PHILIPS

Pinnacle³

P³IMRT

Instructions for Use

Release 16.2 (English)

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Medical Device Directive
Pinnacle³ Radiation Therapy Planning
System is CE Marked to the Medical
Device Directive 93/42/EEC.

$C\epsilon_{0086}$

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Device Description

The Pinnacle³® Radiation Therapy Planning (RTP) software is composed of several modules including the core Pinnacle³ functionality, Syntegra™, P³IMRT®, P³MD®, and AcQSim³™. The Pinnacle³ RTP software runs on a Solaris UNIX (or UNIX compliant) computer, which allows qualified medical personnel to enter patient data into the system, use that data to construct a plan for radiation therapy, and evaluate the plan. Optionally, the qualified medical personnel may output the plan in an electronic or printed form for use by other systems in the delivery of treatment to a patient.

Pinnacle³ includes networking capabilities to provide connectivity to other Pinnacle³, Syntegra, PC Access Point (remote planning), P³MD, AcQSim³, or P³IMRT workstations, input devices and output devices, as well as access to the Pinnacle³ database from any Pinnacle³ workstation available on the network. The system can be run from a single workstation but has network capability to other Pinnacle³ workstations and to both input and output devices via local area network (LAN) or wide area network (WAN). The Pinnacle³ RTP System also has an enterprise configuration for larger sites requiring a centralized data center environment. This system consists of one or multiple rack mountable servers on which Pinnacle³ sessions run which enables display on any network accessible computer.

Installation instructions appear on the DVD insert included with the software DVD. You only need to load the software on the systems designated as the servers at your site.

To enable use of the software, a licensing key must be issued by a Customer Support representative or your local distributor. You may contact Customer Support at 1-800-722-9377 (US and Canada) or your local distributor for assistance with installation or licensing.

Intended Use

Pinnacle³ Radiation Therapy Planning System is a software package intended to provide planning support for the treatment of disease processes, utilizing photon, proton, electron and brachytherapy techniques.

Indications for Use

Pinnacle³ Radiation Therapy Planning System is a software package intended to provide planning support for the treatment of disease processes. Pinnacle³ Radiation Therapy Planning System incorporates a number of fully integrated subsystems, including Pinnacle³ Proton, which supports proton therapy planning. The full Pinnacle³ Radiation Therapy Planning System software package provides planning support for the treatment of disease processes, utilizing photon, proton, electron and brachytherapy techniques.

Pinnacle³ Radiation Therapy Planning System assists the clinician in formulating a treatment plan that maximizes the dose to the treatment volume while minimizing the dose to the surrounding normal tissues. The system is capable of operating in both the forward planning and inverse planning modes. Plans generated using this system are used in the determination of the course of a patient's radiation treatment. They are to be evaluated, modified and implemented by qualified medical personnel.

Contraindications

There are no known contraindications regarding the use of the Pinnacle³ RTP system.

Intended Audience

This manual is written for qualified medical personnel trained as users of Pinnacle³ RTP systems. You should make sure that you have thoroughly read and completely understand the manuals and release notes that are delivered with the software. Keep this manual and all other manuals delivered with the software near your Pinnacle³ system and review them periodically. The initial installation procedure will be performed by a Field Service Engineer. If you suspect that your system has an error, discontinue its use and contact Customer Support or your local distributor.

⚠ **General Device Warnings**

Do not load non-system software onto the computer used by this system without the direct authorization of Philips Medical Systems. Feature performance and safety may be compromised.

To assure proper treatment, it is critical that a qualified medical person review and verify all system treatment plan parameters using an independent verification method prior to treating patients using the plan.

We recommend that you review TG40, TG53, and other pertinent radiation therapy treatment standards and incorporate those methods into your clinical practice to ensure that your use of the system results in the most accurate treatment plans. TG40, TG53, and other reports are available publicly at the American Association of Physicists in Medicine (AAPM) website.

- **Comprehensive QA for radiation oncology: Report of AAPM Radiation Therapy Committee Task Group 40.** *Medical Physics* **21(4), 1994.**
- **American Association of Physicists in Medicine Radiation Therapy Committee Task Group 53: Quality assurance for clinical radiotherapy treatment planning.** *Medical Physics* **25(10), 1998.**

The following clinical practices are recommended to verify the accuracy of each treatment plan:

- **An independent calculation of the monitor units for each beam of a plan and treatment time for each brachytherapy plan.**
- **Acquisition and review of portal images or review of multi-leaf collimator (MLC) leaf positions after import to the treatment system.**
- **A chart check prior to the plan being delivered or during the first week of treatment.**
- **Independent review of the treatment plan prior to the delivery.**
- **Cross-functional review of the plan in a weekly chart round.**
- **Manual verification of record and verify settings after transfer to the treatment machine.**
- **Verification of the SSD and field shape during patient setup.**

These reviews should be performed for a new plan or when a change is made to any component of a plan.

U.S.A. law: CAUTION: Federal law restricts this device to sale by or on the order of a physician.

Only qualified medical personnel should operate the system. New personnel should receive training prior to unsupervised operation of the system. For more information, contact Customer Support or your local distributor.

Serious injury to patients can result due to the misapplication of this product. Make sure that you thoroughly understand all the user instructions prior to using this device.

Pinnacle³ treatment plans may include the statement NOT FOR CLINICAL USE. Based on the machine or isotope data and the treatment plan, the software determined that the plan cannot be delivered clinically. Do not treat patients with plans that are not for clinical use.

Pinnacle³ includes sample data. This information is for reference purposes only. Do not treat patients with plans based on sample machines or other sample data.

Use of Symbols in Labeling

Philips Healthcare complies with International Standards and FDA requirements for the use of symbols in labeling. An online glossary of symbols used by Philips Healthcare is available at http://www.symbols.philips.com.

Notes

Equipment specifications are subject to alteration without notice. All changes will be in compliance with regulations governing manufacture of medical equipment.

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1 Getting Started

Introduction

Inverse planning intensity-modulated radiation therapy (IMRT) is a treatment technique using beams with varying intensities to conform the high dose region to a target volume while sparing normal tissue structures, enabling dose escalation and reduced normal tissue complications. Beam intensities are modulated using tissue compensators or multi-leaf collimators (MLCs). The term "inverse" is used because you begin with the solution you want in terms of dose distribution and the system develops the plan.

> **NOTE**
> Before you use P³IMRT, you must create a treatment plan using Pinnacle³. See the *Pinnacle³ Planning Instructions for Use* for information and procedures.

The basic process for creating an inverse-planning procedure is:

- Import patient image data.
- Create ROIs for both target and critical structures. Add safety margins where necessary.
- Add points of interest, beams, and isocenters.
- Set up a dose grid and isodoses.
- Add the prescription(s).
- Set up DVHs for all the ROIs you intend to use for specifying treatment objectives or constraints. Set the **Dose Axis Display** to **Absolute Dose**.
- Add treatment objectives and constraints.
- Select the optimization parameters for the beams.
- Optimize the plan.
- For intensity modulation plans, convert the ideal opening density matrix (ODM) of each beam to a physical compensator or a set of MLC control points.
- Compute the final dose distribution.
- Review and print the plan.
- Export the plan using DICOM RT.
- Perform necessary quality assurance procedures using standard Pinnacle³ plan evaluation tools.

DICOM conformance

DICOM (Digital Imaging and Communications in Medicine) is a standard for the electronic transfer of digital images and associated information, developed by the American College of Radiology and the National Electrical Manufacturers Association. The Pinnacle[3] software operates within DICOM standards and within the standards of the manufacturer's Conformance Statement for DICOM. The DICOM conformance statement is available on the Philips Healthcare website (www.healthcare.philips.com).

Terminology

Control point

P³IMRT uses control points to describe the dynamic aspects of a beam. A control point is a general concept for specifying any changes to the beam during treatment. Aspects of a control point that may change during treatment include gantry, collimator, and couch angles, MLC leaf positions, jaw positions, wedge states, and MUs/weight.

Static beams have only one control point. Arc beams have two control points (beginning and ending points) and the blocking shape remains the same for both. For conformal arc beams and dynamic arc beams, the number of control points depends on the arc length and the gantry spacing, the blocking shape varies for each control point, and dose is automatically stored for each control point. For step-and-shoot MLC beams in forward planning, you can set the blocking and choose to store the dose for each control point. For step-and-shoot MLC beams in inverse planning, the blocking is set during optimization and dose is not stored for control points.

Storing the dose allows you to re-weight the individual control points in the beam and see the dose update in real time. If dose is stored for each control point, the control points can be optimized. Dose is automatically stored for each control point if the **Optimization Type** is **Segment Weight**. You will have to choose to store dose if you manually add control points to a beam.

> **NOTE**
> You cannot re-weight control points if the beam is a dynamic arc beam. See the *SmartArc* chapter for a list of restrictions that apply to dynamic arc beams after you optimize a SmartArc plan.

If a parameter affects all control points for a beam, and that parameter is changed, the dose for all control points is invalidated. For example, changing the isocenter, the dose grid, or the machine, or adding or removing wedges changes the dose for the beam and all control points.

Segment

A segment (or MLC control point) is a control point that only allows changes in MLC leaf positions, jaw positions, and MUs/weight during delivery.

Opening density matrix (ODM)

The ODM is a transmission filter that the software uses for Intensity Modulation and DMPO plans. The matrix is a plane normal to the beam direction that represents the relative intensity of a modulated radiation beam with respect to the intensity of an open field. The beam's "normal" intensity is multiplied by its corresponding value in the opening density matrix (if every element of the opening density matrix has the same value, the beam is not modified at all—a "normal" beam is the result). The program calculates an ODM for a beam only if you select **Intensity Modulation** as the **Optimization Type** for the beam.

P^{3}IMRT creates two different ODMs: the ideal ODM and the deliverable ODM. The ideal ODM is the ODM created during optimization. The deliverable ODM is the actual transmission values delivered by the converted beam, either through multiple control points or a compensator.

P³IMRT user interface

The P³IMRT interface is one large window that allows you to set constraints and objectives, optimize your plan, convert the plan to a delivery device, and evaluate the plan. The icons along the top of the window allow you to view the three panels in the window.

The patient information always appears at the top of the window, along with a field that lets you select the trial that you want to use.

Main icons

The icons that take you to the major inverse-planning functions appear at the top of the **Inverse Planning** window.

Icon	Panel	Description
	Optimization	Define the treatment goals and the optimization and conversion parameters.
	Conversion	After you optimize the plan, convert each beam's opening density matrix into a format for your delivery device (compensator or MLC), and then evaluate the plan.
	Auto-Planning	Rapidly create high-quality treatment plans based on clinical goals for either SmartArc or DMPO optimization. See *Use Auto-Planning*.

Optimization fields and buttons

The **Dose Volume Histogram** tab displays objectives, constraints, and a dose volume histogram (DVH) for each ROI. When you click the **Viewing Window** tab, the DVH is replaced by a viewing window that displays a patient image with the dose distribution and ROIs.

The **Progress of Optimization** graph shows the rate at which the optimization is converging. The X axis is the iteration number and the Y axis is the composite objective function.

The spreadsheet at the bottom of the panel lists all defined objectives and constraints and the objective value for each one. Below this list is the **Composite objective value** for all ROIs.

For Intensity Modulation and DMPO plans, the ideal ODM of the selected beam appears in the viewing window in the center of the **Optimization** panel.

> **NOTE**
> You can resize the **Inverse Planning** window so that more data can be displayed in the **Objectives** spreadsheet.

The following fields and buttons are available in the **Optimization** panel of the **Inverse Planning** window and other referenced windows.

Title	Description
% Variation	The maximum relative dose variation the software will allow in the ROI.
% Volume	The percentage of the region of interest's volume that should satisfy the specified objective.
a	The biological parameter used by the EUD model that controls the sensitivity to cold or hot dose within the ROI. (Note: This column only appears in the **Objectives** spreadsheet if you are licensed for Biological Evaluation.)
Absolute Dose	Click this radio button to set the dose axis of the DVH to show absolute dose to the ROI (in cGy or Gy).
Absolute Volume	Click this radio button to set the volume axis of the DVH to show the actual volume (in cm³) receiving a given dose.
Add	Click this button in the **IMRT Protocols** window to add a new protocol.
Add Objective	Click this button to add an objective to the **Objectives** spreadsheet.
Beam	The names of the beams in the plan.
Composite objective value	Displays a combined deviation from the set of objectives. The software uses the objective values and considers the weights you assigned to each objective in determining the composite objective value.
Constrain	Click in this column if the objective should constrain the optimization.
Current Iteration	Once you start the optimization, this field displays the current iteration being attempted by the software.
Delete	Click this button in the **IMRT Protocols** window to delete the selected protocol.
Delete Objective	Click this button to delete the selected objective from the **Objectives** spreadsheet.
Dose Status	Shows whether or not dose is computed for a beam.
gEUD	The generalized equivalent uniform dose (EUD) value. (Note: This column only appears in the **Objectives** spreadsheet if you are licensed for Biological Evaluation.)
IMRT Parameters	Click this button to open the **IMRT Parameters** window.
Load	Click this button in the **IMRT Protocols** window to load the selected protocol into the plan.
Machine	From this option list, select the machine from which you want to copy defaults.
Max iterations	The maximum number of times the software should optimize the plan.
Name	Displays the name of the selected protocol in the **IMRT Protocols** window. You can change the name of the protocol in this field.
Normalized Dose	Click this radio button if you want the dose to the ROI to be normalized to 1.0 (100%), and the dose axis of the DVH to show the percent of maximum dose to the specified ROI.
Normalized Volume	Click this radio button if you want the volume to be normalized to 1.0 (100%), and the volume axis of the DVH to show the percent of the ROI volume receiving a given dose.
Objective Value	The value of each objective function multiplied by its weight.

Title	Description
Opening Density Matrix	From this option list, select the beam whose opening density matrix you want to display in the adjacent viewing window.
Parameters	The number of parameters the software is optimizing.
Plan Eval	Click this button to open the **Plan Evaluation** window.
Recompute Values	Click this button to recalculate the objective values.
Reset Beams	Click this button to return the plan to the state it was in prior to the start of the present optimization. The software does the following: • Restores each ODM to full transmission values for all beams whose **Optimization Type** is **Intensity Modulation** or **DMPO**. • Equalizes the weights for all beams whose **Optimization Type** is not **None**. • Removes the control points from beams whose **Optimization Type** is **Intensity Modulation**, **DMPO**, or **SmartArc**. • Removes any beams that the software created as a result of a beam being split. If you selected the Allow jaw motion check box for a beam, the software resets the jaw positions for that beam to expose all target ROIs.
ROI	The regions of interest for which objectives have been defined.
Save	Click this button in the **IMRT Protocols** window to save the current combination of objectives and constraints as the protocol identified in the **Name** field.
Sort Objectives	Click this button to sort the list of objectives based on the ROI name.
Start Optimization	Click this button to start optimizing the plan.
Stop Optimization	Click this button to stop the optimization. The plan you see when you stop the optimization is the last fully completed iteration.
Target cGy (or **Gy**)	The target dose of the objective or constraint.
Type	The type of objective or constraint.
Weight	The relative weight of the objective (the higher the number, the more important the objective).

Conversion fields and buttons

Use the **Single MLC control point BEV display** to display one BEV for the current beam. Use the **Consecutive MLC control point BEV display** to display a set of several BEVs for the current beam.

Use the **Redo spreadsheet** tool to apply the last change to a parameter in a spreadsheet to all entries in a spreadsheet.

The following fields and buttons are available in the **Conversion** panel of the **Inverse Planning** window.

Title	Description
Beam	The **Beam** field lets you select the beam for which you want to view MLC control points and leaf positions. The **Beam** column in the **Beams** spreadsheet displays the beams in the plan.
Beam MU/Fraction	Displays the MU per fraction for the current beam.
Clip leaves	Select this check box to clip the display of the MLC leaves to the jaws. If this check box is not selected, the entire MLC is shown in the BEV viewing window.

Title	Description
Compute	Click this button to compute dose for the corresponding beam.
Compute ODM Difference	This button appears after conversion if you chose not to compute the ODM difference. Click the button to compute the ODM difference.
Control Point	The **Control Point** column in the **Control Points** spreadsheet lists the MLC control points in the current beam. The highlighted radio button marks the MLC control point that is displayed in the BEV.
Convert	Click this button to convert a particular beam.
Convert All	Click this button to convert all beams.
Delete Current Control Point	Click this button to delete the selected MLC control point.
Deliverable ODM	The ODM created by the conversion process for the current beam.
Dose Engine	Select the dose engine to be used to compute dose for the beam.
Fill in leaves	Select this check box to fill in the MLC leaves with color so they are easier to see. If this check box is not selected, the MLC leaves are displayed as outlines.
Filter Beams	Click this button to filter all of the beams using the filter settings, sort the beams to minimize delivery time, and round the control point MUs to match the delivery precision of the machine.
IMRT Parameters	Click this button to open the **IMRT Parameters** window.
Locked	Shows if weight is locked for an MLC control point. Click the **Yes/No** button to change the status of the lock.
MLC Options	Opens the **Beam MLC Leaf Position Editor** window.
MU	The monitor units of the MLC control point.
ODM Difference	The difference between the ideal ODM and the deliverable ODM for the current beam.
Sort Control Points	Sorts the control points in the current beam. This button has no effect on Sliding Window beams.
Status	Shows if dose is computed for a beam.
Total control points for beam	Lists the total number of MLC control points in the current beam.
Total control points for trial	Lists the total number of MLC control points in the trial.
Weight	For all beam types except Sliding Window, this is the weight of the MLC control point as a percentage of total MUs for the beam. For Sliding Window beams, the weights of the control points are displayed as cumulative weights.

Auto-Planning fields and buttons

For information on the fields and buttons in the Auto-Planning panel, see *Use Auto-Planning*.

Restrictions and considerations for IMRT

You must create a standard treatment plan in Pinnacle³ before you enter the P³IMRT module. How you define the regions of interest, set up beams and jaws, and define the dose grid in the standard treatment plan can impact the efficiency of the IMRT optimization algorithm.

General

- The following options are available for IMRT optimization for each treatment modality:

    Photon beams—Intensity Modulation, **DMPO**, **SmartArc**, **Segment Weight**, or **Beam Weight**

    Electron beams—Beam Weight

    Stereotactic beams—Beam Weight

    Double scattering beams and uniform scanning beams—None

    Spot scanning beams—IMPT or Beam Weight

    > **NOTE**
    > Spot scanning beams cannot be assigned to the same prescriptions as the other beam types.

    For all treatment modalities, including brachytherapy, you can choose not to optimize the treatment parameters but still include the absolute dose contributions from the beams or sources as background dose by selecting the optimization type **None**.

- You cannot perform IMRT functions in the Irreg application.
- You must set up a prescription that specifies a number of fractions.
- You must define a dose grid before you start an optimization in P³IMRT. See the *Dose calculation* section for more information.

Physics setup

- IMRT involves the use of very small, heavily blocked fields. Validate your machines (beam models) at each field size you are likely to treat prior to creating plans. You may need to collect output factors down to 2 cm x 2 cm or 1 cm x 1 cm fields to ensure your machine can calculate MUs for small fields. If your MLC is set to replace the jaws, the field size is the actual open area of the MLC.
- Validate the output factors for all field sizes you are going to treat.
- Make sure your machines are set up to use the correct precision for monitor units. When delivering a plan, the ideal continuous beam weights in the plan are quantized at specific discrete values. This is done because monitor units are not continuous but can only have certain values (usually integers). If you do not set the MU precision (decimal places) accurately for your machine, the beam weights delivered will not be exactly the same as those in the plan due to rounding. For most plans, typical fields have a large number of monitor units, so this is a relatively small effect. However, in IMRT, some fields may have a small number of monitor units, so this rounding becomes more important.

- During the commissioning process, be sure to set a machine type and an MLC vendor when you enter the physical machine characteristics.
- If the MLC on your machine has a carriage, verify that the machine is commissioned to allow the leaves to interdigitate. If the **Allow opposing adjacent leaves to overlap** option is set to **Yes** in the **MLC Editor** window in the physics tool, then the leaves are allowed to interdigitate. Enabling this option allows Pinnacle³ to move the junctions between closed leaf pairs underneath the jaws during conversion.

  If you have a Varian machine, interdigitation allows you to use the Sliding Window conversion algorithm. If interdigitation is not enabled on a Varian machine, the junctions may be positioned within the field, and you will not be able to convert an IMRT plan using the Sliding Window algorithm.

Regions of interest

- P³IMRT optimizes trials based on dose to be delivered to ROIs, so when you create contours, be sure to define both target and critical structures as accurately as possible. You may need to contour more ROIs than you do for 3D conformal planning.
- If the machine has a static jaw conformance, you may want to add extra margins around target ROIs to ensure that the entire target is included in the ROI and to reduce the chance that a high-dose gradient region will occur at the periphery of the target volume. We recommend a margin of at least 0.7 cm. If you add margins to ROIs, specify your objectives to the expanded ROIs to ensure that the entire region is treated. Avoid extending ROIs outside the patient's external contour.
- In many cases, critical structure and target ROIs will intersect. See *Objectives and Constraints* for information about how to work with intersecting ROIs.

Beam setup

- You can increase the speed of the optimization by carefully specifying beam positions and jaw sizes. If you position beams to avoid critical structures and set the jaws to block critical structures, rather than relying only on the optimization to reduce the dose to structures for you, the complexity of the plan will be reduced, thereby reducing the time required for optimization.
- You can use the HotScript feature to quickly record and load standard IMRT beam arrangements.
- The software will not let you create a plan that violates the constraints of machines or delivery devices you have set up in the physics tool. The machine constraints must be met in order for delivery to be possible.

Isocenter placement

Generally, you should place the isocenter in the center of the target volume(s), as you do for 3D planning. If you are planning a head-and-neck case with multiple target volumes that are dispersed throughout the treatment area (such as lymph nodes), you may want to place the isocenter in the center of the head. Another option is to place the isocenter at the geometric center of all targets.

You should also consider any dosimetry, QA, or patient setup issues that might be affected by the isocenter location.

Number of beams

To reduce planning, setup, and delivery time, avoid using more beams than are necessary to meet your treatment objectives. An acceptable IMRT plan can usually be generated using 5–9 beams. The number of beams required to meet treatment objectives may depend on the complexity of the target shape and its proximity to critical structures. Using an odd number of beams makes it easier to avoid creating opposing beams.

Make sure to set up the number of beams you want to use for the treatment prior to optimizing the plan. If you add beams after you optimize the plan, you will have to optimize the plan again.

Beam directions

When setting beam directions, select directions that not only produce the best possible dose distribution, but also maximize the ease of planning, setup, and treatment delivery. You can use a HotScript to place a standard set of equally spaced beams and then modify the beams if necessary, or you can select all the beam angles manually.

Try to angle the beams so that they miss critical structures, the treatment table, and immobilization devices. Also, try to avoid using opposing beams. You can use either coplanar or non-coplanar beam arrangements.

Beam modifiers

You can add beam modifiers. Wedges and bolus are not optimized. If you add a compensator or MLC, you can choose not to optimize those beams for intensity modulation. If you do optimize beams in which compensators or MLC leaves are defined, those modifiers are removed prior to the optimization. After optimization, the software allows you to convert each beam's opening density matrix to equivalent compensators or MLC settings.

If you plan to treat with a compensator, you should use blocks (see the *Compensators* section for more information); otherwise you should not add blocks. Blocks and wedges are not required for intensity-modulated beams because MLC shapes will be added to each beam during conversion. You can, however, add physical wedges for intensity-modulated beams if you think they will improve the plan. Do not add dynamic, motorized, or virtual wedges.

Do not turn on the MLC. The P^{3}IMRT program will turn on the MLC during the control point conversion. Also, you do not need to turn on the Auto Surround feature because Auto Surround is turned off prior to conversion.

> **NOTE**
> You cannot optimize a beam using DMPO or convert a beam using the K-means clustering, IMFAST, or sliding window algorithms if the beam contains a block. Also, you cannot add a block to a sliding window beam after the beam has been converted.

Beam weights

You can enter beam weights for the optimization to use as initial values. Weight all of the beams equally before you begin the optimization to give the algorithm a better starting position.

Collimator rotation

To maximize the ability of the MLC to block critical structures, you can rotate the collimator for each beam so that the MLC leaves are as close to perpendicular to the long axis of the tumor as possible.

Beam sizes

Set the initial beam sizes as you normally would for the plan. If the machine allows jaw motion and splitting of beams, and you choose to enable these features during optimization, Pinnacle³ will automatically set the jaws to expose all targets as specified by the objectives and constraints plus a margin. If you allow jaw motion, you can also enable the **Use current jaws as max** feature, which lets you limit how wide the jaws can open.

In cases where jaw motion is not allowed, you may want to set the jaws to fully expose all of the target ROIs plus at least a 0.7 cm margin to ensure that the entire target is included in the ROI.

Prescriptions

Set your prescriptions much like you would for 3D planning.

- Specify the prescription to a normalization POI in either the clinical target volume (CTV) or planning target volume (PTV).
- Specify your prescription to the PTV mean dose or the plan maximum dose. If you chose to prescribe to a POI, the POI needs to be placed in a target structure.
- Do not specify your prescription to a POI that is located in the buildup region, a high dose gradient region, or an organ at risk.
- If a beam assigned to the prescription might be split during optimization, you may not want to prescribe to an isocenter. You should prescribe to a point instead. Once the beam is split, it may no longer be reasonable to specify your prescription to the isocenter.

Compensators

It may not be sufficient to block a rectangular compensator with only the jaws. Use a block to improve the dose distribution in the final plan. Prior to launching P³IMRT:

1 Create an ROI for the target volume.
2 Create a block for the beam which exposes the target ROI, plus a margin, and blocks any critical structures.
3 Repeat step 2 for all beams for which you intend to use a compensator to attenuate the beam.

Dose calculation

If your standard plan contains beams that will not be optimized, the software will calculate dose for those beams before starting P³IMRT. Dose for all other beams will be calculated as the first step in optimization.

Dose grid

You must define a dose grid before you start an optimization. When you define the grid, make sure it completely covers all ROIs that are used as objectives. If portions of an ROI fall outside the dose grid, any DVH objectives for the ROI could be compromised. The software will be unable to calculate a DVH for the entire ROI. It will only calculate a DVH for the portion of the ROI that is within the dose grid.

Dose calculation and optimization times increase as the size of the dose grid increases. Dose accuracy, however, is not affected by the size of the grid. To speed up the optimization, define the dose grid so that it includes only the ROIs for which objectives will be defined plus a 1 cm margin. Then, if necessary, increase the size of the grid for the final dose computation after conversion.

Data set extension

Optimization time increases when the CT data set is extended beyond the patient data set. If the CT data set does not need to be extended with respect to primary and scatter effects, set the top and/or bottom extension values to zero.

Dose volume histograms (DVH)

- Set up a DVH for all ROIs to be used for specifying treatment objectives or constraints in the P³IMRT module.
- Set the **Dose Axis Display** to **Absolute Dose**.
- DVH computation, especially for large ROIs, can increase optimization time. Turning off the DVH display in the **Plan Evaluation** window can speed up optimization.

18   Overview

2 Objectives and Constraints

Overview

Before you can optimize a plan, you must first define objectives and (if necessary) constraints. An objective is a desired treatment goal, but the software may not achieve the goal when trying to determine the optimal plan. A constraint tells the software that it must satisfy the goal, regardless of how objectives are changed.

Constraints decrease the speed of the optimization because they restrict the solutions available to the optimization algorithm. The algorithm must try to satisfy the objectives without violating the constraints. When constraints are used, the objective value may rise during optimization until the constraints are met. Once the constraints are met, the optimization will attempt to reduce the objective values. If the values in the **Progress of Optimization** graph continue to rise during optimization, the constraints cannot be met.
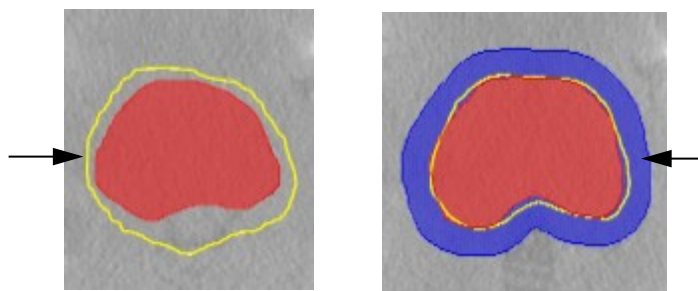
Target objectives and constraints

At least one of the objectives must be a target objective in order for the plan to be optimized. If you use a target constraint, you must use the target constraint in conjunction with a target objective. Target objectives and constraints are those whose goals are to deposit dose within the specified ROI. **Min Dose**, **Min DVH**, **Min EUD**, and **Target EUD** are target objectives/constraints, **Uniform Dose** is a target objective, and **Uniformity** is a target constraint, because the user wants at least a certain amount of dose delivered to the ROI.

When you define objectives and constraints, start with the target(s); the plan is typically not acceptable if the target objectives and constraints are not satisfied. You can specify a **Min Dose** and **Max Dose** objective for the target, although a single **Uniform Dose** objective will work well and accomplish the same goals in most situations. An effective combination for target structures is a **Uniform Dose** or **Min Dose** objective combined with a **Uniformity** constraint.

Specifying **Min Dose**, **Max Dose**, or **Uniform Dose** objectives to the target may not always result in an acceptable dose distribution. To force the dose distribution to better conform to the target, you can create a "ring" ROI around the target ROI and specify a **Max Dose** objective within that volume. First, create an expanded target ROI. An expansion of 0.5 cm to 1.5 cm will usually suffice. Then, specify the expanded ROI as the source ROI and the target ROI (and any overlapping critical structures) as limiting ROIs. Then specify a destination ROI, which will be the ring ROI. Specify a **Max Dose** objective to the ring ROI between 100% and 95% of the prescribed target dose (try 100% first). If you have been overly aggressive, the dose will be too constricted around the target, and if you have not been aggressive enough, the dose will not conform as much as it could.

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In the illustration on the left, dose around the target volume is not conformal when the objective is to give a uniform dose. Dose is much more conformal when a 1-cm ring ROI is used to constrain the dose, as shown in the illustration on the right.

You can also increase the dose conformity around the target by specifying "surrounding tissue" or "dose-shaping" objectives or constraints, as described in the *Dose-shaping objectives and constraints* section.

Avoid specifying target objectives or constraints to ROIs that extend outside the external patient contour. If you specify a minimum dose to an ROI that extends near or outside the patient's skin surface, the optimization algorithm will try to achieve a high dose to the air, resulting in a high dose at the surface. To avoid this, specify a **Min DVH** to the target ROI instead.

Critical structure objectives and constraints

Non-target objectives and constraints are those whose goals are to avoid depositing dose within the specified ROI. **Max Dose**, **Max DVH**, and **Max EUD** are non-target constraints/objectives because the user wants a certain amount of dose not to be delivered to the ROI. The user specifies the maximum dose to be delivered: less dose is fine, but more dose is not.

When you create objectives for critical structures, the most straightforward approach is to create objectives that pull the dose down as low as possible. Keep in mind that once the DVHs meet the goal of a **Max Dose** or **Max DVH** objective, there is no incentive for the optimization algorithm to do better. Therefore, **Max Dose** and **Max DVH** values should be set aggressively.

Another strategy is to create a set of **Max Dose** and **Max DVH** objectives that define a DVH for a critical structure that meets delivery tolerances. Then, add a lightly weighted **Max Dose** or **Max DVH** objective to the same structure for a dose that is 10% to 30% less than the clinically acceptable tolerance levels. This lower dose objective provides an incentive for the optimization algorithm to continue removing dose from that structure even though the other objectives have been met. For example, you may specify a **Max Dose** objective of 4500 cGy to the spinal cord with a weight of 100, and a **Max Dose** objective of 3000 cGy with a weight of 1.

Dose-shaping objectives and constraints

In some instances, you may find that specifying target and critical structure objectives and constraints does not fully define the dose distribution you want. In these cases, it can be beneficial to create other ROIs to help "shape" the dose distribution.

A "surrounding tissue" ROI, which consists of an external patient contour with other target and critical structure ROIs removed from it, can be used to reduce high dose regions outside the target volumes and make the dose to the target volumes more conformal. Use the **ROI Expansion/Contraction** tool to create a surrounding tissue ROI by defining the patient contour as the source, adding all other ROIs to the limiting structure list, and then expanding with a zero margin in all directions. Assign an objective to the patient contour that has a maximum dose of the background radiation level. The illustration below shows a surrounding tissue ROI with the target ROI and critical structures removed.
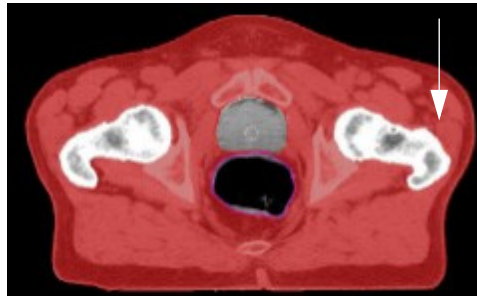
Creating a "dose-shaping" ROI can help the optimization algorithm overachieve goals and direct dose to specific areas. Dose-shaping ROIs do not have to correspond to specific structures. They can simply define an area in which you would like to shape the dose by specifying a suitable objective. In the illustration below, the dose-shaping structure is designed to limit the dose anterior to the target volume.
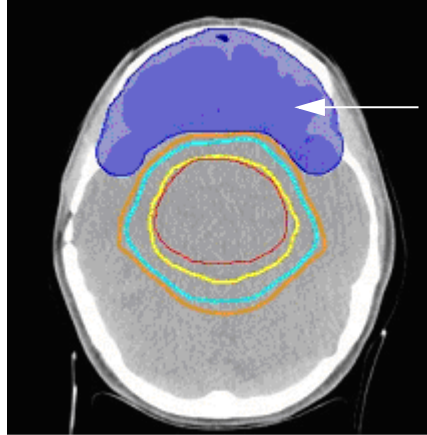
Objective weight considerations

During optimization, the software computes an objective value for each objective based on the difference between the solution and the goal for the objective. As the optimization continues, the software considers the objective values for all objectives and attempts to achieve the goals that you set, with emphasis on the objectives that have the largest objective value. As the solution approaches the goal for an objective, the objective value becomes smaller. If the software reduces an objective value to zero, the software considers the goal for that objective to be achieved.

Any positive objective value indicates that the goal has not been achieved. However, a very small objective value may result in the software considering the goal for that objective as achieved if one or more objectives have much larger objective values assigned to them.

Because the software may determine that the goal for a critical objective is achieved and focus on optimizing other less-important objectives, you can use the **Weight** field to force the software to increase the objective value for certain objectives. The software multiplies the weight value by the internal objective value (shown when the weight value is 1) and uses the product as the new objective value during optimization. The resulting objective value becomes a larger proportion of the composite objective value, thereby forcing the software to spend more time attempting to achieve the goal than it would otherwise.

A common strategy is to start the initial optimization with all the weight values set to 1, which allows the software to optimize the plan using only the internal objective value. You can then increase the weight value during the optimization to force the software to focus on the objectives that are the most important. If the optimization completes and you want to refine the plan further, you can adjust the weights for the objectives and perform the optimization again.

Add objectives and constraints

You can only define objectives and constraints if you have added at least one region of interest to your plan. At least one of the objectives or constraints must be a target objective or constraint.

When you add an objective, an icon appears on the DVH display at a default position for the objective. The icon is the same color as the ROI. For information about dose-based objectives and constraints and their associated icons, see *Dose-based objectives and constraints*.

During optimization, you can change the values in the **Target Dose**, **% Volume**, **% Variation**, **Weight**, and **a** values for objectives and constraints. You can also change the value in the **Target Dose** field by dragging the icon for an objective in the **Dose Volume Histogram** tab. However, you cannot change the **ROI** or **Type** assigned to an objective after optimization begins.

> **NOTE**
> If you are adjusting **Min Dose** or **Max Dose** objectives, **Min Dose** or **Max Dose** constraints, or **Uniform Dose** objectives, you can only move the icon along the **Dose** axis of the DVH.

Add an objective

1   Click the **Add Objective** button. A row is added to the bottom of the **Objectives** spreadsheet.

2   Select the ROI for the objective.

3   Select the type of objective you want to add.

   If you want to set a minimum *and* maximum dose or a minimum *and* maximum DVH for an ROI, you must add two objectives (one for the minimum and one for the maximum) and use the same ROI for both.

   > **NOTE**
   > An alternative to setting a **Uniform Dose** objective is to set **Min Dose** and **Max Dose** objectives for the same ROI and enter target dose values that create tight dose limits. For example, set the target dose to 7800 cGy for the **Min Dose** objective and 8000 cGy for the **Max Dose** objective.

4   Enter the target dose for the objective, if necessary.

5   If you added a **Min DVH** or **Max DVH** objective, enter the percentage of the ROI's volume that should receive the target dose.

6   If necessary, adjust the weight for the objective. The value that you enter in the **Weight** field influences how much time the software spends on the problem for the objective. For more information, see *Objective weight considerations*.

   If you assign a weight of zero, the software does not optimize that objective. You can also give an objective a very high weight to approximate a constraint.

7   If you added an EUD objective, enter an **a** value. For more information, see *EUD-based objectives and constraints*.

Add a constraint

NOTE
You cannot optimize constraints with the SmartArc optimization type. Do not add constraints if you intend to perform a SmartArc optimization.
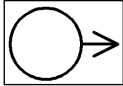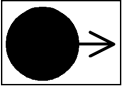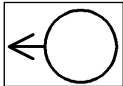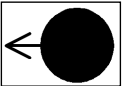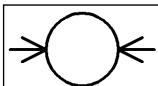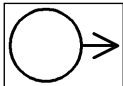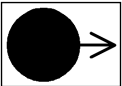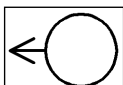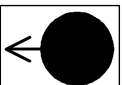
1   Click the **Add Objective** button. A row is added to the bottom of the **Objectives** spreadsheet.

2   Select the ROI for the objective.

3   In the **Type** column, select the type of objective that you want to add, then click the check box in the **Constrain** column. If the type of objective you selected cannot be a constraint, you will not be able to select **Constrain** for that objective.

4   Enter the target dose for the constraint, if necessary.

5   If you added a **Uniformity** constraint, enter the % variation you want to allow the software when it is attempting to uniformly apply dose to the ROI.

6   If you added an EUD constraint, enter an **a** value. For information about the **a** parameter, see *EUD-based objectives and constraints*.

Delete objectives or constraints

Select the objective or constraint you want to delete and click the **Delete Objective** button.

Dose-based objectives and constraints

The table below shows the objectives and constraints and their associated icons that are displayed on the DVH on the **Dose Volume Histogram** tab in the **Optimization** panel. The table also explains how the software determines when a constraint or objective has been met.

Type	Icons		Optimization
Min Dose	Objective	Constraint	Applies to the whole ROI volume. The constraint or objective is met when the region of interest has a minimum dose that is greater than or equal to the target dose. The icon appears at the 100% volume level of the DVH.
Max Dose	Objective	Constraint	Applies to the whole ROI volume. The constraint or objective is met when the region of interest has a maximum dose that is less than or equal to the target dose. The icon appears at the 0% volume level of the DVH.
Uniform Dose	Objective	NA	Applies to the whole ROI volume. Can only be used as an objective. The objective comes closer to being satisfied as the dose throughout the ROI's volume becomes more uniform.
Min DVH	Objective	Constraint	Applies only to a percent volume of the ROI. The constraint or objective is satisfied if the % volume of the ROI which exceeds the specified target dose is greater than the specified % volume.
Max DVH	Objective	Constraint	Applies only to a percent volume of the ROI. The constraint or objective is satisfied if the % volume of the ROI which exceeds the specified target dose is less than the specified % volume.
Target EUD	(No icon)	(No icon)	Applies to the whole ROI volume. The constraint or objective is met when the **gEUD** value is equal to the target **cGy** value. The gEUD computation uses the value entered in the **a** field.
Min EUD	(No icon)	(No icon)	Applies to the whole ROI volume. The constraint or objective is met when the **gEUD** value is greater than or equal to the target **cGy** value. The gEUD computation uses the value entered in the **a** field.
Max EUD	(No icon)	(No icon)	Applies to the whole ROI volume. The constraint or objective is met when the **gEUD** value is less than or equal to the target **cGy** value. The gEUD computation uses the value entered in the **a** field.
Uniformity	NA	(No icon)	Applies to the whole ROI volume. Can only be used to set a constraint. The constraint is met when the variation of dose within the ROI is less than the specified % variation. The objective value for uniformity constraints is the percent uniformity that the software achieves. The objective value for uniformity constraints will be less than or equal to the specified % variation.

EUD-based objectives and constraints

> **NOTE**
> EUD is available only if you are licensed for Biological Evaluation.

EUD-based objectives and constraints use the generalized EUD (gEUD) equation[1] to direct the optimization algorithm toward specific EUD goals. Specific EUD objective and constraint types are described in the *Dose-based objectives and constraints* section.

The gEUD equation requires a single parameter **a**. The **a** parameter controls the sensitivity of the gEUD computation to hot or cold dose areas within the specified ROI.

If you change dose, edit an ROI, or change the **a** parameter after optimization, the software invalidates the **Objective Value** and **gEUD** field. Click the **Recompute Values** button to recompute the **gEUD** value.

- **a < 1**—appropriate for ROIs representing targets. As the **a** value becomes smaller (or more negative), the gEUD computation becomes more sensitive to cold spots.
- **a = 1**—corresponds to the mean dose to the target.
- **a > 1**—appropriate for ROIs representing critical structures. As the **a** value becomes larger, the gEUD computation becomes more sensitive to hot spots.

The optimization algorithm attempts to achieve a computed gEUD goal based on the dose value specified in the target dose field of the objective or constraint.

[1]Niemierko, A. A generalized concept of equivalent uniform dose (EUD). *Medical Physics* 26(6): 1101, 1999.

Overlapping ROIs and conflicting objectives

Plans often contain target and critical structures that overlap. When specifying objectives and constraints for overlapping ROIs, it is possible to create conflicting objectives and constraints that will cause difficulties during optimization. For example, if you specify a **Uniform Dose** objective of Dose1 to a target ROI, and a **Max Dose** objective that is lower than Dose1 to a structure that overlaps the target, the optimization algorithm will probably not achieve an acceptable plan.

It is important to avoid creating conflicting objectives and constraints, and the best way to avoid this is to not overlap ROIs. Unfortunately, in many cases it is impossible to avoid overlaps. The following sections explain four strategies for dealing with situations where ROIs overlap.

Strategy 1: Use DVH-based objectives

DVH-based objectives help diminish conflicts caused by overlapping ROI objectives because they only consider the dose in a portion of the ROI designated by the user. For example, the plan might contain a target structure that overlaps a critical structure. The region of overlap is likely the highest-dose portion of the critical structure. If you use a **Max DVH** objective in the critical structure, the percentage of the volume of high dose you specify will not be included in the evaluation of the objective, so that volume will no longer cause a conflict in objectives. If this volume is greater than the volume of overlap, there will not be a significant conflict in objectives.

If one ROI is encompassed by the other, you can specify a **Uniform Dose** objective to the inside structure and a **Min Dose** or **Min DVH** to the larger ROI (for example, Dose1 to the CTV and at least Dose2 to 95% or 100% of the PTV). In the case of lymph nodes, you might specify Dose1 to the CTV, Dose2 to at least 95% of the PTV, and Dose3 to at least 90% of the lymph nodes.

If the ROIs intersect, define a DVH-type objective or constraint for one of the ROIs, rather than a Dose-type objective or constraint. Specify a percentage volume large enough so that the volume where the ROIs overlap can receive appropriate dose (for example, **Uniform Dose** Dose1 to the target and a **Max DVH** Dose2 to 5% of the critical structure ROI).

Strategy 2: Remove overlaps in ROIs

One strategy is to use the **ROI Expansion/Contraction** tool to create ROIs that remove the overlaps from the original ROIs. Once the separation is made, treatment objectives maybe specified to the new, non-overlapping ROIs.

If one ROI is encompassed by the other, subtract the smaller ROI from the larger one. Then specify dose objectives to the small ROI and the "ring" ROI independently.

If the ROIs intersect, remove the intersecting region from both original ROIs and create a third ROI of the intersecting region. Then specify the dose objectives for the three ROIs (ROI_1 minus the intersection, ROI_2 minus the intersection, and the new intersection ROI).
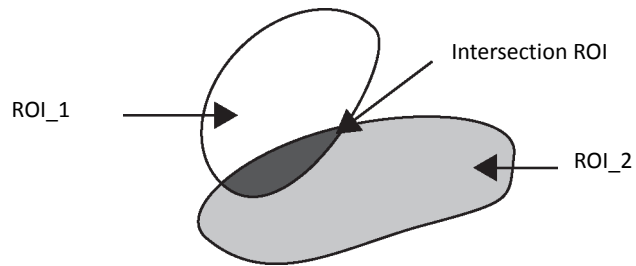
Strategy 3: Adjust weights to minimize conflict

Adjusting the weights of conflicting objectives can reduce, though not eliminate, the conflicts. When adjusting the weights, be sure to consider the desired dose distribution and which ROIs are more important.

Strategy 4: Apply tumor overlap fraction

In the **IMRT Parameters** window, select the **Apply tumor overlap fraction** check box. A field appears in which you can specify a percentage value. If you enter a value of 100%, the optimization process treats the entire overlapping region as if it is part of the tumor ROI. If you enter a value of 0%, the optimization process treats the entire overlapping region as if it is part of the critical structure ROI. A value between 0%–100% causes the optimization process to weight each voxel's contribution to the objective value based on the percentage entered. For example, if you enter a value of 75%, 75% of the volume of each voxel will be considered tumor and 25% will be considered critical structure.

3 Intensity Modulation

Overview

A standard intensity modulation plan requires you to optimize the beam parameters and then convert the resulting plan to a delivery device. Optimization is an iterative process, so you may need to optimize the plan several times before you are ready to convert the plan.

You can view the progress of the optimization and modify the objectives if the optimization is not resulting in a treatment that you desire. If necessary, you can stop the optimization if it has already come close enough to the treatment goal (as defined by your clinical practices).

When you are satisfied with the optimized plan, you must convert the settings to a delivery device (compensators or multi-leaf collimators).

Optimization

Set IMRT optimization parameters for intensity modulation

1   In the **Inverse Planning** window, click the **IMRT Parameters** button. The **IMRT Parameters** window appears.

2   Click the **Optimization** tab to display the optimization parameters. Optimization parameters are saved for each trial.

3   In the **Max iterations** field, set the maximum number of times the software should refine the plan. The optimization algorithm can usually find an optimal solution in 25–40 iterations.

4   In the **Convolution dose iteration** field, enter the number of iterations the software should perform before it computes the convolution dose during optimization.

   If you do not want to perform the convolution dose computation, enter "0" in this field. However, to ensure the closest match between the optimization dose computation and the final dose computation after conversion, you should always compute convolution dose during optimization.

5   In the **Stopping tolerance** field, change the stopping tolerance (if necessary).

   The stopping tolerance is the sensitivity to change between objective values for successive iterations. If the objective values do not improve by greater than the stopping tolerance for two successive iterations, the optimization is considered satisfied and stops.

6   If the plan contains target ROIs that overlap critical structure ROIs, you may want to select the **Apply tumor overlap fraction** check box. If you select this option, a field appears in which you can specify the percentage of the weighting value describing how overlapping voxels will be treated during evaluation of the objective function. For more information, see *Overlapping ROIs and conflicting objectives* in the *Objectives and Constraints* chapter.

7   In the beams panel, select **Intensity Modulation** as the optimization type for each beam. The opening density matrix of the beam is optimized.

8   Does the machine that you are using allow the jaws to move during treatment?

   • **Yes**—The software optimizes the trial such that the jaws adjust to conform to the shape of each segment. The software automatically selects the **Allow jaw motion** check box, and you cannot deselect it.

   • **No**—Select the **Allow jaw motion** check box if you want the jaws to conform to the target prior to optimization and maintain that position throughout treatment. Do not select the **Allow jaw motion** check box if you want the machine to maintain the current jaw positions.

9   Select the **Use current jaws as max** check box if you want to use the current position of the jaws as the maximum position of the jaws during the optimization.

10 For each beam, select the **Split if necessary** check box if you want to allow the beam to split.

   NOTE
   The software cannot split a beam if the beam contains a wedge or a block.

> **NOTE**
> If a beam splits, the software names each resulting beam with a letter (a, b, c, etc.,
> depending on the number of beams created) followed by the original beam name. The
> beams are grouped together in the beam spreadsheet.

11 Select the **Intensity Modulation** tab and use the fields available to set the specific parameters
for intensity modulation. For more information, see *Intensity modulation parameters*.

Intensity modulation parameters

These settings appear in the **Intensity Modulation** tab and are applied only to beams that use the
Intensity Modulation optimization type.

Parameter	Description
MLC delivery	Select this check box if the treatment machine uses an MLC.
	Do not select the **MLC delivery** check box if you want to deliver treatment with a compensator. The **Minimum transmission** appears when you deselect the **MLC delivery** check box.
Minimum transmission	Enter the minimum transmission through the thickest part of the compensator. This value limits the transmission values of the ideal ODMs so that the ideal ODMs can be more accurately converted into a deliverable compensator.
	For best results, if you enter a **Minimum transmission** value that is greater than 0.0, enter a **Convolution dose iteration** value that is 5 less than the **Max iterations** value. For example, if the **Minimum transmission** value is 0.3 and the **Max iterations** value is 40, set the **Convolution dose iteration** value to 35.
Compute final dose	Select this check box if you want to automatically compute dose when the conversion is complete.
	If you select both the **Convert after optimization** check box and the **Compute final dose** check box, the software will compute dose after the conversion.
Convert after optimization	Select this check box if you want to automatically convert the beams when optimization is complete.
	Do not select the **Convert after optimization** check box until you are satisfied with your optimization results. Optimization is an iterative process. If you convert the plan after each optimization, you add unnecessary time to the process.
Use SVD for dose calculation	If you select **Yes**, the software uses the SVD dose engine during optimization. If you select **No**, the software uses the TPB dose engine during optimization. For more information, see *Iterative dose computation* in the *Reference Information* chapter.
	If you select **Yes**, the **Fine Resolution ODM** option appears.
Fine resolution ODM	If you select **Yes**, the software uses an ODM resolution that matches the smallest MLC leaf width that is commissioned for the machine. (The smallest ODM resolution that the software allows is 0.2 cm x 0.2 cm.) The optimization takes longer if you use a fine resolution ODM.
	If you select **No**, the software uses an ODM resolution of 0.5 cm x 0.5 cm.

Optimize the plan

In the **Inverse Planning** window, click the **Start Optimization** button. The software optimizes the
plan.

During optimization, you can change the values in the dose, **% Volume**, **% Variation**, **Weight**, and **a** fields. You can also change the value in the dose field by clicking and dragging the corresponding objective's icon in the **Dose Volume Histogram** tab.

If necessary, you can click the **Stop Optimization** button to stop the current optimization. If you stop optimization before the software reaches the optimal plan or completes all the iterations, the results that appear are from the best iteration up to the point that you stopped the optimization.

⚠ **CAUTION**
If you have made significant changes since the last optimization, you should reset the beams before you optimize again. A significant change includes adding new objectives or constraints, removing objectives or constraints that were previously defined, and changing anything that changes the size or orientation of the field. For example, if you increase the size of a target ROI, you should reset the beams before you optimize again. Changing weight, dose, or volume values of objectives or constraints that are already defined do not require you to reset the beams. See *Modify the plan*.

> **NOTE**
> For Intensity Modulation: You cannot perform an optimization if a beam in the plan contains a dynamic wedge, a motorized wedge, or a compensator. If you chose to use the SVD dose engine during optimization, you also cannot perform an optimization if a beam in the plan contains a standard wedge or a block.

Evaluate optimization results

⚠ **CAUTION**
Prior to conversion, monitor units appear with a tilde (~), which indicates that the values are approximate. If you print the trial, the words "Not for Clinical Use" will appear on the printout.

When you evaluate the results of an Intensity Modulation optimization, remember that the dose distribution will change after conversion. This change is inherent in the process of converting from an ideal ODM to a physical delivery device such as an MLC or compensator.

After you optimize the plan, you must evaluate the dose results to ensure that the plan meets your clinical criteria for treatment.

- Look at a DVH for each ROI.
- View DVHs and ROI statistics for the trial in the **Plan Evaluation** window.
- View the 2D dose distribution.
- View dose clouds and ROIs in 3D.
- Look at the opening density matrix for each beam.
- Review the objective values calculated for each ROI during optimization.
- Review the biological response data in the **Plan Evaluation** window (if you are licensed for Biological Evaluation).

You can use the Pinnacle³ 2D tools to modify the display and obtain information about the ODM data. Right-click on the ODM viewing window to display the 2D menu and tools. See the *Pinnacle³ Planning Instructions for Use* for information about the 2D tools.

If no adjustments to the plan are necessary, continue to the *Conversion* section.

> **NOTE**
> If you print a trial that contains at least one valid ideal ODM, the words "Not for Clinical Use" will appear on the printout and you are not allowed to export the trial. Ideal ODMs have not been converted to a delivery device and cannot be used to deliver a treatment.

Modify the plan

If you need to make significant changes to the plan, reset the beams before you make your changes.

1   Click the **Reset Beams** button. The software does the following:

   • Restores each ODM to full transmission values for all beams.

   • Equalizes the weights for all beams whose **Optimization Type** is not **None**.

   • Removes the control points from all beams.

   • Removes any beams that the software created as a result of a beam being split. If you selected the **Allow jaw motion** check box for a beam, the software resets the jaw positions for that beam to expose all target ROIs.

2   Make changes to the objectives, constraints, or parameters as necessary.

3   Repeat the optimization.

Conversion

The software uses conversion algorithms to convert ideal ODMs to a form that is deliverable by a specific delivery device. P³IMRT currently supports conversion to MLC control point and compensator delivery devices. The following sections provide detailed information about the conversion algorithms used by P³IMRT. For more information on each conversion algorithm, see the *Reference Information* chapter.

Set IMRT conversion parameters for intensity modulation

Before you perform the conversion, you must enter the parameters that you want the software to use to convert the beams. If you already set the conversion parameters, you should review them before you perform the conversion.

In the **Inverse Planning** window, click the **IMRT Parameters** button. The **IMRT Parameters window** appears. The conversion parameters that appear in the **IMRT Parameters** window are described in the tables that follow. Parameters are saved for each trial.

> **NOTE**
> Not all of the conversion algorithms are available for all machines. IMFAST is available for Siemens machines only. Sliding Window is only available if you are licensed for sliding window.

General

These settings appear at the top of the **Conversion** tab in the **IMRT Parameters** window and are enforced regardless of which conversion algorithm you choose.

Parameter	Description
Convert after optimization	Select this check box if you want to automatically convert the beams when optimization is complete.
	Do not select the **Convert after optimization** check box until you are satisfied with your optimization results. Optimization is an iterative process. If you convert the plan after each optimization, you add unnecessary time to the process.
Compute final dose	Select this check box if you want to automatically compute dose when the conversion is complete.
	If you select both the **Convert after optimization** check box and the **Compute final dose** check box, the software will compute dose after the conversion.
Optimize weights after final dose	For Intensity Modulation plans: Select this check box if you want to automatically optimize beam weights when conversion is complete.
	For SmartArc plans: Select this check box if you want to automatically optimize segment weights when optimization is complete.

K-Means Clustering parameters

K-Means Clustering is step-and-shoot conversion algorithm that can be used by all machines. These settings appear when you select **K-Means Clustering** in the **Converter** option list.

Parameter	Description
Filter ODM prior to conversion?	Select **Yes** to have the software apply a 3x3-pixel median filter to the ODM prior to conversion. This removes large spikes from the ODM. As a result, fewer control points are required to deliver this smoother ODM, and the open area of the segments is larger in size, on average.
Compute ODM difference?	Select **Yes** to have the software automatically compute the ODM difference after conversion. If you select **Yes**, the conversion takes longer to complete.
	If you select **No**, the **Compute ODM Difference** button appears below the BEV viewing window when the conversion is complete. Click this button to compute the ODM difference manually.
Error tolerance	Enter the maximum percentage of error that you want to allow between the ideal ODM and the ODM created by the clustering algorithm prior to segment extraction.
	A smaller error tolerance generally results in a larger number of MLC control points and a more accurate representation of the ideal ODM.
Maximum levels	Enter the maximum number of discrete fluence levels that the K-means clustering algorithm uses when it attempts to achieve the specified error tolerance.
Minimize: • **Tongue and Groove Effect** • **Number of Segments**	Choose to minimize either the tongue and groove effect during final conversion or the number of segments in the final plan.
	By default, the K-means Clustering algorithm minimizes the tongue and groove effect. This can increase the number of control points in the final plan. To reduce the number of control points, select the **Number of segments** option. The algorithm will create fewer segments in the plan and will not minimize the tongue and groove effect.
Minimum segment area	Enter the minimum contiguous area that should be exposed by any MLC control point, regardless of whether it is exposed by the jaws.
Minimum segment MUs	Enter the minimum MUs required for each MLC control point.
	Do not use this option to reduce the number of control points per beam. This will degrade the accuracy of the conversion and make the conversion slower. You should only use this option to address the limitations of your linear accelerator. Enter the number of MUs below which your linear accelerator is no longer stable.
Beam splitting overlap distance	Enter the minimum distance that two beams should overlap if the software must split the beams. This value is approximate; the actual overlap distance after conversion may be smaller than the value that you enter.
	If the beam splitting overlap distance cannot be met sufficiently, the software splits the beams into more beams until the beam splitting overlap distance can be met.

IMFAST parameters

IMFAST is a step-and-shoot conversion algorithm that can be used by Siemens machines. The settings appear when you select **IMFAST** in the **Converter** option list.

NOTE

The software does not split beams if you choose the IMFAST conversion algorithm.

NOTE

If your plan uses the Siemens Artiste machine and you perform an IMFAST conversion on a field that is wider than 20 cm, a gap may remain between the MLC leaves and the virtual jaw for some control points. If you must treat a wide field with the Siemens Artiste machine, you must either use the **Use current jaws as max** option to limit the jaw width to 20 cm or perform a DMPO optimization to obtain acceptable results.

Parameter	Description
Filter ODM prior to conversion?	Select **Yes** to have the software apply a 3x3-pixel median filter to the ODM prior to conversion. This removes large spikes from the ODM. As a result, fewer control points are required to deliver this smoother ODM, and the open area of the segments is larger in size, on average.
Compute ODM difference?	Select **Yes** to have the software automatically compute the ODM difference after conversion. If you select **Yes**, the conversion takes longer to complete.
	If you select **No**, the **Compute ODM Difference** button appears below the BEV viewing window when the conversion is complete. Click this button to compute the ODM difference manually.
Number of levels	Enter the number of discrete fluence levels to be used by the clustering algorithm. Increasing the number of levels increases both the accuracy of the dose and the number of control points. Generally, you should set the number of levels between 5 and 20.
Number of extracts	Enter the number of extracts to be extracted from the ODM before the rod-pushing algorithm is applied.
Minimum segment area	Enter the minimum contiguous area that should be exposed by any MLC control point, regardless of whether it is exposed by the jaws.
Minimum segment MUs	Enter the minimum MUs required for each MLC control point.
	Do not use this option to reduce the number of control points per beam. This will degrade the accuracy of the conversion and make the conversion slower. You should only use this option to address the limitations of your linear accelerator. Enter the number of MUs below which your linear accelerator is no longer stable.

Sliding Window parameters

Sliding Window is a conversion algorithm that allows for a dynamic delivery. Because Sliding Window beams are complex, once a beam has been converted to a Sliding Window beam, you cannot do any of the following:

- Copy and oppose the beam
- Filter the beam
- Add or delete control points
- Change weights of control points
- Sort control points
- Change MLC leaf positions
- Change MUs of the control points or the beam

- Save dose for control points
- Add a block to the beam

You can change the couch position, gantry angle, and collimator as necessary.

> **NOTE**
> In order to compute dose for a Sliding Window beam, each control point in the beam must use the same jaw settings.

> **NOTE**
> After the conversion is complete, the weights for Sliding Window beams are displayed as cumulative weights. This means the weight displayed for each control point is not the weight of the individual control point, but it is the cumulative weight of all control points previous to and including the control point. The weights are not a percentage of total MUs for the beam as they are for other beam types.

These settings appear when you select **Sliding Window** in the **Converter** option list.

Parameter	Description
Filter ODM prior to conversion?	Select **Yes** to have the software apply a 3x3-pixel median filter to the ODM prior to conversion. This removes large spikes from the ODM.
Max control points	Enter the maximum number of control points each beam should contain.
Beam splitting overlap distance	Enter the minimum distance that two beams should overlap if the software must split the beams. This value is approximate; the actual overlap distance after conversion may be smaller than the value that you enter. If the beam splitting overlap distance cannot be met sufficiently, the software splits the beams into more beams until the beam splitting overlap distance can be met.

Compensator parameters

The Compensator conversion algorithm allows you to convert each beam's ideal ODM to a matrix of compensator thicknesses. These settings appear when you select **Compensator** in the **Converter** option list.

Parameter	Description
Filter ODM prior to conversion?	Select **Yes** to have the software apply a 3x3-pixel median filter to the ODM prior to conversion. This removes large spikes from the ODM.
Resolution	Enter the X and Y values for the compensator output resolution. The compensator is divided into a grid with this resolution. Thicknesses are determined for each section of the grid.
Density	Enter the density of the compensator material (in g/cm^3).
Source to compensator distance	Enter the distance from the source to the top of the compensator tray.
Field edge border	Enter the width of a border at the edge of the field, which defines the limits of the compensator design for the field. You can use this parameter to avoid optimizing the compensator in the penumbra region of the beam. This is applied to blocked field shapes and flash.
Max allowable thickness	Enter the maximum physical thickness for the compensator.

Parameter	Description
Thickness outside field	Sets the method of determining the thickness of the compensator outside the field. If you select **Mean Thickness**, the software uses the mean thickness of all compensator segments as the thickness outside the field.
	If you select **Zero Thickness**, **Min Thickness**, or **Max Thickness**, the software uses zero, the minimum compensator segment thickness, or the maximum compensator segment thickness, respectively, as the thickness outside the field. If you select **Specified Thickness**, a new field appears to let you specify the thickness outside the field, in cm.
	If you select the **Edge Thickness** option, the software uses the values from the closest edge of the optimized area. These values are projected out to the side of the compensator array.

Convert the ideal ODM

⚠️ **CAUTION**
Prior to converting the ideal ODMs to deliverable beams, we recommend that you copy the plan to a new trial. This will allow you to compare the dose delivered by the ideal ODMs with the dose delivered by the deliverable ODMs.

> **NOTE**
> You cannot convert beams using the K-means Clustering, IMFAST, or Sliding Window algorithms if the beam contains a block.

1   Click the **IMRT Parameters** button and review the conversion settings. Change the settings as necessary.

2   Convert the beams. To convert all the beams, click the **Convert All** button. To convert the beams individually, click the **Convert** button next to each beam that you want to convert.

When the conversion starts, the **Convert All** button becomes the **Cancel** button. If necessary, click the **Cancel** button to stop the conversion.

Review ODM difference

The deliverable ODM and ODM difference are shown below the BEV viewing window if the ODM difference was computed after conversion. The ODM difference shows the difference between the deliverable ODM and the ideal ODM for the selected beam. Black areas indicate areas where less dose will be delivered by the beam than would have been delivered by the ideal ODM. White areas indicate areas where more dose will be delivered by the beam than would have been delivered by the ideal ODM. The various shades of grey show the varying degrees of difference between the ideal and deliverable ODMs.

> **NOTE**
> If the **Compute ODM difference?** parameter is set to **No**, the **Compute ODM Difference** button appears below the BEV viewing window instead of the ODMs. Click the button to compute the ODM difference for the current beam.

You can use the Pinnacle³ 2D tools to modify the display and obtain information about the ODM difference data. Right-click on the ODM difference viewing window to display the 2D menu and tools. See the *Pinnacle³ Planning Instructions for Use* for information about the 2D tools.

> **NOTE**
> If you print a trial that contains a deliverable ODM, the color scale in the IMRT summary is inverted relative to the deliverable ODM in Pinnacle³. This is intentional, to make the color scale conform to the appearance of film.

4 DMPO

Overview

NOTE
DMPO is available only if you are licensed for DMPO.

A DMPO optimization is essentially equivalent to an intensity modulation optimization followed by conversion followed by an optimization of the MLC leaf positions and segment weights. MLC settings are produced during the optimization process, so no conversion, filtering, or weight optimization is necessary. In many cases, DMPO can result in a plan that can be delivered more efficiently than an intensity modulation plan.

Set IMRT parameters for DMPO

1   In the **Inverse Planning** window, click the **IMRT Parameters** button. The **IMRT Parameters** window appears.

2   Click the **Optimization** tab to display the optimization parameters. Optimization parameters are saved for each trial.

3   In the **Max iterations** field, set the maximum number of times the software should refine the plan.

4   In the **Convolution dose iteration** field, enter the number of iterations the software should perform before it computes the convolution dose and converts the trial to MLC segments.

5   In the **Stopping tolerance** field, change the stopping tolerance (if necessary).

The stopping tolerance is the sensitivity to change between objective values for successive iterations. If the objective values do not improve by greater than the stopping tolerance for two successive iterations, the optimization is considered satisfied and stops.

6   If the plan contains target ROIs that overlap critical structure ROIs, you may want to select the **Apply tumor overlap fraction** check box. If you select this option, a field appears in which you can specify the percentage of the weighting value describing how overlapping voxels will be treated during evaluation of the objective function. For more information, see *Overlapping ROIs and conflicting objectives* in the *Objectives and Constraints* chapter.

7   In the beams panel, select DMPO as the optimization type for each beam.

DMPO is available only for static photon beams that do not contain dynamic wedges, motorized wedges, compensators, or blocks.

8   Does the machine that you are using allow the jaws to move during treatment?

- Yes—The software optimizes the trial such that the jaws adjust to conform to the shape of each segment. The software automatically selects the **Allow jaw motion** check box, and you cannot deselect it.

- No—Select the **Allow jaw motion** check box if you want the jaws to conform to the target prior to optimization and maintain that position throughout treatment. Do not select the **Allow jaw motion** check box if you want the machine to maintain the current jaw positions.

9   Select the **Use current jaws as max** check box if you want to use the current position of the jaws as the maximum position of the jaws during the optimization.

10 For each beam, select the **Split if necessary** check box if you want to allow the beam to split.

> **NOTE**
> The software cannot split a beam if the beam contains a wedge.

> **NOTE**
> If a beam splits, the software names each resulting beam with a letter (a, b, c, etc., depending on the number of beams created) followed by the original beam name. The beams are grouped together in the beam spreadsheet.

11 Select the **DMPO** tab and use the fields available to set the specific parameters for DMPO. For more information, see *DMPO parameters*.

DMPO parameters

These settings appear in the **DMPO** tab and are applied only to beams that use the DMPO optimization type.

Parameter	Description
Maximum number of segments	Enter the maximum number of segments that should be distributed among all DMPO beams in the plan during optimization.
	If you change this value after your initial optimization, you must reset the beams before you optimize the plan using the new value.
Minimum segment area	Enter the minimum contiguous area that should be exposed by any MLC control point, regardless of whether it is exposed by the jaws.
Minimum segment MUs	Enter the minimum MUs required for each MLC control point.
	Do not use this option to reduce the number of control points per beam. This will degrade the accuracy of the conversion and make the conversion slower. You should only use this option to address the limitations of your linear accelerator. Enter the number of MUs below which your linear accelerator is no longer stable.
Compute final dose	Select this check box if you want to automatically compute dose when the conversion is complete.
Use SVD for dose calculation	If you select **Yes**, the software uses the SVD dose engine during optimization. If you select **No**, the software uses the TPB dose engine during optimization. For more information, see *Iterative dose computation* in the *Reference Information* chapter.
	If you select **Yes**, the **Fine Resolution ODM** option appears.
Fine resolution ODM	If you select **Yes**, the software uses an ODM resolution that matches the smallest MLC leaf width that is commissioned for the machine. (The smallest ODM resolution that the software allows is 0.2 cm x 0.2 cm.) The optimization takes longer if you use a fine resolution ODM.
	If you select **No**, the software uses an ODM resolution of 0.5 cm x 0.5 cm.
Minimum number of leaf pairs	Enter the minimum number of leaf pairs that should be allowed to create a segment for DMPO.
	If you set this value to 1, the software may create segments with only one leaf pair.
Minimum leaf end separation	Enter the minimum leaf end separation that should be allowed to create a segment.
	This value is applied to all leaf pairs in each segment opening, except for the two uppermost and the two lowermost leaf pairs. This prevents the occurrence of thin segments while allowing segments to close tightly.
	This value has no effect if the value that you enter is less than or equal to the minimum dynamic leaf gap that you set in Physics.
Beam splitting overlap distance	Enter the minimum distance that two beams should overlap if the software must split the beams. This value is approximate; the actual overlap distance after conversion may be smaller than the value that you enter.
	If the beam splitting overlap distance cannot be met sufficiently, the software splits the beams into more beams until the beam splitting overlap distance can be met.

Optimize the plan

In the **Inverse Planning** window, click the **Start Optimization** button. The software optimizes the plan.

During optimization, you can change the values in the **Target Dose**, **% Volume**, **% Variation**, **Weight**, and **a** fields. You can also change the value in the **Target Dose** field by clicking and dragging the corresponding objective's icon in the **Dose Volume Histogram** tab.

If necessary, you can click the **Stop Optimization** button to stop the current optimization. If you stop optimization before the software reaches the optimal plan or completes all the iterations, the results that appear are from the best iteration up to the point that you stopped the optimization.

⚠ **CAUTION**
If you have made significant changes since the last optimization, you should reset the beams. A significant change includes adding new objectives or constraints, removing objectives or constraints that were previously defined, and changing anything that changes the size or orientation of the field. For example, if you increase the size of a target ROI, you should reset the beams before you optimize again. Changing weight, dose, or volume values of objectives or constraints that are already defined do not require you to reset the beams.

> **NOTE**
> For DMPO: You cannot perform an optimization if a beam in the plan contains a dynamic wedge, a motorized wedge, a compensator, or a block. If you chose to use the SVD dose engine during optimization, you also cannot perform an optimization if a beam in the plan contains a standard wedge.

Modify the plan

If you need to make significant changes to the plan, reset the beams before you make your changes.

1 Click the **Reset Beams** button. The software does the following:

- Restores each ODM to full transmission values for all beams.

- Equalizes the weights for all beams whose **Optimization Type** is not **None**.

- Removes the control points from all beams.

- Removes any beams that the software created as a result of a beam being split. If you selected the **Allow jaw motion** check box for a beam, the software resets the jaw positions for that beam to expose all target ROIs.

2 Make changes to the objectives, constraints, or parameters as necessary.

3 Repeat the optimization.

5 SmartArc

Overview

> **NOTE**
> SmartArc is available only if you are licensed for SmartArc.

SmartArc plans use dynamic arc beams that allow you to deliver an optimized IMRT plan in a single gantry rotation.

You cannot do any of the following after the SmartArc optimization is complete:

- Copy and oppose the beams
- Filter the beams
- Add or delete control points
- Sort control points
- Change the MUs of individual control points (you can change the total MUs for a prescription)
- Change weights of control points
- Change the dose rate of control points
- Change MLC leaf positions
- Change the gantry angle, collimator angle, or couch angle
- Change the jaw positions

> **NOTE**
> SmartArc optimizations use an extremely memory-intensive algorithm. If you perform multiple SmartArc optimizations on the same system or network, you may notice a significant slowdown. See the *Troubleshooting and Performance* chapter in the *Pinnacle³ Planning Reference Guide* for suggestions on how to improve the performance of the software. If you require further assistance, contact Customer Support at 1-800-722-9377 (US and Canada) or your local distributor.

Set IMRT parameters for SmartArc

1 In the **Inverse Planning** window, click the **IMRT Parameters** button. The **IMRT Parameters** window appears.

2 Select the **Optimization** tab to display the optimization parameters. Optimization parameters are saved for each trial.

3 In the **Max iterations** field, set the maximum number of times the software should refine the plan.

A SmartArc optimization is divided up into several phases, in which different aspects of the problem are prioritized. As a result, most SmartArc optimizations require the maximum number of iterations. Therefore, you should allow the optimization to proceed until the software reaches the maximum number of iterations or finds an optimal solution.

4 In the **Convolution dose iteration** field, enter the number of iterations the software should perform before it computes the convolution dose and converts the trial to MLC segments.

If you do not select the **Compute intermediate dose** check box in the **SmartArc** tab, the software converts the trial to MLC segments without computing the convolution dose.

> **NOTE**
> If you intend to use SmartArc to treat a target objective that is highly convex and has few adjacent critical structures, you may obtain better dosimetric results if you set the convolution dose iteration to zero.

5 In the **Stopping tolerance** field, change the stopping tolerance (if necessary).

The stopping tolerance is the sensitivity to change between objective values for successive iterations. If the objective values do not improve by greater than the stopping tolerance for two successive iterations, the optimization is considered satisfied and stops.

6 If the plan contains target ROIs that overlap critical structure ROIs, you may want to select the **Apply tumor overlap fraction** check box. If you select this option, a field appears in which you can specify the percentage of the weighting value describing how overlapping voxels will be treated during evaluation of the objective function. For more information, see *Overlapping ROIs and conflicting objectives* in the *Objectives and Constraints* chapter.

7 In the beams panel, select **SmartArc** as the optimization type for the beams that you want to optimize. The SmartArc optimization type is available only for dynamic arc beams.

8 Does the machine that you are using allow the jaws to move during treatment?

- Yes—The software optimizes the trial such that the jaws adjust to conform to the shape of each segment. The software automatically selects the **Allow jaw motion** check box, and you cannot deselect it.

- No—Select the **Allow jaw motion** check box if you want the jaws to conform to the target prior to optimization and maintain that position throughout treatment. Do not select the **Allow jaw motion** check box if you want the machine to maintain the current jaw positions.

9 Select the **Use current jaws as max** check box if you want to use the position of the jaws for the first control point in the dynamic arc beam as the maximum position of the jaws during the optimization.

10 In the **# of arcs to create** option list, select the number of passes that the gantry should make for each dynamic arc beam. If you choose to have the gantry make two passes, the software creates an additional dynamic arc beam that has the opposite rotation direction as the initial beam. All other beam geometry for the new beam is the same as the initial beam.

> **NOTE**
> If you choose to have the gantry make two passes and your machine cannot deliver treatment in both a clockwise and counter-clockwise rotation, the additional dynamic arc beam is created with the same rotation direction as the initial dynamic arc beam.

You should use multiple arcs if the plan requires you to treat multiple target regions or if you are having trouble satisfying the objectives with a single arc. All arcs are optimized at the same time. However, if you use multiple arcs, optimization time and delivery time are longer.

11 In the **Final gantry spacing** option list, select the angle spacing (in degrees) that should remain between adjacent control points after optimization.

12 In the **Maximum delivery time** field, enter the approximate amount of time (in seconds) that the SmartArc treatment should last.

We recommend that you set a maximum delivery time that is a realistic estimate of the desired treatment time. Do not enter an unrealistically long maximum delivery time for a dynamic arc beam. If the maximum delivery time is too long, the software allows the MLC leaves to move slower, which may require lower dose rates in order to avoid delivering too much dose. This can result in a poor dose distribution when compared to a plan that uses a realistic maximum delivery time.

The actual delivery time may be different from the estimated delivery time that the software displays. The actual delivery time depends on how the machine controller interprets the segments.

> **NOTE**
> If you use an Elekta machine that does not have fixed jaws to deliver SmartArc treatments, you may obtain less than optimal dosimetric results if you specify an aggressive treatment delivery time. If you experience this issue, we recommend that you increase the delivery time slightly so that your delivery is not affected by jaw speed limitations.
>
> If you do not want to increase the treatment delivery time, you can change the **Default jaw behavior** parameter for the machine to **Static**. Some users have found that changing this parameter can produce better results for SmartArc plans. If you choose to change this parameter, you should commission a new machine to use for SmartArc treatments because the change in jaw behavior will apply to all beams that you create with the machine.

13 Select the **SmartArc** tab and set the parameters for SmartArc. For more information, see *SmartArc parameters*.

SmartArc parameters

These settings appear in the **SmartArc** tab and are applied only to beams that use the SmartArc optimization type.

Parameter	Description
Beam	Select the beam to which you want to apply the SmartArc settings.
Rotation direction	Click the **Rotation direction** button to reverse the rotation of the gantry.
Start angle **Stop angle**	Enter the angles at which the gantry should start and stop rotation. The smallest arc that can be defined is 24 degrees, so the start and stop angle must have at least a 24 degree difference.
Constrain leaf motion	Limit the distance that any given leaf can move during one degree of gantry rotation. When you select this check box, a field appears that allows you to enter the restriction (in cm/deg).
Compute intermediate dose	Select this check box to perform a fast convolve or adaptive convolve dose computation at the convolution dose iteration.
Compute final dose	Select this check box to compute final dose automatically when the optimization is complete.
Fine resolution ODM	If you select **Yes**, the software uses an ODM resolution that matches the smallest MLC leaf width that is commissioned for the machine. (The smallest ODM resolution that the software allows is 0.2 cm x 0.2 cm.) The optimization takes longer if you use a fine resolution ODM. If you select **No**, the software uses an ODM resolution of 0.5 cm x 0.5 cm.

Optimize the plan

In the **Inverse Planning** window, click the **Start Optimization** button. The software optimizes the plan.

During optimization, you can change the values in the **Target Dose**, **% Volume**, **% Variation**, **Weight**, and **a** values for objectives and constraints. You can also change the value in the **Target Dose** field by dragging the icon for an objective in the **Dose Volume Histogram** tab. However, you cannot change the **ROI** or **Type** assigned to an objective after optimization begins.

If necessary, you can click the **Stop Optimization** button to stop the current optimization. If you stop optimization before the software reaches the optimal plan or completes all the iterations, the results that appear are from the best iteration up to the point that you stopped the optimization.

⚠ **CAUTION**

If you have made significant changes since the last optimization, you should reset the beams. A significant change includes adding new objectives or constraints, removing objectives or constraints that were previously defined, and changing anything that changes the size or orientation of the field. For example, if you increase the size of a target ROI, you should reset the beams before you optimize again. Changing weight, dose, or volume values of objectives or constraints that are already defined do not require you to reset the beams.

NOTE
For SmartArc: You cannot perform an optimization if the plan uses constraints. You also cannot perform an optimization if a beam in the plan contains a compensator, block, or any type of wedge.

Modify the plan

If you need to make significant changes to the plan, reset the beams before you make your changes.

1   Click the **Reset Beams** button. The software does the following:

  • Equalizes the weights for all beams whose **Optimization Type** is not **None**.

  • Removes the control points from all beams.

  • Removes any beams that the software created as a result of a beam being split. If you selected the **Allow jaw motion** check box for a beam, the software resets the jaw positions for that beam to expose all target ROIs.

2   Make changes to the objectives, constraints, or parameters as necessary.

3   Repeat the optimization.

6 Evaluate IMRT Results

Overview

When the optimization is complete, you should review the control points and the MLC leaf positions. To use the MLC review tools, click the **Conversion** icon at the top of the **Inverse Planning** window to display the **Conversion** panel.

Intensity modulation and DMPO plans

Control points are automatically filtered during optimization. However, you can adjust the filter settings and filter the beams after optimization. For more information, see *Filter beams*.

Control points are automatically sorted after conversion to minimize delivery time. If you make changes to the control points manually, you can click the **Sort Control Points** button to sort the control points.

In the **Preferences** window, you can specify whether the software automatically rounds control point MUs for step-and-shoot beams. For more information, see the *Pinnacle³ Planning Reference Guide*.

SmartArc plans

The software displays the monitor units and weight of each control point in a dynamic arc beam as a cumulative value from the starting point in the arc up to the control point.

If you optimized a dynamic arc beam with a 4 degree final gantry spacing, you can click the **Interpolate** button to approximate an additional control point between each current control point. The result is a dynamic arc beam with a 2 degree final gantry spacing.

See the *SmartArc* chapter for a list of restrictions that apply to dynamic arc beams after you optimize a SmartArc trial.

Review MLC leaves

Use this procedure to review each control point. To review beams that contain many control points, use the **MLC movie** tool. For more information, see *MLC Movie tool*.

1   In the **Beam** option list above the **Control Point** spreadsheet, select the beam that has control points you want to review.

2   Review the MUs and weights for each control point.

    You can review detailed information for each control point in the **Control Points** window. To display this window, select **Options** - **Control Points**.

For SmartArc plans: The **Control Points** window contains several additional fields that are specific to dynamic arc beams.

3   Select the **Single MLC control point BEV display** or the **Consecutive MLC control point BEV display** and review the MLC leaf positions for each control point:
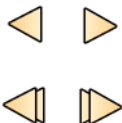
- Click the **Previous control point** and **Next control point** buttons to move backward and forward through the control points one at a time.

  If you chose the **Consecutive MLC control point BEV display**, you can also use the **Previous 12 control points** and **Next 12 control points** buttons to move through the control points. For example, if you are viewing control points 1 through 12 and you click the **Next 12 control points** button, the **Conversion** panel displays control points 13 through 24.

- To clip the MLC leaves to the jaws in the BEV viewing window, click the check box next to the **Clip leaves** option.

- To fill in the MLC leaves to make them easier to see, click the check box next to the **Fill in leaves** option.

- To display the maximum extent of the leaf openings across control points for step-and-shoot beams, click the check box next to the **Max leaf motion** option.

4   For intensity modulation or DMPO plans: You can modify the MLC leaves and control points.

- To modify a leaf position, click the **MLC Options** button. The **Beam MLC Leaf Position Editor** window appears. Edit the leaf positions as you would in a conventional plan. See the *Beam Modifiers* chapter in the *Pinnacle³ Planning Instructions for Use* for more information about editing MLC leaves.

- To delete a control point, select the control point and click the **Delete Current Control Point** button.

5   Repeat this procedure for each beam. You should also review the MLC settings after you load the information into your accelerator or MLC software.

MLC Movie tool

An alternative to reviewing each control point is to use the **MLC movie** tool to view a dynamic display of the MLC leaf positions.

1   Click the **MLC movie** icon. The MLC Movie options appear below the BEV viewing window.

2   Click the **Create Images** button. The software creates the MLC images.

3   View the images.

- To view the images one at a time, click the **Prev** and **Next** buttons to move backward and forward through the images.

- To view the MLC movie, click the **Play** button. The MLC leaf positions are displayed one at a time at the interval shown in the **Images/second** field. Click the **Stop** button to stop the movie.

Filter beams

> **NOTE**
> You cannot use the filter beam settings if you optimized the beams with the SmartArc optimization type.

The settings you choose for filtering affect how well the converted plan matches the optimized plan and the speed with which the converted plan can be delivered. Aggressive filter settings (large MU settings, large minimum field size) create plans with fewer control points and decreased delivery time, but the plans may not closely match the optimized plan. Less aggressive filter settings create plans that match the optimized plan more closely but require more control points. As a result, optimization and dose computation time is increased.

1   Click the **Filter Beams** button. The **Filter Beams** window appears.

2   Change the filter settings, if necessary.

Filter setting	Description
Minimum segment area	Enter the minimum contiguous area that should be exposed by any MLC control point, regardless of whether it is exposed by the jaws. MLC control points that expose less area are discarded, and the remaining control points are adjusted accordingly.
Minimum segment MUs	Enter the minimum MUs required for each MLC control point. MLC control points delivering fewer MUs are discarded, and the MUs of the remaining control points are adjusted accordingly.
	Do not use this option to reduce the number of control points per beam. This will degrade the accuracy of the conversion and make the conversion slower. You should only use this option to address the limitations of your linear accelerator. Enter the number of MUs below which your linear accelerator is no longer stable.
Minimum equivalent square	Enter the minimum equivalent square field size that you want to use. MLC control points whose jaws define an equivalent square less than this value are discarded, and the remaining control points are adjusted accordingly.
	The equivalent square used to look up OFc depends on your particular machine. If the MLC replaces one of the jaws, the equivalent square is defined by the maximum opening of the MLC leaves and the perpendicular jaw settings. Otherwise, the jaw settings are used.

3   Click the **Filter Current Beam** button to filter only the current beam, or click the **Filter All Beams** button to filter all the beams in the trial.

• The beams are filtered according to the filter settings.

• The individual areas of each control point are filtered rather than the total of all non-contiguous areas for each control point.

• The control points are sorted to minimize delivery time.

• Control point MUs are rounded to match the delivery precision of the machine.

NOTE
If dose is not computed for a beam and the prescription is in **Prescribe** mode prior to filtering, segments for that beam will not be filtered based on the minimum segment MU setting. Segments will be filtered according to the minimum area and minimum equivalent square settings.

7 Compute Final Dose

Overview

The software calculates the final dose after optimization as absolute dose, which means the machine assigned to each beam must have defined output factors. See the *Calculate Dose* chapter in the *Pinnacle³ Planning Instructions for Use* for information about the dose engines.

The final dose for a single beam direction, even one made of MLC control points, is computed with a single TERMA (total energy released per unit mass) and superposition computation, and takes into account the effects of each delivery device used by the beam.

Compute dose

⚠ **WARNING**
To ensure accurate dose computation, the final dose computation must be performed using the CC Convolution or Adaptive Convolve dose engine.

⚠ **CAUTION**
If the monitor units appear with a tilde (~), the values are approximate. Monitor units are approximate if you use the Fast Convolve dose engine, if you have a dose grid resolution of more than 0.5 cm in any dimension, or if you have not yet computed final dose. In these cases, you cannot export the prescription and, if you print the trial, the words "Not for Clinical Use" appear on the printout.

If you set the **Compute final dose** option to **Yes** on the **Optimization** tab of the **IMRT Parameters** window, the software automatically computes the final dose after optimization using the dose engine that you selected in the **Preferences** window. See the *Pinnacle³ Planning Reference Guide* for more information on preferences.

If you set the **Compute final dose** option to **No**, you can optimize the plan again or use the following procedure to compute the final dose manually.

1   In the **Beams** spreadsheet on the **Conversion** panel, select the dose engine to be used for each beam.

2   Click the **Compute** button for each beam to compute final dose.

To compute dose for all beams, click the **Compute** button for one beam, then click the **Redo spreadsheet** tool to compute dose for the remaining beams.

You can adjust the monitor units or the percent of dose in the **Prescription** window to scale the DVHs uniformly for the plan. If you change any control points after you compute final dose, dose is invalidated.

Finalize monitor unit precision

> **NOTE**
> If you choose to round control point monitor units (MUs), we recommend that you
> normalize your plan according to the prescription that you want to use before you
> round the MUs.

Starting with Pinnacle³ 9.0, the optimization algorithm always sets the prescription to **Set Monitor Units** and then optimizes the MUs for each control point. At the end of the optimization, the MU precision for each *beam* should match the precision commissioned in the physics tool. However, the *control point* MU may not match the precision that you commissioned if you did not choose to round MUs in the **Preferences** window. In this case, a tilde (~) appears next to the MUs to indicate that the MU precision does not match. However, the presence of the tilde does not prevent you from using the plan clinically because the MUs are still valid. If you prefer that the tildes do not appear, click the **Finalize MU Rounding** button. This will invalidate the dose because rounding the MUs may change the dose distribution, and you will have to recompute. Final MUs will be at the precision that was commissioned in the physics tool, however. After recomputing the plan, we recommend that you review it due to the potential changes in the dose distribution.

> **NOTE**
> The **Finalize MU Rounding** button only appears if you chose to round MUs in the
> **Preferences** window.

> **NOTE**
> There are scenarios that would cause the tilde to appear and the plan to not be valid,
> including the use of **Fast Convolve** as your dose engine or a dose grid resolution of
> greater than 0.5 cm. In these cases, the software will prevent you from exporting the
> plan and the printed trial report will include the words "Not for Clinical Use."

Refine dose

If the final dose does not meet your objectives closely enough, you can perform segment weight or beam weight optimization to refine the final dose.

Segment weight optimization

> **NOTE**
> Segment weight optimization is not an option for electron, stereotactic, or proton beam
> types.

Intensity modulation and DMPO plans

Segment weight optimization may be time consuming because the software must compute dose for each control point in each beam prior to the initial optimization. Dose is computed using the dose engine that is currently selected in the **Conversion** window. You can reduce the overall optimization time by selecting **Adaptive Convolve** rather than **CC Convolution** prior to optimization. Subsequent optimizations during the same planning session take less time because

the dose for each control point is saved during the initial segment weight optimization. (Dose for the control points is not saved when you end the planning session.)

Constraints in intensity modulation and DMPO plans may not be satisfied because of the reduced number of parameters used in segment weight optimization. To avoid this problem, convert the constraints to objectives before you start the segment weight optimization.

SmartArc plans

Segment weight optimization is fast because the software computes and stores dose for each control point during the SmartArc optimization. We recommend that you perform a segment weight optimization after your SmartArc optimization to improve the quality of the plan.

To have the software automatically perform a segment weight optimization after you optimize a SmartArc plan, set the **Optimize weights after final dose** option to **Yes** on the **Conversion** tab of the **IMRT Parameters** window.

Procedure

1   Click the **Optimization** icon to return to the **Optimization** panel.
2   Click the **IMRT Parameters** button. The **IMRT Parameters** window appears.
3   Change the optimization type of each beam to **Segment Weight**.
4   Are the beams dynamic arc beams?
    • Yes—The software optimizes the trial based on the optimization parameters for the beam and the delivery capabilities of your machine.
    • No—Select the **Segment Weight** tab and enter the minimum MUs required for each MLC control point.
5   In the **Inverse Planning** window, click the **Start Optimization** button.

Beam weight optimization

> **NOTE**
> Beam weight optimization is not an option for beams that were optimized with the SmartArc optimization type.

1   Click the **Optimization** icon to return to the **Optimization** panel.
2   Click the **IMRT Parameters** button. The **IMRT Parameters** window appears.
3   Change the optimization type of each beam to **Beam Weight**.
4   Click the **Start Optimization** button.

Change the prescription

⚠ **CAUTION**
For SmartArc plans: If you change the total monitor units for a beam such that the gantry speed or the MLC leaf speed exceeds the limitations of the machine, the field becomes red to indicate

that the beam is not deliverable. When the field is red, the printed report marks the beam MUs with "++" and indicates that the prescription exceeds machine limitations.

P³IMRT changes the prescription from **Prescribe** mode to **Set Monitor Units** mode at the beginning of an optimization so that dose is not normalized during optimization or conversion. During optimization, the MUs for the prescription are modified and beam weights are specified proportional to monitor units to meet the stated objectives.

When approving a plan, the physician may prefer to review the prescription in **Prescribe** mode rather than **Set Monitor Units** mode. If necessary, follow the procedure below to reset the prescription to the **Prescribe** mode so that it matches the prescription as it was originally stated by the physician.

1   Select **Options** - **Prescriptions**. The **Prescription Window** appears.

2   Click the **Edit** button. The **Edit Prescription** window appears.

3   Click the **Prescribe** radio button. Verify the dose and the other prescription parameters.

> **NOTE**
> If the physician's prescription is specified relative to **Point Dose**, the beam weights should be specified proportional to monitor units. If beam weights are specified proportional to **Point Dose**, the resulting dose distribution will not reflect the optimal solution found during optimization. This will be reflected when you compare DVHs before and after you change the prescription.

4   Click **Close**.

Refer to the *Pinnacle³ Planning Instructions for Use* for information about setting up a prescription.

> **NOTE**
> For intensity modulation and DMPO plans: If you filter beams after conversion and then change the prescription as described in this section, the number of MUs for a given control point may be less than the minimum segment MUs you set in the filter settings. Re-filter the beams when you are finished resetting the prescription.

8 Plan Evaluation Tools

Overview

The software provides a variety of tools for evaluating and comparing treatment plans. This chapter describes how to use the following plan evaluation tools:

- Evaluate trials with a scorecard
- Evaluate plans with dose volume histograms
- Compute dose to a plane
- Evaluate plans with QA phantoms
- Evaluate plans with DRRs

Evaluate trials with a scorecard

In the **Scorecard** window, you can define clinical goals and then evaluate how well the trials in the plan meet those goals. When you save your plan, the scorecard is saved along with it, although the computed results are not saved.

You can define goals for a plan, and then save those goals to a library to use with other plans.

You can open the **Scorecard** window by clicking the **Scorecard** button at the top of the **Plan Evaluation** window. You can also open it from the **Utilities** menu in either the **Planning** window or the **Plan Evaluation** window.

About sample scorecards

There are sample scorecards in the scorecard library to provide you with a starting point as you develop your scorecards. These sample scorecards were developed based on RTOG protocols. We recommend that you create copies of the sample scorecards (by saving the sample scorecards with new names that are appropriate for your clinical practices) and then change the copied scorecards as needed.

> **NOTE**
> If you reinstall Pinnacle³ or install a new version of Pinnacle³, any changes you have made to the sample scorecards are overwritten and the original samples are restored. To retain your changes to the sample scorecards, save the sample scorecards with new names before you change them.

Create a scorecard

1   On the **Utilities** menu in either the **Planning** window or the **Plan Evaluation** window, click **Scorecards**, and then click **Scorecard Library**. The **Scorecard Library** window opens.

2   Do you want to create a new scorecard or create a copy of a sample scorecard?

   • Create a new scorecard—Click **New**. The **Scorecard** window opens.

   • Create a copy of a sample scorecard—Select a sample scorecard (or any existing scorecard) from the list and click **Load**. The **Scorecard** window opens. On the **File** menu, click **Save Scorecard to Library**. In the window that opens, type a name for the scorecard and click **OK**. The scorecard name displays in the **Name** field at the top of the **Scorecard** window.

3   In the **Description** field, type a description for the scorecard.

4   At the bottom of the window, click **Add Goal**, and then set the values for the goal appropriately.

Field	Description
ROI	ROI for which you set a goal (see *About ROIs and POIs in treatment techniques and scorecards*)

Field	Description
Type	Type of goal. The goal is met under the following conditions:
	• **Min DVH (%)**—At the volume (%) that you specify in the goal, the dose that is delivered to the ROI is greater than or equal to the dose value that you specify in the goal.
	• **Max DVH (%)**—At the volume (%) that you specify in the goal, the dose that is delivered to the ROI is less than or equal to the dose value that you specify in the goal.
	• **Min DVH (cm3)**—At the volume (cm^3) that you specify in the goal, the dose that is delivered to the ROI is greater than or equal to the dose value that you specify in the goal.
	• **Max DVH (cm3)**—At the volume (cm^3) that you specify in the goal, the dose that is delivered to the ROI is less than or equal to the dose value that you specify in the goal.
	• **Min Dose**—The minimum dose that is delivered to the ROI is greater than or equal to the dose value that you specify in the goal.
	• **Max Dose**—The maximum dose that is delivered to the ROI is less than or equal to the dose value that you specify in the goal.
	• **Mean Dose**—The mean dose that is delivered to the ROI is less than or equal to the dose value that you specify in the goal. This goal is intended for use with OARs (organs at risk) rather than targets.
Primary Goal Dose **Primary Goal Volume**	Dose goal that the trial must meet. For dose goals that require a volume, set the volume for the dose goal.
Secondary Goal Dose **Secondary Goal Volume**	Dose goal that the trial should meet if the **Primary Goal Dose** cannot be met. (The **Secondary Goal Dose** is the goal that is less stringent but still acceptable.) For dose goals that require a volume, set the volume for the dose goal.

5   Continue to add goals and set the values until you are satisfied with the goals.

6   Do you want to use this scorecard for other plans?

- No—Continue to *Compute a scorecard*.

- Yes—On the **File** menu, click **Save Scorecard to Library**. In the window that opens, type a name for the scorecard and click **OK**. The scorecard name displays in the **Name** field at the top of the **Scorecard** window. Continue to *Compute a scorecard*.

Compute a scorecard

Before you compute a scorecard, compute dose for the trial that you want to evaluate. If you have already created a scorecard for this plan, you can open the **Scorecard** window and go to step 3.

When prior dose is included, the **Dose Display Mode** (either **Prior Dose Only** or **Current Dose and Prior Dose**) displays to the left of the trial name. See *Assess the impact of prior dose* in the *Planning Instructions for Use*.

⚠ **CAUTION**
Scorecard results are intended to be used in conjunction with other plan evaluation tools. We recommend that you follow the established clinical procedures for plan review and approval.

1   On the **Utilities** menu in either the **Planning** window or the **Plan Evaluation** window, click **Scorecards**, and then click **Scorecard Library**. The **Scorecard Library** window opens.

2   Create a scorecard (see *Create a scorecard*) or load a scorecard from the library. To load a scorecard, select the scorecard from the list and click **Load**.

If you have a large number of scorecards, you can filter the list using search terms. For example:

- To display only those scorecards with the word "breast" anywhere in the name, type "breast" in the **Scorecard Name** field and click **Filter**.

- To display only those scorecards with the words "head and neck" anywhere in the name and the words "DMPO trial" anywhere in the description, type "head and neck" in the **Scorecard Name** field, type "DMPO trial" in the **Description** field, and then click **Filter**.

Click **Show All** to clear the filter and show the full list again.

3   In the upper-right corner of the **Scorecard** window, select the trial that you want to evaluate.

4   Click **Compute**.

The software analyzes the trial and determines how well the trial meets the clinical goals. The results of the analysis display in the scorecard.

Field	Description
Dose	Dose statistic for the dose to the ROI that is used in the goal. The type of dose statistic that displays varies based on the type of goal: • **Min DVH** or **Min Dose**—Minimum dose from the trial to the ROI • **Max DVH** or **Max Dose**—Maximum dose from the trial to the ROI • **Mean Dose**—Mean dose from the trial to the ROI
Volume at Primary Goal Dose	For DVH goals, the actual volume receiving the amount of dose that is specified in the **Primary Goal Dose**
Result	Result of the goal: • **Met**—**Primary Goal Dose** is met • **OK**—**Primary Goal Dose** is not met, but **Secondary Goal Dose** is met • **Not Met**—Neither **Primary Goal Dose** nor **Secondary Goal Dose** is met

5   In the upper-right corner of the **Scorecard** window, select a different trial and click **Compute** to display the scorecard results for that trial.

6   Continue to select different trials and click **Compute** to see the results of the analysis for each trial and to compare the results of the different trials. You can also click **ROI Statistics** to view the statistics for the ROIs, if needed.

7   On the **File** menu, click **Close Window** to close the **Scorecard** window.

> **NOTE**
> When you compute a scorecard, the result may be unclear when the goal and the computed result are very close. For dose values, this is more likely to occur when the **Dose Display Decimal places** field in the **Preferences** window has a low value. For example, a goal may display as **Not Met** even when the values for the **Primary Goal Dose** and **Dose** appear to be the same. When this occurs, the two values differ, but the difference is so small that the difference is not evident because there are insufficient decimal places displayed to show the difference. To avoid this issue with regard to dose values, set the **Dose Display Decimal places** field to a higher value.

Delete a scorecard

1   On the **Utilities** menu in either the **Planning** window or the **Plan Evaluation** window, click **Scorecards**, and then click **Scorecard Library**. The **Scorecard Library** window opens.

2   Select a scorecard from the list and click **Delete**.

Evaluate plans with dose volume histograms

⚠️ **CAUTION**
The DVH default is normalized to the percent of maximum dose. The maximum dose is the maximum anywhere in the dose grid and may cause the DVH to be misinterpreted. We recommend that you select absolute dose or specify the maximum dose rather than using the default. For detailed information about how maximum dose is calculated, see the *Pinnacle³ Planning Reference Guide*.

⚠️ **CAUTION**
The ROI statistics shown in the Regions Of Interest window and the Dose Volume Histogram panel of the Plan Evaluation window may not exactly match those shown in the Optimization panel. The values in the Optimization panel are calculated using a coarser resolution to improve the speed of the objective function computation and do not take into account the tumor overlap fraction. This means that the graphical indicators for the objectives shown on the DVH may indicate that the objective is met while the numeric values may indicate it is not, or vice versa.

You can summarize the dose distribution for selected regions of interest (ROIs) across multiple trials with dose volume histograms (DVHs). You can also summarize dose distribution for ROI groups across both trials and records. DVHs provide plots of normalized or absolute dose versus normalized or absolute volume. From the DVHs you can determine the distribution of dose within given volumes. However, the DVHs do not provide any spatial information about the dose distribution.

If any of the trials selected in the DVH include prior dose (the **Dose Display Mode** is either **Prior Dose Only** or **Current Dose and Prior Dose**), then those trials are indicated in orange in the **Trials** list, and the text "**Includes Prior Dose**" displays on the DVH. See *Assess the impact of prior dose*.

> **NOTE**
> When you copy a plan to a new image set with or without deformation, prior dose values for the new plan will be slightly different than those of the original plan. Small differences in prior dose values are expected because the resolution, size, and alignment of the dose grid for each plan are inherently different.

1   Select **Options** - **Plan Evaluation**.

The **Plan Evaluation** window appears. The **Dose Volume Histogram** panel is selected.

> **NOTE**
> To return to the **Dose Volume Histogram** panel from another panel, at the top of the **Plan Evaluation** window click the **DVH** button.

2   In either the **Trials** list or the **Trials and Records** list on the **ROI Group** tab, select the **Display** check box for the trials or records that you want to evaluate. If you want to display multiple items, use the **Line Type** option lists to distinguish among DVH line types.

You can clear the **Display** check box for an item to remove all DVH lines for that trial or record.

3   In either the **ROIs** list or the **ROI Groups** list on the **ROI Group** tab, select the **Display** check box for the ROIs or ROI groups that you want to evaluate. The DVHs appear for the ROIs in the selected trials and records using the current DVH calculation and display options.

You can clear the **Display** check box for an ROI or ROI group to remove all DVH lines for that ROI or ROI group.

> **NOTE**
> If beams are re-weighted or recalculated or if ROI volumes change, the DVHs are automatically recalculated.

> **NOTE**
> The color of the DVH line is linked to the ROI or ROI group color, so the line color cannot be changed.

> **NOTE**
> You can obtain NTCP and TCP response values for an ROI using the Lyman-Kutcher model. In the **Plan Evaluation** window, select **Utilities** - **Edit NTCP/TCP**. For more information, see the *Plan Evaluation Tools* chapter in the *Pinnacle³ Planning Reference Guide*.

> **NOTE**
> For proton spot scanning beams, if the energy defined for a beam is not sufficient to completely cover the target ROI, the software will compute dose for that beam for as much of the ROI as possible. Review the DVH for the ROI to confirm that the trial dose distribution is what you expect for the ROI, and adjust the plan if necessary.

4   In the **ROIs** list, enter a value for the 'a' parameter for each ROI. The generalized EUD (gEUD) equation requires a single parameter 'a'. The 'a' parameter controls the sensitivity of the gEUD computation to hot or cold dose areas within the specified ROI. (This parameter is not available on the **ROI Group** tab.)

Click the **Compute** button above the **gEUD** column to compute gEUD values. If you change dose or edit an ROI, the software invalidates gEUD values. If you change the 'a' parameter for an ROI after you compute gEUD values, the software automatically recomputes the gEUD value for that ROI.

- **a < 1**—appropriate for ROIs representing targets. As the 'a' value becomes smaller (or more negative), the gEUD computation becomes more sensitive to cold spots.
- **a = 1**—corresponds to the mean dose to the target.
- **a > 1**—appropriate for ROIs representing critical structures. As the 'a' value becomes larger, the gEUD computation becomes more sensitive to hot spots.

> **NOTE**
> The 'a' parameter field (in the **ROIs** list) and the **Generalized EUD** field (in the **ROI Statistics** spreadsheet) appear only if you are licensed for Biological Evaluation.

5   Select the desired DVH calculation and axis display options. The DVH is automatically recalculated and displayed using the new settings.

Group	Option	Description
DVH Calculation	**Cumulative**	DVH displays the total volume that has received a given dose or more.
	Differential	DVH displays the distribution of dose received by each volume unit of the specified structure.
Dose Axis Display	**Normalized Dose**	The dose to the ROI is normalized to 1.0 (100%), and the dose axis of the DVH shows the percent of maximum dose to the specified ROI.
	Absolute Dose	The dose axis of the DVH shows absolute dose to the ROI (in cGy or Gy).
	Auto-Compute Max	Select this option to let the software compute the maximum dose value in the ROI. This option is selected by default.
	Specify Max Dose	Select this option to specify the maximum dose yourself. This option is commonly used with brachytherapy plans, which sometimes have high doses that fall outside the maximum range of the histogram. The percentage of the structure volume with a dose greater than the maximum histogram dose is shown in the **% > Max** column of the **ROI Statistics** spreadsheet.
Volume Axis Display	**Normalized Volume**	The volume is normalized to 1.0 (100%), and the volume axis of the DVH shows the percent of the ROI volume receiving a given dose.
	Absolute Volume	The volume axis of the DVH shows the actual volume (in cm^3) receiving a given dose.

NOTE
The software calculates the **% > Max** value by dividing the volume of all voxels whose values exceed the range of the last histogram bin by the total volume of the ROI. Therefore, the value that the software uses to calculate the **% > Max** value may not be the same as the value that you enter in the **Specify Max Dose** field.

6   If you want to view the DVH for an ROI in tabular format, select the ROI in the **ROI Statistics** spreadsheet and click the **Tabular DVH** button.

The tabular DVH display is controlled by the following parameters in the top section of the window. These controls also affect the graphical DVH display.

- **DVH**—Select the DVH for tabular display.
- **Include in plan report**—Choose whether the currently displayed tabular DVH prints with the plan report.
- **Set Number of Bins/Set Bin Size**—Choose how the DVH table is generated. Changes to these parameters also affect the DVH plots.
  - Use the **Set Number of Bins** option to specify the number of bins in the histogram. Bin size is calculated by dividing the maximum dose by the number of bins.
  - If you choose **Set Bin Size**, you can specify the size of the bins in the histogram in cGy. The number of bins are calculated by dividing the maximum dose by the bin size.
- **Columns**—Specify the number of columns used to display and print the tabular DVH.

- **Copy All Settings to Other DVHs**—Click this button to copy the tabular settings for the currently selected DVH to all other DVHs.

7 Use the **DVH Tools** to get dose and volume values for a point on a curve and to zoom into the graph.

- Click the **Track** tool, then click on or near a point on a curve. The dose and volume values appear in a box in the upper right corner of the graph. At the bottom of the box are the curve's trial and record information. Moving the mouse allows you to see the changes in values.

  To switch to a different curve, click on the curve or select it from the list in the **ROI Statistics** spreadsheet at the bottom of the window. This selects the point on the curve at the same dose. To stop tracking, click the tool again to turn it off. To return the DVH to its original state before any tracking or zooming, click **Reset**.

- Click the **Box Zoom 2D** tool and click and drag to create a rectangle to define a subset of the graph to display. You can zoom further by clicking and dragging again. To reset the zoom level to the default setting, click the tool again to turn it off. To return the DVH to its original state before any tracking or zooming, click **Reset**.

Compute dose to a plane

The Planar Dose option lets you generate a two-dimensional dose array (planar dose) for any beam at a given depth in a flat water phantom or the current image set. The dose map is displayed by default in inverse greyscale. Planar dose maps may be printed or exported to files for comparison with measurements.
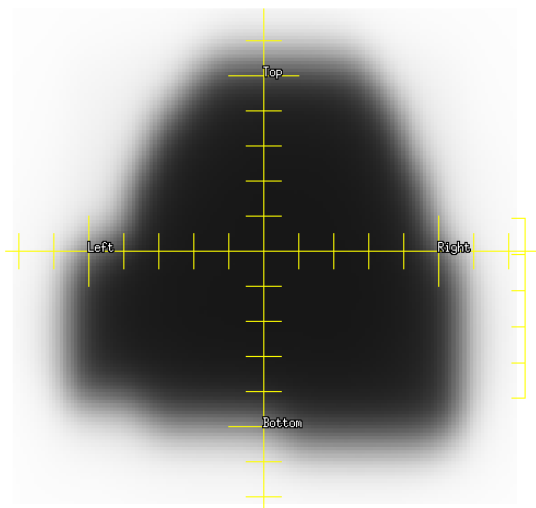
NOTE
In the sample dose plane shown above, the negative y-axis points upward in the beam's eye view because the machine was commissioned with the tray opening toward the bottom of the image. Pinnacle[3] ignores collimator rotations for planar dose reconstruction, and the negative y-axis is always opposite the tray opening.

NOTE
The planar dose algorithm only computes dose within the volume of the patient or water phantom, including any extension you defined when you set up the dose grid.

See the *Pinnacle[3] Planning Reference Guide* for more information on the planar dose settings.

Compute planar dose on static and step-and-shoot beams

1   Select **Utilities** - **Planar Dose**.

The **Planar Dose Computation** window opens.

2   Select the appropriate trial from the **Trial** option list.

3   Click the **Add Plane** button to add a new dose computation, or click the **Add Plane Per Beam** button to add dose planes for all beams in the trial.

NOTE
To delete the selected dose plane, click the **Delete Plane** button. To delete all dose planes, click the **Delete All** button.

4   If you want to label the dose plane, type a name in the **Name** field.

5   Click the **Beam** option list and select the beam for which you want to calculate dose.

6   Do you want dose calculated as if the beam is being delivered to a flat water phantom or the current patient image set?

- Flat water phantom—In the image set option list on the **Planes** tab, select **Phantom**. The software computes planar dose based on the geometry of the beam that is selected.

- Patient image set—Select **Primary data** from the image set option list on the **Planes** tab.

   > **NOTE**
   > If the beam is a proton beam, or if you added a static beam to compute planar dose on a plan that uses arc beams, conformal arc beams, dynamic arc beams, or beams with motorized wedges, select the **Primary data** option from the image set option list on the **Planes** tab.

7   If necessary, change the couch angle by typing a new value in the **Couch** field.

8   If necessary, change the gantry angle by typing a new value in the **Gantry Start** field.

9   If you selected **Primary data** in step 6, then go to step 11. Otherwise, go to step 10.

10 Type the source to plane distance (**SPD**) and the source to surface distance (**SSD**) of the beam to the phantom. Go to step 13.

11 Type the source to plane distance (SPD) of the beam in the **SPD** field.

12 If you selected **Primary data** on the **Planes** tab, the dose grid settings option list appears. You can then select one of the two options that follow:

- **Compute beam**—The software computes planar dose based on the gantry and couch angles that you enter in the fields available and the geometry of the beam selected.

- **Sample trial**—The software interpolates planar dose from the trial dose grid. Using the **Sample trial** option is equivalent to a composite dose. When prior dose is included, the **Dose Display Mode** (either **Prior Dose Only** or **Current Dose and Prior Dose**) displays on the planar dose image. See *Assess the impact of prior dose*.

   > **NOTE**
   > If the beam is a proton beam, or if you added a static beam to compute planar dose on a plan that uses arc beams, conformal arc beams, dynamic arc beams, or beams with motorized wedges, select the **Sample trial** option from the image set option list on the **Planes** tab.

13 On the **Dose** tab, use the **Resolution** field to set the resolution of the dose distribution. The smaller the resolution, the finer the dose display, and the longer the calculation time.

The TERMA grid resolution is determined by either the trial dose grid or the user-specified resolution. Therefore, you should set the planar dose grid resolution to match the TERMA grid resolution to avoid a loss of resolution in the planar dose image.

14 Set the dimensions of the dose map in the **Dimension** fields. As a default, the dose map dimensions are set to include a 1.5 cm margin around the exposed field.

15 If necessary, change the display color of the dose map in the **Color** option list.

16 Click the **Compute** button. When the planar dose computation is complete, the dose distribution appears in the viewing window.

The planar dose is computed in cGy/MU for the selected beam. If you chose to sample the trial dose grid, the dose values in the plane are in cGy or Gy, depending on the **Dose Display** setting in the **Preferences** window.

> **NOTE**
> If you are licensed for proton treatment planning and the trial contains a proton beam, dose values in the plane are computed in cGy(RBE) or Gy(RBE).

To compute multiple dose planes, click the **Compute** button for the first plane, and then click the **Redo spreadsheet** button to compute the remaining planes.

> **NOTE**
> The trial dose grid must be large enough to encompass all of the high dose region. Otherwise planar dose may be incorrect.

If necessary, you can use the 2D tools to modify the display and obtain information about the data. Right-click the planar dose viewing window to display the 2D menu and tools. For more information on the viewing windows, see the *View Patient Data* chapter in the *Pinnacle³ Planning Instructions for Use*.

Troubleshoot planar dose

- If the planar dose image appears to be cut off, go to the **Dose Grid** panel in the **Planning** window and extend the top or bottom slice of the CT image. This should make the rest of the planar dose image visible.

- On a plan with uncomputed beams, planar dose may not compute properly. To avoid this issue, compute all beams in the plan before computing planar dose.

Compute planar dose on other beam types

⚠ **CAUTION**
If you select Primary data and Sample trial for an arc beam, conformal arc beam, or dynamic arc beam, the software uses the gantry start angle for the arc to define the plane.

To compute planar dose on plans that use arc beams, conformal arc beams, dynamic arc beams, or beams with motorized wedges, add a new static beam to the plan and compute planar dose using the geometry of the static beam.

1   Compute dose on all beams in the original plan.

2   Add a new static beam. Ensure that the relative weight for this beam is zero.

3   Compute dose on the new static beam.

4   To define a plane within the dose grid, set the couch, collimator, and gantry angle for the static beam to reflect the desired plane orientation.

5   Compute planar dose for the new static beam. See *Compute planar dose on static and step-and-shoot beams*.

Use arbitrary point files for defining points on film

You can use a point file that defines the *x,y,z* locations of the planar dose pixels in world coordinates. This allows you to specify a spiral (or any other shape) phantom and compute dose to each point on the "plane."

The point file is a space-delimited ASCII text file in the following format:

```
x_dim y_dim resolution
point1.x point1.y point1.z
point2.x point2.y point2.z
...
```

The following is a sample point file:

```
84 13 0.500
15.110 30.680 11.700
14.919 30.189 11.700
15.034 29.658 11.700
15.351 29.215 11.700
15.818 28.980 11.700
...
```

where 84 is the *x* dimension, 13 is the *y* dimension and 0.500 is the resolution. In this example there are 84*13 sets of *x,y,z* coordinates representing the world location of each pixel in the 84x13 pixel array.

> **NOTE**
> You can only use point files for dose planes that use the patient image set. You cannot use point files with water phantoms.

1 If a dose plane does not exist, create one before proceeding.

2 In the **Planar Dose Computation** window on the **Dose** tab, click the **File Input** button. The **Select Point File For Planar Dose** window opens.

3 Select the **Yes** radio button to use the point file for plane definition.

4 Use the directory tools to locate and select the point file.

5 Click the **OK** button.

Print planar dose

After you compute planar dose, you can print the dose plane.

1 In the **Planar Dose Computation** window, change the **Scale** value, if necessary, to print a dose display that is smaller or larger than the value currently shown.

   A value of "1" creates a life-sized print of the dose distribution.

2 Click the **Print Using X:1 Scale** button. The **Print** window opens. Adjust the print settings as needed. For information about the settings, see the *Print* chapter in the *Pinnacle³ Planning Instructions for Use*.

3   Click the **Proceed** button.

4   From the confirmation dialog box that opens, choose **Yes** to print the image. Choose **No** to cancel printing.

Print planar dose to a DICOM printer

After you compute planar dose, you can preview and print the dose plane to a DICOM printer. You can also print the dose plane as a secondary capture or computed radiography image. For more information about how to print DICOM images, see the *Print* chapter in the *Pinnacle³ Planning Instructions for Use*.

1   In the **Planar Dose Computation** window, click the **DICOM Print Preview** button to preview the dose plane. Click the button again to return to the normal view.

     When you print a dose plane using DICOM, the annotations are "burned" onto the image. Before printing, verify that the annotations do not overlap something important. If necessary, you can use the Pinnacle³ 2D tools to modify the display before printing.

     You can choose which annotations are included when the dose plane is printed by selecting film annotation options in **Preferences**.

2   Click the **DICOM Print** button. The **Print** window opens. Adjust the print settings as needed. For information about the settings, see the *Print* chapter in the *Pinnacle³ Planning Instructions for Use*.

3   Click the **Proceed** button.

4   From the confirmation dialog box that opens, choose **Yes** to print the image. Choose **No** to cancel printing.

Export planar dose

After you compute planar dose, you can export the information to a file.

1   In the **Planar Dose Computation** window, type the name of the directory to which you want to export the file. If necessary, click the **Browse** button to locate a directory.

2   Select either ASCII or binary as the export format.

3   Do you want to export the selected dose plane or all dose planes?

     • Selected dose plane—go to step 4.

     • All dose planes—go to step 6.

4   Type a name for the file.

5   Click the **Export Plane To File** button. A message confirms that the dose plane was exported successfully. This procedure is complete.

6   Click the **Export All Planes To File** button. The software exports a file for each dose plane to the selected directory. File names are based on the dose plane names. A message confirms that the dose planes were exported successfully.

Evaluate plans with QA phantoms

The Copy to Phantom option lets you copy the beams from a plan to one of your stored quality assurance (QA) phantoms to verify the dose distribution or the dose at given points of interest.

Define a QA phantom

⚠ **CAUTION**
Define a QA phantom for each patient orientation you expect to treat. When you evaluate a plan, we recommend that the orientation of the QA phantom match the patient orientation in the plan. If the orientations do not match, the plan will be incorrectly oriented with respect to the phantom and you will not be able to accurately verify the dose distribution.

⚠ **CAUTION**
Do not select the Water Phantom option in the Edit Plan Data window when you add a plan to the phantom patient. If you select Water Phantom, you will not be able to save the plan as a phantom.

1   In the **Patient Select** window, add a patient in which to store phantoms.

2   Import the phantom images.

3   Add a plan that uses the images you just imported.

4   Click the **Planning** button to enter the treatment planning software.

5   In the **Confirm Plan Setup** window, verify that the patient orientation is correct.

6   Add POIs and ROIs to the phantom as necessary.

Choose names for the POIs that are different from names used in patient plans. During plan evaluation, it will be easier to differentiate between phantom and patient POIs if they have different names.

7   End the planning session and save the data files.

8   In the **Patient Select** window, click the **QA Tools** button. The **QA Tools** window appears.

9   Click the **Save as Phantom** button. The **Save Phantom** window appears.

10 Enter a name for the phantom.

11 Click the **Save** button.

Copy a plan to a QA phantom

> **NOTE**
> You cannot copy a plan that was created in Pinnacle³ version 8.0 or earlier to a phantom that was created in Pinnacle³ 9 or later.

If you have saved a data set as a QA phantom, you can copy a plan to the phantom for quality assurance and plan verification.

1   In the **Patient Select** window, select a patient and the plan you want to copy.

2   Click the **QA Tools** button. The **QA Tools** window appears.

3   Click the **Copy to Phantom** button. The **CT Patient/Directory List** window appears.

4   Select the phantom data set you want to use. We recommend that you use a phantom data set that has the same patient orientation as the patient plan you selected.

5   Click the **Import** button.

A new plan is added to the **Plans** list. This new plan is the result of copying the patient plan to the phantom plan. This is the plan you will use to validate your patient plan.

> **NOTE**
> When you copy a plan to a QA phantom, the following actions occur:
> • The dose is invalidated.
> • All boluses are removed from the plan.
> • Each prescription in the new plan is set to the **Set Monitor Units** option.
> • The MUs for each beam are retained.
> • The dose grid is adjusted so that it covers the entire image set in the new plan.

Evaluate the plan

⚠ **CAUTION**
You cannot return to the Phantom POI Adjust window once you click the Close button. Be sure you are finished aligning the patient and phantom plans before you click the Close button.

⚠ **CAUTION**
The software does not prevent you from moving beams or POIs once you close the Phantom POI Adjust window. DO NOT change any beam or POI locations. If you change these settings, this plan will no longer match your patient plan, and the dose calculations you make will not be valid for your patient plan.

1   In the **Patient Select** window, select the plan that was created when you copied the patient's data to a phantom.

2   Click the **Planning** button.

The **Phantom POI Adjust** window appears. Use this window to align the coordinate systems of the patient and phantom plans.

3   In the **Target POI** option list, select the phantom POI you want to use as the target POI.

4   In the **Target Beam** option list, select the beam you want to align to the coordinates of the target POI.

5   Click the **Move beams to new position** button. The software aligns the POI of the target beam to the coordinates of the target POI. The spatial relationship between all beams and their associated POIs is maintained.

6   Click the **Close** button.

7   Adjust the size and location of the dose grid, if necessary.

8   Calculate dose for the beams.

9   Evaluate the results against film dosimetry, planar dose, or other measurements.

NOTE
When you back up patients that contain QA phantom plans, Pinnacle³ also backs up the phantoms. See the *Launch Pad Instructions for Use* for information on backing up patient data.

Delete a QA phantom

You can delete QA phantoms that do not have patient plans copied to them. If a patient plan is associated with a QA phantom, you must delete the plan before you can delete the QA phantom.

1   In the **Patient Select** window, click the **QA Tools** button. The **QA Tools** window appears.

2   Click the **Delete Phantom** button. The **CT Patient/Directory List** window appears.

3   Select the phantom to be deleted from the list and click the **Delete** button.

4   Click the **Close** buttons in the **CT Patient/Directory List** window and the **QA Tools** window.

Evaluate plans with DRRs

Use the **Plan Evaluation DRRs** window to view and print beam's eye views (BEVs) that help you verify the isocenter of a completed plan.

1   Select **Utilities** - **Plan Eval DRRs**.

If virtual setup beams are not configured, the **Select Setup Beam POI** window appears. In this window, you must select the isocenter and machine that the software uses to create the evaluation DRRs. Then, click the **Plan Eval DRRs** button to access the **Plan Evaluation DRRs** window.

If virtual setup beams are already configured, the **Plan Evaluation DRRs** window appears.

- To create DRRs for non-proton beams, see *Create non-proton beam DRRs*.
- To create DRRs for proton beams, see *Create proton beam DRRs*.

Create non-proton beam DRRs

For non-proton beams, you can display or print AP or PA, Left or Right, and Superior or Inferior DRRs to verify your plan.

1   In the **Plan Evaluation DRRs** window, select an orientation for viewing the DRRs.

> **NOTE**
> The software calculates the source to surface distance (SSD) using the CT to density table that you selected in the **Beam's Eye View Options** window. If you use a different CT to Density table in the **Plan Evaluation DRRs** window than you do in Planning, the SSD in the **Plan Evaluation DRRs** window may be slightly different than the SSD in your plan.

2   Specify the jaw positions for each beam. The default jaw names and positions are set in Physics during commissioning.

> **NOTE**
> If the machine is commissioned with stereotactic or electron energies and with no photon energies, you are not allowed to change the jaw positions. If the machine is a fixed jaw machine, you cannot change the jaw positions even though the software allows you to enter new values. The jaw position values are set as they were commissioned with the machine and you cannot change them.

3   If necessary, adjust the DRR display parameters in the **Plan Evaluation DRRs** window. Right-click in a viewing window and then click the **BEV Options** button. For more information on the display parameters, see the *View Patient Data* chapter in the *Pinnacle³ Planning Instructions for Use*.

> **NOTE**
> The window and level settings are percentages of the maximum DRR volume value.

4   To display all multi-leaf collimator (MLC) leaves for all beams in the trial, deselect the **Clip Setup MLCs** check box.

5   To change the isocenter or machine, select a different option from the **Isocenter** or **Machine** option list.

6   To print the DRRs, click the **Print Window** button. The **Print** window appears. For more information about how to print viewing windows, see the *Print* chapter in the *Pinnacle³ Planning Instructions for Use*.

7   Click the **Close** button.

> **NOTE**
> To delete all setup beams, click the **Delete Setup Beams** button. When you click the **Delete Setup Beams** button, the **Plan Evaluation DRRs** window and the **DICOM Export** window are both closed.

Create proton beam DRRs

For proton beams, you can display or print AP or PA, Left or Right, and Superior or Inferior DRRs to verify your plan, or you can specify an angle from which to create the DRR.

1   In the **Plan Evaluation DRRs** window, select an imaging device from the option list.

   • If you selected a continuous imaging device, go to step 2.

   • If you selected a fixed imaging device, go to step 4.

> **NOTE**
> The **Angle** and **SAD** values displayed in the window are the values that were commissioned for the imaging device.

2   Select an orientation for viewing the DRRs.

3   If you selected **Other** as the orientation, specify the angle that should be used to create the DRR.

4   If necessary, adjust the DRR display parameters in the **Plan Evaluation DRRs** window. Right-click in a viewing window and then click the **BEV Options** button. For more information on the display parameters, see the *View Patient Data* chapter in the *Pinnacle³ Planning Instructions for Use*.

> **NOTE**
> The window and level settings are percentages of the maximum DRR volume value.

5   To change the isocenter or machine, select a different option from the **Isocenter** or **Machine** option list.

6   To print the DRRs, click the **Print Window** button. The **Print** window appears. For more information about how to print viewing windows, see the *Print* chapter in the *Pinnacle³ Planning Instructions for Use*.

7   Click the **Close** button.

> **NOTE**
> To delete all setup beams, click the **Delete Setup Beams** button. When you click the **Delete Setup Beams** button, the **Plan Evaluation DRRs** window and the **DICOM Export** window are both closed.

9 Export

Overview

⚠️ **WARNING**
Plans may include the statement NOT FOR CLINICAL USE. Based on the machine or isotope data and the plan, the software determined that the plan cannot be delivered clinically. Do not treat patients with plans that are not for clinical use.

DICOM RT is the most common method of export. You can also export some plan information without using DICOM RT.

This chapter describes how to export the following:

• Export DICOM plan information

Export DICOM plan information

⚠ **CAUTION**
We recommend that you test the output from the software to your receiving DICOM system to confirm that parameters are being transferred correctly. Confirm that the plan information at the receiving system console is the same as the plan information you set up in the software.

For information about Pinnacle³ DICOM conformance, see *DICOM conformance* in the *Getting Started* chapter.

> **NOTE**
> You can export DICOM information only if you are licensed for DICOM RT.

> **NOTE**
> When you export a plan, DICOM RT samples the dose grid at the reference point specified in the **Monitor Units** window in order to determine the dose per beam to export. If you prescribe to something other than a POI, we recommend that you create a new POI in a region of the patient with the desired prescription dose. Specify this new POI as the dose reference point for each beam.

> **NOTE**
> If you are licensed for protons, all dose that you export is assumed to be cobalt-equivalent effective dose, not physical dose. For information, see the *Calculate Dose* chapter. For information about how the software exports dose, see the Pinnacle³ DICOM Conformance Statement, which is available on the Philips Healthcare website (www.healthcare.philips.com).

Transfer limitations

- In Launch Pad, make sure that the patient and plan information does not contain any of the following characters. If the patient or plan information contains these characters, you cannot export the plan.

  . ' ~ & ( ) | < > + * \ / ; : @ ! [ ] #

- In Launch Pad, you must enter a last name, first name, and medical record number. If any of these fields are blank, you cannot export the plan.

- In Launch Pad, if you make any of the following changes to an image set, you cannot export structure sets, dose, or spatial registration for the modified image set. You can still export a plan, but the software does not include the isocenter in the plan.

  – change the patient position
  – change the patient orientation
  – change the treatment position
  – change the X/Y pixel size
  – change the Z coordinate for a slice
  – delete a slice

- You cannot export a trial that is not selected for treatment or that cannot be delivered clinically.

- You cannot export a locked plan that has been changed.
- You cannot export structure sets, dose, or spatial registration from a decubitus image set.
- You can export structure sets only if you used DICOM Image 4.2d or later to import the images in the plan.
- You can export spatial registration only if you used DICOM Image 9 or later to import the images in the plan.
- You cannot export an entire trial in one export if the trial contains both proton and non-proton beams. You must export the trial prescription-by-prescription in order to export all beams for that trial.
- You cannot export a proton plan for which dose is not computed.

Export plan information

DICOM RT Export must be configured properly before you can export DICOM information. For assistance with configuring DICOM RT Export, contact Customer Support at 1-800-722-9377 (US and Canada) or your local distributor. Contact the appropriate target system representative for details regarding your target system.

1   On the **File** menu, click **Export**, and then click **DICOM**.

    The **DICOM Export** window opens.

2   Select the trial that contains the information that you want to export from the **Trial to export** list.

3   Select the destination to which you want to export plan information from the **Destination AE Title** list.

    The **Destination AE Title** list identifies the possible DICOM target systems. If no choice is available, obtain the appropriate AE (Application Entity) title from your IT department, and then contact Customer Support or your local distributor for assistance in entering it.

4   Select the information that you want to export. See *Fields and buttons*.

5   Click **Transmit Data** to export the information to the AE destination.

    If the export cannot be completed within the number of seconds you specify in the **DICOM Timeout** field, the export may fail.

> **NOTE**
> The Pinnacle[3] software does not include a mechanism for the electronic approval of plans prior to export. For this reason, the software always exports the approval status of plans as UNAPPROVED. This information is explicitly stated in the following message that is displayed in the DICOM Export window:
>
> "The Approval Status DICOM tag (300E, 0002) is always sent as UNAPPROVED."

Fields and buttons

Title	Description
Trial to export	The trial that contains the information that you want to export.
Local AE Title	The local site from which you want to export the information.
Series Number **Series Description**	Enter a series number and series description to associate with the current export (optional).
Destination AE Title	The remote site to which you want to export the information.
DICOM Timeout	The amount of time (in seconds) before the software cancels the DICOM export.
DRR Resolution	If you will export **RT Image** or **Setup Beams**, set the resolution of the DRRs to be exported. The default value is 512, and you can set the value within the range 256–4096.
Plan Intent	Select the purpose for this export. Select **None** if you do not want to include this information in the DICOM export.
Transmit Data	Transmit (export) the selected information.
RT Plan	Export the prescriptions that you select. Only the prescriptions that have non-proton beams assigned to them will appear in the **Prescription** list. You can also choose which tolerance table the machine uses for the prescription. If a prescription uses multiple machines, you cannot export a tolerance table for that prescription. Relative couch shifts between the patient setup and the treatment positions are exported if the lasers have been set for the plan and the plan contains only one isocenter. If the plan contains multiple isocenters, then the shifts are not exported.
RT Ion Plan	Export the prescription that you select. Only the prescriptions that have proton beams assigned to them will appear in the **Prescription** list. The **RT Ion Plan** check box only appears if you are licensed for proton treatment planning.
Send SSDs in all arc control points	Include the Source to Surface Distance (SSD) for each control point in each arc beam that is in the prescriptions that you select for export. This option applies only to plans that use arc, conformal arc, and dynamic arc beams.
RT Structures	Export the ROIs and POIs that are associated with the image sets that you select. Only valid DICOM image sets appear under **RT Structures**. A DICOM image set is invalid if you changed any of the following for the image set: patient position, patient orientation, treatment position, X/Y pixel size, or the Z coordinate for a slice.
Select ROI	Click **Select ROI** to view the list of ROIs that are associated with the selected image sets. The **Select ROIs to Export** window opens. Select the ROIs that you want to export and then click **Close**. ROIs that are created by the Auto-Planning tool during optimization appear dimmed in the window if you set the **Include Auto-Planning ROIs in plan output** preference to **No** in the IMRT category of the **Preferences** window. See the *Utilities* chapter in the *Pinnacle³ Planning Reference Guide* for more information. Available only if you select the **RT Structures** and the related image set check boxes.

Title	Description
RT Image	Export a DRR for each treatment beam that is associated with the trial. Available only if you select **RT Plan** or **RT Ion Plan**. You can set the resolution of the DRRs to be exported in the **DRR Resolution** field.
Annotate Images	Annotate the treatment beam DRRs that you export. Available only if you select **RT Image**.
RT Dose	Export dose grids for the plan. The software allows you to export the following: • **Dose per control point**—Export a dose grid for each control point in each beam that is associated with the prescriptions that you select for export. (This option is not available if you select **RT Ion Plan**.) • **Dose per beam**—Export a dose grid for each beam that is associated with the prescriptions that you select for export. • **Dose per prescription**—Export a dose grid for each prescription that you select for export. Each dose grid is the sum of the dose grids for all beams in the prescription. • **Sum of selected prescriptions**—Export one dose grid that is the sum of the dose grids in the prescriptions that you select for export. • **Current dose and prior dose**—Export both the computed dose and prior dose. This option is available only when the **Dose Display Mode** in the **Prescriptions** window is set to **Current Dose and Prior Dose**. All other DICOM export options except **DICOM Image** are unavailable when prior dose is included. See *Assess the impact of prior dose*. The check boxes listed above are available only if you have computed dose and you select **RT Plan** or **RT Ion Plan**.
Spatial Registration	Export the spatial registration for each secondary image set.
DICOM Image	Export the DICOM image sets that you select. The software exports the original DICOM image set. Any changes that you made to the image set do not export.
Setup Beams	Export two setup beams for the isocenter that you select. If no setup beams are configured, the **Select Setup Beam POI** window opens and you must select the isocenter and machine for the setup beams. For proton DRRs, you can select imaging devices and orientations for the setup beams. Available only if you select **RT Plan** or **RT Ion Plan**.
Annotate Setup Beams	Annotate the setup beam DRRs that you export. Annotations include a crosshair, an orientation cube, and information about the plan, machine, energy, prescription, patient setup, and beam modifiers. Available only if you select the **Setup Beams** check box. You can set the resolution of the DRRs to be exported in the **DRR Resolution** field.
Setup Beam Viewer	Use the **Isocenter** and **Machine** lists to define the setup beam DRR that you want to export. For non-proton DRRs, use the orientation lists to view the DRR. However, the software always exports one left and one anterior setup beam DRR for the selected POI, regardless of the settings that you select in the orientation lists. For proton DRRs, use the **Imaging Device** lists to select imaging devices for the DRRs. If you select a **Continuous** imaging device, use the orientation list to view the DRR. For an orientation of **Other**, type an angle for the DRR. Available only if you select the **Setup Beams** check box.

Export ODM

The Export ODM feature lets you export the opening density values of an ODM to an ASCII or binary file. You can export both ideal and deliverable ODMs.

1   In the **Inverse Planning** window, select **File** - **Export** - **ODM**. The **Opening Density Matrix Export** window appears.

2   Select the trial that contains the ODM you want to export.

3   Enter the name of the directory to which you want to export the file. If necessary, click the **Browse** button to locate a directory.

4   Select whether you want to export the ODM in ASCII or binary format.

5   Click the **Beam to Export** option list and select the beam whose ODM you want to export.

6   Select whether you want to export the ideal ODM or the deliverable ODM.

7   Enter a name for the exported file.

8   Click the **Export ODM** button. The software exports the ODM to the directory you specified in the **Export Directory** field.

9   Analyze the transmission values. If the values are satisfactory, export and print the plan information for use in your treatment plan.

   If the values are not satisfactory, you can re-optimize the plan starting with new objectives and constraints or optimize the plan further based on the current plan data.

10 Plan Automation

Several tools can help you to automate your planning tasks:

- **Auto-Segmentation with SPICE:** Auto-Segmentation is a tool that automatically produces contours for normal tissues in CT image sets. Auto-Segmentation comes pre-loaded with factory atlases, which include the abdomen, head and neck, male pelvis, and thorax atlases. See the *Auto-Segmentation* chapter in the *Pinnacle³ Planning Instructions for Use.*

- **Auto-Planning techniques:** An Auto-Planning technique is a template for a standard IMRT trial that includes ROIs, POIs, beams, prescriptions, and clinical goals. You can apply a technique to a plan to rapidly create a standard DMPO or SmartArc trial and optimize it. See *Use treatment techniques*.

- **Auto-Planning:** The Auto-Planning tool allows you to automate the IMRT process for DMPO or SmartArc trials. You set goals for targets and organs at risk (OARs) and allow the Auto-Planning engine to complete the IMRT process for you. See *Use Auto-Planning*.

- **Protocols:** Protocols are stored settings of objectives, constraints, and optimization and conversion parameters. You can create protocols for common classes of treatments specific to your clinic. See *Protocols*.

- **Scripting:** The Scripting utility allows you to record and play back "scripts" of software operations. Scripts can be used for everything from repeating simple operations, such as setting the window and level for prostate CT data, to complex beam setup operations. See the *Utilities* chapter in the *Pinnacle³ Planning Instructions for Use*.

Use treatment techniques

A treatment technique is a template for a standard IMRT trial that includes ROIs, POIs, dose grid placement, beams, prescriptions, and clinical goals. After you create a technique, you can apply it to a plan to rapidly create a standard DMPO or SmartArc trial and optimize it using the Auto-Planning tool. You can save the technique in the technique library and reuse the technique over and over.

You can create a treatment technique in several ways: by specifying all of the technique parameters manually, by modifying a sample technique, or by creating a technique based on an existing trial.

> **NOTE**
> Treatment techniques are available only if you are licensed for Auto-Planning. Contact Customer Support for licensing information.

About sample treatment techniques

There are sample techniques in the technique library to provide you with a starting point as you develop your techniques. These sample techniques were developed based on RTOG protocols. We recommend that you create copies of the sample techniques (by saving the sample techniques with new names that are appropriate for your clinical practices) and then change the copied techniques as needed.

> **NOTE**
> If you reinstall Pinnacle³ or install a new version of Pinnacle³, any changes you have made to the sample techniques are overwritten and the original samples are restored. To retain your changes to the sample techniques, save the sample techniques with new names before you change them.

Create a treatment technique

1   On the **Utilities** menu in either the **Planning** window or the **Inverse Planning** window, click **Treatment Techniques**, and then click **Technique Library**. The **Technique Library** window opens.

2   Do you want to create a new technique or create a copy of a sample technique?

- Create a new technique—Click **New**. The **Treatment Techniques** window opens.

- Create a copy of a sample technique—Select a sample technique (or any existing technique) from the list and click **Load**. The **Treatment Techniques** window opens. On the **File** menu, click **Save Technique to Library**. In the window that opens, type a name for the technique and click **OK**. The technique name displays at the top of the **Treatment Techniques** window.

The icons at the top of the window allow you to view three panels.

Icon	Panel	Description
	Planning	Define the ROIs, isocenter, and prescription for the trial to be created.

Icon	Panel	Description
	Beams	Define the beams for the trial to be created.
	Auto-Planning	Define the settings for the Auto-Planning tool for the trial to be created. See *Use Auto-Planning*.

Create a treatment technique by entering information at the top of the window, entering information in the three panels, and saving the technique. See *Save a treatment technique*. At any time, you can start over and create a new technique by clicking **New** in the **Technique Library** window.

General treatment technique information

Complete the fields at the top of the window.

Field	Description
Technique Name	Name for the technique. A default name appears here until you save the technique and type a name. See *Save a treatment technique*.
Description	Description of the technique. When you search for techniques in the technique library, you can filter the library based on the technique name and description. See *Apply a treatment technique*.
Trial to Create	Name of the trial that the technique will create.

Planning panel

1 Click the **Planning** icon. The **Planning** panel displays.

2 In the **ROI Creation Setup** area, define the ROIs that the technique will create.

Be aware that the technique creates ROIs according to the order in the **ROI Creation Setup** area. For example, if you will expand ROI_*x* to create ROI_*y*, ensure that the technique creates ROI_*x* before ROI_*y*.

> **NOTE**
> Wherever you specify ROIs or POIs in the technique, you can select an ROI or POI from the current plan or type the name of a new ROI or POI that does not exist in the current plan. For more information, see *About ROIs and POIs in treatment techniques and scorecards*.

Below the **Destination ROIs** list, click **Add** to specify an ROI that the technique will create. Then complete the fields to the right of the **Destination ROIs** list to define the new ROI. Repeat the process to add as many Destination ROIs as you need.

Field	Description
Destination ROI	Name of the currently selected Destination ROI in the list.
Destination ROI Color	Color for the Destination ROI.

Field	Description
Operation	How the technique will create the Destination ROI from the Source ROIs.
	• **Expand**—Expand the Source ROI by the margin that you have defined in the **Margin** field.
	• **Contract**—Contract the Source ROI by the margin that you have defined in the **Margin** field.
	• **Create Ring ROI**—Create a new "ring" ROI around the Source ROI. The margin that you define in the **Margin** field sets the thickness of the ring. A ring ROI can be useful for surface structures such as the rectum wall.
Margin Type	Margin that the technique applies when creating the Destination ROI (either Uniform or Variable). To define the margin, enter the appropriate margin values in the fields below the **Margin Type**.
	(Note: When creating a ring ROI with a uniform margin, set the margin at least 1.5 times the minimum voxel size of the image set.)
Source and Avoidance ROIs	Specify a Source ROI or Avoidance ROI. Click **Add** and repeat the process to add as many Source ROIs or Avoidance ROIs as you need.
	• **Source**—ROI that the technique will use to create the Destination ROI. Specify the ROI and then select the **Source** check box.
	• **Avoid Interior**—The Destination ROI will avoid the overlapped region inside of the Source ROI. Specify the ROI and then select the **Avoid Interior** check box.
	• **Avoid Exterior**—The Destination ROI will not include the region outside of the Source ROI. Specify the ROI and then select the **Avoid Exterior** check box. (For example, you can contour the skin surface, then select the **Avoid Exterior** check box for the skin surface ROI in order to keep the Destination ROI within the patient volume.)

For more information about expansion and contraction, see *Expand and contract ROIs* in the *Pinnacle³ Planning Instructions for Use*.

3   In the **Isocenter** area, determine whether the technique will use an existing POI for the isocenter or create a new POI for the isocenter. For more information, see *About ROIs and POIs in treatment techniques and scorecards*.

• Specify a POI—Select the POI to be used as the isocenter from the **Name** list.

• Create a new POI—Type a name for the POI in the **Name** list, and then define the diameter, color, and ROI within which the POI should be positioned. The POI will be positioned within the selected ROI using Box as the POI placement method. See *Position isocenters automatically* in the *Pinnacle³ Planning Instructions for Use*.

4   Define the prescription in the **Prescription** area.

If you define an ROI or POI for which you are prescribing dose, you have two options:

• Select the ROI or POI from the list of ROIs and POIs in the current plan.

• Type the name of a new ROI or POI.

For more information about prescriptions, see the *Calculate Dose* chapter in the *Pinnacle³ Planning Instructions for Use*.

Beams panel

1   Click the **Beams** icon. The **Beams** panel displays.

2   In the **Machine Parameters** area, define the parameters for the machine.

Field	Description
Optimization Type	Select either **DMPO** or **SmartArc** optimization type. If you override this selection when you apply a technique to a plan, all beams in the technique are deleted.
Machine	Select the machine for the beams that the technique will create. However, you can override this selection when you apply a technique to a plan so that a single technique can be used for multiple linacs.

3   In the **Optimization Parameters** area, define the DMPO or SmartArc parameters for the beams that the technique will create. For more information, see either *DMPO parameters* or *SmartArc parameters*.

4   On the **Beam Setup** tab, define the beams that the technique will create. Click **Add** to add a beam, and then set the parameters for that beam. For more information, see the *Beams* chapter in the *Pinnacle[3] Planning Instructions for Use.*

5   On the **Beam Parameters** tab, define the parameters for the beams that the technique will create. For more information, see either *Set IMRT parameters for DMPO* or *Set IMRT parameters for SmartArc*.

> **NOTE**
> Click the **Redo Spreadsheet** button on the **Beam Setup** tab or **Beam Parameters** tab to apply a parameter setting to all beams in the technique.

Auto-Planning panel

1   Click the **Auto-Planning** icon. The **Auto-Planning** panel displays.

2   In the **Auto-Planning Settings** area, enter the maximum number of iterations and the engine type to be used. The minimum allowable value for the **Max Iterations** field is 40, and the standard value is 50.

> **NOTE**
> The **Engine Type** is available only if you are licensed for Biological Evaluation. For more information, see the *Pinnacle[3] Planning Instructions for Use*.

> **NOTE**
> You can click **Advanced Settings** to fine-tune the Auto-Planning tool. See *About Auto-Planning advanced settings*.

3   In the **Scorecard** area, you can select a scorecard to be loaded when you apply the technique. See *Evaluate trials with a scorecard*.

4   In the **Target Optimization Goals** area, click **Add** to add a new optimization goal, and then define the target ROI and the prescribed dose to that ROI. Repeat the process to add as many optimization goals as you need; however, you can set only one optimization goal for each target ROI.

5   In the **Organ At Risk (OAR) Optimization Goals** area, click **Add** to add a new optimization goal, and then define the optimization goal for an OAR. Repeat the process to add as many optimization goals as you need.

Field	Description
ROI	ROI for the OAR
Type	Goal type (**Max Dose**, **Mean Dose**, or **Max DVH**)
Dose	Dose goal for the OAR
Volume	Percentage of volume of the OAR that should satisfy the specified goal (when the **Type** is **Max DVH**)
Priority	Priority of this goal (**Constrain**, **High**, **Medium**, or **Low**)
Compromise	Set the behavior when a target and OAR overlap. When you select **Compromise**, the overlapping region is assigned to the target. When you deselect **Compromise**, the overlapping region is assigned to the OAR.

About ROIs and POIs in treatment techniques and scorecards

When you create a treatment technique or a scorecard (see *Evaluate trials with a scorecard*), you specify ROIs (for example, the ROI for which you set a clinical goal) and POIs (for example, the POI that you specify as the isocenter). Wherever you specify ROIs or POIs in the technique or scorecard, you can select an ROI or POI from the current plan or type the name of a new ROI or POI that does not exist in the current plan. The new ROI may be a standard structure that the technique creates, a standard structure that an Auto-Segmentation atlas creates, or a standard structure that you manually create based on your clinical practices. Similarly, the new POI may be a standard POI that the technique creates or a standard POI that you manually create based on your clinical practices.

Once you have typed the name of a new ROI or POI in a technique or scorecard, you can select that ROI or POI elsewhere in the window. When you select an ROI from a list, the ROIs at the top of the list are the ROIs in your plan; the ROIs below the dashed line in the list are the new ROIs that you have specified in the technique. POIs follow this same pattern.

Later, when you prepare to apply the technique or compute the scorecard, the ROI or POI either must be created by the technique or must already exist in that plan. If it does not exist, a pencil will display to the left of the ROI or POI name wherever it appears.
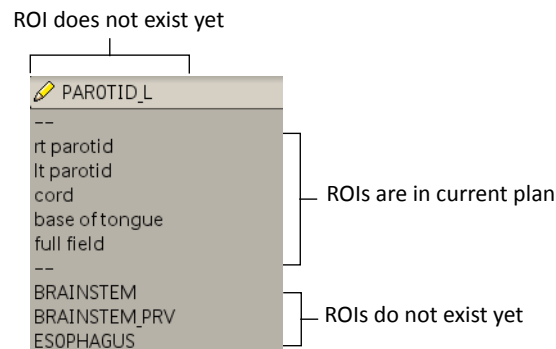
Create a treatment technique from the current trial

You can create a technique based on a standard DMPO or SmartArc trial. The new technique uses the beams, isocenter, prescription, and optimization type from the current trial.

> **NOTE**
> The software uses the currently selected beam in the current trial as the starting point for the new technique. Only those beams with the same isocenter, prescription, machine, and optimization type as the currently selected beam are included in the technique.

1   Open a plan that contains a standard DMPO or SmartArc trial. Select the trial that you want to use as the basis for the new technique, and ensure that the currently selected beam is a beam that you want to include in the technique.

2   On the **Utilities** menu in either the **Planning** window or the **Inverse Planning** window, click **Treatment Techniques**, and then click **Technique Window**. The **Treatment Techniques** window opens.

3   At the bottom of the window, click **Create Technique from Current Trial**.

The software creates the new technique, which includes the beams, isocenter, prescription, and optimization type of the current trial. Examine the **Planning**, **Beams**, and **Auto-Planning** panels in the **Treatment Technique** window and modify the settings as needed.

Save a treatment technique

When you create a technique or load a technique and then save the plan, the technique is saved as part of the plan. However, in order to apply the technique to other plans, you must save it to the library.

1   On the **File** menu in the **Treatment Techniques** window, click **Save Technique to Library**.

2   In the window that opens, type a name and click **OK**.

The technique is saved in the library, and the technique name displays at the top of the **Treatment Techniques** window.

Apply a treatment technique

You can apply a technique, or apply a technique and optimize the trial using the Auto-Planning tool:

• **Apply**—Apply the technique and create a new trial. After the technique creates the trial, you can review the overlap statistics, priorities, and optimization goals for the trial before using the Auto-Planning tool to optimize it. You may prefer this option if you are an advanced user or if the plan requires the careful selection of beam angles.

• **Apply and Optimize**—Apply the technique, create a new trial, and optimize it using the Auto-Planning tool. The Auto-Planning tool automatically updates the **Priority** values for OAR optimization goals based on ROI overlap statistics. See *Use Auto-Planning*.

Before you apply a treatment technique, the plan should have ROIs for the targets and organs at risk, and the standard setup tasks (such as removing the couch, setting the laser center, etc.) should be complete.

1   Create a technique (see *Create a treatment technique*) or load a technique. To load a technique, on the **Utilities** menu in either the **Planning** window or the **Inverse Planning** window, click **Treatment Techniques**, and then click **Technique Library**. The **Technique Library** window opens. Select the technique from the list and click **Load**. The technique displays in the **Treatment Techniques** window.

If you have a large number of techniques, you can filter the list using search terms. For example:

- To display only those techniques with the word "breast" anywhere in the name, type "breast" in the **Technique Name** field and click **Filter**.

- To display only those techniques with the words "head and neck" anywhere in the name and the words "DMPO trial" anywhere in the description, type "head and neck" in the **Technique Name** field, type "DMPO trial" in the **Description** field, and then click **Filter**.

Click **Show All** to clear the filter and show the full list again.

2   Review the technique and adjust any parameters as needed. For any ROIs and POIs that are outlined in yellow, verify that those structures will be created as part of the technique and are not absent in your plan. If any are absent, either select a different ROI or POI from the list for that structure or add the appropriate ROIs or POIs to the plan before applying the technique.

3   Do you want to create a new trial or create a new trial and optimize it using the Auto-Planning tool?

- Create a new trial—Click **Apply**. The technique creates a new trial. The trial includes the ROIs, isocenter, beams, and prescription specified in the technique. The dose grid is placed such that it includes all ROIs that are used in optimization goals with an added 5 cm margin. The **Inverse Planning** window opens and displays the **Auto-Planning** panel so that you can review and modify the Auto-Planning settings as needed before you optimize the trial. You may also choose to review and modify the beams, isocenter, and dose grid before you optimize the trial.

- Create a new trial and optimize it—Click **Apply and Optimize**. The technique creates a new trial and optimizes it using the Auto-Planning tool (see *Use Auto-Planning*). The trial includes the ROIs, isocenter, beams, and prescription specified in the technique. The dose grid is placed such that it includes all ROIs that are used in optimization goals with an added 5 cm margin. The **Inverse Planning** window opens and displays the **Auto-Planning** panel.

⚠ CAUTION
Please confirm the setup of the new trial before you continue, including the prescription, optimization goals, ROIs, POIs, beams, and dose grid.

Delete a treatment technique

1   On the **Utilities** menu in either the **Planning** window or the **Inverse Planning** window, click **Treatment Techniques**, and then click **Technique Library**. The **Technique Library** window opens.

2   Select the technique that you want to delete and click **Delete**.

Use Auto-Planning

The Auto-Planning tool allows you to rapidly create high-quality treatment plans based on clinical goals for either SmartArc optimization or DMPO optimization. Alternately, you can use a treatment technique to rapidly create a standard DMPO or SmartArc plan and optimize it using the Auto-Planning tool. For more information, see *Use treatment techniques*.

> **NOTE**
>
> The Auto-Planning tool is available only if you are licensed for Auto-Planning. Contact Customer Support for licensing information.

1   In the **Inverse Planning** window, click the **Auto-Planning** icon. The **Auto-Planning** panel appears.

2   In the **Auto-Planning Settings** area, enter the maximum number of iterations and the engine type to be used. The minimum allowable value for the **Max Iterations** field is 40, and the standard value is 50.

> **NOTE**
>
> The **Engine Type** field is available only if you are licensed for Biological Evaluation. For more information, see the *Pinnacle³ Planning Instructions for Use*.

3   In the **Target Optimization Goals** area, click **Add** to add a new optimization goal, and then define the target ROI and the prescribed dose to that ROI. Repeat the process to add as many optimization goals as you need; however, you can set only one optimization goal for each target ROI.

4   In the **Organ At Risk (OAR) Optimization Goals** area, click **Add** to add a new optimization goal, and then define the optimization goal for an OAR. Repeat the process to add as many optimization goals as you need.

Field	Description
ROI	ROI for the OAR
Type	Goal type (**Max Dose**, **Mean Dose**, or **Max DVH**)
Dose	Dose goal for the OAR
Volume	Percentage of the OAR that should satisfy the specified goal (when the **Type** is **Max DVH**)

Field	Description
Priority	Priority of this goal (**Constrain**, **High**, **Medium**, or **Low**)
	The Auto-Planning tool attempts to spare OARs irrespective of the priority of an OAR optimization goal. However, for image sets in which a trade-off must be made between the OAR optimization goal and the target optimization goal, the tool attempts to force additional sparing based on the priority value. For example, in case of a head-and-neck plan, you might select **High** for the spinal cord, the brain stem, and the parotid glands, while you might select **Medium** or **Low** for the submandibular glands (because they may not be as important in a trade-off).
	You can choose to allow the Auto-Planning tool to automatically adjust the priority values of OAR optimization goals based on ROI overlap statistics. The Auto-Planning tool adjusts the priority of only those OAR optimization goals where the **Type** is **Mean Dose** or **Max DVH** and the **Compromise** option is selected. If the ROI used in an OAR optimization goal substantially overlaps any targets, the Auto-Planning tool lowers the priority (because the sparing of the OAR based on the original priority may result in a less effective target coverage). For example, in a head-and-neck plan, you might select **High** priority for the parotid glands, and if the parotid glands have minimal or no overlap with the PTV (planning target volume), the Auto-Planning tool does not adjust the priority. However, if a substantial part of the parotid glands overlap any of the PTVs, the Auto-Planning tool adjusts the priority to a lower value (for example, a 35% overlap results in a **Medium** priority, and a 65% overlap results in a **Low** priority).
Compromise	Set the behavior when a target and OAR overlap. When you select **Compromise**, the overlapping region is assigned to the target. When you deselect **Compromise**, the overlapping region is assigned to the OAR. If you create multiple goals for a single ROI, those goals must have the same **Compromise** setting.
	For example, in a standard head-and-neck trial, you might deselect **Compromise** for a critical serial organ like the spinal cord or the brain stem because you do not want to compromise any part of a critical organ (even if it overlaps a target). On the other hand, you might select **Compromise** for a parallel organ like the parotid glands so that any overlapping region is assigned to the target.

5   To evaluate the overlap statistics, click **Compute Overlap** at the bottom of the window. The software computes the overlap statistics for the targets and OARs and displays the statistics in the **Overlap Report** areas. After you evaluate the overlap statistics, you can review and modify the optimization goals appropriately.

Overlap Report – OARs

Field	Description
OAR	OAR that overlaps a target and has **Compromise** selected
Overlapping Target	Target that the OAR overlaps
Overlapping Volume (%)	Percentage of the OAR that is included in the overlapping region
Total Overlap Volume (%)	Total percentage of the OAR that is overlapped by all targets

Overlap Report – Targets

Field	Description
Target	Target that overlaps an OAR, where the OAR has **Compromise** deselected

Field	Description
Overlapping OAR	OAR that the target overlaps
Overlapping Volume (%)	Percentage of the target that is included in the overlapping region
Total Overlap Volume (%)	Total percentage of the target that is overlapped by all OARs

6   If you want the software to automatically adjust the **Priority** values for OAR optimization goals based on ROI overlap statistics, click **Adjust Priorities Based on Overlap**. The software adjusts the **Priority** values to a lower priority for OARs for which you have selected **Compromise** and where the overlapping region is substantial.

> **NOTE**
> After you use the Auto-Planning tool to create OAR and target goals for a trial, you can use PlanIQ to adjust the trial's goals and then import them back into Pinnacle³ for use in planning. See *Import goals from PlanIQ*.

7   When you are satisfied with the optimization goals and overlap statistics, click **Start Auto-Planning**. The Auto-Planning tool starts.

During Auto-Planning, a window displays the current status. You cannot perform any other tasks during Auto-Planning; however, you can click **Cancel** to stop the tool at any time.

The Auto-Planning tool creates new ROIs that are used during optimization. The names of these new ROIs end in "_AP". You can delete the ROIs that the Auto-Planning tool creates as a group, if desired. See *Delete ROIs and ROI contours* in the *Pinnacle³ Planning Instructions for Use*.

> **NOTE**
> You may notice that using the Auto-Planning tool in separate sessions on the same plan may produce slightly different results. The optimization process normally can produce results where the differences are too small to be noticed. However, because the Auto-Planning tool uses a large number of optimization cycles, these small differences can be magnified by the multiple optimization cycles. The differences, however, do not affect the clinical value of the resulting plan.

About Auto-Planning advanced settings

In the **Auto-Planning Settings** area, click **Advanced Settings** to fine-tune the Auto-Planning tool.

Field	Description
Tuning Balance	Adjust the balance between the competing goals of conforming to targets and sparing OARs. The default value of 11 is appropriate for most plans, but you can adjust the value as needed to fine-tune the tool (for example, if you want to improve the sparing of OARs at the possible cost of target coverage). Please note, however, that the **Tuning Balance** value is a subtle adjustment to the tool, and is not a mutually exclusive selection; in other words, setting the **Tuning Balance** to 100% does not mean that the tool only spares OARs and does not conform to targets, but rather that it focuses more heavily on sparing OARs than conforming to targets.

Field	Description
Dose Fall-Off Margin	Adjust the margin around targets for dose fall-off. In the region outside of this margin, the Auto-Planning tool makes stronger attempts to reduce dose. The default value of 2.6 cm is appropriate for most plans, but you can adjust the value as needed to fine-tune the tool (for example, if you are unable to reduce the integral body dose using other methods).
Hot-Spot Maximum Goal	Adjust the hot-spot percentage with respect to the maximum prescribed dose to the target. The default value of 107% is appropriate for most plans, but you can adjust the value as needed to fine-tune the tool (for example, if a case requires more sparing of critical organs and increased dose heterogeneity across the target).
Use Cold-Spot ROIs	Select whether the Auto-Planning tool creates objectives for cold-spot ROIs. When you select **Yes**, the Auto-Planning tool creates ROIs for any cold spots (areas within a target ROI that receive less than the prescribed dose) and creates objectives for those cold-spot ROIs. However, when cold-spot ROIs are very small, the optimization problem is more complex, which can result in additional modulation in the plan. When you select **No**, the Auto-Planning tool does not create objectives for cold-spot ROIs but instead creates objectives for the entire target ROI in order to increase the minimum dose to the target.

Import goals from PlanIQ

> **NOTE**
> The instructions in this section require the use of PlanIQ. To purchase PlanIQ, contact your Philips sales representative or local distributor.

After you use the Auto-Planning tool to create OAR and target goals for a trial, you can use PlanIQ to assess, adjust, and then export the trial's goals to a script file. You can then run the script file to import the trial's adjusted goals back into Pinnacle³ and continue planning.

⚠ **CAUTION**

When the import is complete, verify all target and OAR goals before continuing the planning process in Pinnacle³.

> **NOTE**
> Specific directories are required to transfer files between Pinnacle³ and other software applications such as PlanIQ and RadCalc. For more information about these directories and instructions to change them, see the *System Administration* chapter in the *Pinnacle³ Launch Pad Instructions for Use*.

1 Click the **Auto-Planning** icon in the **Inverse Planning** window. The **Auto-Planning** panel opens.

2 Click **Export to PlanIQ**. The trial's files are stored in the **Pinnacle to PlanIQ** directory. These are the files that you will import into PlanIQ

3 After you have used PlanIQ to assess the goals and update them as necessary, export the script file from PlanIQ to the **PlanIQ to Pinnacle** directory.

4 From the **Auto-Planning** panel, click **Import from PlanIQ**. The **PlanIQ Import** window opens.

The **PlanIQ Import** window lists the file name and date for each script that matches the patient's MRN.

5   From the **PlanIQ Import** window, select the script file that contains the goals you want to import.

6   Select one of the following import options:

- To import the goals into a new trial, select **Import into new trial**. When you run the script, the current trial is copied to a new trial and then the existing goals are replaced with the updated goals.

- To import the goals into the current trial, select **Import into current trial**. When you run the script, goals in the current trial are replaced with the imported goals.

> **NOTE**
> When **Delete upon import** is selected, the script file you selected is deleted from the **PlanIQ to Pinnacle** directory after the goals are imported into Pinnacle[3]. This option is selected by default.

7   Click **OK** to run the script. The goals are imported into Pinnacle[3] based on the import option you selected.

Protocols

Overview

Protocols are stored settings of objectives, constraints, and optimization and conversion parameters. You can create protocols for common classes of treatments specific to your clinic. All available protocols are listed in the **IMRT Protocols** window. Select **File - Protocols** to display the **IMRT Protocols** window.

Creating protocols is an iterative process. As you develop the objectives and constraints that will make up your protocols, it is best to perform an optimization, make small adjustments to your objectives, optimize again, and repeat the process until you achieve the results you need. Once you have achieved the desired results, reset the beams and optimize once more. Then verify the results of the new optimization and save the protocol if the results are acceptable.

Add and save a protocol

⚠ **CAUTION**
All defined objectives, constraints, and optimization and conversion parameters are saved when you click the Save button. This includes any objectives, constraints, or parameters that were defined before you clicked the Add button.

1   Set up your objectives and constraints.

2   Set up your optimization and conversion parameters.

3   In the IMRT Protocols window, click the **Add** button.

4   In the **Name** field, enter the name of your protocol.

If you do not enter a name, the software assigns a unique name for you. The new protocol is automatically selected in the list. You can change the name of a protocol at any time by selecting it in the list and editing the name in the **Name** field.

> **NOTE**
> You can use only letters, numbers, and underscores (_) in the name of the protocol. The software displays a warning message and will not save the protocol if you use special characters or spaces in the protocol name.

5   Click the **Save** button.

The protocol is now available for subsequent planning sessions.

Load a protocol

⚠ **CAUTION**
You cannot load a protocol if the current plan does not contain at least one ROI.
If a protocol contains an objective or constraint for an ROI that does not exist in the current plan, the software will assign the objective or constraint to the first ROI listed in the Regions Of Interest window.

When you load a protocol, the optimization and conversion parameter settings are changed to the settings that are saved in the protocol. The objectives and constraints in the protocol are added to the objectives and constraints in the current trial. Objectives and constraints already defined in the trial are not overwritten. ROI names are saved with the protocol, so the ROI names contained in the protocol must correspond to ROIs in the trial before you load the protocol.

1   In the **IMRT Protocols** window, select the protocol you want to load.

2   Click the **Load** button. The software loads the objectives, constraints, and parameters.

Edit a protocol

⚠️ CAUTION
All defined objectives, constraints, and optimization and conversion parameters are saved in the protocol when you click the Save button. This includes any objectives or constraints that were defined before the protocol was loaded.

1   Load the protocol.

2   Make the necessary changes.

3   In the **IMRT Protocols** window, click the **Save** button.

Delete a protocol

1   In the **IMRT Protocols** window, select the protocol you want to remove.

2   Click the **Delete** button.

11 Advanced Strategies

Speed up optimization

DVH displays are updated during optimization. If your plan contains large ROIs or surrounding tissue ROIs, updating the DVHs can add significant time to optimization.

To speed up optimization, do not display DVHs for large and surrounding tissue ROIs. An alternative is to turn off the display of the DVHs for the trial during optimization. Then display the DVHs again when optimization is complete. The DVH display is controlled from the **Dose Volume Histogram** panel in the **Plan Evaluation** window. Click the **Plan Eval** button on the **Optimization** panel to open the **Plan Evaluation** window.

Optimize plans that use multiple beam modalities

> **NOTE**
> You must be licensed for proton treatment planning in order to include proton beams in your plans.

You can optimize plans that combine the use of photon, electron, stereotactic, and proton beams. However, the following restrictions apply to proton beams:

- Proton beams can only use the optimization type **None**. (Proton beams cannot be optimized, but the dose from proton beams can be included in the objective evaluation.)
- Proton beams cannot be assigned to the same prescriptions as non-proton beams.
- Proton beams must be configured to use absolute dose (see *Monitor unit calculation* in the *Pinnacle³ Planning Instructions for Use)*.

1 Define objectives and constraints as necessary.

2 Set the optimization type of the electron or stereotactic beams to **Beam Weight**. If your plan includes proton beams, set the optimization type for those beams to **None**.

> **NOTE**
> If you do not want to optimize an electron or stereotactic beam but still want to include dose from the beam in the objective evaluation, set the optimization type for the beam to **None**. You must assign any beams that have an optimization type of **None** to a prescription that is different from the beams that will be optimized. For more information, see *Optimize plans that use multiple optimization types*.

3 Set the optimization type of the photon beams as necessary.

4 Optimize the plan.

Optimize plans that use multiple optimization types

The three main optimization types are Intensity Modulation, DMPO, and SmartArc. You cannot optimize the trial if you select more than one of these three optimization types within the same trial.

Use multiple optimization types in the same trial

After you perform the initial Intensity Modulation, DMPO, or SmartArc optimization, you can use various optimization types as described in the table below.

Intensity Modulation	DMPO	SmartArc
Prior to conversion, you can reoptimize the Intensity Modulation plan with the following optimization types: • Intensity Modulation • Beam Weight	After the initial optimization, you can reoptimize the DMPO plan with the following optimization types: • DMPO • Segment Weight • Beam Weight	After the initial optimization, you can reoptimize the SmartArc plan with the following optimization types: • SmartArc • Segment Weight
After conversion, you can reoptimize the Intensity Modulation plan with the following optimization types: • Segment Weight • Beam Weight		

Use multiple optimization types in the same optimization

If you choose to use the SVD dose engine with Intensity Modulation, DMPO, or SmartArc, you can optimize the trial only if all beams in the trial use the same optimization type. Since you can use the SmartArc optimization type only with the SVD dose engine, you cannot combine the SmartArc optimization type with any other optimization type in the same optimization.

If you choose not to use the SVD dose engine, the software uses the TPB dose engine and you can combine the optimization types that are specified in the previous section for Intensity Modulation and DMPO.

Use the optimization type None

In order to use the optimization type **None**, all beams in the prescription must use the optimization type **None**. You cannot combine the optimization type **None** with any other optimization type within the same prescription.

Additionally, if you set the prescription to normalize the dose relative to Max Dose for the plan, the MUs for beams that use the optimization type **None** may change. The MUs may change because the additional dose delivered by the newly optimized beams changes the Max Dose for the plan, which in turn changes the normalization of the non-optimized beams. To avoid this problem, either do not assign a Max Dose prescription to a beam that is not being optimized or set the prescription that you do not want to optimize to the **Set Monitor Units** mode.

Optimize boost treatments

You can use P³IMRT to optimize boost treatments that account for dose from previous treatments.

1   Add a new prescription.

2   Create the boost beams and assign them to the new prescription.

3   Select the new prescription that is used by the boost beams as the current prescription for the trial.

4   Add objectives and constraints as necessary.

5   Set the optimization type of the original beams to **None**.

6   Set the optimization type for the boost beams as appropriate for your plan.

7   Optimize the plan.

   The original beams will remain unchanged while the ODM values for the boost beams will be modified to achieve the new objectives of the treatment.

Optimize external beam plans that include brachytherapy dose

The optimization of external beam boost treatments to brachytherapy treatments is similar to that of other boost treatments, but several issues can arise.

• **Dose units**—The units of the external beam dose and the brachytherapy dose must match. For example, the brachytherapy dose cannot be specified in terms of dose rate.

• **Dose grid resolution**—Due to the large gradients in brachytherapy dose distributions, you should use a dose grid resolution of 0.3 cm or smaller. If you compute dose on a coarser grid, the software will warn you that the grid is too large, although the software will allow you to compute dose as long as the resolution is 2.0 cm or less.

   However, using such a small dose grid can significantly slow down the P³IMRT optimization, especially if the dose volume is large and there are several beams in the plan. One strategy to speed up optimization is to do the initial calculations and optimization on a coarser dose grid (0.5 cm) and then recompute the final dose on a finer grid as necessary.

• **Max Dose- vs. Dose Volume-type objectives**—The large dose gradients in brachytherapy present unique challenges for the optimization algorithm. The maximum dose in the computed volume can be very large and sensitive to small changes in the position of the source or the dose grid. Maximum dose objectives and constraints will generally not work well for brachytherapy plans unless the region of interest in question is a sufficient distance from the source. Using dose volume objectives and constraints is more effective. To estimate the percentage volume that you will be allowed to exceed the maximum dose, compute brachytherapy dose only and look at a DVH for the ROI. (Note that if there are uncomputed beams in the plan, dose will not be displayed. To view just the brachytherapy dose, you must either remove all the beams or compute dose and set the beams' prescription to zero.)

Similarly, uniform dose objectives and uniformity constraints will not work well for plans involving brachytherapy sources. You can combine minimum dose (or dose volume) objectives and constraints with maximum dose volume objectives and constraints to define the dose uniformity you want over a given fraction of the ROI.

12 Reference Information

Optimization algorithm

The optimization algorithm uses a sequential quadratic programming method to minimize a quadratic objective function, which is constructed from a set of dose-based or dose-volume-based objectives for individual regions of interest. The objective function is subject to a set of linear and non-linear constraints. An example of a linear constraint is requiring a transmission factor to be positive. An example of a non-linear constraint is a dose-based or dose-volume-based limit, such as keeping the dose below *X* cGy in *Y* % of the region of interest volume.

Conversion algorithms

Conversion algorithms convert ideal ODMs to a form deliverable by a specific delivery device. P³IMRT currently supports conversion to MLC control point and compensator delivery devices. The following sections provide detailed information about the conversion algorithms used by P³IMRT.

Segmented multi-leaf collimators (MLCs)

P³IMRT uses step-and-shoot converters to convert the ODM of each beam into MLC control points. A step-and-shoot converter consists of two independent algorithms: a clustering algorithm and a segment extraction algorithm.

The clustering algorithm transforms the ideal ODM, with its quasi-continuous distribution of opening densities (transmission values), into a clustered ODM, with only a relatively small number of opening densities (typically about 5). It is this number of opening densities (or levels) used in the clustered ODM that determines how accurately the final dose distribution will reflect the dose distribution produced by the optimization. The larger the number of levels, the more accurate the dose distribution will be, and vice-versa, when all other parameters are constant.

Several segment extraction algorithms can be used to produce segments from the clustered ODM. The segment extraction algorithms that Pinnacle³ uses are theoretically lossless, unlike the clustering algorithms. This means the sum of the segment shapes weighted by their respective intensities is usually exactly equal to the clustered ODM. This is the case for most step-and-shoot converters.

When converting the ideal ODM to MLC control points, the software takes into account the machine constraints of the MLC as set in the physics tool. The software also incorporates head scatter differences between MLC control points and the effects of leaf transmission and rounded leaf tips. Due to these factors, the dose after conversion will not exactly match the dose using the ideal ODM. Use the tools described in the *Plan Evaluation Tools* chapter to evaluate the results of the conversion.

P[3]IMRT offers two step-and-shoot converters: K-means Clustering and IMFAST. All machines can use the K-means Clustering converter to produce weighted beam MLC control points. Siemens machines can also use the IMFAST converter.

K-means Clustering

- **Clustering algorithm**–This method uses the K-means Clustering algorithm to break the ideal ODM into smaller groups, or clusters, of equal opening densities. The algorithm finds the optimal, non-uniformly spaced opening density levels to use in the clustered ODM by minimizing the root-mean-square (RMS) difference between the ideal and clustered ODMs. The maximum number of opening density levels allowed is specified in the **Maximum levels** field.

- **Segment extraction algorithm**–The K-means Clustering converter uses a recursive algorithm to extract deliverable (meeting the limitations of the MLC) segment shapes. Each level of the clustered ODM is processed individually to produce segment shapes and intensities. After all segments have been extracted, the complete list of segments is then scanned; segments that have the same shape are combined by adding their respective intensities, and segments that have the same intensities and whose combined segment shape is deliverable are also combined by adding their respective shapes. Leaf positions are then determined for each segment shape.

IMFAST

- **Clustering algorithm**–In the IMFAST converter, the clustering of the ideal ODM is performed by discretely sampling the ODM between the smallest non-zero and the largest opening densities in the ideal ODM. This creates a set of uniformly spaced clusters based on the user-specified number of levels.

- **Segment extraction algorithm: Extracts**–An extract is a deliverable segment shape whose corresponding non-zero opening densities, in the clustered ODM, are all larger or equal to a specific minimum value. In the IMFAST converter, the extraction process looks for the largest such extract, subtracts it from the clustered ODM, and repeats the procedure until the user-specified number of extracts have been extracted. Every extract is a segment. The remainder of the clustered ODM will be converted to segments using the Rod pushing method, which seeks to minimize delivery time.

- **Segment extraction algorithm: Rod Pushing**–This algorithm is fundamental because it produces the theoretical minimum beam on time, and it forms the basis for pseudo-dynamic techniques. The idea is based on visualizing the clustered ODM as a solid composed of vertical rods whose heights are equal to the opening densities in the clustered ODM that correspond to the locations of the rods. If we consider this process for one leaf pair, we follow two simple rules as we move from one rod to the next in one direction: (1) if the current rod is shorter than the previous rod, push the current rod so that its top matches the top of the previous rod, and (2) if the current rod is longer than the previous rod, push the current rod up so that their bases match. If a rod has zero height, then it can be imagined as an infinitesimally thin rod with the top and base being at the same location. The top and base of this zero-height rod must also be moved according to the two rules. If you now slice up the resulting solid everywhere that you see a top or a base, you will get a set of slabs. Each slab represents a segment whose intensity is equal to the thickness of the slab.

Dynamic delivery

During Sliding Window conversion, each beam's ideal ODM is converted to optimum leaf trajectories, or leaf motion sequences, as a function of monitor units for delivery. Groups of leaf pairs form a sequence of windows to modulate intensities in order to produce a two-dimensional non-uniform intensity profile. The gap formed by each pair of opposing leaves sweeps monotonically across the targeted volume while the radiation beam is on. The gap's width and speed are varied across the field.

Because the dose rate of the machine might fluctuate slightly, the motion is indexed to monitor units rather than time. As the gap sweeps across a point, the dose received directly by the point is proportional to the number of monitor units elapsed from the time the tip of the leading leaf moves past the point and exposes it until the tip of the following leaf moves in to block it again. Knowledge of the maximum leaf speed is used to maximize the gap between the opposing pairs of leaves and, therefore, to minimize the number of monitor units required for delivering the treatment.

Approximate empirical corrections are applied during dose computation to account for various MLC characteristics including rounded leaf tips, tongue-and-groove leaf design, leaf transmission, leaf scatter, and collimator scatter upstream from the MLC.

Compensators

The software allows you to convert each beam's ideal ODM to a matrix of compensator thicknesses. The software produces the resulting compensators at the specified resolution and source-to-compensator distance during the conversion. Conversion uses the commissioned beam model and energy spectrum to determine the attenuation coefficients for the conversions. The software also ensures that the minimum transmission values of the matrix are deliverable by the maximum compensator thicknesses. The minimum transmission value is user-specified. In addition, the software performs an iterative optimization of the compensator thicknesses to obtain the best least-squares fit to the ideal incident energy fluence of each beam.

Iterative dose computation

The dose engines used for optimization do not require you to do additional machine modeling beyond what the software currently requires for the convolution model.

Delta Pixel Beam

The optimization of intensity-modulated fields requires many dose computations while searching for the optimal solution. The dose computation must be fast as well as accurate to obtain clinically acceptable results in a reasonable amount of time. The Delta Pixel Beam approach used by P³IMRT lets the optimization compute dose quickly and accurately.

The Delta Pixel Beam approach uses a combination of standard dose engines and either the TPB dose engine or the SVD dose engine. The software uses TPB or SVD until the optimization reaches the convolution dose iteration that you set. At the convolution dose iteration, the software uses

either Adaptive Convolve or the Fast Convolve to compute the intermediate dose. Then, for iterations after the convolution dose iteration, the software uses TPB or SVD to calculate the difference in the dose due to changes in the ODM. These dose differences are then used to recalculate the dose at each iteration.

If you chose to compute final dose automatically after the optimization is complete, the software computes final dose using either Adaptive Convolve or CC Convolution. The optimization is complete when the optimizer reaches the final iteration or finds an optimal solution to the plan.

In the **Preferences** window, you can choose which dose engines the software uses for the intermediate and final dose calculations. For more information, see the *Pinnacle³ Planning Reference Guide*.

For intensity modulation and DMPO plans, you can choose whether the software uses the TPB dose engine or the SVD dose engine when you set the optimization parameters. For SmartArc plans, the software always uses the SVD dose engine.

> **NOTE**
> For SmartArc plans, intermediate dose computation is optional. If you do not select the **Compute intermediate dose** check box in the **IMRT Parameters** window, the software only uses the SVD method.

Finite-Size Pencil Beam (TPB Dose)

The finite-size pencil beam method uses a set of precalculated mono-energetic pencil beam kernels representing a single 5 x 5 mm incident energy fluence pixel. The kernels represent dose in a flat water phantom and are functions of SSD, depth, azimuthal angle, and radius. The mono-energetic kernels are summed, according to the spectrum of the particular machine in use, to form the poly-energetic kernel used in the dose computation.

To compute dose, rays are cast in the primary direction from each pixel in the incident fluence grid through the patient density volume. At each position along the ray, the density-scaled depth is determined to account for patient heterogeneities.

At each voxel in the dose grid, the dose contribution from each pencil beam is accumulated to determine the delivered dose. The dose contribution from a pencil beam is found by determining the position of each voxel with respect to the pencil beam and looking up the contribution from the poly-energetic pencil beam kernel. The contribution is interpolated from the kernel using the SSD, density-scaled depth, azimuthal angle, and radial distance.

The pencil beam computation thus accounts for heterogeneities in the primary direction of the beam. Secondary scatter is treated as homogeneous.

Singular Value Decomposition (SVD Dose)

The SVD method uses singular value decomposition[1] to parameterize the dose deposition kernel for ease of computation.

In the full Collapsed Cone Convolution method, the dose deposition kernel is a 3D function of the distance between the point at which the TERMA is calculated and the point at which dose is

deposited. The kernel is pre-computed using Monte Carlo methods. No attempt is made to parameterize it, and no assumptions are made about kernel invariance.

The kernel can be approximately modeled in a cylindrical geometry as the product of a function that depends only on the 2D coordinates in the fluence plane normal to the beam and a function that depends only on radiological depth.

In the SVD method, the kernel is represented by a small series of terms. Each term in the series is a product of a lateral function and a depth-dependent function. This series is a better approximation of a true 3D kernel than a single function.

This separation assumes the kernel is laterally invariant. The usual 3D superposition of the TERMA and the dose deposition kernel then become a series of simpler terms, each of which contains a true 2D convolution multiplied by a term that depends only on radiological depth.

SVD dose calculation is much faster than the full collapsed cone convolution/superposition method, and does not require the fixed 5 mm pixel size inherent in the TPB method. But due to the assumption of lateral invariance of the kernel, the SVD method neglects off-axis softening and the effects of heterogeneities on lateral scatter.

Heterogeneities in the direction of the primary beam are taken into account.

[1]Bortfeld, T., W. Schlegel, and B. Rhein. 1993. Decomposition of pencil beam kernels for fast dose calculation in three-dimensional treatment planning. *Medical Physics* 20(2): 311-318.