …

- **Estimation of the dose delivered to prostate**

- **Comparison with prescribed dose**

- **Dose distribution inside prostate**

Prostate brachytherapy

- **Seed implantation inside prostate**
  - ^{241}Am, ^{125}I, ^{103}Pd

- **^{125}I seeds – Amersham Health 6711**
  - Titanium encapsulation
  - Radionuclide adsorded into inner metallic rod
  - Maximum energy emitted of 35.5 keV
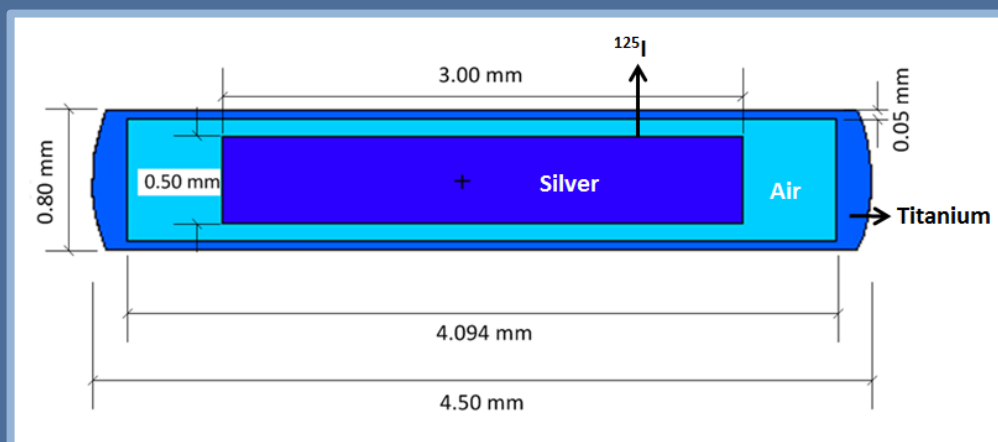
Prostate brachytherapy

- **Number of seeds**
  - 60 to 120 depending on prostate volume

- **Seed distribution – seeds spaced by 0.5 cm**
  - Uniform loading
    - Distributed uniformly in several planes, along the vertical axis of the prostate
  - Peripheral loading
    - Different layers of seeds placed on a circle

- **Permanent implants**

Prostate brachytherapy

- **Parameters that influence the dose to the prostate:**

  → **Interseed effect**

  - may lead to differences in dose between 3% and 5%.

  → **Prostate volume**

  - volume increases by 40% to 50% after seed insertion, due swelling, leading to a dose reduction

  → **Seed description**

  - point source vs. detailed seed approximation. Point source approximation is taken in treatment plannings.

Experimental setup

- **Geometric prostate phantom**

  – Square slabs of RW3: 0.5 cm thickness and 7 cm edge. 14 slabs pilled up.

  – Holes distanced 0.5 cm from each other, as in planning systems

  – Holes accomodate the seed and TLD's (Harshaw TLD-100)

RW3 square slab

14 slabs pilled up
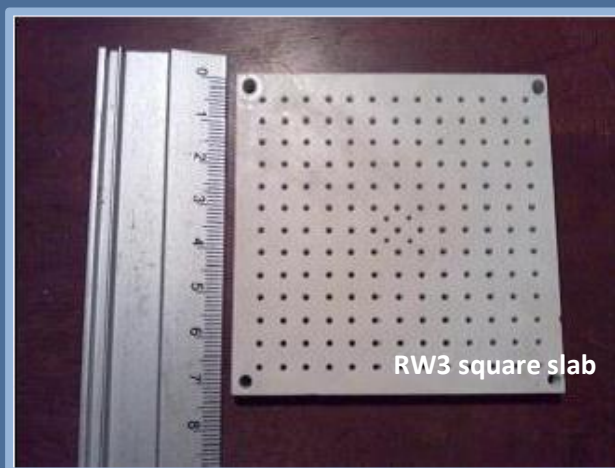
MC simulations

- **MCNPX**

  – To simulate experimental setup and estimate the dose in the TLD's positions

  – To use GOLEM voxel phantom to reproduce the experimental setup

  – Comparison between TLD's measurements and simulations

MCNPX simulated experimental setup

GOLEM's prostate
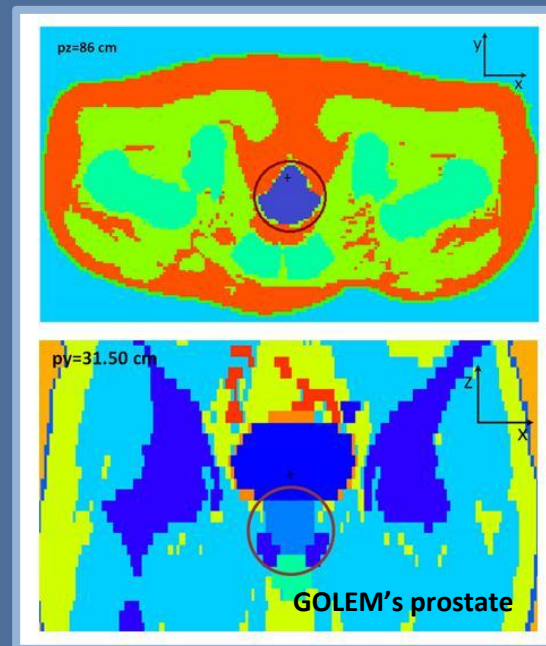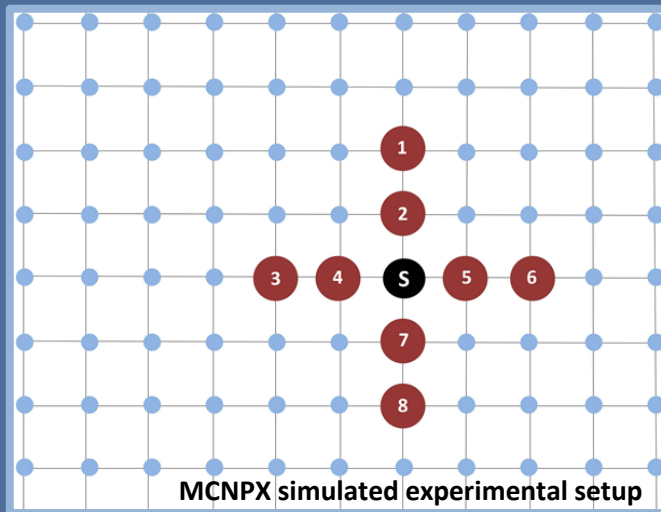
Measurements vs. simulations

Point	EXPERIMENTAL		SIMULATIONS (CUBIC PHANTOM)		SIMULATIONS (VOXEL PHANTOM)		COMPARISON	
	Dose (Gy)	Uncertainty (%)	Dose (Gy)	Uncertainty (%)	Dose (Gy)	Uncertainty (%)	Exp/Cubic Phantom simulation	Exp/Voxel Phantom simulation
1	1.186	3.32%	1.299	3.83%	1.274	2.08%	0.91	0.93
3	1.165	4.66%	1.325	3.81%	1.266	2.09%	0.88	0.92
6	1.207	3.66%	1.191	4.01%	1.281	2.08%	1.01	0.94
8	1.245	4.94%	1.242	3.94%	1.263	2.09%	1.00	0.98

– Experimental results in agreement with voxel phantom and cubic phantom simulation results

GOLEM simulations

- **Variation of the dose with:**

  - **Prostate swelling**:

    - variation of the prostate's volume

  - **Source description**

    - point sources (assumed in treatment plannings) vs. detailed simulation of the seed

  - **Variation of interseed spacing**

    - analyze interseed effect

  - **Source distribution inside prostate**

    - uniform vs. peripheral loading

Variation of prostate volume

- **Simulation of a hipothetical treatment**

  - 65 seeds implemented inside GOLEM's prostate

  - Uniform loading

  - Prostate's volume changed by varying voxel dimensions

    - Entire phantom is scaled accordingly

    - Only dose to the prostate was estimated

  - Interseed distance was not changed

  - Studied volumes: 52.10 cm^3, 45.00 cm^3, 40.00 cm^3, 35.00 cm^3 and 30.02 cm^3

  - Seed description

    - Detailed description of the seed

  - All computational uncertainties below 0.5%

Variation of prostate volume

| Volume (cm³)	Absorbed dose per source (Gy/source)	Total absorbed dose (Gy)
30.02	1.93	125.58
35.00	1.79	116.21
40.00	1.65	107.54
45.00	1.53	99.70
52.10	1.39	90.30

– Total dose to the prostate decreases with increasing prostate volume

– Assuming 30.02 cm3 as initial prostate volume and 52.10 cm3 is the post-insertion volume

– Dose during swelling (~ 2 weeks) is 28% lower than the prescribed dose:

- Total delivered dose of 120.28 Gy (4.22% lower than the prescribed dose of 125.58 Gy)

Seed distribution

- **Simulation of a hipothetical treatment**

  - 65 seeds implemented inside GOLEM's prostate

  - Uniform loading

  - Peripheral loading

  - Studied volumes: 52.10 cm^3, 45.00 cm^3, 40.00 cm^3, 35.00 cm^3 and 30.02 cm^3

  - Seed description

    - Detailed description of the seed

  - All computational uncertainties below 0.5%

Seed distribution

- **Seed distribution in Golem's prostate**

GOLEM's prostate: axial view

GOLEM's prostate: coronal view
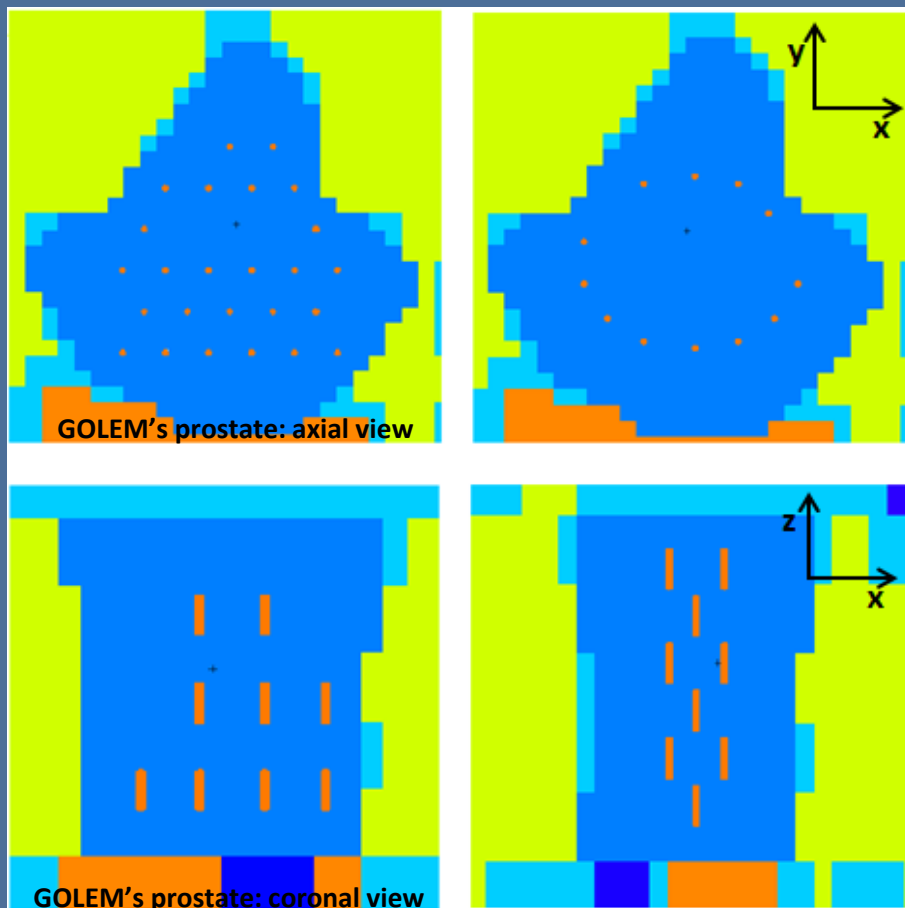
— Uniform loading: left image

— Peripheral loading: right image

Seed distribution

Volume (cm³)	Arrangement	Absorbed dose per seed (Gy/seed)	Total absorbed dose (Gy)
30.02	uniform	1.93	125.58
	peripheral	1.92	124.62
35.00	uniform	1.79	116.21
	peripheral	1.77	114.96
40.00	uniform	1.65	107.54
	peripheral	1.64	106.73
45.00	uniform	1.53	99.70
	peripheral	1.53	99.57
52.10	uniform	1.39	90.30
	peripheral	1.35	89.33

– Uniform loading of the seeds results in a slightly higher total dose (of around 1%) delivered to the prostate than the peripheral loading.
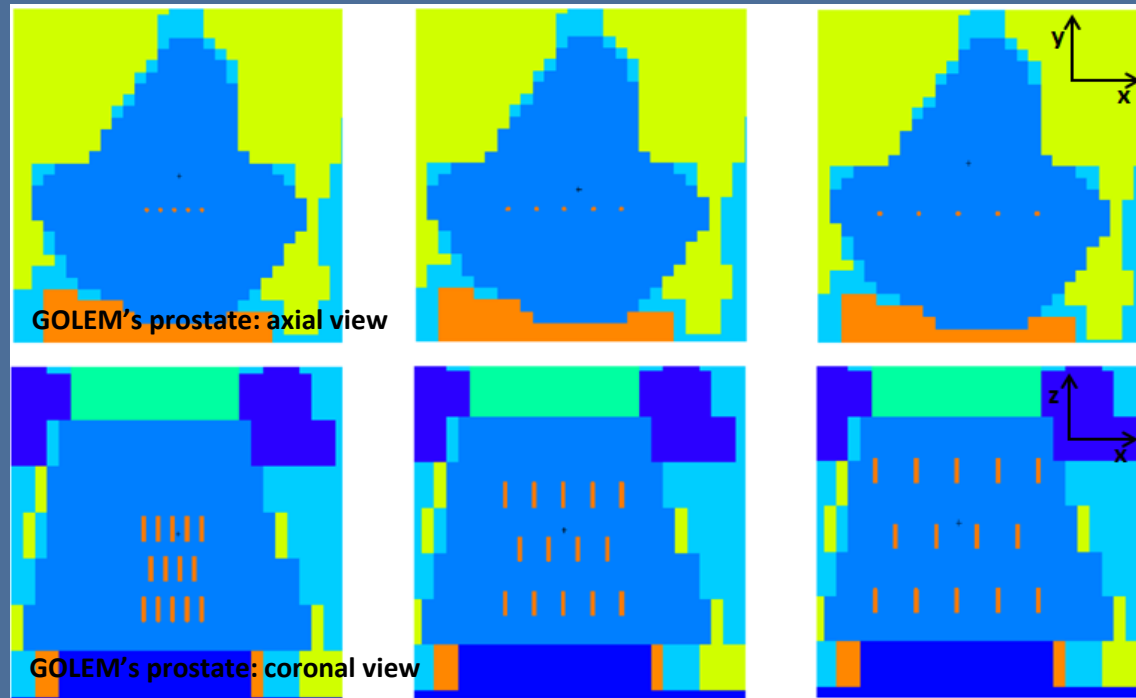
Interseed spacing

- **Simulation of a layer of seeds**

  - 14 seeds implemented inside GOLEM's prostate

    - Approximatelly the number of seeds in a layer in uniform loading

  - Uniform loading

  - Studied volumes: 52.10 cm^3

  - Interseed spacing: 0.25 cm, 0.50 cm and 0.70 cm

  - Seed description

    - Detailed description of the seed

  - All computational uncertainties below 0.5%

Interseed spacing

- **Interseed spacing variation in Golem's prostate**

GOLEM's prostate: axial view

GOLEM's prostate: coronal view

- – From left to right: interseed spacing of 0.25 cm, 0.50 cm, 0.70 cm

Interseed spacing

Spacing (cm)	Absorbed dose per seed (Gy/seed)	Total absorbed dose (Gy)
0.25	1.555	21.768
0.50	1.551	21.716
0.70	1.463	20.482

– Spacing between the seeds influences the total dose to the prostate

– From 0.25 cm to 0.70 cm spacing the dose decreases by 5.93%

– When the swelling of the prostate occurs, the seed spacing increases and this effect leads to a further decrease of the total dose

Interseed effect

- **Simulation of a hypotethical treatment**

  - Comparison between doses per seeds

    - Using 14 and 65 seeds

  - Uniform loading

  - Studied volumes: 52.10 cm^3

  - Seed description

    - Detailed description of the seed

  - All computational uncertainties below 0.5%

Interseed effect

| Number of seeds	Absorbed dose per seed (Gy/seed)
14	1.93
65	1.39

- Increasing the number of seeds by 51 reduces the total prostate absorbed dose /seed by around 28%

- Dose is affected by the surrounding seeds, since neighbouring seeds will absorb part of the emitted radiation

Real treatment simulation

- **Simulation of a real treatment**

  - 84 seeds implemented inside GOLEM's prostate

  - Uniform loading

  - Studied volumes: 57.02 cm^3, 52.10 cm^3, 38.01 cm^3 (patient's prostate volume)

  - Seed description

    - Point source (as assumed in treatment plannings)

    - Detailed description of the seed

 - All computational uncertainties below 0.5%

Real treatment

- **Prescribed dose: 144 Gy**
- **Seed position**
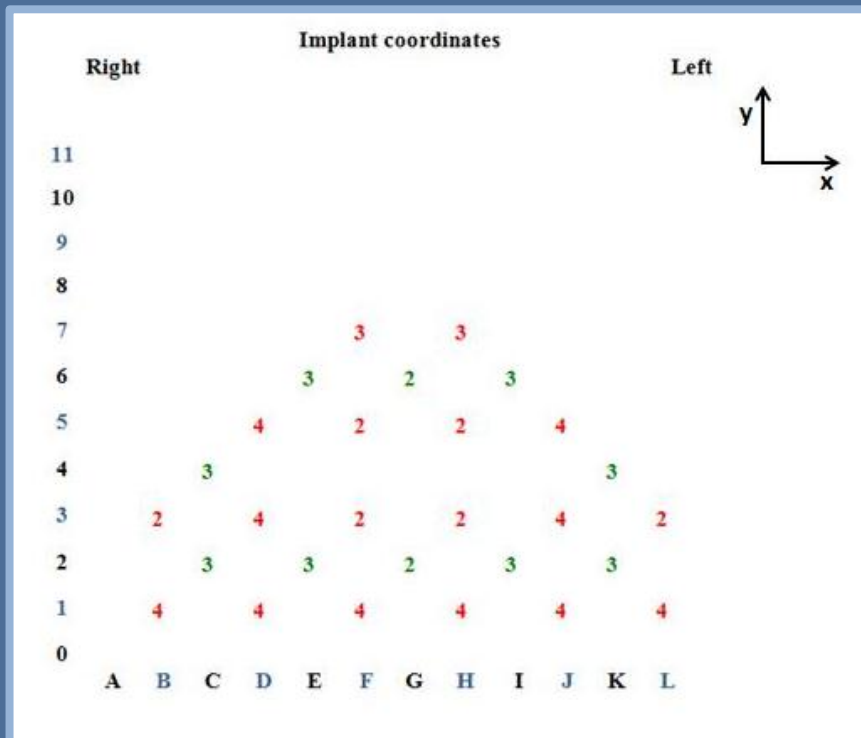
- Vertical axis: height positions (0 to 11)
- Horizontal axis: horizontal positions (A to L)
- At each array position: number of seeds implanted at several depths (z coordinates) along a line with the corresponding x and y coordinates
- Distance between each horizontal, vertical and depth positions: 0.5 cm

Real treatment simulation

- **Seed position**

GOLEM's prostate: axial view   GOLEM's prostate: coronal view
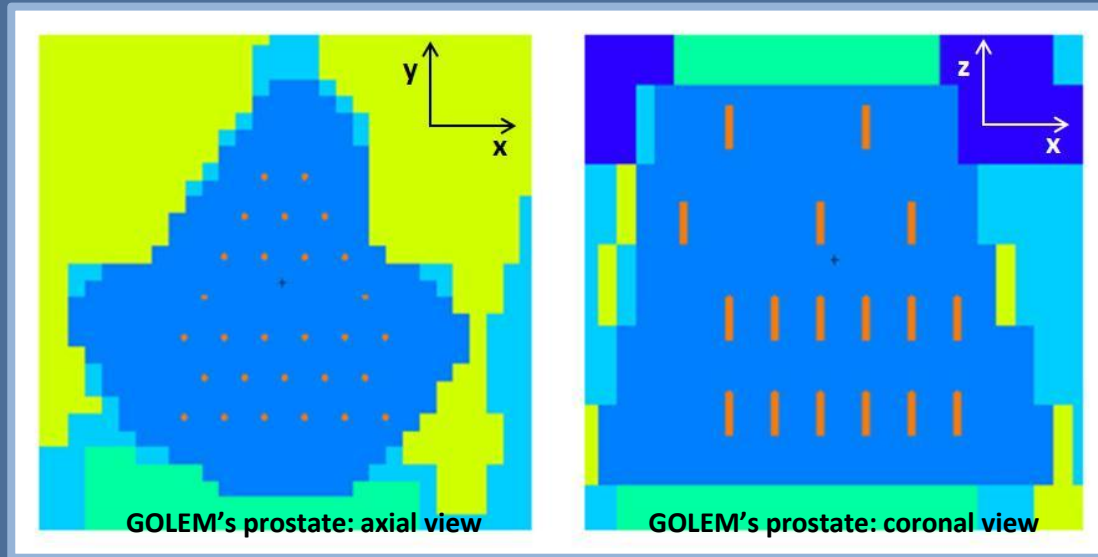
- In dose calculations, the swelling period of 2 weeks was taken into account

- Original volume: $38.01 cm^3$

- Swollen volume: $57.02 cm^3$

Real treatment simulation

Volume (cm³)	Description	Gy/seed	Gy total	Comparison
38.01	Detailed seeds	1.32	110.96	10.75 %
	Point sources	1.48	124.33	
52.01	Detailed seeds	1.12	94.23	12.57 %
	Point sources	1.28	107.77	
57.02	Detailed seeds	1.07	89.77	11.78 %
	Point sources	1.21	101.75	

- Total dose to the prostate assuming point sources around 10.75% - 12.57% higher than assuming seeds' real description

- Total dose when assuming swollen period os 25.16% lower than prescribed dose

- When assuming a constant volume the dose is oversetimated by around 3%.

Conclusions

- Seeds' distribution inside prostate does not significantly change the dose delivered to prostate;

- Increasing interseed spacing by 0.45 cm led to a decrease on the dose delivered to the prostate by 6%;

- Changing prostate volume from 30.02 to 52.10 cm3 led to a reduction in the total dose of about 28%;

- The values obtained with simulations are 16% lower than the treatment planning values, assuming the same conditions;

- The values obtained with simulations are 16% lower than the treatment planning values, assuming the same conditions;

- The values obtained with simulations assuming real conditions are 25% lower than the prescribed dose.

Thank you!