ELEKTA

Monaco VMAT

The Next Generation in IMRT/VMAT Planning

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Customer Support TPS Application
11.05.2011

Background

What is Monaco?

- Advanced IMRT/VMAT treatment planning system from Elekta Software
- Collaboration with University of Tübingen (UKT)
- Based on the Hyperion project started in 2000 (M. Alber, et al)
- Monaco 1.0 released July 2007

Unique Features

Biological Modeling

Constrained Optimization

Voxel-based Structure Control

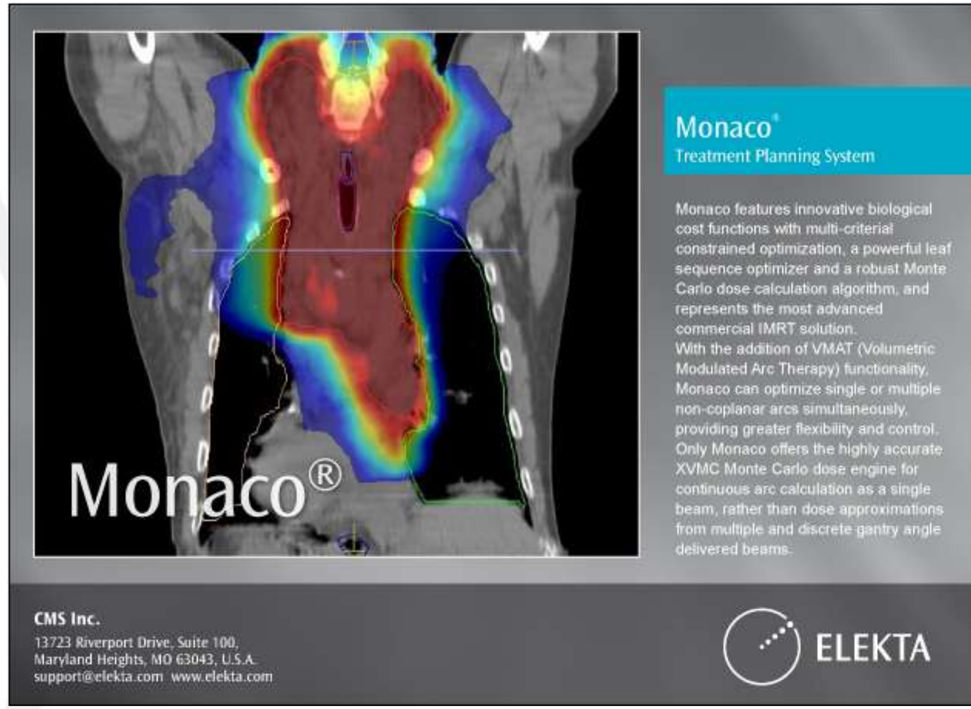
Sensitivity Analysis

Smart Sequencing™

Monte Carlo Dose Algorithm

VMAT

SRS Planning/Dynamic Conformal Arc



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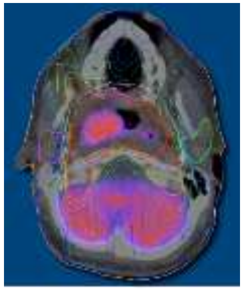
Biological Modeling

Biological cost functions allow us to model tissue-specific dose responses, that is the *volume effect*.

Serial
(small volume effect)

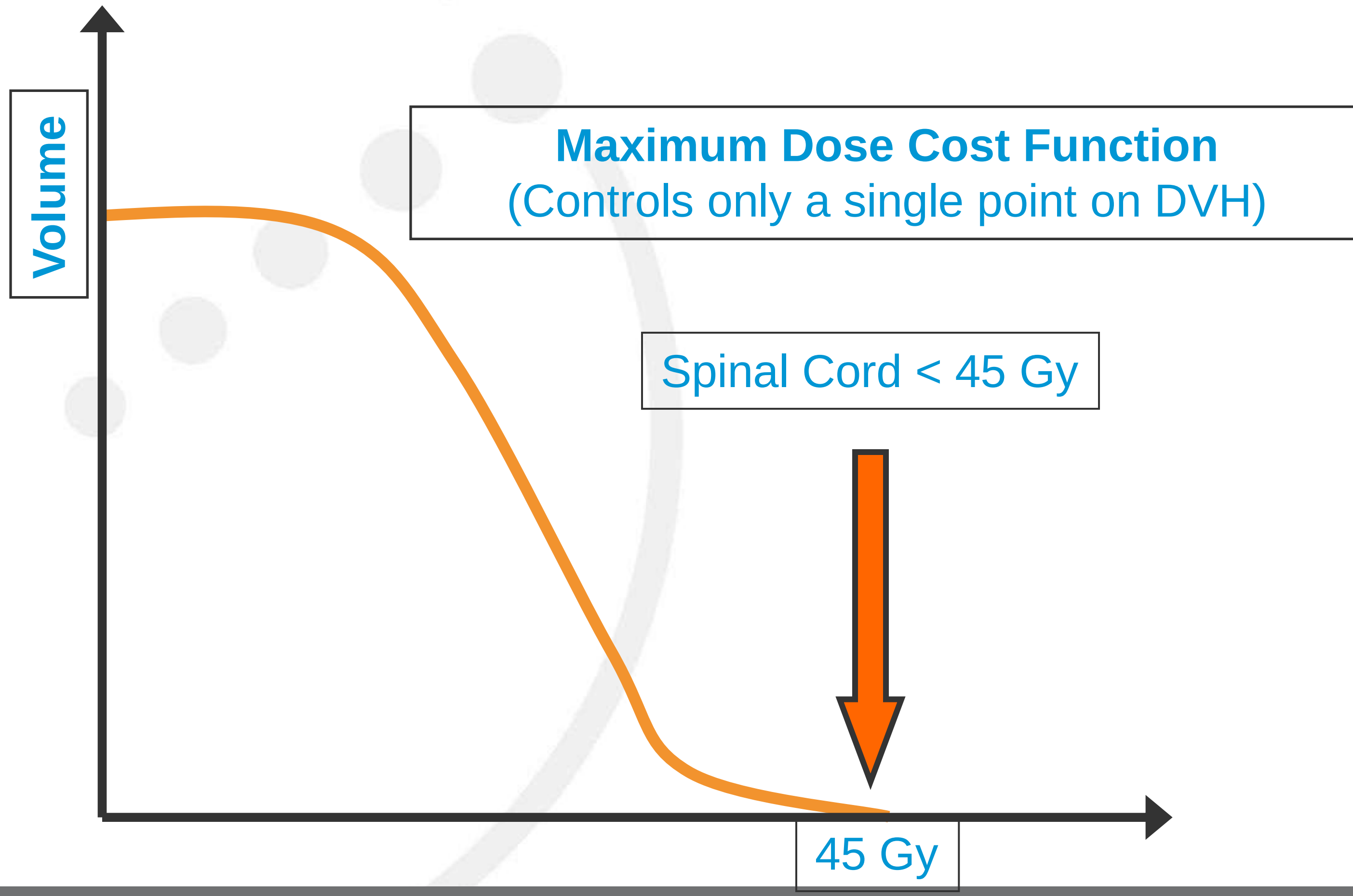
Parallel
(large volume effect)



Tumor
(sensitive to cold spots)

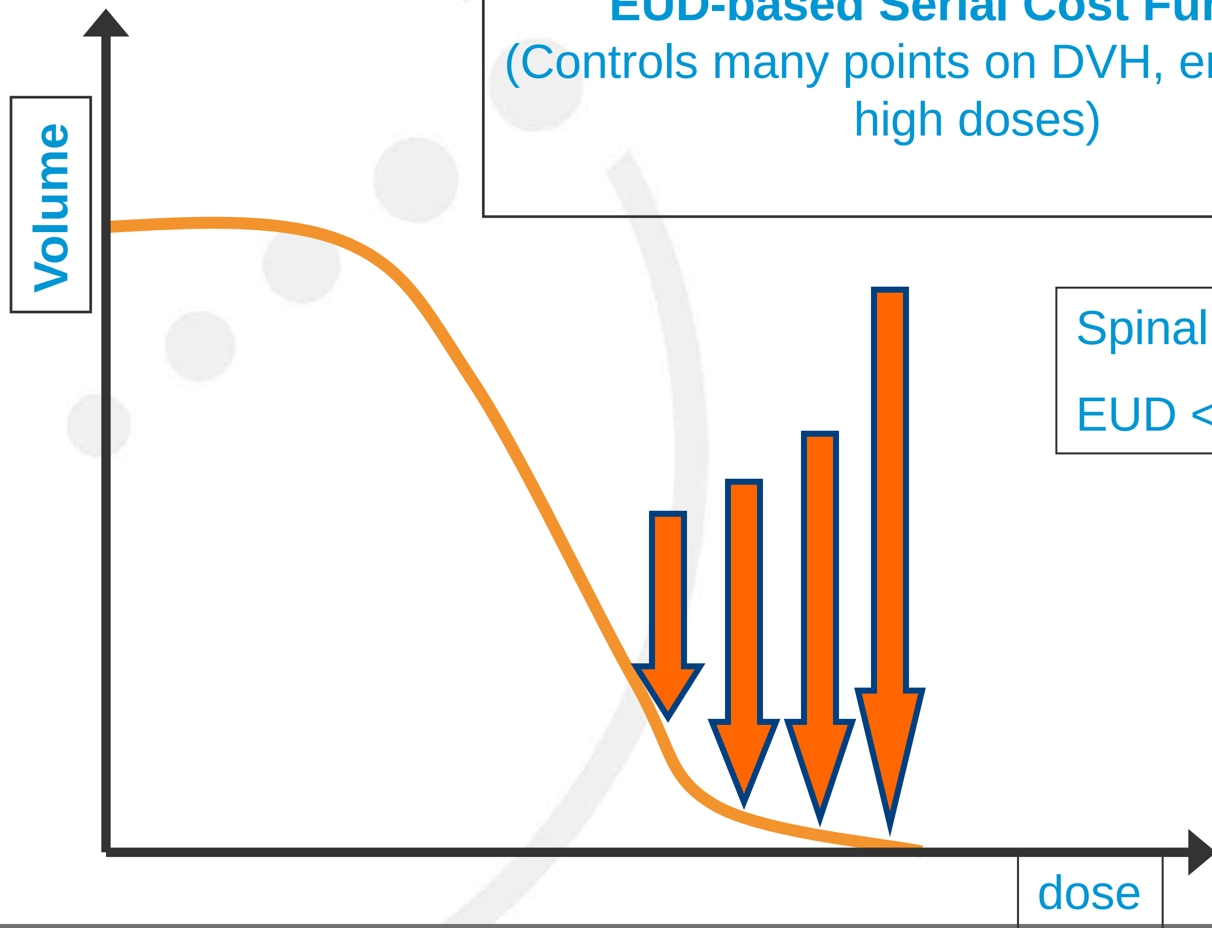
But, for treatment planning, these cost functions really allow us to *control the shape of the DVH…*

Biological Modeling: Controlling the DVH
Serial Tissues



Biological Modeling: Controlling the DVH
Serial Tissues

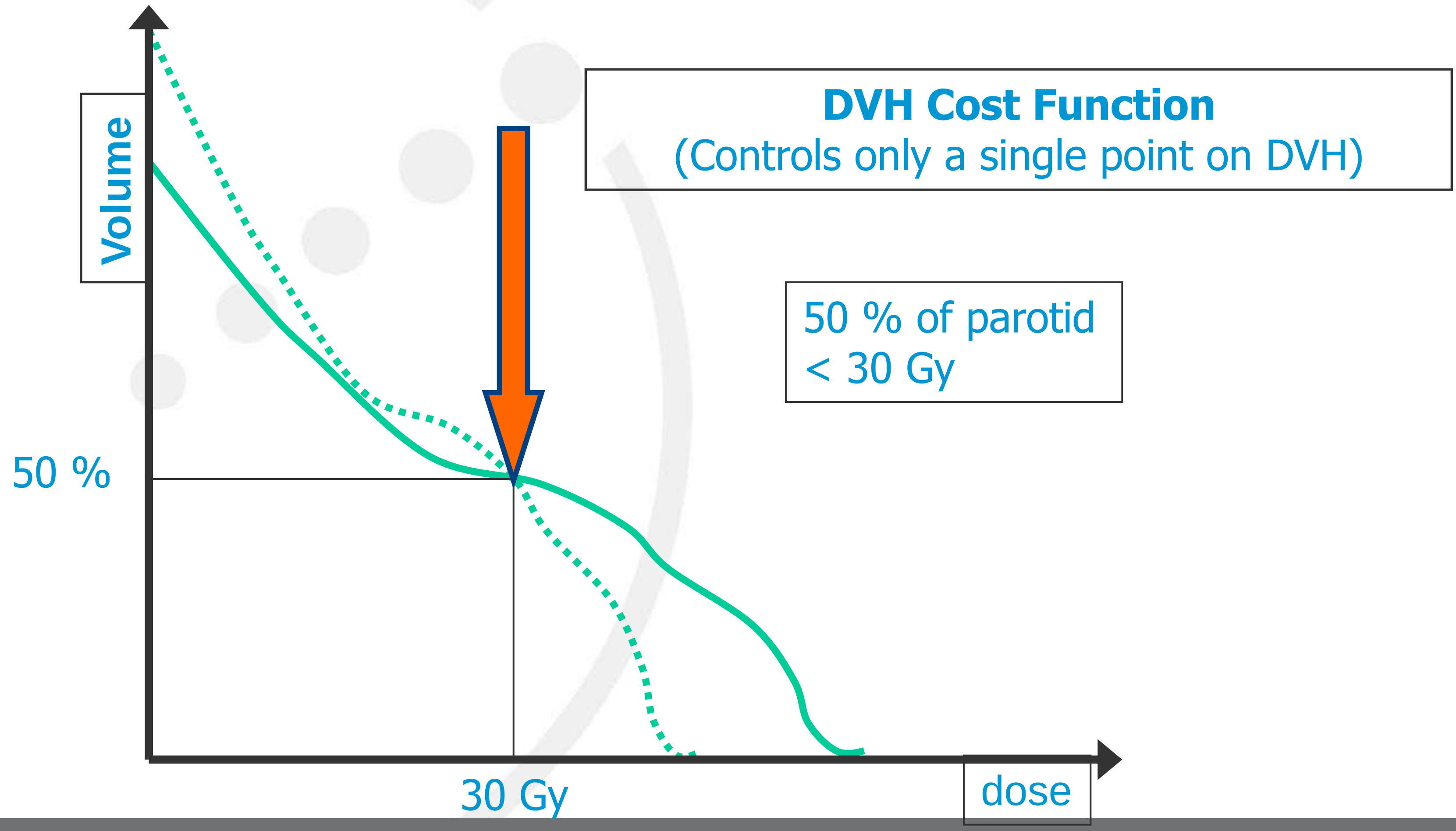
EUD-based Serial Cost Function
(Controls many points on DVH, emphasis on high doses)



Spinal Cord

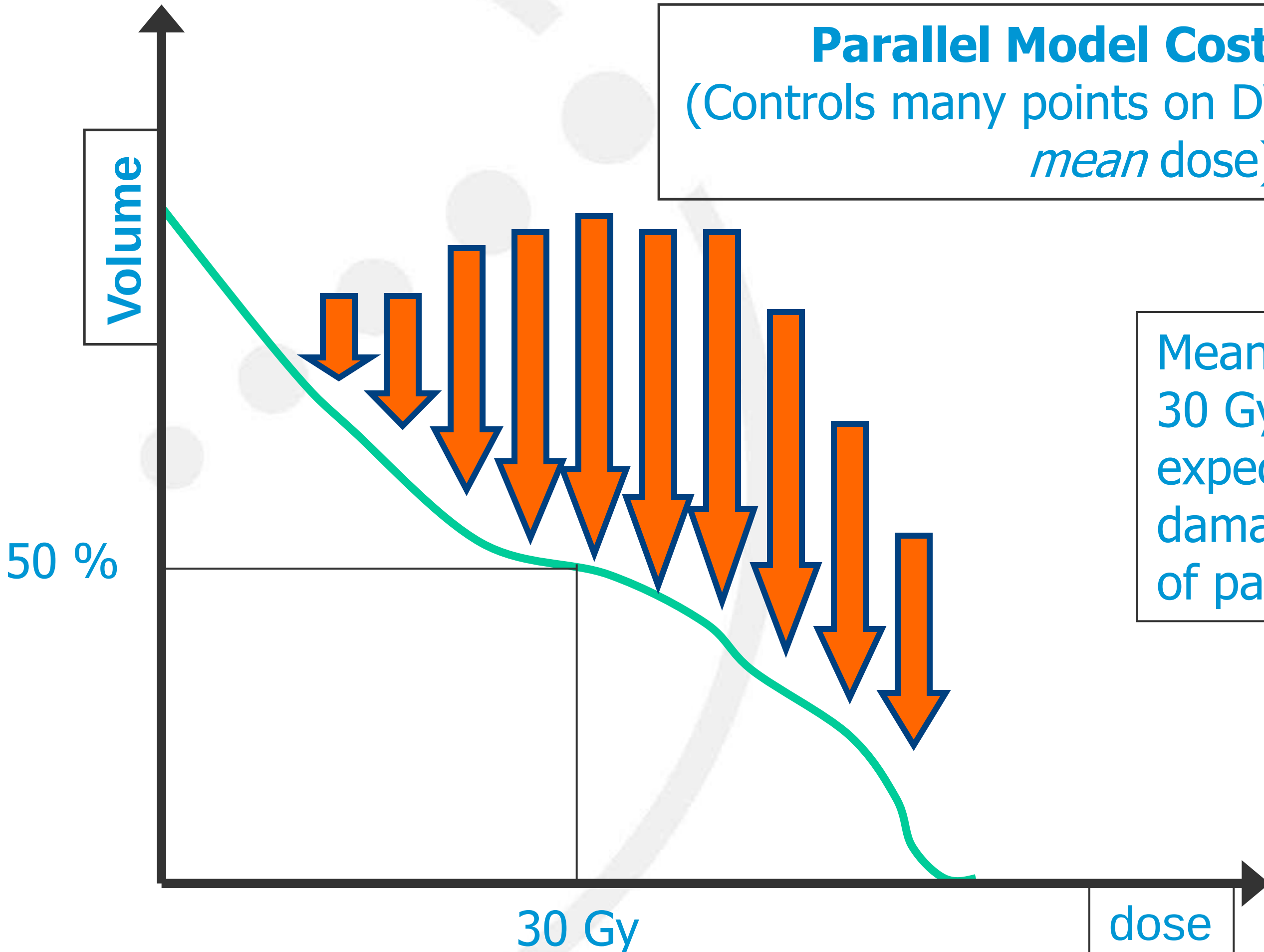
EUD < 35 Gy

Biological Modeling: Controlling the DVH
Parallel Tissues



Biological Modeling: Controlling the DVH Parallel Tissues

Parallel Model Cost Function
(Controls many points on DVH, emphasis on *mean* dose)



Mean dose of 30 Gy is expected to damage 50 % of parotid

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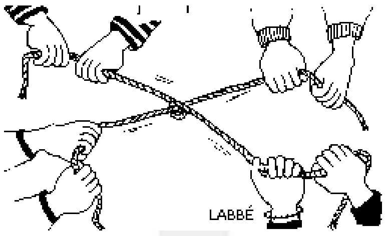
Constrained Optimization

Unconstrained Optimization
(Most current IMRT systems)

PTV1 OAR

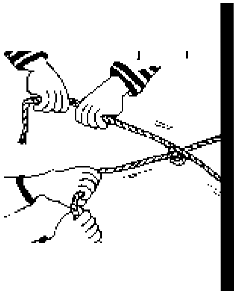


PTV2 OAR

Trade off between all objectives

Constrained Optimization
(Monaco)

PTV1 OAR



PTV2 OAR

Constraints may limit target objectives

But conflicts become apparent!

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Sensitivity Analysis

Changing the isoconstraint of PAROTID_RT by 1% improves the dose to PTV4 by 52 cGY

Prescription

Constraints | Sensitivities

Structure	Cost Function	Isoconstraint	Isoeffect	Relative Impact	ptv1	ptv2	ptv3	ptv4	Point Se
ptv1	Target EUD	6600.0	6806.0						
	Quadratic Overdose	120.0	116.0	++	75.8	14.7	10.1	10.0	
	Underdose DVH	90.00	96.98	+	10.0	0.0	0.0	0.0	
ptv2	Target EUD	6000.0	6378.3						
	Quadratic Overdose	150.0	145.7	+	10.3	28.6	10.0	10.0	
	Underdose DVH	90.00	99.84		0.0	0.0	0.0	0.0	
	Quadratic Overdose	50.0	44.5	+	25.8	10.4	10.0	10.0	
ptv3	Target EUD	5400.0	5810.3						
	Quadratic Overdose	50.0	43.1		11.2	10.0	10.0	10.0	
	Quadratic Overdose	300.0	298.4	++	17.5	11.0	31.8	10.0	
	Underdose DVH	90.00	99.44		0.0	0.0	0.0	0.0	
ptv4	Target EUD	5400.0	5781.4						
	Quadratic Overdose	50.0	38.3		10.0	10.0	10.0	10.0	
	Quadratic Overdose	300.0	301.1	+++	21.6	16.4	10.3	38.3	
	Underdose DVH	90.00	99.24		0.0	0.0	0.0	0.0	
cordplus	Serial	3300.0	3231.7	+	10.0	0.0	10.0	0.0	
ltpar	Parallel	55.00	49.58	++++	11.1	24.9	37.9	11.8	
rtpar	Parallel	55.00	50.86	++++	10.9	34.8	13.6	52.0	
patient	Quadratic Overdose	10.0	3.3		10.0	10.0	10.0	10.0	
	Quadratic Overdose	80.0	35.8		10.0	10.0	10.0	0.0	
	Quadratic Overdose	200.0	164.9	+	10.0	10.0	10.0	10.0	
	Maximum Dose	7200.0	6924.7		10.0	0.0	0.0	0.0	

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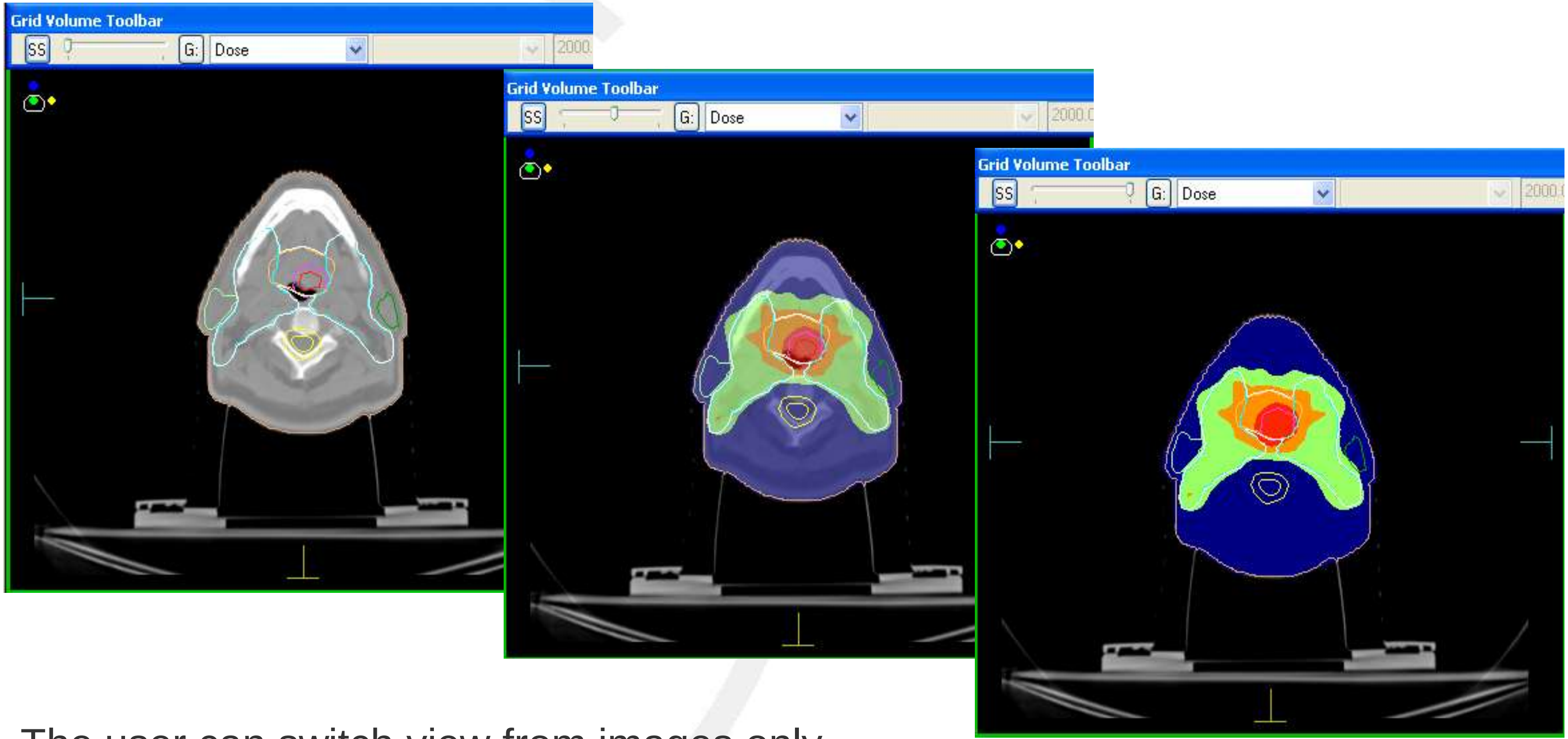
Voxel-based Structure Control:

Volume ToolBar: Dose Option

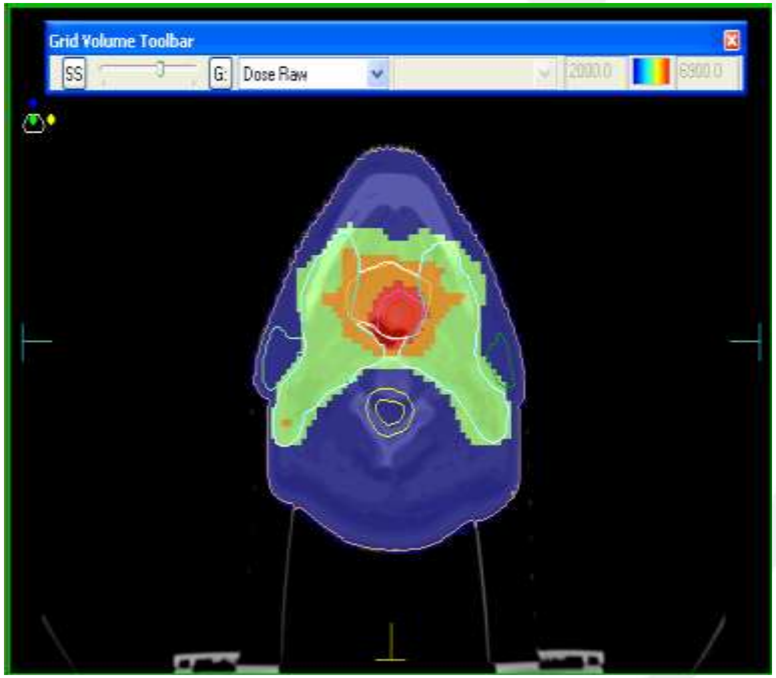


The user can switch view from images only and dose overlay with different intensities

Voxel-based Structure Control:

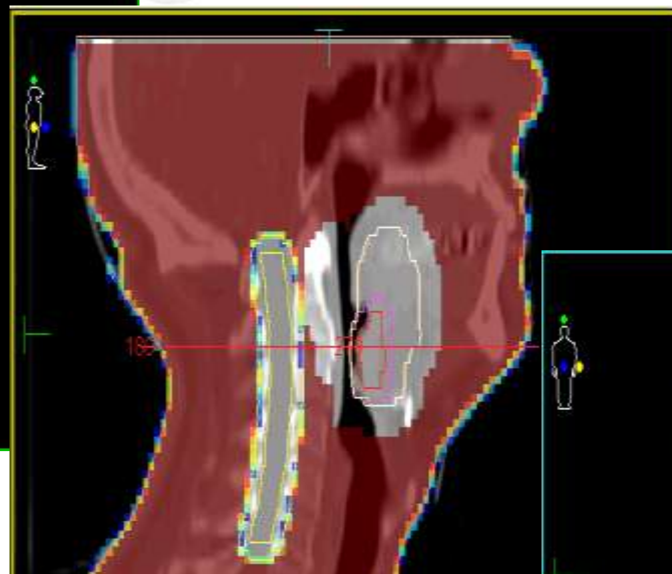
Volume ToolBar: Dose Raw and Electron Density

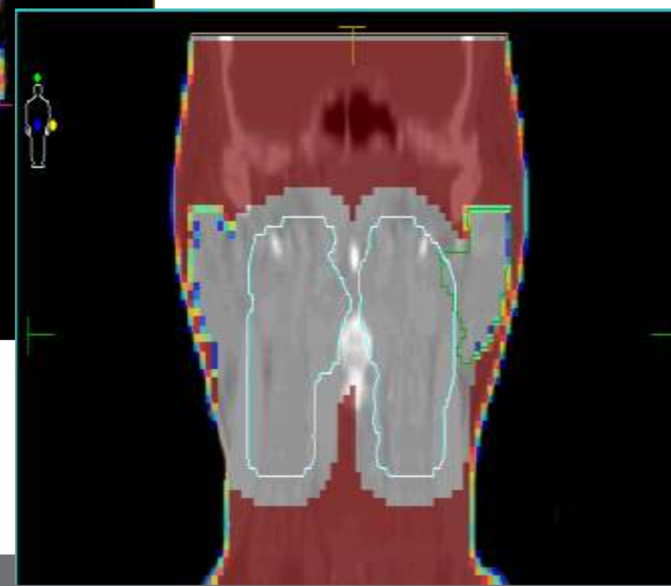
The user can switch view to un-interpolated dose and full electron density according to pixel and user defined voxel

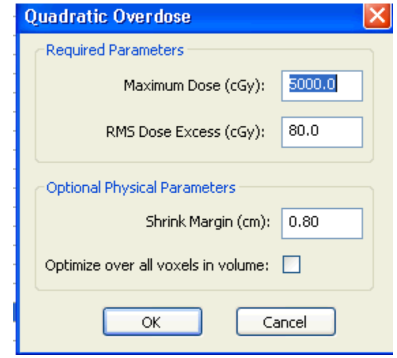


Voxel-based Structure Control:

Volume ToolBar: Cost Function Occupancy

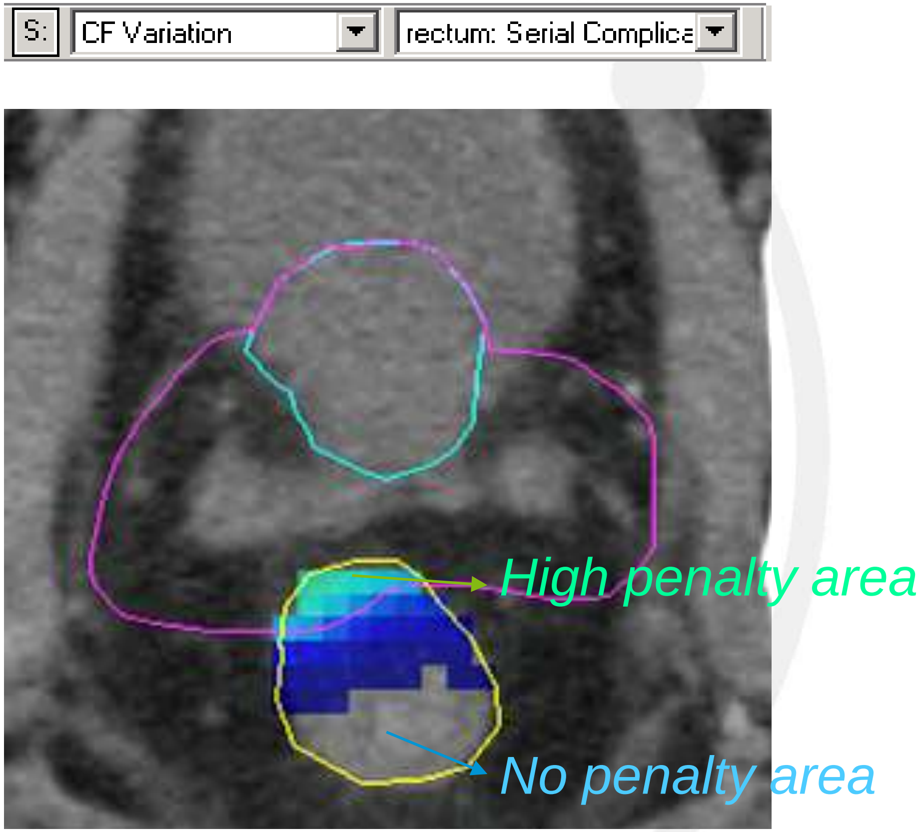


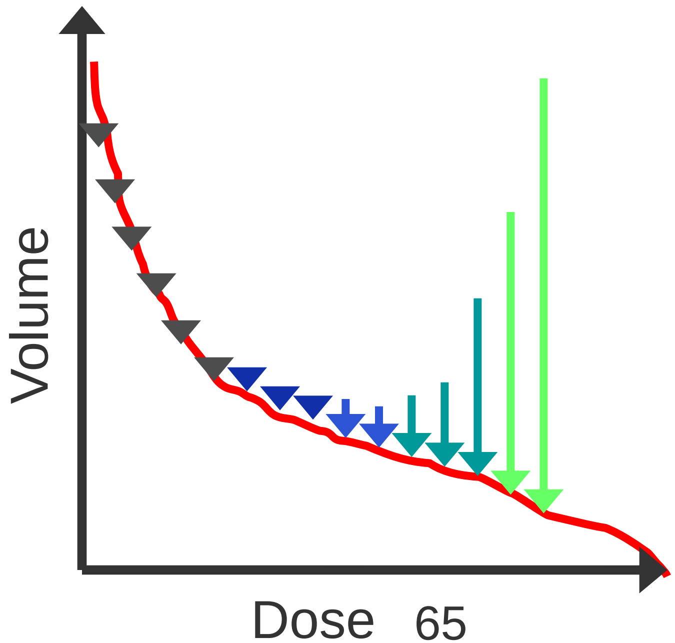




Displays which voxels are being used for a particular structure's cost function.
Takes into account layering order, **shrink margin**, optimize over all voxels, clear etc

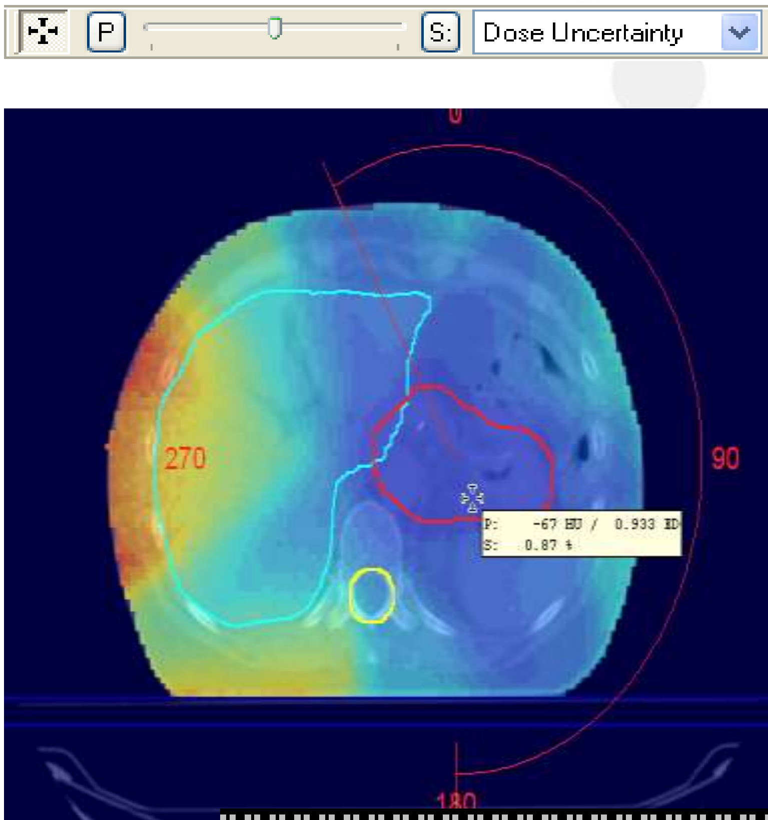
Voxel-based Structure Control:
Volume ToolBar: Cost Function Variation





Voxel-based Structure Control:

Volume ToolBar: Monte Carlo Dose Uncertainty



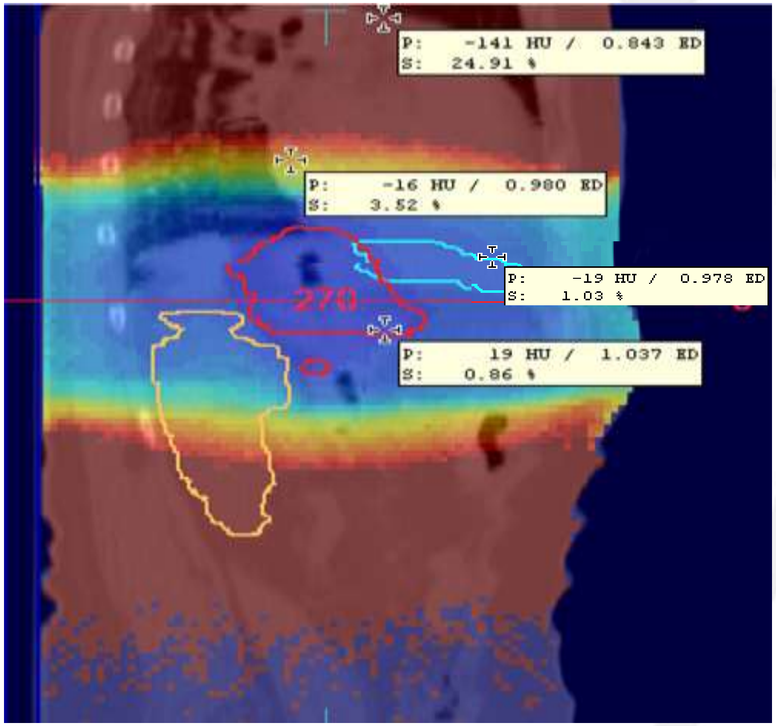
Displays the Dose uncertainty throughout the patient.

The Dose uncertainty of the target region will also be displayed in the console window during stage 2 optimization

```
############################################################
# Current dose uncertainty of MC calculation: 0.9 per cent #
############################################################
```

Voxel-based Structure Control:

Volume ToolBar: MC Dose Uncertainty



The Dose Uncertainty, specified by the user, is per segment. Therefore the uncertainty over the target will always be less

The peripheral uncertainty will increase as the doses become lower and more insignificant.

Voxel-based Structure Controls:

Minimum electron density fill

Automatic clearing of air voxels

Auto-flash margins

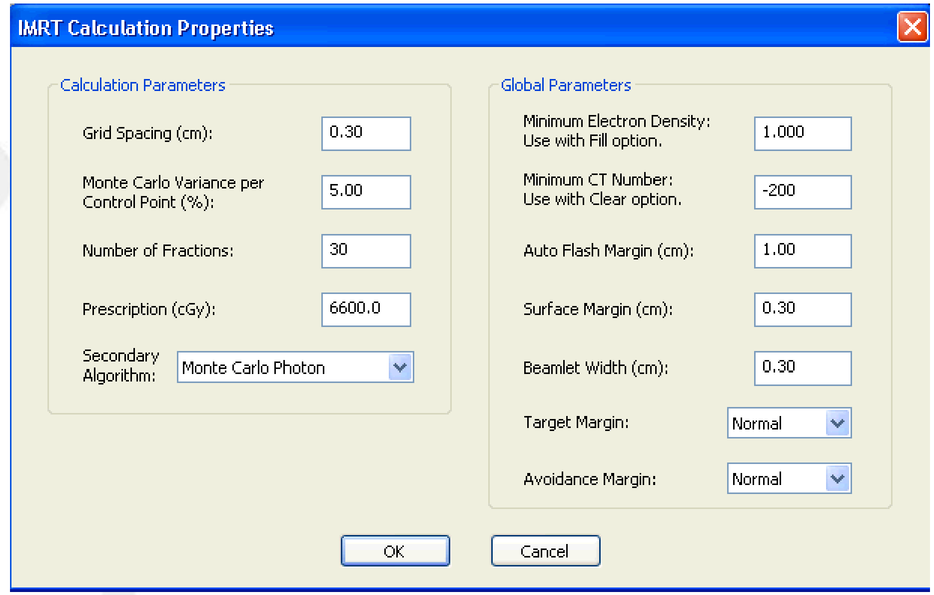
Surface Margin

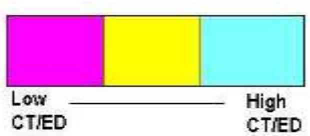
Beamlet width

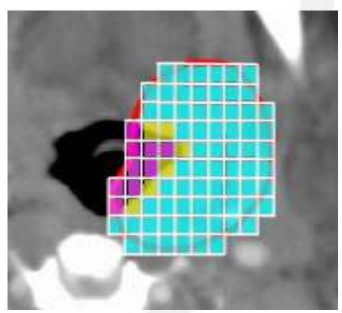
Target Margin

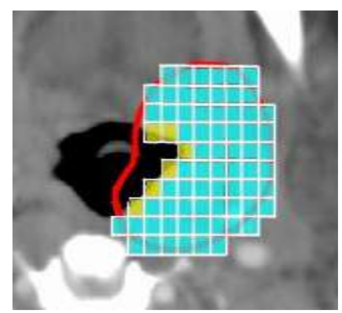
Avoidance Margin

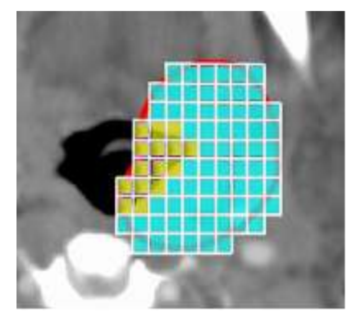
- ***Clear and Fill***











Voxelized Structure	Application of Clear	Application of Fill

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5. Sensitivity Analysis
6. **Smart Sequencing™**
7. Monte Carlo Dose Algorithm
8. VMAT
9. SRS Planning/Dynamic Conformal Arc

Smart Sequencing

Segmentation is integrated in the final optimization loop using XVMC Monte Carlo Dose calculations for each segment

Fluence smoothing

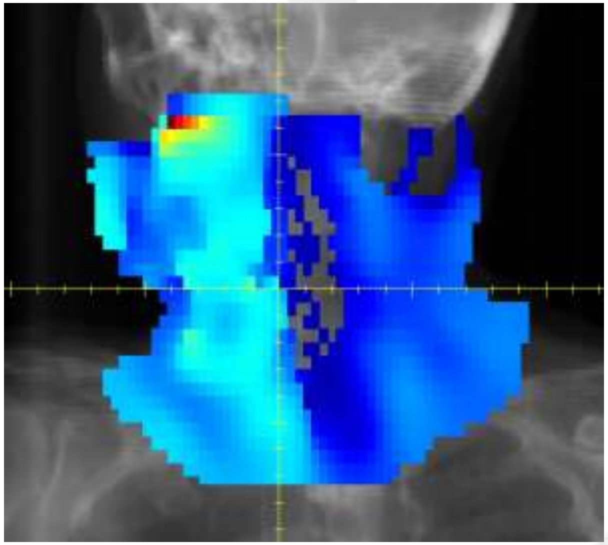
Shape optimization

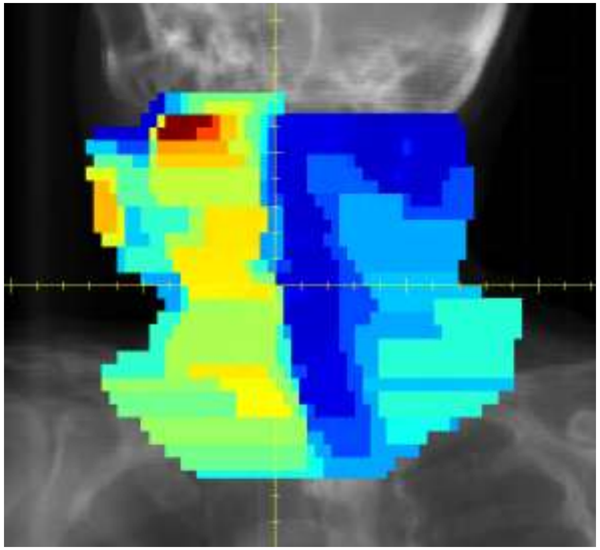
Weight optimization

Minimum MU/segment

Minimum segment area (cm^2)

Max. # Control Points/Arc





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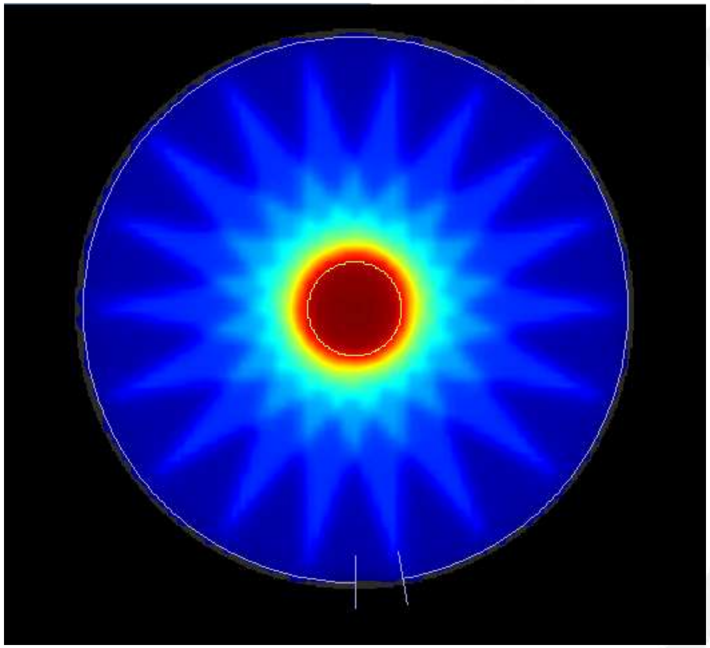
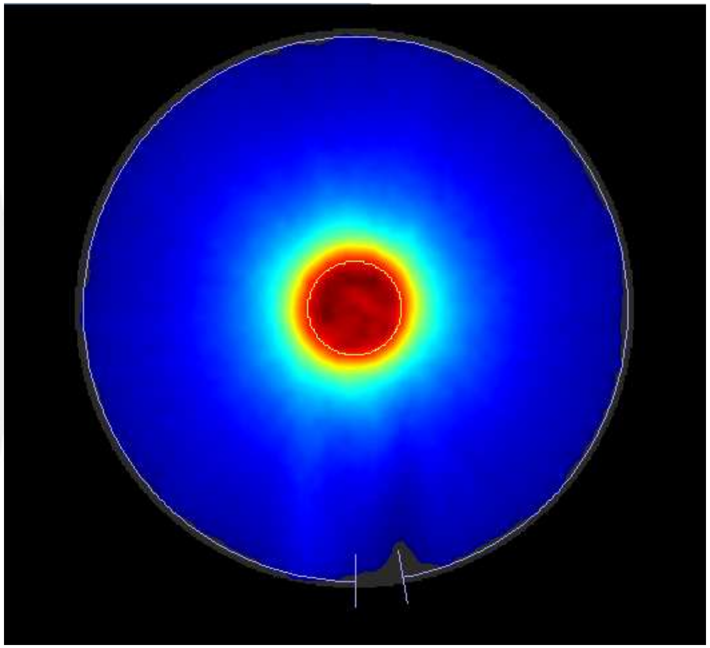
Advantages of Monte Carlo in VMAT

No need to discretize arc into sub beams for dose calculation



Discretized Pencil Beam Arc

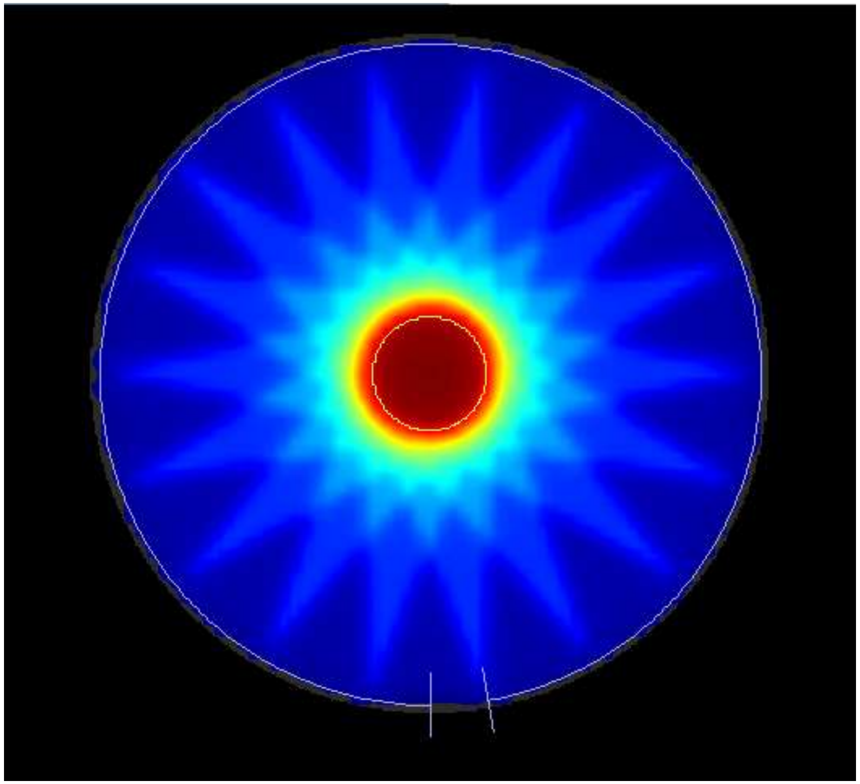


Continuous Monte Carlo Arc

Stage 2 Comparison

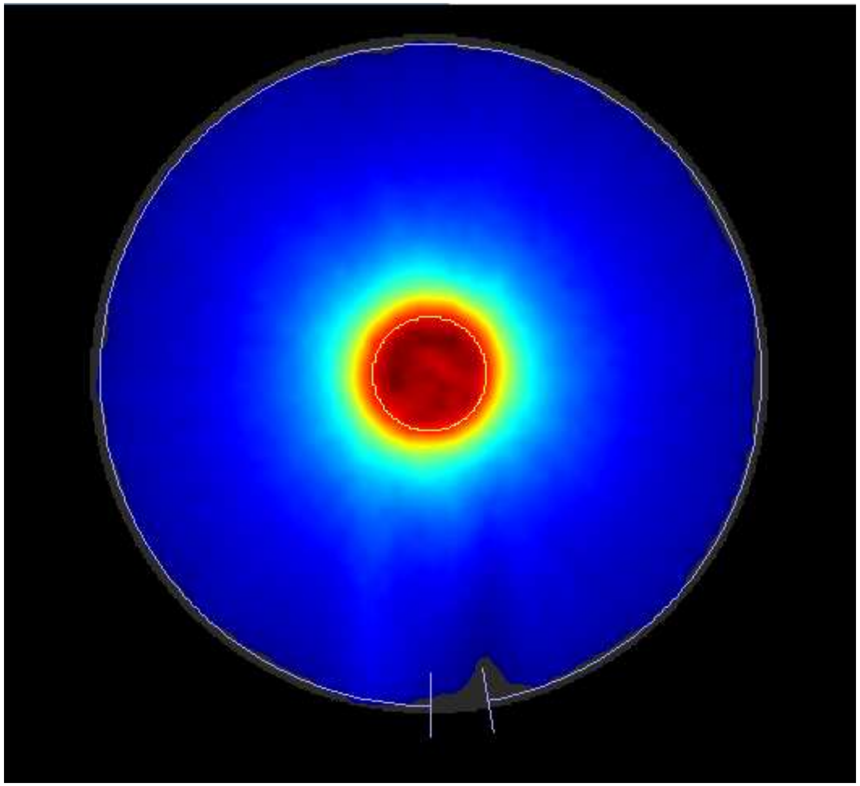
Advantages of Monte Carlo in VMAT

- Pencil Beam rays are calculated at at each segment (CP) within the arc
  - Star pattern effect
  - Looks like a static gantry calculation, not reality
  - As overlap between PB rays decreases, information becomes less accurate
  - This type of calculation is similar to what other systems offer



Advantages of Monte Carlo in VMAT

- Monte Carlo calculations are done to mimic the gantry rotation around the patient
  - Every photon particle is simulated at a random gantry angle somewhere along the arc
  - Produces a smooth distribution of photon particles completely around the arc
  - Artifacts from discretized control points are smoothed out
  - MC is the only algorithm that performs the calculation in this



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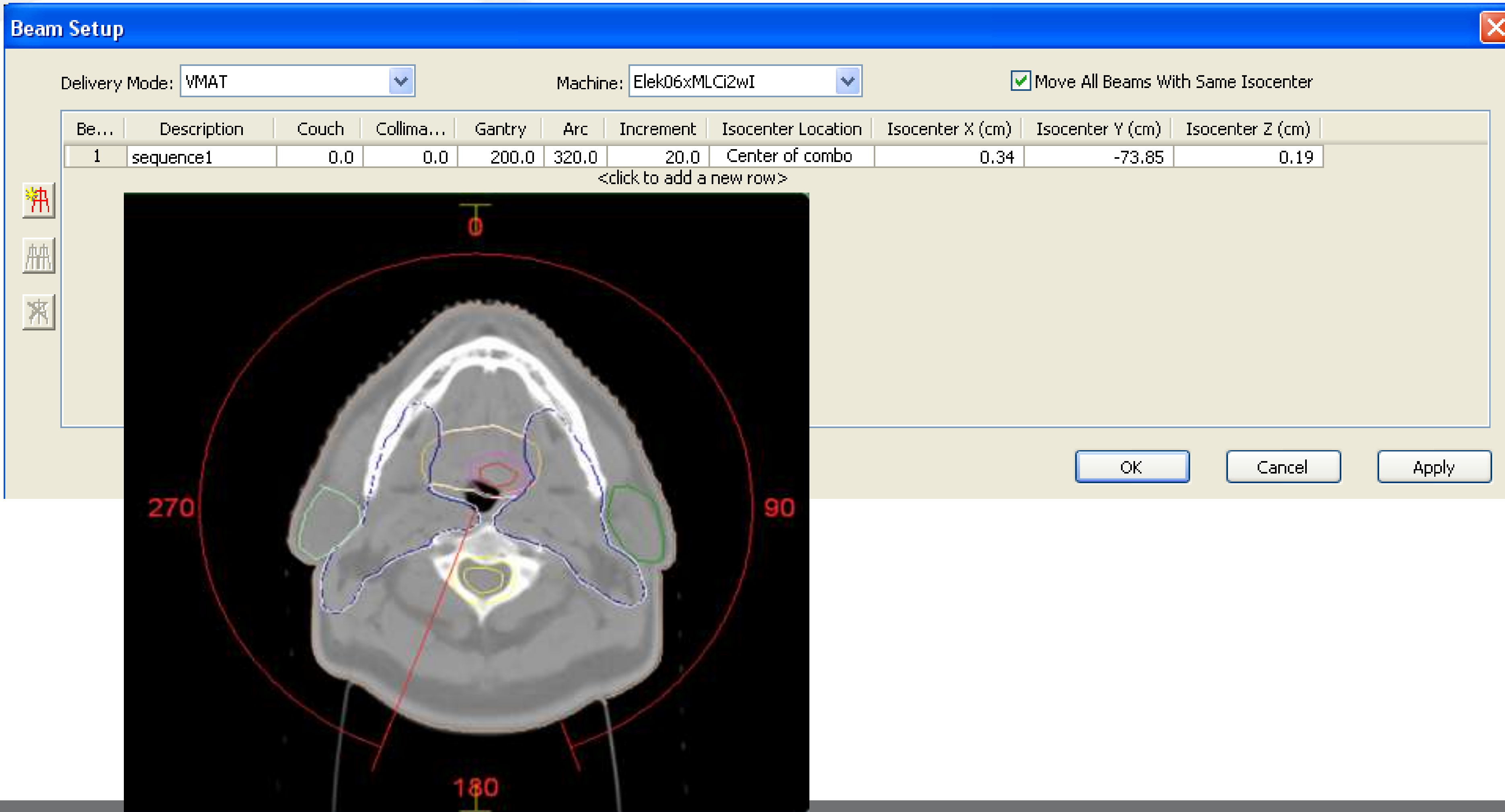
VMAT Planning

- Single or Multiple Arc plans
- Specify: Collimator Angles, Gantry Start Angles, Couch Kicks, Arc Increments
- Ability to optimize multiple arcs simultaneously
- Creation of a multiple arc plan that can be treated with a single button push at the linac console
- MC dose engine allows for continuous arc calculation instead of being limited to dose approximations with discrete gantry positions

VMAT Planning: Example 2: Partial Arc 320^0



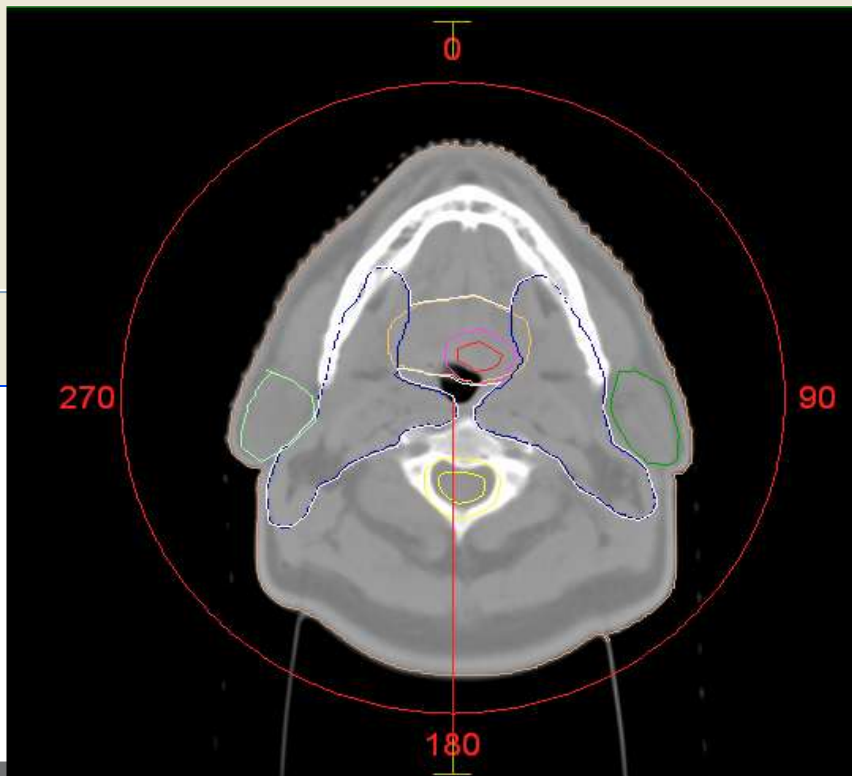
VMAT Planning: Example 1: Single Arc Setup 360^0

Beam Setup

Delivery Mode: VMAT   Machine: Elek06xMLCi2wI   ☑ Move All Beams With Same Isocenter

Be...	Description	Couch	Collima...	Gantry	Arc	Increment	Isocenter Location	Isocenter X (cm)	Isocenter Y (cm)	Isocenter Z (cm)
1	sequence1	0.0	0.0	180.0	360.0	30.0	Center of combo	0.34	-73.85	0.19

<click to add a new row>



OK   Cancel   Apply

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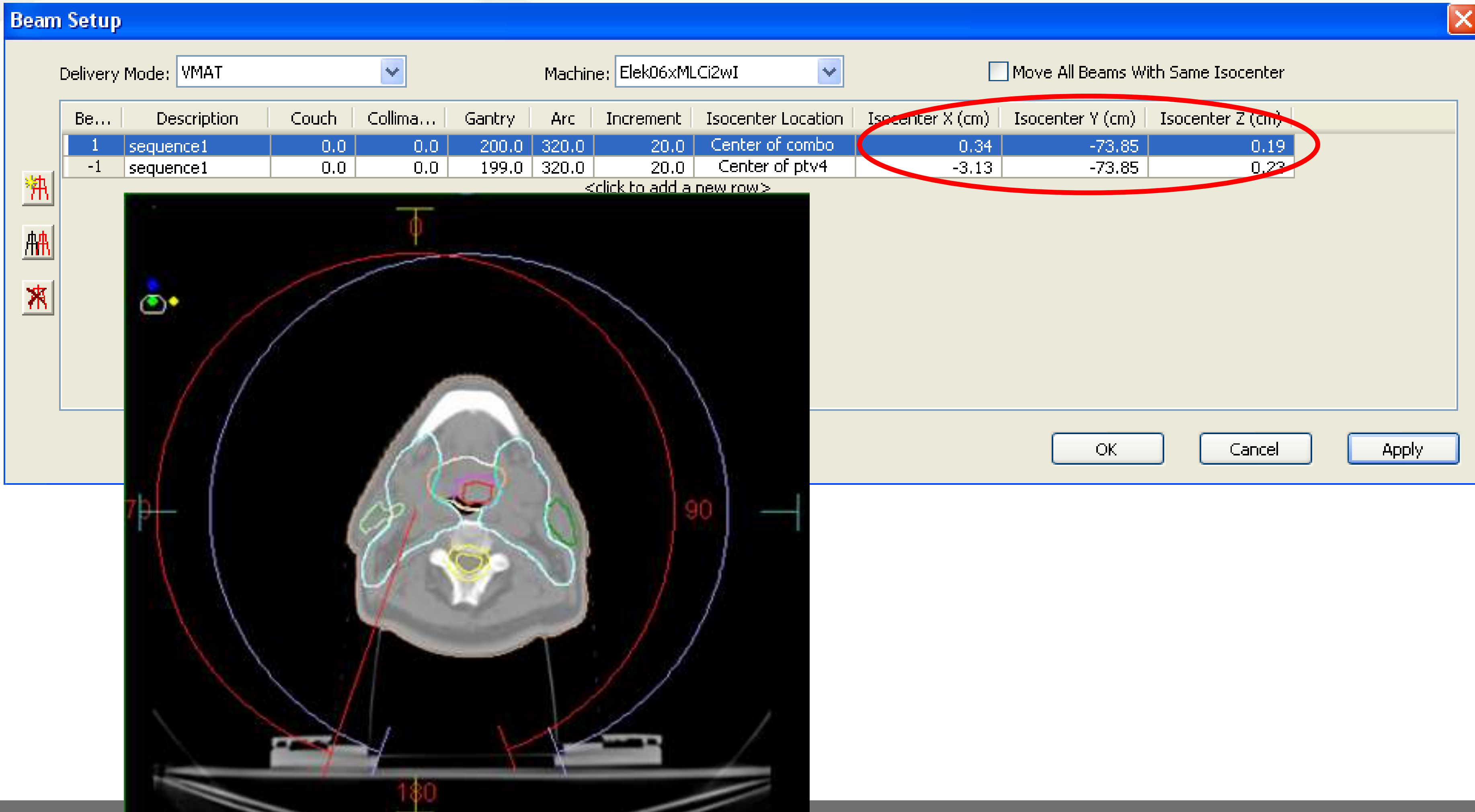
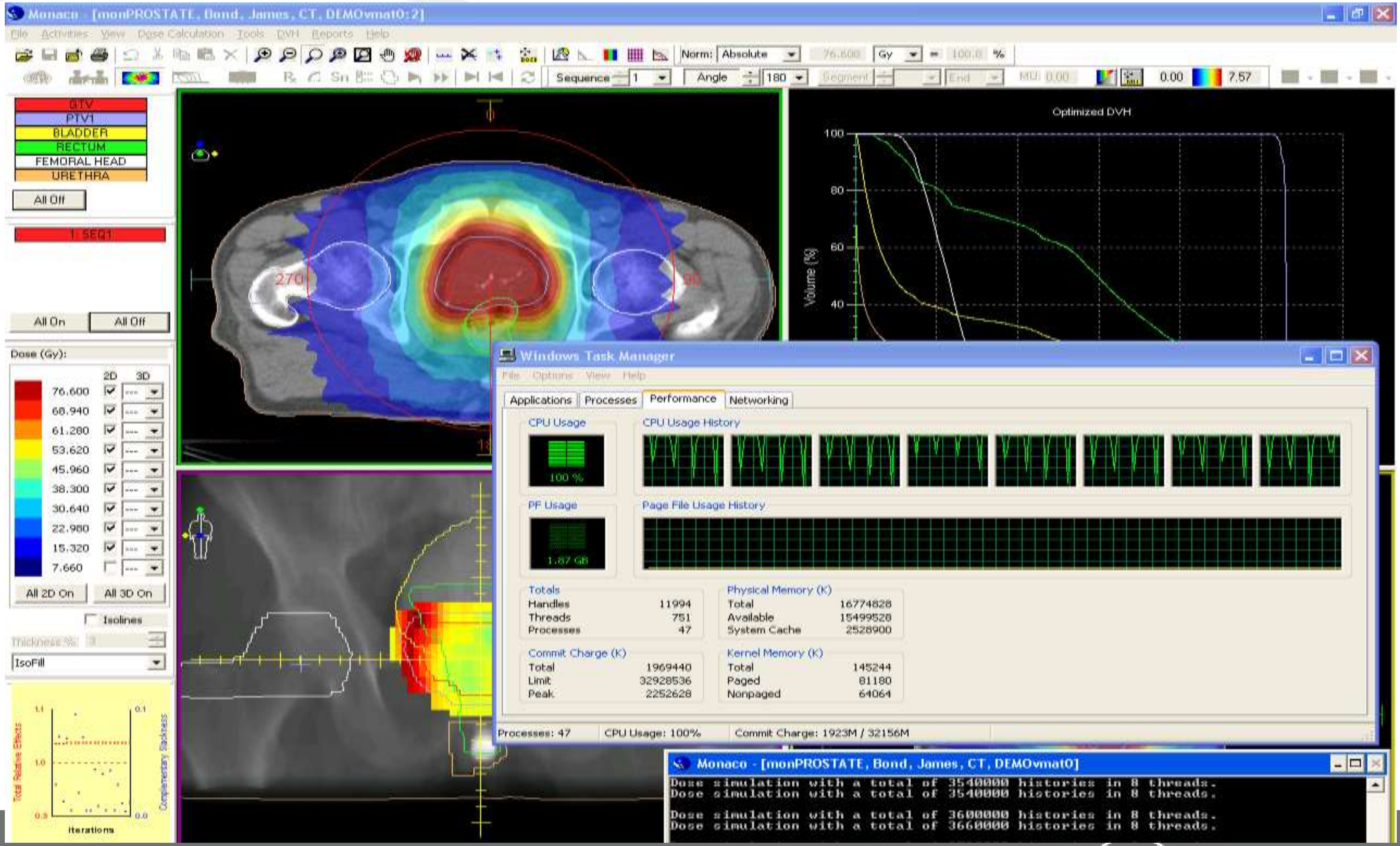
VMAT Planning: Example 3: Two Arcs with different Isocenters



VMAT: Sequencing



Monaco 3.0 – Varian VMAT

Varian VMAT Arc Info

- User can decrease the total number of arcs by increasing the Target Dose Rate (up to maximum) prior to stage 2 optimization.
- At the beginning of stage 2, the console will indicate the number of arcs used.
- Varian arcs are automatically sorted and split upon DICOM export.
- User should reduce the parameter ***Max # Control Points / Arc*** accordingly for Varian VMAT plans.

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SRS Planning/Dynamic Conformal Arc

- Stereotactic planning with dynamic conformal arcs and Apex mMLC
- Support for multiple isocenters
- Frame based stereotactic localization using Ergo++ Localizer module

Monaco: The Next Generation in IMRT Planning

- Monaco as **dedicated IMRT/VMAT** system
- Meaningful way of prescribing using **Biological cost functions**
- **Optimization**
  - Changes applicable during optimization
  - Constrained optimization
  - Evaluation tools (impact factor, sensitivity analysis)
- **No final "Recalculation"**
  - optimization of segment shape and weight
  - Monte Carlo Simulations during optimization

Muchas gracias!