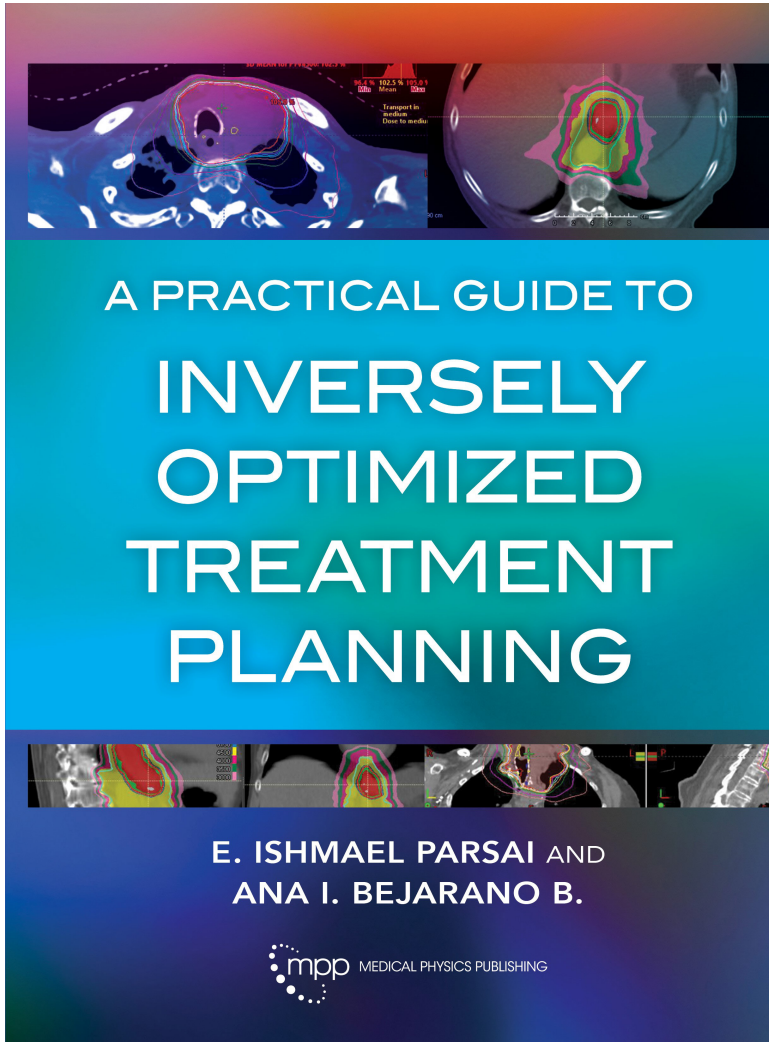




MEDICAL PHYSICS PUBLISHING



Please enjoy your sample of
A Practical Guide to Inversely Optimized Treatment Planning.

This complimentary chapter is copyrighted and made available for personal use only. No part of this chapter may be reproduced or distributed in any form without prior written permission of Medical Physics Publishing.

Choose from:
Hardcover ISBN: 978-1-951134-20-4
eBook ISBN: 978-1-951134-21-1

To learn more or to place an order:
medicalphysics.org | mpp@medicalphysics.org | 800.442.5778

medicalphysics.org

4. Planning

This chapter encompasses inverse planning techniques across different treatment planning systems. The different cases presented here should not be taken as step-by-step instructions, but rather as a source of reference for the many different cases that the planner may encounter in the clinical setting.

4.1 Contouring

Contouring consists of drawing volumes of particular structures on a CT dataset, and it is essential to any planning technique, especially with the arrival of sophisticated planning systems. Contours are important since the planner assigns names and characteristics to a volume in the CT dataset that enables the optimization process and dose quantification to each of the structures. These contours can be targets, organs at risk, or optimization contours. They simply identify the enclosed volume so it can be used for a variety of purposes.

4.1.1 Organs at Risk

Organ-at-risk (OAR) contours represent the patient's healthy tissue. These contours can be drawn according

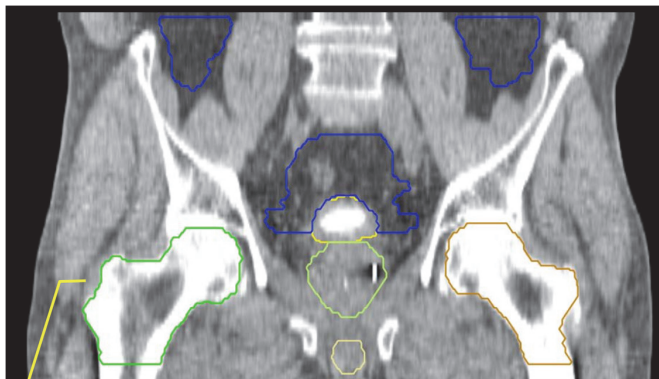


Figure 4.1 Sample contouring for male pelvis. (RTOG contouring atlas).

to consensus data, such as the RTOG contouring guides (Figure 4.1), and they must be contoured as accurately as possible.

There are reputable websites that offer guidance on contouring with free registration:

- **“ProKnow” and “Contouring Accuracy” by Elekta (proknowsystems.com).** This Elekta website contains how-to presentations as well as practice online datasets with scoring capabilities. Users can learn to contour challenging anatomy (such as brachial plexus, head and neck structures, and others) and have their practice contours compared to expert datasets with feedback.
- ***E-Contour* (e-contour.org).** This physician-led website contains a variety of CT datasets, giving the user the experience of having a 3D image encyclopedia of contours for quick reference.

It is also important to know the difference between *serial organs* and *parallel organs* in terms of sensitivity to radiation. The dose and dose distribution can affect the sensitivity of an organ. One might think of all organs as divided into subunits, which can be functional or non-functional after radiation damage. Serial organs can fail entirely if any subunit has been damaged (examples include the spinal cord, optic nerves, and the brainstem). Parallel organs can fail entirely if many or all subunits are damaged (examples include the liver, lungs, and kidneys).

All plans must be approved and signed by the radiation oncologist after reviewing target coverage and dose to OARs.

4.1.2 Optimization Contours

Optimization contours are drawn and used with the sole purpose of helping enhance the dose distribution during inverse planning. Overlapping optimization contours can cause conflicts in the optimizer. To avoid unneces-

sarily overlapping structures for optimization, here is some guidance:

- **Separating dose levels into targets that have more than one dose level is important.** Overlaps create conflicts for most optimizers. Create one contour for each individual dose level. Targets (GTV, CTV, ITV, and PTV) are drawn by the radiation oncologist.
- **In cases where the radiation oncologist wishes to spare healthy tissue at the cost of target coverage, the planner can use Boolean operators to create a special optimization structure without modifying the original target structures.** A subtraction of the target minus the OAR (typically with a 2-mm margin) can become an optimization target structure that can be used in the optimizer for planning.
- **In cases where the radiation oncologist wishes to cover the target at the expense of healthy tissue, the planner can use Boolean operators to create an OAR optimization structure that avoids the target with a margin of typically 2 mm.** This structure can be used in the optimizer for planning.
- **Planners can choose to leave margins in their optimization target contours or to draw “rings” around them.** Rings are structures that act like “barriers” between dose levels to achieve the desired dose falloff or to avoid *dose spills* (high dose going in regions of low dose). In cases in which the TPS system does not have an optimization option to spare normal tissue, the user can use

a series of concentric rings around the target. Another option is to make a 2- to 3-cm “rind” from the external or body contour.

4.2 Isocenter Placement

The beam isocenter is the point at which the central axis of the beams will be directed during treatment. In the case of having a moving laser system or a static laser system, the placement of a point within the patient can be achievable during the simulation process or the planning process. Labeling these points correctly is imperative to avoid mistakes through planning, quality assurance, and delivery. There are usually two points of interest at which beams can be directed: the isocenter from CT simulation or the beam isocenter.

4.2.1 Isocenter from CT Simulation

This is the point at which the patient is marked during the simulation process. If the institution counts with a moving laser system, during the simulation process it is possible to “drop” a point in a particular part of the body (generally the middle of the target) and make the lasers move to that point so that tattoos and marks can be drawn at the actual site of alignment for treatment. If the location of this isocenter is optimal, then it can also be used as an isocenter of the beams, instead of just using it as a point to set the lasers. If the location is not optimal, then another point can be placed on the planning system (i.e., the beam isocenter).

4.2.2 Beam Isocenter

Throughout this book, “beam isocenter” is the point at which all beams converge (Figure 4.2). Prior to treat-

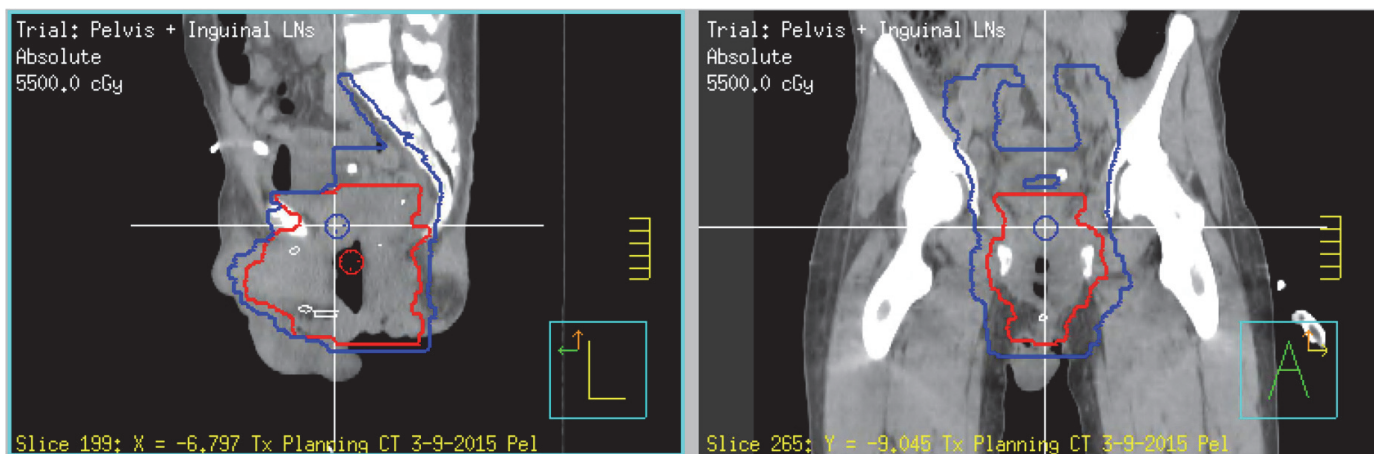


Figure 4.2 Isocenter position (blue POI) in the central aspect of the target.

ment, therapists will receive shifts from the marked isocenter in simulation to the true beam isocenter. In this case, for treatment, the patient will be set to the tattoos of the original isocenter and then moved to the beam isocenter by shifts provided by the planning system.

A good general placement of a beam isocenter is one that is in the middle of the target, with relatively easy-to-make shifts from the original simulation isocenter (if applicable). Not placing the isocenter for the beams in the middle of the target could compromise conformity of the planned dose since most accelerators have high-definition MLCs only in the middle of their field.

4.3 Beam Arrangement

4.3.1 IMRT Beam Arrangement

IMRT can have a variety of beam arrangements depending on the target location and coverage needed. A traditional plan will involve 7 to 9 beams (Figure 4.3) located around the patient at fixed or variable gantry angle intervals. Collimator rotations are not needed, but the planner is encouraged to use them in cases where they are valuable to spare an organ, cover a target, etc.

For fixed-jaw machines, the use of split beams can help cover wide targets. Other options include:

- *manual setup of split fields* (have one beam divided into two beams with different MLC carriage positions), and

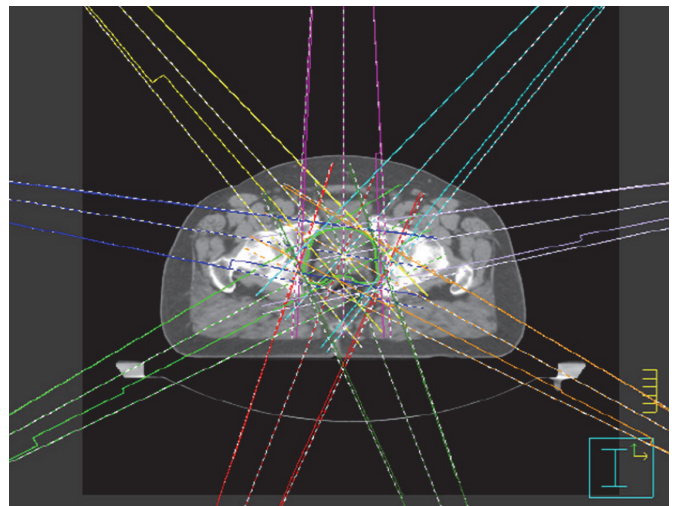


Figure 4.3 A typical 9-beam IMRT beam arrangement.

- *vendor-specific packages*, such as the large-field IMRT provided by Varian Eclipse.

The beam arrangement can be one-sided if the lesion to be treated is not located centrally in the body (Figure 4.4). The planner must avoid irradiating healthy structures as much as possible, unless coverage of the lesion is greatly improved and desired and the dose to healthy tissue is under reasonable tolerance.

4.3.2 VMAT Beam Arrangement

The most common VMAT beam arrangement encompasses two or more arcs around the patient. The collima-

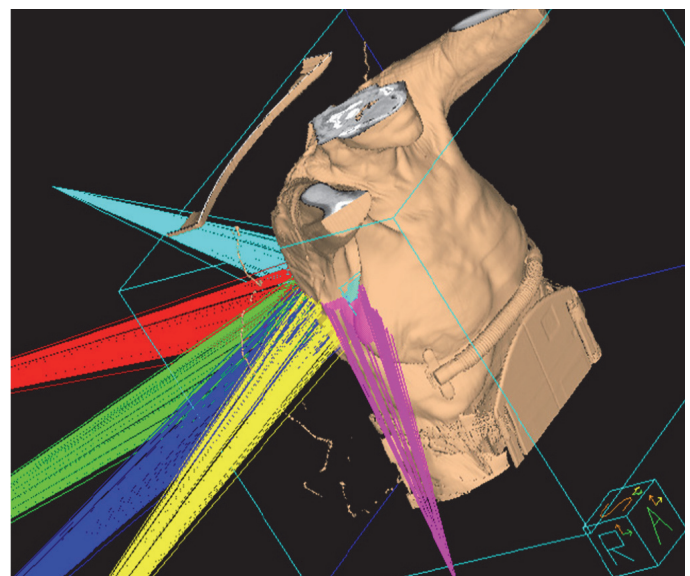
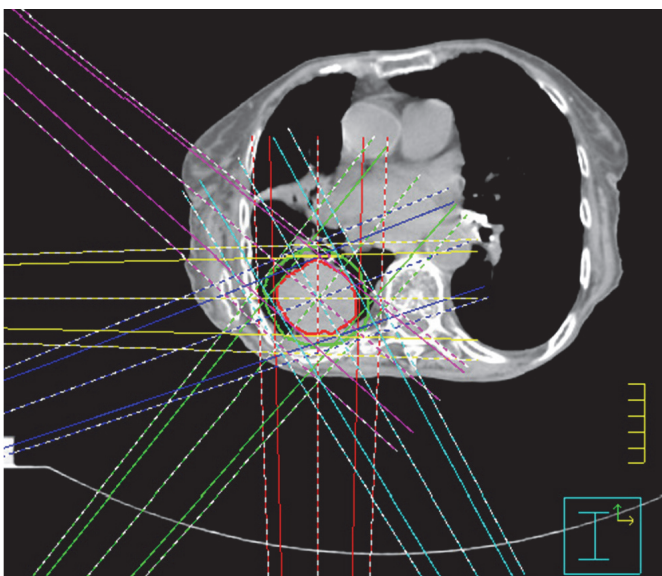


Figure 4.4 A typical beam arrangement for a lesion located on the posterior chest wall.

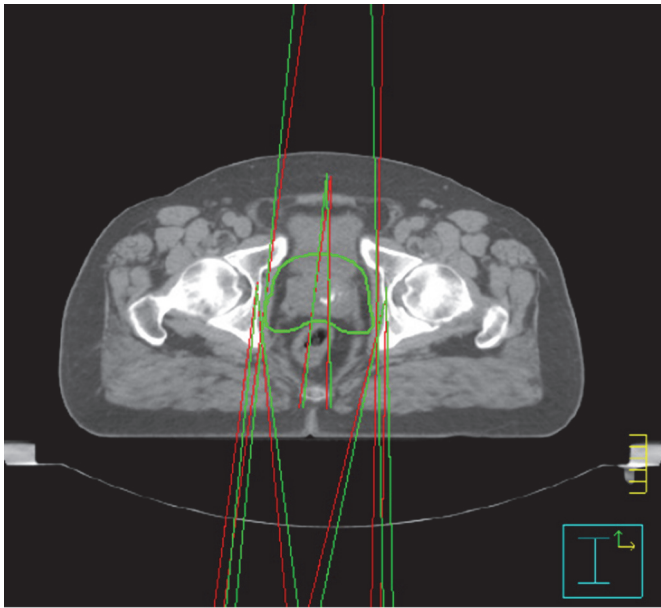


Figure 4.5 Two VMAT arcs with a 2-degree offset.

tor can be placed at an angle (30 to 90 degrees) to decrease the inter-leaf leakage. It is important to know the machine and system limitations in terms of start and stop angles for an arc.

Another parameter to keep in mind is the gantry spacing or space between control points. In some planning systems, the user has the option to set control points every 5, 4, 3, or 2 degrees. The increased resolution would take more system resources to optimize and calculate, which might make the calculation long and

impractical. One way to offset the disadvantages of this scenario is to offset the start and stop angles of each arc by the gantry spacing divided by two. For example, if the gantry spacing is 4 degrees, the planner can create a plan with two VMAT arcs offset by 2 degrees from each other's start and stopping angles (Figure 4.5).

The planner must be aware of the capabilities of the accelerator and R&V system, especially in terms of delivery, gantry rotation, and collision. For example, some systems might allow a 180- to 179.9-degree gantry rotation (almost 360 degrees), while others allow a 181- to 179-degree gantry rotation. Since the gantry will be going around the patient, the planner must be careful to not set a beam arrangement that could cause a collision.

The arcs can be set to cover 360 degrees, as well as partial arcs when needed, for one-sided lesions (Figure 4.6).

4.4 Optimization

Inverse planning refers to planning done by providing the computer with a description of the desired solution for which to develop a plan. The solution the user provides to the computer is the desired dose distribution, and the development of a plan refers to the creation of control points or beamlets to achieve the solution. Different planning systems have different nomenclature for the optimization process, but the IMRT/VMAT basis is still the same.

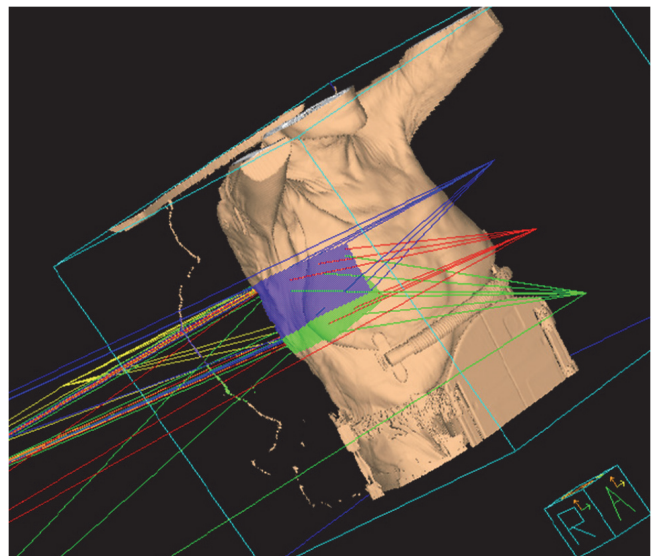
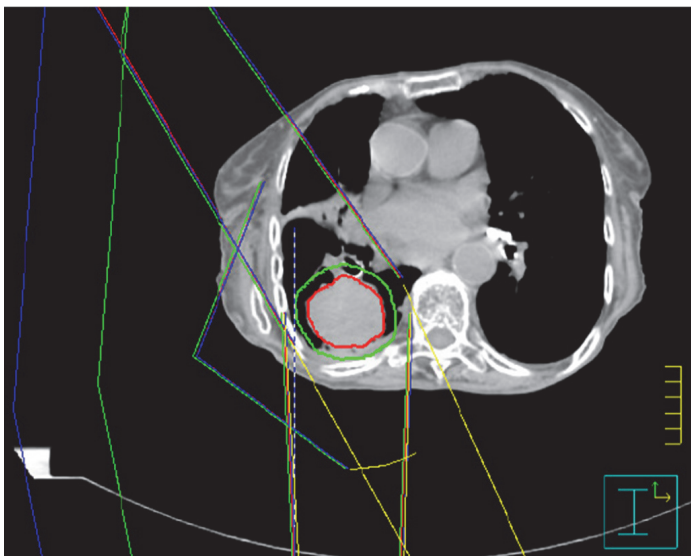


Figure 4.6 Partial VMAT arcs for a one-sided lesion.

For each beam placed on the patient, the IMRT optimization will try to find the best control points/MLC positions to achieve the desired dose distribution (Figure 4.7). *Control points* or *beamlets* are individual parts of a dynamic IMRT beam to regulate dose to a certain area.

To start the optimization, one needs to have targets defined by a physician, the beams set up, and all necessary contours defined. For the TPS to achieve an opti-

mal dose distribution, it is important to set appropriate objectives, constraints, and beam parameters.

Some planning systems require the user to convert the dose fluence map to a deliverable plan, while others do this automatically after the optimization process. Several optimizations can be necessary to achieve the desired dose distribution.

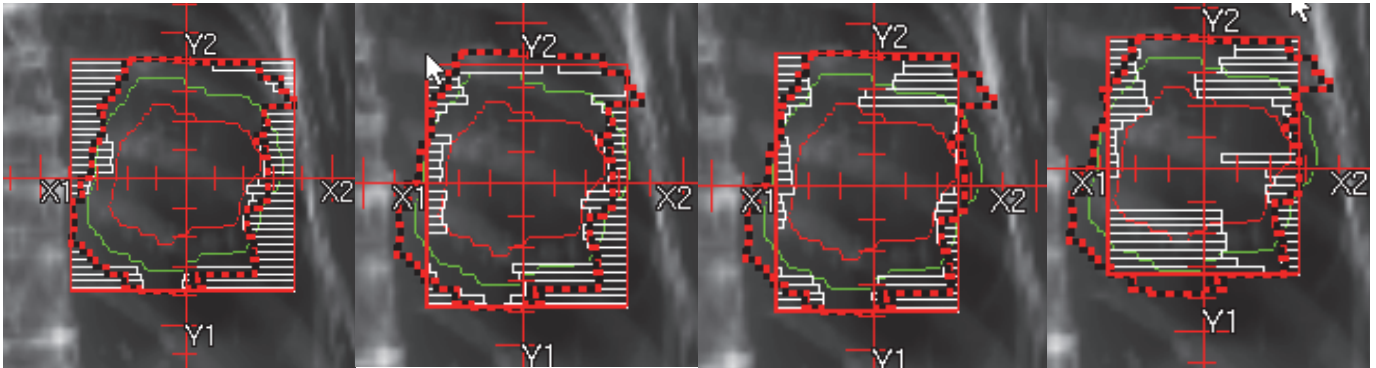


Figure 4.7 Series of images of different control points for one beam in an IMRT plan. The green and red outlines are PTV/GTV target contours.

Optimization		Conversion		Tri	
Max iterations	<input type="text" value="135"/>	Stopping tolerance	<input type="text" value="1e-05"/>		
Convolution dose iteration	<input type="text" value="35"/>	<input type="checkbox"/> Apply tumor overlap fraction			
Beam	Optimization Type	Allow jaw motion	Use current jaws as max	Split if necessary	
180	DMPO	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
220	DMPO	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
250	DMPO	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
270	DMPO	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
310	DMPO	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
DMPO		Intensity Modulation		SmartArc	
Maximum number of segments	<input type="text" value="90"/>	Minimum number of leaf pairs	<input type="text" value="4"/>		
Minimum segment area	<input type="text" value="6"/> cm ²	Minimum leaf end separation	<input type="text" value="1.5"/> cm		
Minimum segment MUs	<input type="text" value="6"/>	Beam Splitting			
<input checked="" type="checkbox"/> Compute final dose		Minimum overlap distance	<input type="text" value="2"/> cm		
Use SVD for dose calculation	<input checked="" type="radio"/> Yes <input type="radio"/> No	Maximum overlap distance	<input type="text" value="4"/> cm		
Fine resolution ODM	<input checked="" type="radio"/> Yes <input type="radio"/> No				

Figure 4.8 Sample IMRT Parameters menu under the IMRT tab in Pinnacle 9.8. Similar options can be found in other versions of the TPS.

Figure 4.9 DMPO options in Pinnacle 9.8.

4.4.1 Pinnacle Optimization

4.4.1.1 Pinnacle IMRT/VMAT Parameters

Pinnacle IMRT parameters are shown in Figure 4.8. The following settings are found in Pinnacle version 9.8. However, they are still applicable for newer versions of the software.

For IMRT, the following beam parameters are of importance:

- **Maximum iterations.** The basic rule is to set the convolution dose iteration to one quarter to one third of the maximum iteration number. For example, one can set up 75 maximum iterations with convolution dose calculation at 25. The user is free to choose any number of iterations, but it is important to keep in mind that choosing a low value does not give the system enough iterations to achieve the best optimization results.
- **Convolution dose iteration.** This sets up the number of iterations before computing the convolution dose, adding machine parameters (close to a real deliverable plan).
- **Stopping tolerance.** The *objective value* (defined later) at which the software will stop working on achieving a certain objective because it is considered achieved or it is not possible to be achieved.
- **Moving jaws.** If the user allows the machine to move jaws during the treatment, these will adjust to the shape of each control point. This option is important to decrease the MLC scattering and leakage, but it depends on the capabilities of the machine.
- **Use current jaws as max.** The current position of the jaws will be the maximum limit during the optimization. Though rarely used, this can be

selected only when the warning of the “field size too large” shows up during optimization.

- **Split if necessary.** This automatically splits beams by making another one.

4.4.1.2 Pinnacle Optimization Types

- **DMPO.** The acronym DMPO stands for *direct machine parameter optimization*. Instead of just providing an intensity modulation dose, it also includes machine characteristics, MLC position, and segment/control point weights (Figure 4.9). DMPO produces plans that are delivered more efficiently than an intensity modulation plan because machine parameters have been used in the optimization. The number of segments refers to the number of control points per plan (step and shoot IMRT).

The more complicated the shape of the target is or the closest a target is to organs at risk, the more control points the plan will need to achieve the desired isodose distribution. For example, in this example, the number of segments has a default of 50, which can be increased according to how many control points the system ends up using to control the dose. Too many control points can increase the delivery time, so a good rule is to set

Figure 4.10 Intensity modulation options in Pinnacle 9.8.

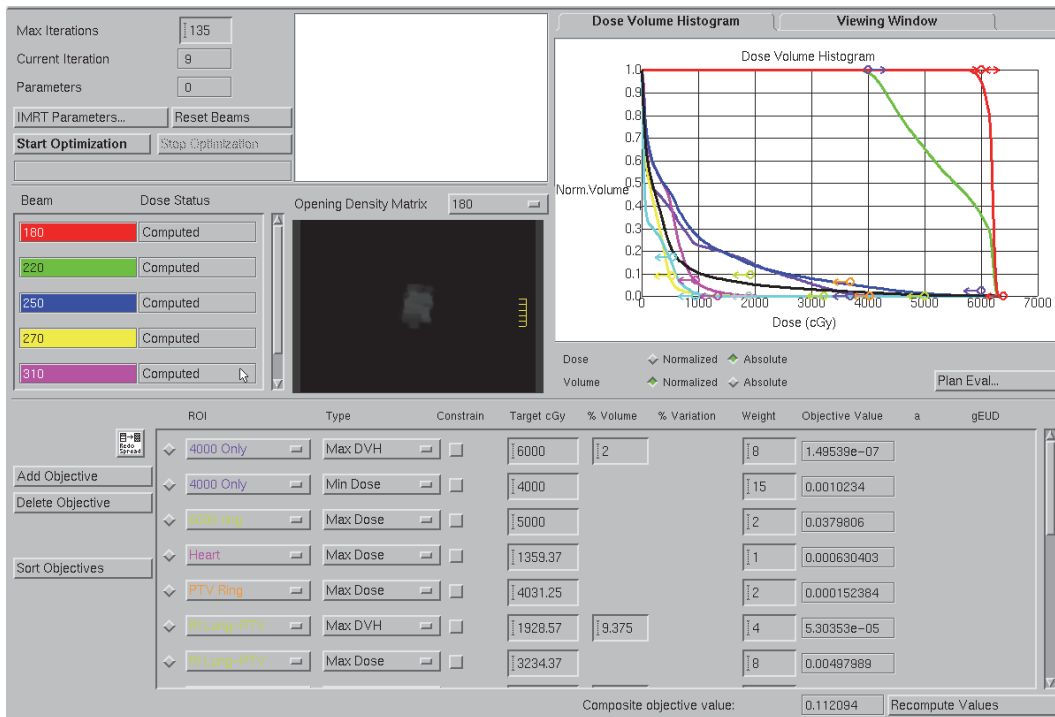


Figure 4.11 IMRT optimizer screen in Pinnacle.

a maximum number of segments equal to 10 times the field number.

- **Intensity modulation.** “MLC delivery” is selected if the machine will use MLC for delivery (Figure 4.10). Leave this option unchecked if using a compensator (less common nowadays).

4.4.1.3 Pinnacle Optimization Process

Pinnacle’s IMRT optimization process screen is shown in Figure 4.11 and features the following:

- **ODM** is a transmission filter used by the software to represent a matrix with the relative fluence of a modulated beam of radiation with respect to the intensity of an open field.
- **Objectives:**
 - Max dose**—accomplished when maximum dose = 0% of the target
 - Min dose**—accomplished when minimum dose = 100% of target
 - Max DVH**—accomplished when maximum DVH = specified percentage
 - Min DVH**—accomplished when minimum DVH= specified percentage
 - Uniform dose**—accomplished when the dose is uniform at specified dose

- **Constrain.** By checking this box, the system tries to accomplish the objective regardless of other objectives being met. One must be careful in using constraints since it might make the plan unable to go through optimization since it cannot meet too many conflicting constraints. Figure 4.12 shows a representation of minimum/maximum dose and minimum/maximum DVH point objectives.
- **Target (cGy).** The dose value in cGy for the objective for that particular ROI.

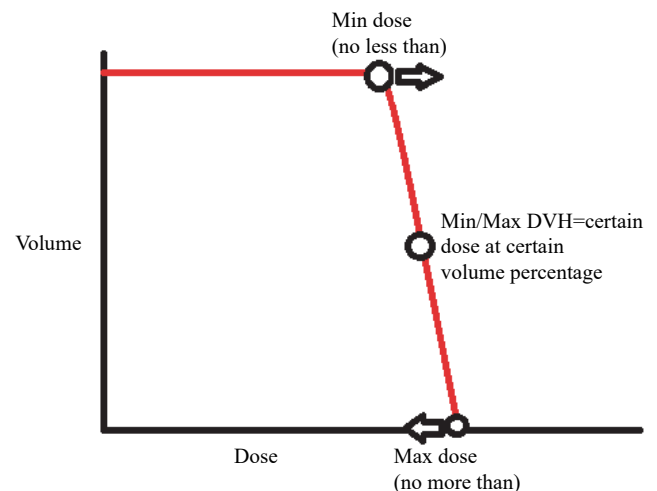


Figure 4.12 IMRT objectives.

- **% Volume.** Applicable to certain objectives only, usually “Max and Min DVH.”
- **% Variation.** Applicable to certain objectives only, usually “Uniformity.”
- **Weight.** On a scale from 1 to 100, this determines how much priority the planner would like the system to put into achieving a particular objective or constraint. Once set, they are all relative to each other.
- **Objective value.** This is the value of each objective function multiplied by its weight. The higher it is (compared with the others), the harder the system is working to accomplish that particular objective.
- **gEUD (available in some systems).** This stands for *generalized equivalent uniform dose value*.
- **a-value (or a-parameter).** This is available in some systems. This is a parameter used by the EUD model that controls hot or cold spots. Less than 1 is appropriate for targets. The smaller the a-value, the more sensitive to cold spots the computation becomes. The higher the value, the more sensitive to hot spots the calculation becomes, with a = 1 corresponding to the mean dose to the target.

4.4.2 Eclipse Optimization

4.4.2.1 Eclipse IMRT Parameters

Eclipse version 13 uses a separate optimizer for IMRT and VMAT (Figure 4.13) Both optimizers are accessible from the planning menu. The user can hover over the buttons to see a description of their function. Eclipse offers two main optimizers: PRO (Progressive Resolution Optimizer) and PO (Photon Optimizer). The options on the user interface are similar. There are a variety of studies comparing the two optimization algorithms, and users are encouraged to read Varian’s documentation on both optimizers. This book uses samples of the PRO optimizer only.

- **Load templates.** This option allows the planner to load, save, or manage optimization objective templates. These templates can be created from an ideal optimized plan to be used in future, similar cases.
- **Exclude structures.** This allows the planner to remove structures from the optimization window to simplify the display.
- **Use Normal Tissue Objective (NTO).** This enables the built-in dose fall-off objective in Eclipse. The distance from the target border defines the distance in cm from the target that the

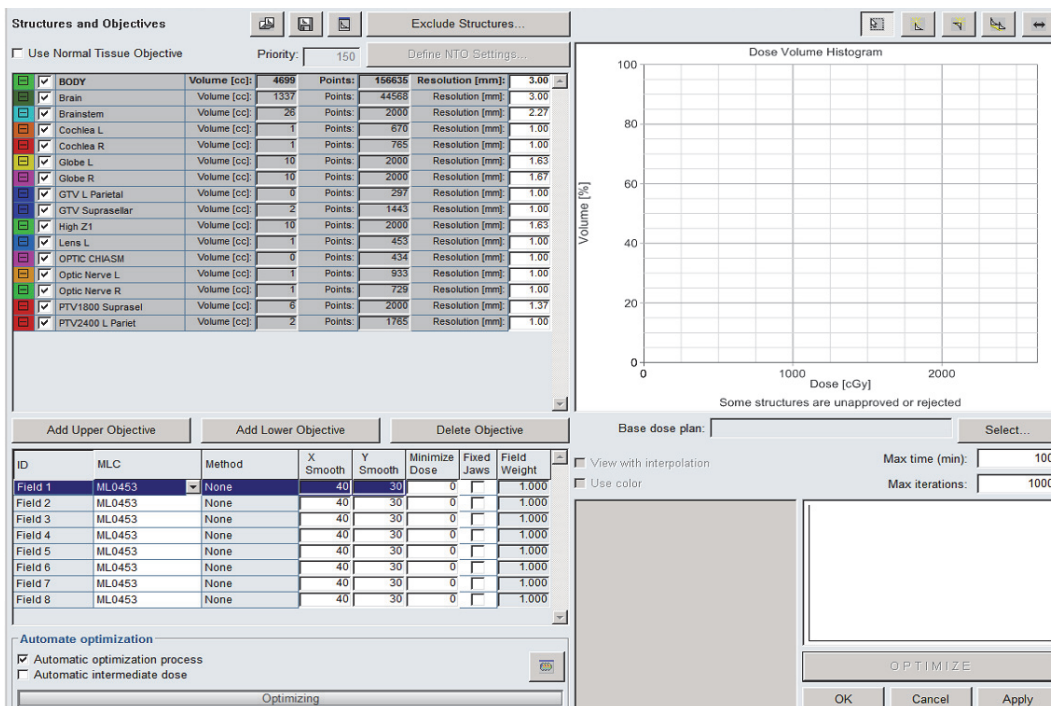


Figure 4.13 IMRT dose volume optimizer in Eclipse.

optimizer will start trying to achieve the objective (Figure 4.14). A common setting is 0.1 cm from the target with a start dose of 100% and an end dose of 60% to 50%, with a fall-off of 0.05 for standard fractionated treatments, or 0.15 to 0.2 for stereotactic cases where a steeper dose gradient is required.

NTO works very well for spherical or cylindrical targets and can frequently eliminate the need for ring optimization structures. In cases of irregular geometry or if NTO does not create an acceptable plan, rings can be created and used as an alternative without NTO enabled. The priority sets how hard the optimizer should work on a particular objective (defaulted to 150).

- **Objectives.** Upper or lower objectives can be added from the buttons in the top right of the optimizer window or the large labeled buttons below the structure list.

4.4.2.2 Eclipse VMAT Parameters

The VMAT optimizer window (Figure 4.15) is similar to the IMRT window with a few differences. This section will focus on explaining these settings.

- **Avoidance sectors.** This feature allows the user to define up to two lengths of arc per field where the

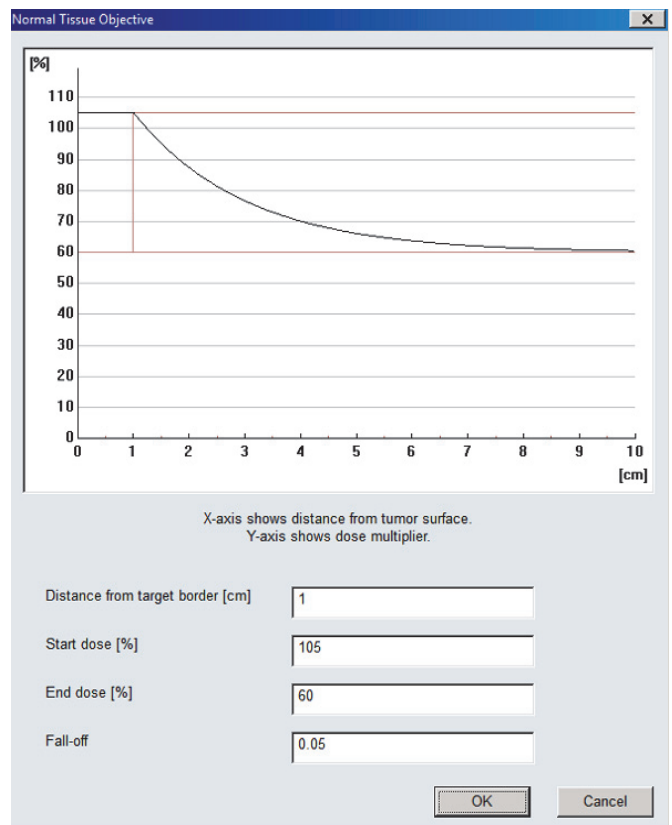


Figure 4.14 NTO settings. In this case, Eclipse will reduce dose starting at 1 cm out from the target and starting at 105% of the lowest maximum dose objective at a fall-off of 0.05.

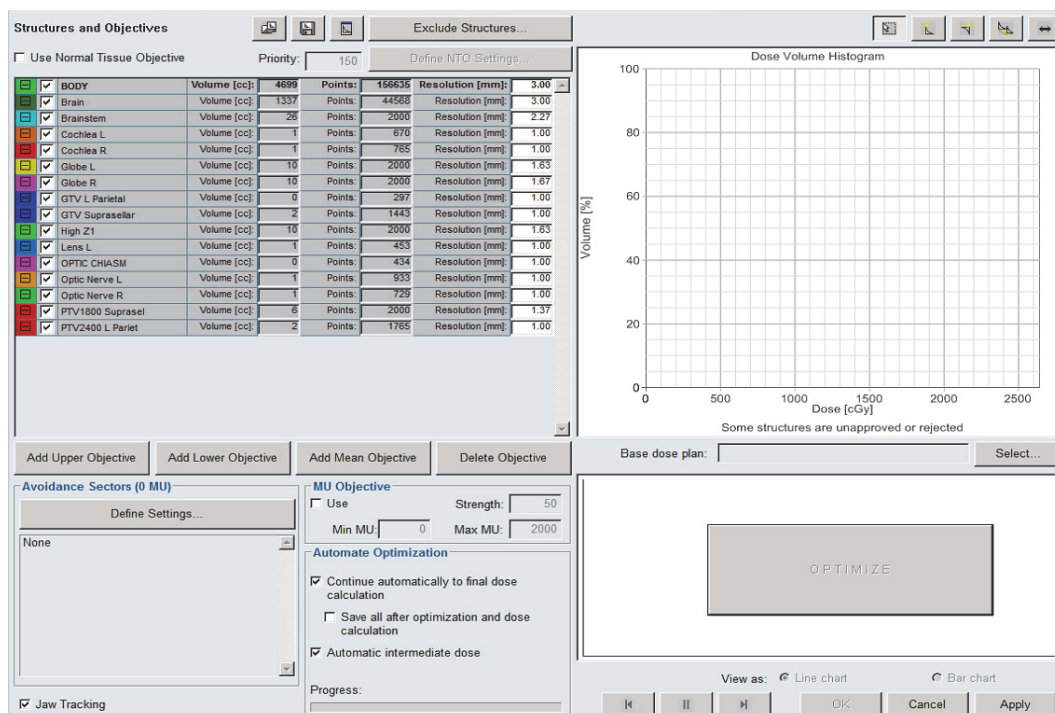


Figure 4.15 VMAT dose volume optimizer in Eclipse.

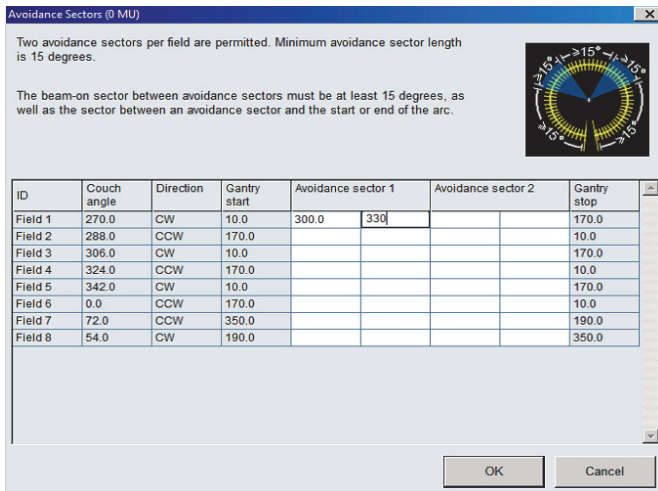


Figure 4.16 Settings for avoidance sectors.

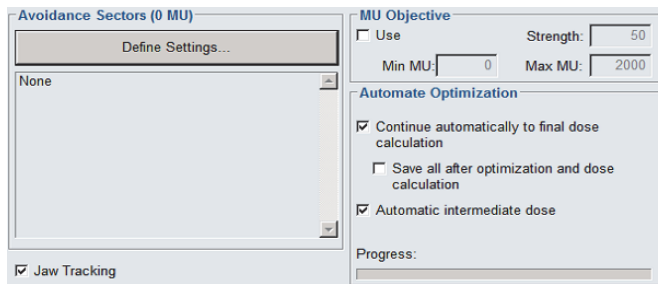


Figure 4.17 Additional VMAT settings.

treatment machine will hold the beam and deliver zero monitor units (Figure 4.16). This can be particularly useful if the planner is trying to avoid dose entering through a certain region, such as the arms or eyes of the patient.

- **MU objective.** This setting allows the user to assign a minimum and maximum number of monitor units to limit modulation for the plan. The strength sets how hard the planning system should work to achieve the limit MU.

- **Automate optimization.** All check boxes for the automate optimization options should also be checked to allow the optimizer to complete the process and save the plan without need for input from the user (Figure 4.17).
- **Optimization progress.** The bottom right-hand corner of the optimizer window can show either a line or bar chart during the optimization for the cost function, depicting how hard the optimizer is working on objectives for a given structure and other plan settings (Figure 4.18). The bottom options allow the user to progress through the optimizer and *machine resolution* (MR) levels or go backwards, if necessary, along with other basic optimizer controls.

4.4.2.3 Eclipse Optimization Process

Upon launching the IMRT optimizer in Eclipse version 13, the user can see the window shown in Figure 4.19 where the following options are offered:

- **Objectives.** Upper or lower objectives can be added from the buttons in the top right of the optimizer window or the large labeled buttons below the structure list. Additional options for displaying contours on the DVH can be displayed by right clicking in this window. The volume, number of points, and resolution (determined from the contour volume) are shown to the right of the contour name. Most of the options should be set based on user preference and to allow automation of the optimization process. While the IMRT and VMAT have slightly different options, including avoidance sectors, they share common optimization objectives (Figure 4.20):

Upper Objective—used to minimize dose to a relative volume; a volume of 0% indicates a maximum dose

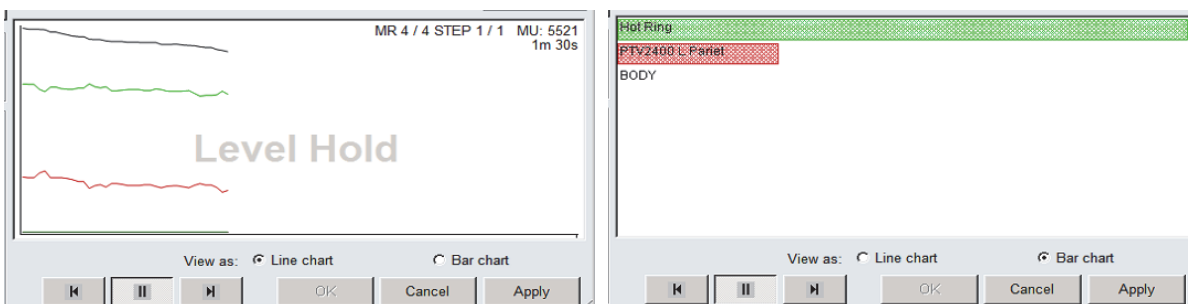


Figure 4.18 Optimization process view options.

Lower Objective—used to deliver a minimum dose to a relative volume; a volume of 100% indicates a minimum dose

Mean Objective—used to keep the mean dose value to that structure below the set value, only available on VMAT optimizations

- **Priority.** Assigns an importance to the associated objective. Values can be adjusted by the user from 1–1000, with a value of 1000 indicating the highest importance and 1 being the lowest. The NTO is set to 150 by default, so objectives are often scaled relative to NTO. Objectives with high importance can routinely be set to 250 and those with low importance to 50.
- **DVH display.** The sample objectives of Figure 4.20 can be seen in Figure 4.21 with the corresponding DVH display. The directions of the

arrows indicate upper or lower objectives, and vertical lines appear when the relative volume is set to 0% or 100%, respectively. Mean objectives are displayed as small diamonds, corresponding to the dose value.

- **Field parameters.** The selectable MLC dropdown (Figure 4.22) is predetermined based on the treatment machine. The X and Y smoothing gives a degree of smoothing to the dose in those directions with acceptable default values. Minimize dose is how much the planning system tries to limit the dose, with 0 being the ideal and default value. Fixed jaws can be selected if excessively large fields are causing an issue with the optimization process. Both options for automatic optimization should be checked to enable the planning system to proceed through the entire optimization

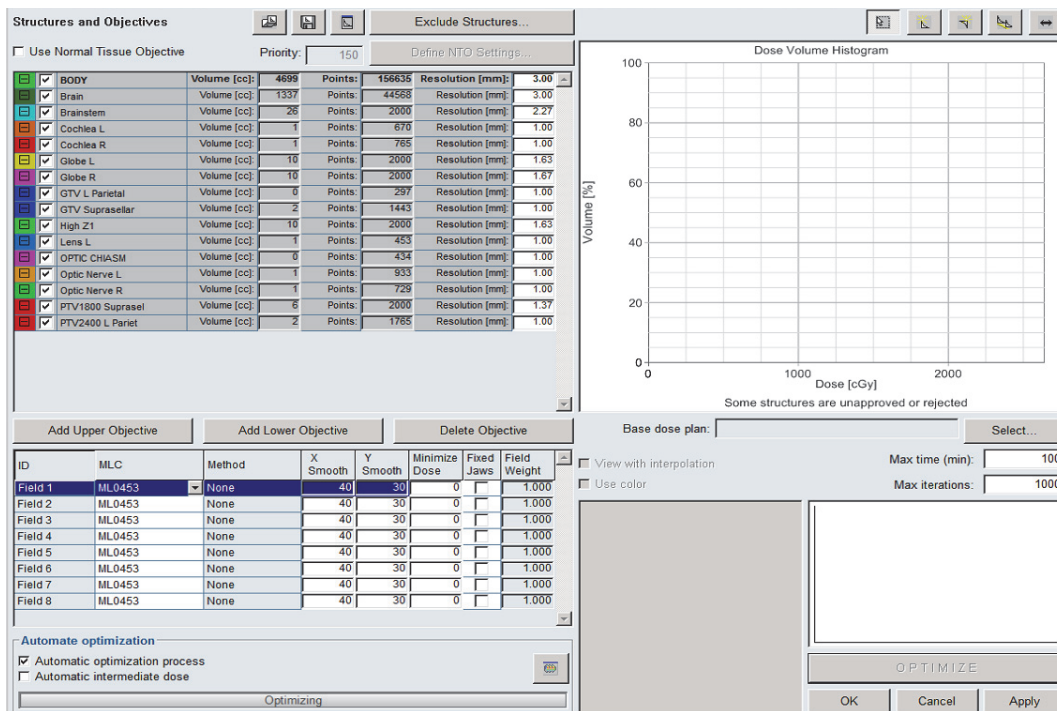


Figure 4.19 Eclipse optimization window.

<input checked="" type="checkbox"/>	Brainstem	Volume [cc]:	26	Points:	2000	Resolution [mm]:	2.27
	Upper	Volume [%]:	5.0	Dose [cGy]:	1500.0	Priority:	160
	Upper		30.0		500.0		160
<input checked="" type="checkbox"/>	PTV2400 L Pariet	Volume [cc]:	2	Points:	1765	Resolution [mm]:	1.00
	Upper	Volume [%]:	0.0	Dose [cGy]:	2600.0	Priority:	50
	Lower	Volume [%]:	100.0	Dose [cGy]:	2400.0	Priority:	50
	Mean			Dose [cGy]:	2500.0	Priority:	50

Figure 4.20 Objective sample in Eclipse.

process without the need for user input, and the bottom bar shows the optimization progress.

- **Optimization process and Fluence Display.** The maximum time is expressed in minutes and the number of iterations can be set here based on user preference (Figure 4.23). The default values of 100 minutes or 1000 iterations tends to be suffi-

cient as it is an upper maximum, and the optimizer typically does not run for the full length of time. However, if the user wants to complete the optimization within a given time frame, this setting can be reduced. The lower window shows how hard the optimizer is working on the colored structure, and the general options for the optimization process are below.

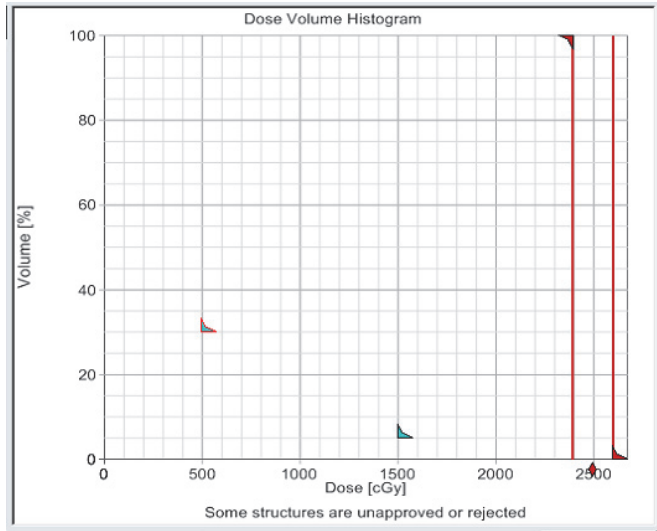


Figure 4.21 DVH display with objective points.

ID	MLC	Method	X Smooth	Y Smooth	Minimize Dose	Fixed Jaws	Field Weight
Field 1	ML0453	None	40	30	0	<input type="checkbox"/>	1.000
Field 2	ML0453	None	40	30	0	<input type="checkbox"/>	1.000
Field 3	ML0453	None	40	30	0	<input type="checkbox"/>	1.000
Field 4	ML0453	None	40	30	0	<input type="checkbox"/>	1.000
Field 5	ML0453	None	40	30	0	<input type="checkbox"/>	1.000
Field 6	ML0453	None	40	30	0	<input type="checkbox"/>	1.000
Field 7	ML0453	None	40	30	0	<input type="checkbox"/>	1.000
Field 8	ML0453	None	40	30	0	<input type="checkbox"/>	1.000

Automate optimization

Automatic optimization process

Automatic intermediate dose

Optimizing Intermediate dose Optimizing

Figure 4.22 Field parameters section.

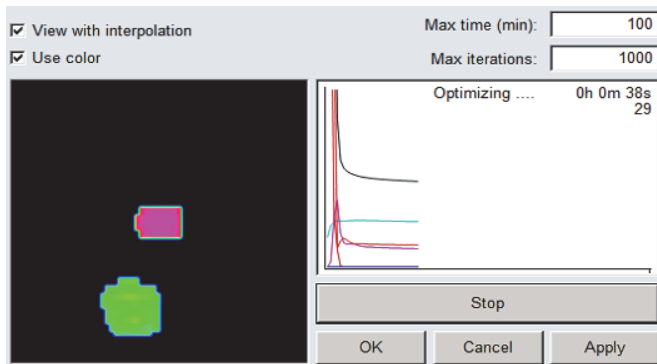


Figure 4.23 Optimization process and fluence display.

4.4.3 RayStation Optimization

4.4.3.1 RayStation IMRT Parameters

The IMRT optimization type can be selected for RayStation version 6 in the Plan Design window under the Photons modality (Figure 4.24). The TPS is able to optimize step-and-shoot (SMLC) and sliding window plans (DMLC), but the delivery depends on machine capabilities. The planner can review the Pinnacle optimization guide, since most parameters are similar.

- **Optimization tolerance.** This is the objective value at which the software will stop working on achieving a certain objective because it is considered achieved or it is not possible to achieve.
- **Max number of iterations.** This sets up the maximum number of times the software refines the plan. The user is free to choose the number of iterations, but it is important to keep in mind that choosing a low value may not give the system enough iterations to achieve the best optimization results, while a high value increases the computation time.
- **Iterations before conversion.** This establishes the number of iterations before computing the convolution dose and converting the plan to MLC segments (the real deliverable plan). For example, for 75 iterations, the convolution dose iteration in the iteration field is set to 15–20.
- **Compute intermediate dose.** This box should be checked to allow automatic conversion and for most of the optimization process to proceed automatically.
- **Compute final dose.** This box should be checked to allow final dose computation using the collapsed cone convolution algorithm.
- **Max number of segments.** This refers to the number of control points per plan.
- **Min segment area.** This is the open area of control points or beamlets. It can be used to prevent

the optimizer from creating very small, unpractical control points. The default of 4 cm² is often sufficient.

- **Min segment MU per fraction.** The minimum number of monitor units a control point can deliver.
- **Min number of open leaf pairs.** The minimum number of leaf pairs that must be open for a control point.
- **Min leaf end separation.** The minimum distance between two leaf ends.
- **Max number of control points per beam (DMLC only).** This is similar to the max number of seg-

ments, but a sliding window needs many more to create an acceptable plan. The user can edit this field as necessary, but the default of 100 tends to be sufficient.

- **Exclude.** Allows the user to exclude select beams from the optimization process (Figure 4.25).
- **Segment shapes.** Allows the system to determine the optimal segment shapes.
- **Segment MU.** Allows the system to determine the optimal weight for the segment MU.
- **Beam MU.** If control points and segment MU have already been created, the Beam MU box can be checked to optimize beam weights.

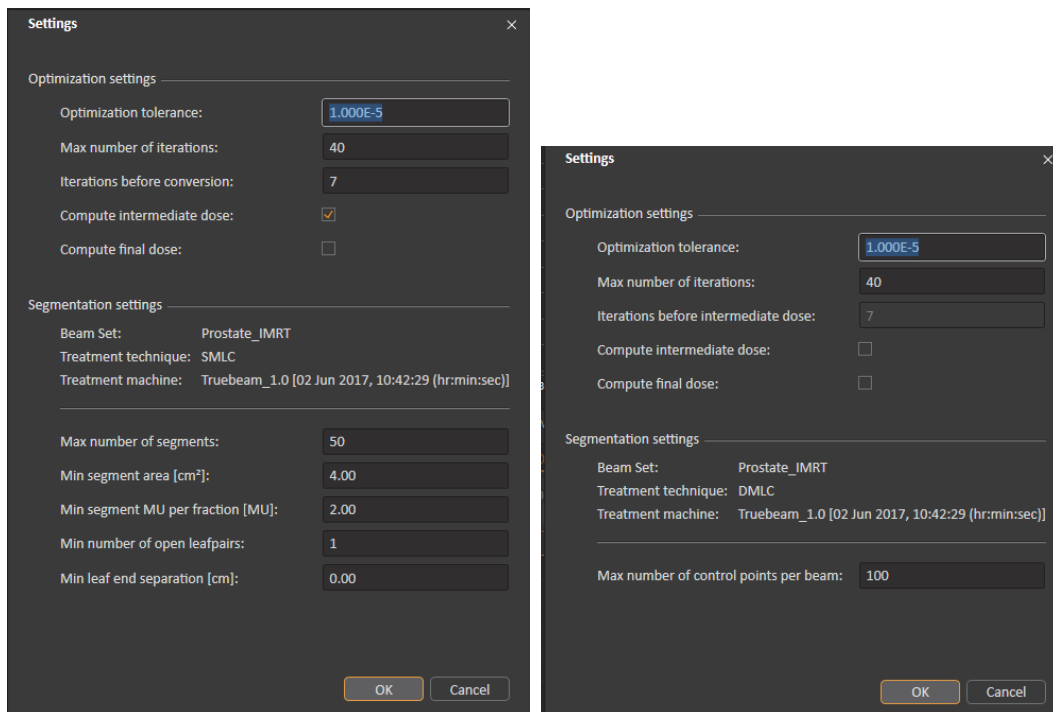


Figure 4.24 Optimization settings for SMLC (left) and DMLC (right).

No.	Name	<input type="checkbox"/> Exclude	Beam Optimization Settings				Jaw assignment	Jaw limits [cm Non-IEC]			
			<input checked="" type="checkbox"/> Segment shapes	<input checked="" type="checkbox"/> Segment MU	<input type="checkbox"/> Beam MU	<input checked="" type="checkbox"/> Split if necessary		X1	X2	Y1	Y2
1	200	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
2	240	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
3	280	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
4	320	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
5	0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
6	40	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
7	80	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
8	120	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
9	160	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Automatic	-	-	-	-

Figure 4.25 Beam optimization settings for SMLC.

No.	Name	<input checked="" type="checkbox"/> Split if necessary	Jaw assignment	Jaw limits [cm Non-IEC]			
				X1	X2	Y1	Y2
1	200	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
2	240	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
3	280	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
4	320	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
5	0	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
6	40	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
7	80	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
8	120	<input checked="" type="checkbox"/>	Automatic	-	-	-	-
9	160	<input checked="" type="checkbox"/>	Automatic	-	-	-	-

Figure 4.26 Beam optimization settings for DMLC.

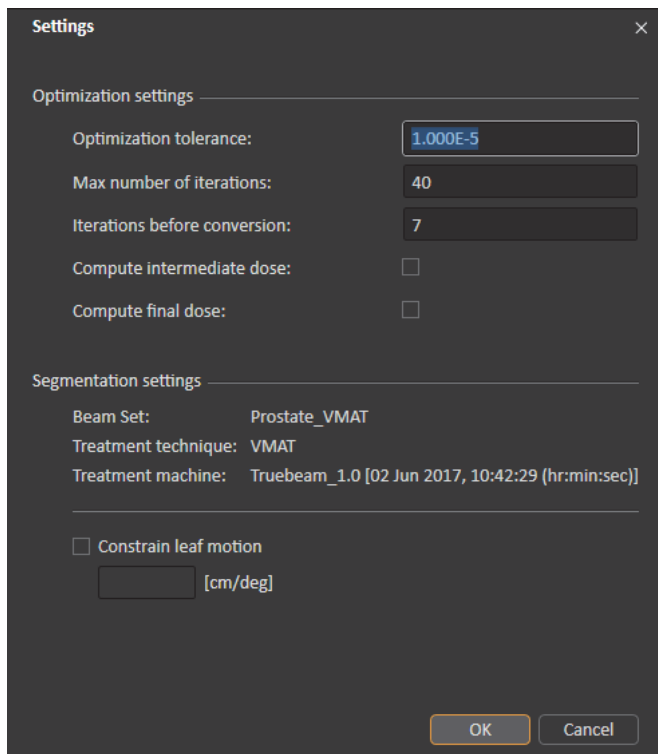


Figure 4.27 VMAT optimization settings.

- **Split if necessary.** If the optimizer created control points that are too wide to avoid open leaves in the field, “split if necessary” can be selected to split the control points and jaw assignment to allow sufficient modulation of the entire field width (Figure 4.26).
- **Jaw assignment.** This can be set to automatic, which allows the optimizer to determine the best jaw positions to limit leakage from the leaves, or to use limits as max if there is a wide field and the user does not want jaw positions larger than a fixed limit.

4.4.3.2 RayStation VMAT Parameters

The VMAT optimization type can be selected for RayStation version 6 in the Plan Design window under the Photons modality (Figure 4.27).

Most options work identically to those found in the IMRT settings window (refer to Section 4.4.3.1).

- **Constrain leaf motion.** This value should be entered based on the physical limitations of the treatment machine. It can also be set by default in the physics module of the planning system.
- **Create Dual Arcs.** If this option is checked, the optimizer will automatically create another arc of the same length going the opposite direction. This can be checked to minimize set-up by the planner and allow for more modulation of the field (Figure 4.28).
- **Gantry spacing.** This is the spacing in degrees between control points. Entering a gantry spacing of 4 degrees will create a new control point every 4 degrees.
- **Max deliver time.** This is the maximum delivery time for a particular arc.
- **Limit MU and Max MU/fx.** This is used to limit the total number of monitor units to either decrease modulation or to help decrease treatment time. This option can also be used to create an approximate conformal arc plan using VMAT.

4.4.3.3 RayStation Optimization Process

Options and buttons for controlling or evaluating the optimization are located at the top of the optimizer window screen (Figure 4.29). The user can see the DVH, the clinical goals with physician-set dose objectives, the dose statistics for the visible contours, or a 2D view of the dose distribution. The top right can be set as a 2D view of the dose distribution, BEV (beam’s-eye view), or 3D dose cloud or visualization of the structure set. The bottom left is currently selected to show the objectives/constraints, but it can also be set to any of the other options for editing beam parameters. During the optimization process, the progress can be viewed in the bottom right hand corner with the function values versus iteration number.

Optimization objectives (Figure 4.30) can be selected and configured.

- **Optimization objectives:**

Min dose—used to deliver a minimum dose, dose to 100% of contour

No.	Name	Exclude	Segment shapes	Segment MU	Jaw assignment	Jaw limits [cm Non-IEC]	Create dual arcs	Gantry spacing [deg]	Max del. time [sec]	Limit MU Apply	Max MU/tx
1	G181-179CW	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Automatic	- - - -	<input type="checkbox"/>	4.00	90.00	<input type="checkbox"/>	-
2	G179-181CCW	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Automatic	- - - -	<input type="checkbox"/>	4.00	90.00	<input type="checkbox"/>	-

Figure 4.28 Beam optimization settings for VMAT.

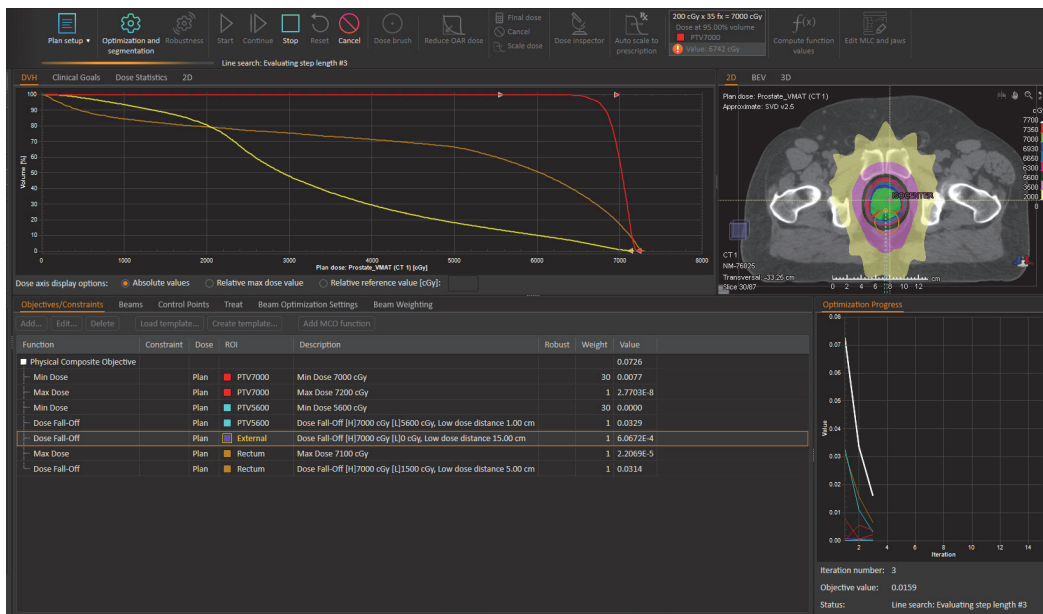


Figure 4.29 Optimizer window in RayStation.

Max dose—used to limit maximum dose, dose to 0% of the contour

Min DVH—used to deliver a minimum dose to a relative volume of a contour

Max DVH—used to minimize a set dose to a relative volume of the contour

Uniform dose—sets a min and max dose for a given contour to deliver a uniform dose

Min EUD—Uses an “a” value of less than or equal to 1. $a=1$ defines a mean dose, giving cold and hot spots equal weighting; $a<1$ gives lower doses a higher weight and more importance to cold spots, approaching a min dose as a approaches negative infinity.

Max EUD—Uses an “a” value of greater than or equal to 1. $a=1$ defines a mean dose, giving cold and hot spots equal weighting; $a>1$ gives higher dose more importance and approaches a max dose as a approaches infinity.

Target EUD—Pushes to achieve an EUD for the given A value.

Dose Fall-Off—Can be applied to OARs or targets. Allows the max dose level to fall-off linearly at the dose distance from target. Can be selected to adapt to target dose levels for the dose level of each target volume.

Uniformity Constraint—Can be applied to OARs or targets. Sets the variation of dose within the ROI.

a-parameter (for min and max EUD)—This is a biological parameter used by the EUD model that controls hot or cold spots. Less than 1 is appropriate for targets. The smaller the “a” value, the more sensitive to cold spots the computation becomes, approaching a minimum dose. An “a” value equal to or more

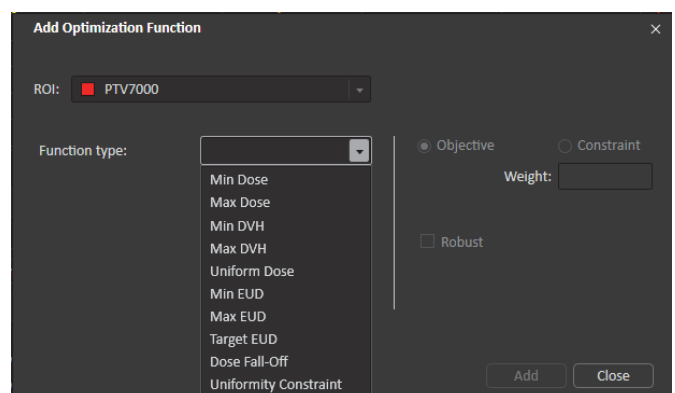


Figure 4.30 RayStation’s Add Optimization window.

than 1 is more applicable to critical structures. The higher the value, the more sensitive to hot spots the calculation becomes, approaching a maximum dose. $a=1$ corresponds to the mean dose to the target.

- **Robustness.** This can be set to allow for variability in setup or tumor motion. Robustness allows the user to set a direction and magnitude for an ROI's positional uncertainty and optimize the plan to account for it.

RayStation also includes functions such as Reduce OAR Dose and the Dose Brush to further edit isodose volumes or automatically reduce dose to OAR structures. These advanced functions and Multi-Criteria Optimization can be explored using the user manual and trial and error (if those licenses are purchased) to allow the user to gain experience.

4.4.4 Basic Guidelines for Optimization

The following is an overview of how to start the optimization process. The user can opt for an initial optimization for target coverage purposes only and then include other structures during subsequent optimizations. The weight indicates how much the system will work on a particular objective, which is indicated on the objective value. The higher the value, the harder the work to obtain what the parameter asks for.

After the first optimization, the planner can increase the number of parameters and change existing parameters having an idea of what the DVH looks like. This process might take several repetitions until the desired isodose distribution is achieved.

4.4.4.1 The First Optimization

These are general guidelines on the objectives to introduce into the planning system for the first optimization. After the first dose distribution, these objectives can be modified, and more can be added to limit the doses in each area (contour).

Generally, check all beam parameters that can affect optimization or the final result:

- No collimators are at 0 degrees in VMAT arcs.
- No IMRT fields are directly opposing each other.
- In cases of step-and-shoot IMRT cases, make sure that there is an acceptable number of control points set up for the optimization to take place.

Plans that require more modulation (irregular or unusual target shapes, targets close to critical organs, or targets with several dose levels) can be set up to have more con-

trol points than what is set up by the institution. As an example, one could set up 50 control points per plan. This number can be increased to higher values, such as 75, 80, 90, 100, 110, 120, etc. Too many control points can result in very long treatment times with little or no dosimetric benefit.

General checks before optimizing could include:

- The correct beam isocenter location is selected.
- The correct machine is selected for optimization in case the center has more than one machine.
- The appropriate beam energy and beam parameters are entered, such as gantry and collimator settings.
- The appropriate jaw is specified.
- The dose grid is drawn correctly with the right resolution for the case (usually matching CT slice thickness).
- The correct prescription is entered on the system.
- The target, organs at risk, and optimization contours are drawn correctly.

Sample objectives for the first optimization are:

- Targets = minimum dose set to prescription, min DVH set to prescription covering 95% of target, and maximum dose set to 110% as a starting point.
- Use of NTO or rings (described below).
- Ring (separating dose levels) = maximum dose of a value halfway between the two dose levels it separates.
- PTV ring (the ring immediately outside PTV) = maximum dose value equivalent of slightly less than the PTV prescription.
- Body ring (a ring made of the body or external contour and its contraction by 2 to 3 cm) = maximum dose of 50% of high dose region prescription.
- Organs at risk = work according to dose tolerances for the case.
- The weights could be left at 1 for the first optimization so the system can work with the inherent objective values. The user can also opt for changing the weights as well. One could place more weight for coverage on min dose or min DVH objectives for targets at first optimization.

After the first optimization, make sure the dose is normalized correctly. Additional and current objectives may be added or modified.

4.4.4.2 Objectives to be Added After the First Optimization

Look at the DVH and dose distribution on the CT dataset, and ask the following questions:

- Are all OARs being taken into consideration?
- Does a dose in the target need to be uniform?
- Is the target meeting the right hot spot?
- Is the hot spot inside the GTV contour?
- Is significant dose leaking from the PTV into healthy tissue? Add more weight into the max dose objective of the PTV ring as well as decrease the dose or modify the NTO objective.
- Are there streaks going on the outside of the body? If so, check the NTO or the body ring and add additional max DVH objectives.

4.4.5 Introductory Case: A Lung Lesion IMRT

Now let's put all of our optimization tools and understandings to work on a sample case. The lesion to treat is on the right lung (Figure 4.31). There are two PTVs:

1. PTV 6000 (inner red PTV) and
2. PTV 4000 (green outer PTV).

The PTV 6000 is prescribed 6000 cGy in 5 fractions, while the PTV 4000 is prescribed 4000 cGy in 5 fractions.

The PTV 4000 contour contains the PTV 6000 contour, so they will need to be subtracted from one another for optimization. For this case, organs at risk include the lungs, the spinal cord, and the heart.

Since the lesion is located at one side of the thoracic cavity only, the placement of the beams is such that minimum irradiation is delivered to healthy tissue. A typical beam placement of 360 degrees around the patient is not recommended in this case since the lesion is not in a central location. This even beam placement would not yield a good dose distribution, and it might also lead to gantry table collisions during treatment given the position of the isocenter and machine limitations.

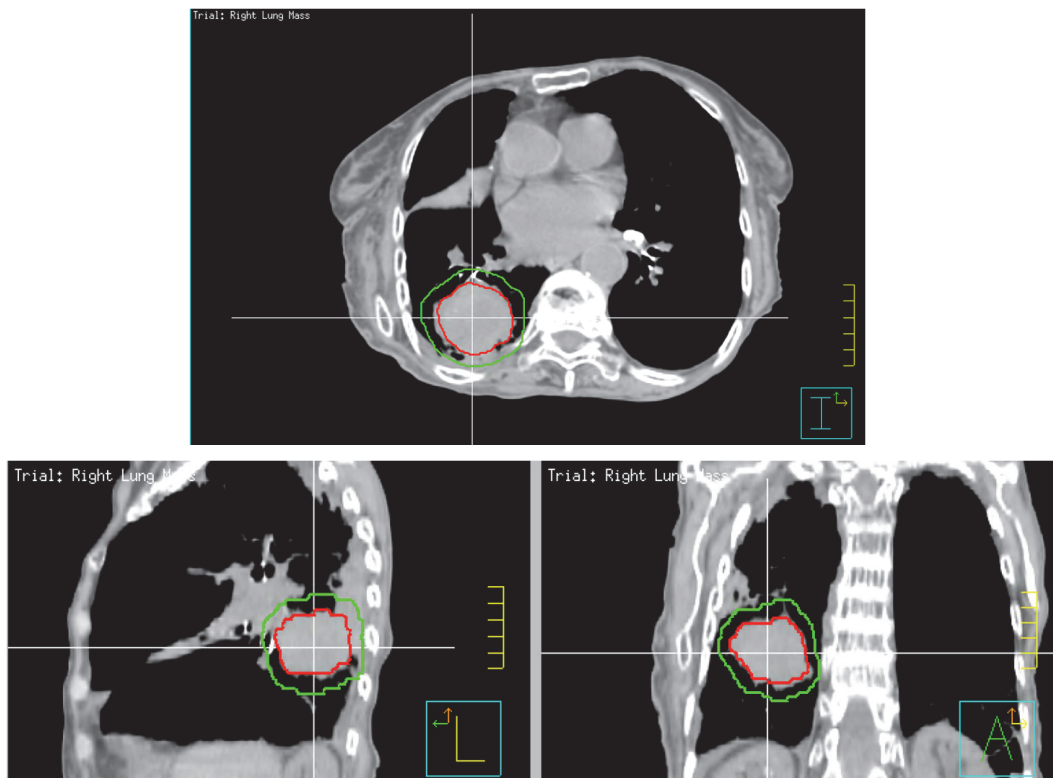


Figure 4.31 Contours of PTV 6000 (red) and PTV 4000 (green).

For this lesion, a nonstandard six-beam placement has been chosen (Figure 4.32). The beams have been placed in a way such that the lesion can receive dose from almost all possible sides, while trying to avoid the organs at risk (spinal cord, heart, and lungs). A sufficient number of control points per plan is also an important parameter to assure a good dose distribution. In this case, the final plan contains 90 control points.

The “dose painting” process starts with a series of contours to control the dose distribution.

1. **Separating dose levels.** In this case, the contour PTV 4000 contains PTV 6000 inside. If one optimizes PTV 4000 to have a dose distribution of 4000 cGy, the planning system will not be able to achieve this objective since PTV 6000 will try to achieve 6000 cGy within the same PTV 4000 contour. In this case, the purple contour is “4000 cGy only” (Figure 4.33), which excludes the PTV 6000 contour. The PTV 6000 contour is left

alone since it does not have any conflicts with other dose levels. The ring can also have a 2-mm margin around the high-region PTV to help with dose fall-off, or the user can opt for a thin ring between the two dose levels.

2. **Rings.** A ring around the target can separate the lesion to be treated from healthy tissue. It provides the sufficient dose fall-off between these structures. These rings can have a thickness of 1 to 2 cm. In this case, the PTV ring (orange in Figure 4.34) has a thickness of 1 cm. An additional 2-mm margin from the target can help in dose fall-off from the target to the ring without significant optimizer penalties.

Inner PTV rings are necessary when dealing with several dose levels in a target. In this case, a ring for the PTV 6000 with a thickness of 0.25 cm (the yellow contour in Figure 4.35) was made to help the dose change from 6000 cGy to 4000 cGy. To facilitate optimization, this structure should not overlap other structures. In this

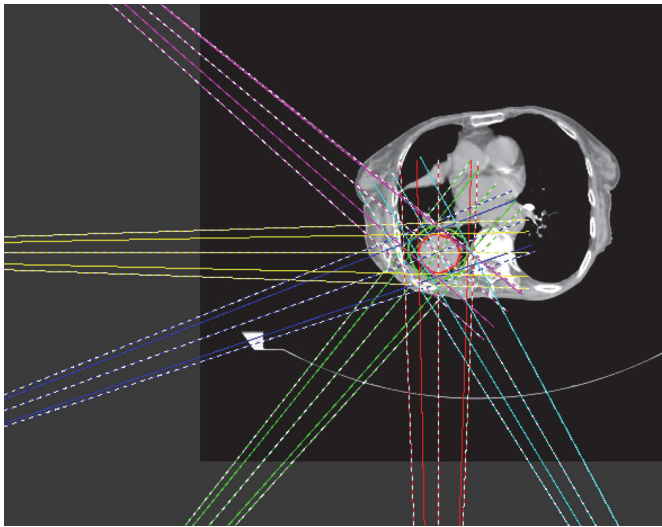


Figure 4.32 IMRT beam arrangement.

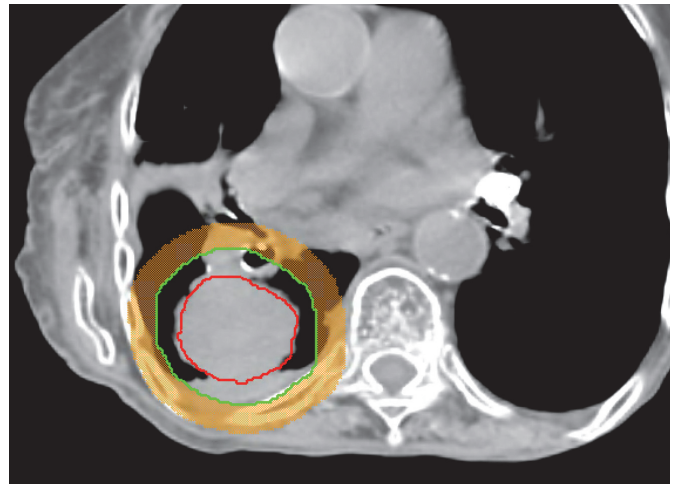


Figure 4.34 PTV ring (orange colorwash).

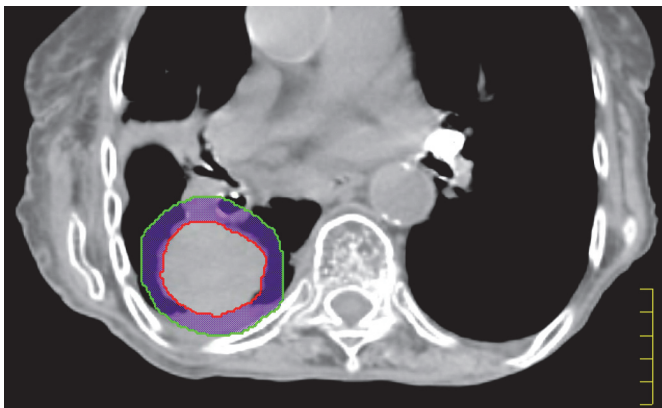


Figure 4.33 Contours of PTV that contain 4000 cGy (purple colorwash).

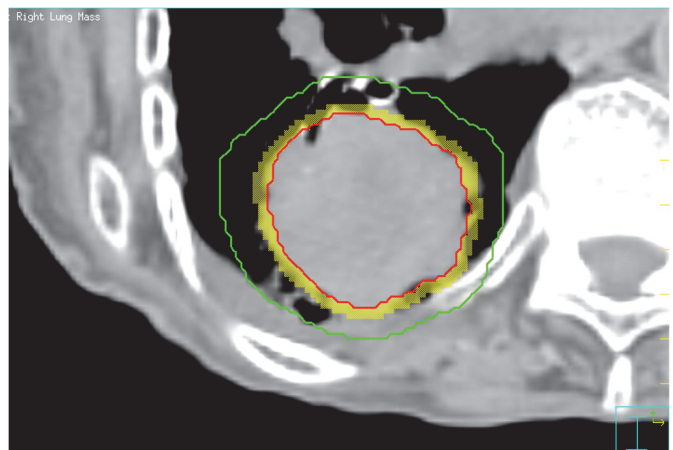


Figure 4.35 Inner PTV ring (yellow colorwash).

case, the PTV 4000 optimization structure could have a margin away from the PTV 6000 structure.

A ring for fall-off dose must be used during optimization to avoid low-dose streaks at the outer borders of the body in case the optimizer does not have an NTO option. This type of structure can be 2 to 3 cm thick and should only cover a few centimeters above and below

the target (Figure 4.36). This structure is made from the external or body contour.

3. **Contours made while optimizing.** During the optimization process, if modifying and adding constraints to the organs at risk and the contours previously reviewed do not deliver an appropriate dose distribution, one of the possible solutions is to contour the problem

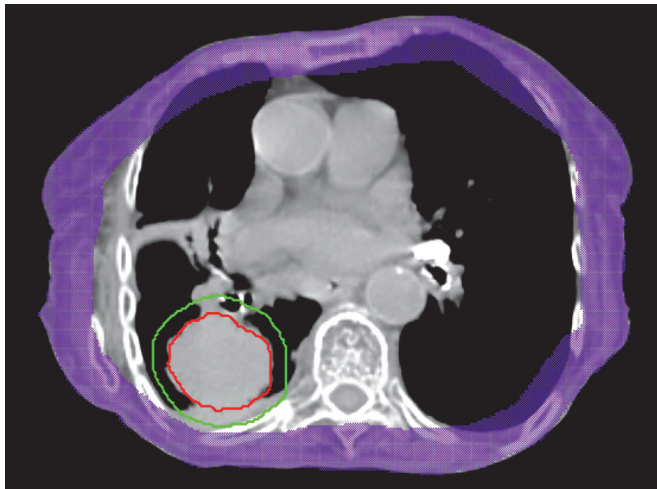


Figure 4.36 Body ring (purple colorwash).

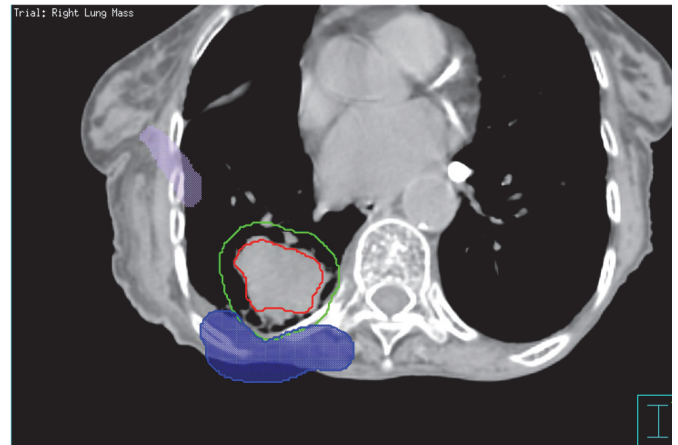


Figure 4.37 Additional optimization contours.

ROI	Type	Constrain	Target cGy	% Volume	% Variation	Weight	Objective Value	a	gEUD
4000 Only	Max DVH		6000	2		8	1.49539e-07		
4000 Only	Min Dose		4000			15	0.0010234		
6000 ring	Max Dose		5000			2	0.0379806		
Chest wall	Max Dose		3700			25	0.000787747		
Heart	Max DVH		953.125	7.0312		5	0		
Heart	Max Dose		1359.37			1	0.000630403		
R Lung	Max DVH		531.25	8.5938		2	0		
PTV Ring	Max DVH		3703.12	5.8594		10	0.00109122		
PTV Ring	Max Dose		4031.25			2	0.000152384		
PTV Ring	Max Dose		4031.25			2	0.000152384		
Rt Lung-PTV	Max DVH		1928.57	9.375		4	5.30353e-05		
Rt Lung-PTV	Max Dose		3234.37			8	0.00497989		
SC	Max DVH		546.875	17.1875		1	0		
SC	Max Dose		953.125			1	0.000176379		
	Max Dose		1900			7	0.000521762		
lung PTV6000	Max Dose		6400			3	0		
lung PTV6000	Min Dose		6000			15	0.000557886		
lung PTV6000	Uniform Dose		6000			55	0.0599015		
spill	Max Dose		3700			15	0.00423808		

Figure 4.38 Optimization parameters for this sample

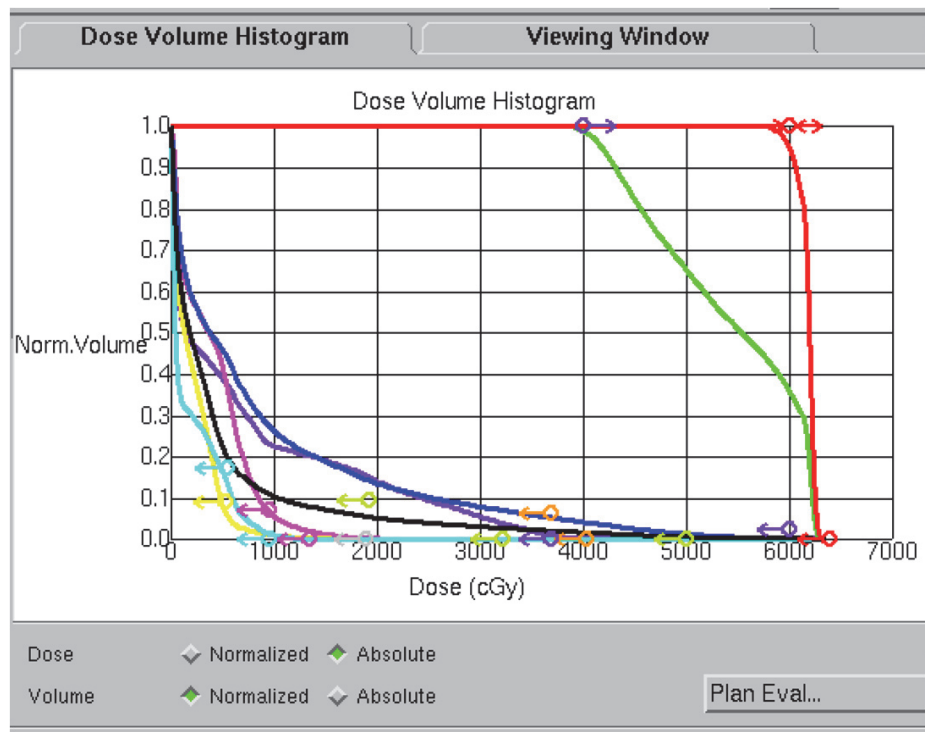


Figure 4.39 DVH in optimization window.

areas and assign them to the optimizer for dose modulation.

In this example, the light purple contour (Figure 4.37) represents a low-dose spill, while the blue contour attempts to fix a dose spill (4000 cGy out of PTV 4000).

4. **Optimization.** For the FIRST optimization, one might choose the following parameters:

PTV 6000 = minimum dose 6000 cGy for good target coverage

PTV 6000 = minimum DVH of 6000 cGy to 95% of the target with greater weight than the minimum dose objective

PTV 6000 = maximum dose to 108% or 110% to reduce hot spots within the target

PTV 4000 only = minimum dose 4000 cGy for that contour coverage

PTV 4000 only = minimum DVH of 4000 cGy to 95% of the target with greater weight than the minimum dose objective

PTV 4000 only = maximum dose of 6000 cGy to avoid dose from the high dose region

PTV 6000 RING = maximum dose of 5000 cGy (usually, a value half way between the two dose levels)

PTV 6000 RING = Instead of maximum dose, one can limit the dose to the desired value to 5% of the volume

PTV RING = maximum dose of 3900 cGy or 4000 cGy to start

Body RING = maximum dose of 50% of high dose region prescription

Organs at risk = maximum dose 50% of high-dose region prescription or work according to dose tolerances used

For example, the optimization process in Pinnacle 9.8 can be found under the IMRT tab. Figure 4.38 shows a sample list of all final objectives.

The “weight” is a way to prioritize certain objectives. The higher the value, the more the system will work on achieving the objective. “Objective Value” shows how much the system will actually work on the objective to meet its criteria. Higher values represent more work toward the objective, while a value close to 0 represents accomplishment or simply an unrealistic objective the system cannot meet (not a high priority on weight, too).

Each constraint can be visualized on the DVH (Figure 4.39) as an arrow that indicates where dose will be directed at that point.