Post-mastectomy radiation therapy (PMRT) RapidPlan Model Description

Purpose:

This document describes the context in which the Post-mastectomy Chest Wall and Nodes (KU_PMRT) Model should be used, as well as how it was configured and validated. All instructions needed to use this model in your clinic can be found when you **read the first 19 pages of this document**.

Applicability:

Note	*RapidPlan knowledge-based planning and its models are not intended to replace clinical decisions, provide medical advice or endorse any particular radiation plan or treatment procedure. The patients' medical professionals are solely responsible for and must rely on their professional clinical judgment when deciding how to plan and provide radiation therapy.*
Note	*The performance of the KU_PMRT model may vary depending on the contouring and planning guidelines. Each site should validate the model with institution-specific contouring and planning guidelines before clinical use.*
Note	*You should validate every DVH estimation model before using it clinically. This applies to any model, whether Varian provided, peer provided or the models you create yourself.*

- KU_PMRT is intended to be used for RapidArc plans of 6 partial arcs on Halcyon/Ethos or TrueBeam.
- KU_PMRT was generated with Eclipse v18.0. Plans were copied to an ARIA v15.6 system to generate a copy of the model compatible with Eclipse v15.6 and beyond. Both the v18.0 and v15.6 models are available for use.
- KU_PMRT is meant to be used for treatment plans where chest wall and nodes are treated in the unilateral setting. All plans used in this model are post-mastectomy cases; intact breast and those involving inflated expanders were not included in the model.
- KU_PMRT supports a range of dose schemes and doses can be scaled accordingly. All cases in the model were planned using a hypofractionated dose scheme of 42.56Gy in 16 fractions; the model has been successfully tested on alternative dose schemes, including 50Gy in 25 fractions. This was created to help with hypofractionated dose schemes supported by CCTG MA.39 and ALLIANCE A221505 clinical trials.
- Ipsilateral and contralateral breasts (or chestwall), humeral heads, and lungs need to be delineated and matched to the model accordingly.
- An associated 36 metric dosimetric scorecard should be used to evaluate plan quality and automatically generate the optimization structures needed (see page **Annex A1-A2** for details or manual creation)
- Due to the large number of structures the "Generate Estimates and Objectives" step when applying this model can take time (5+ minutes), the system isn't locked, please be patient.
- The "**Automatic Intermediate Dose**" function of the Photon Optimizer was utilized with **MR4** return and **convergence mode: ON** selected in the calculation options which provide best results. These **settings should be changed prior to starting the optimization or plan quality will be compromised.** For increased homogeneity, consider re-optimizing the finished plan back to MR2, continuing the optimizing with the

current plan dose. This has been a successful strategy in improving homogeneity within the target structures and helping to improve ipsilateral lung and heart DVH metrics.

- The KU_PMRT model was created using the guidelines described below.

Target contouring guidelines:

Standard Target Name	Example Description
CTV_CW	Includes the Mastectomy Scar CTV, and takes into account the radiopaque markers placed at CT identifying clinical extent of chest wall, surgical changes visualized by CT, and consensus definitions of anatomical borders of chest wall from the RTOG Breast Cancer Atlas
PTV_CW	Chest Wall CTV + 7mm 3D expansion (excludes heart and does not cross midline)
PTV_CW_Eval	As a part of the Chest wall PTV often extends outside the patient, the Chest wall PTV is then copied to a Chest wall PTV Eval which is edited. This Chest wall PTV Eval is limited anteriorly to exclude the part outside the patient and the first 3 mm of tissue under the skin (in order to remove some of the buildup region for the DVH analysis) and posteriorly is limited to no deeper than the posterior rib surface and excludes lung and heart. In general, the Chest wall CTV should not cross midline. This Chest wall PTV Eval is the structure used for DVH constraints and analysis and not for beam aperture generation.
CTVn_Ax	Based on consensus definitions from RTOG Breast Cancer Atlas. Superior extent typically is below the level of the cricoid; medially excludes thyroid, trachea, and esophagus. The lateral border extends to the lateral edge of the sternocleidomastoid muscle superiorly and the clavicle at its more inferior extent, and the inferior border extends to the caudal aspect of the clavicular head.
PTVn_Ax	Supraclavicular CTV + 5 mm margin in all directions. The following structures should be excluded from the Supraclavicular PTV to minimize excess dose to normal tissues: ipsilateral thyroid, trachea, esophagus, and ipsilateral lung. This means that some or all of the medial border of the Supraclavicular CTV and PTV will be similar. The Supraclavicular PTV should exclude the vertebral body.
CTVn_IMN	All patients will be recommended for treatment of IMNs in light of recent studies showing a potential survival benefit when these nodes are included in the treatment field23-24 . Contour should include the internal mammary/thoracic vessels in the first three intercostal spaces. Contours should exclude the lung and should not extend medially past the sternum.
PTVn_IMN	Contour includes the IMN CTV + 5 mm medially, laterally, superiorly, and inferiorly. The IMN PTV is limited medially to not extend into the sternum. In order to minimize excess normal tissue irradiation, no additional expansion of the IMN CTV into the lung or heart should be done for the IMN PTV. The deep edge for the IMN PTV will be similar to the IMN CTV. No anterior expansion of the CTV into the chest wall or breast volumes will be done.
CTVn_SCL	Based on consensus definitions from RTOG Breast Cancer Atlas. Superior extent typically is below the level of the cricoid; medially excludes thyroid, trachea, and esophagus. The lateral border extends to the lateral edge of the sternocleidomastoid

	muscle superiorly and the clavicle at its more inferior extent, and the inferior border extends to the caudal aspect of the clavicular head.
PTVn_SCL	Supraclavicular CTV + 5 mm margin in all directions. The following structures should be excluded from the Supraclavicular PTV to minimize excess dose to normal tissues: ipsilateral thyroid, trachea, esophagus, and ipsilateral lung. This means that some or all of the medial border of the Supraclavicular CTV and PTV will be similar. The Supraclavicular PTV should exclude the vertebral body.
CTV_Scar	Mastectomy scar and associated surgical change + 2cm 3D expansion. Limit the CTV expansion posteriorly at anterior surface of the ribs and anterolaterally at skin
PTV_Scar	Mastectomy Scar CTV + 7cm 3D expansion (excludes heart)
PTV_Scar_Eval	Since a substantial part of the Mastectomy Scar PTV often extends outside the patient – a Mastectomy Scar PTV Eval is created. This Mastectomy Scar PTV Eval is limited to exclude the part that extends outside the ipsilateral body/chest wall and the first 3 mm of tissue under the skin (in order to remove some of the buildup region for the DVH analysis) and posteriorly is limited to exclude lung and heart. The Mastectomy Scar PTV Eval should not cross midline and should be contained within the borders of the Chest wall PTV Eval. This is the structure used for DVH constraints, analysis, and compliance.

All target contouring shall be in accordance to published guidelines, see https://econtour.org/references for various guidelines.

It is recommended that structures be contoured according to the RTOG breast cancer atlas: www.rtog.org/CoreLab/ContouringAtlases/BreastCancerAtlas.aspx

Contour templates have been generated in Radformation AutoContour (New York, NY, USA) to assist in structure creation. A contour template is included with this model to facilitate plan automation for AutoContour users.

Organ At Risk contouring guidelines:

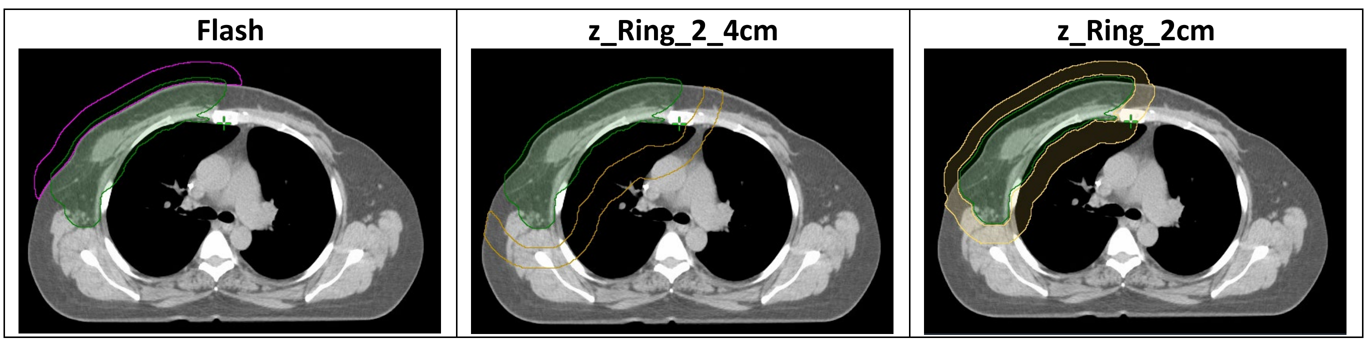
OAR Standard Name	Description
Breast_Contra	The contralateral breast can be at risk for exposure to excess inadvertent dosing, particularly in cases of very medially located lumpectomy sites and the inclusion of the IMN PTV. Therefore, dose to the contralateral breast will be constrained in the treatment planning. The contour includes the apparent CT glandular breast tissue visualized by CT and consensus definitions regarding "breast" of anatomical borders from the RTOG Breast Atlas. In general, the borders are: • Posterior border: At the anterior surface of the pectoralis, serratus anterior muscles excluding chest wall, ribs, boney thorax, and lung/heart • Medial border: The sternal-costal junction • Lateral border: Varies based on the size of the breast but typically is at the midaxillary line and excludes the ipsilateral latissimus dorsi muscle • Cephalad border: First or second rib medially • Caudal: border: Inframammary fold or inferior extent of the breast on CT

	• Anterior border: Skin minus 5 mm to minimize inaccuracy of dose calculation at the skin surface
Chestwall_Contra	The contralateral chestwall should meet consensus definitions of anatomical borders from the RTOG Breast Cancer Atlas. • Posterior border: At the anterior surface of the pectoralis, serratus anterior muscles excluding chest wall, ribs, boney thorax, and lung/heart • Medial border: The sternal-costal junction • Lateral border: Midaxillary line and excludes the ipsilateral latissimus dorsi muscle • Cephalad border: First or second rib medially • Caudal: border: Inframammary fold or inferior extent of the breast on CT • Anterior border: Skin minus 3 mm to minimize inaccuracy of dose calculation at the skin surface
Esophagus	Upper Cervical Esophagus, a tubular structure that starts at the bottom of pharynx (cricopharyngeal inlet) and extends to the level of the carina.
Glnd_Thyroid	The thyroid is easily visible on a non-contrast CT due to its preferential absorption of iodine, rendering it "brighter" or denser than the surrounding neck soft tissues. The left and right lobes of the thyroid are somewhat triangular in shape and often do not converge anteriorly at mid-line. All "bright" thyroid tissue should be contoured.
GreatVes	Includes the arch of the aorta superiorly and pulmonary trunk and vessels inferiorly.
Heart	This is to be contoured on all cases, not just the left-sided. The heart should be contoured beginning just inferior to the level in which the pulmonary trunk branches into the left and right pulmonary arteries (PA). Above the PA, none of the heart's 4 chambers are present. The heart should be contoured on every contiguous slice thereafter to its inferior most extent near the diaphragm. The following structures, if identifiable, should be excluded from the heart contour: esophagus, great vessels (ascending and descending aorta, inferior vena cava). One need not include pericardial fat, if present. Contouring along the pericardium itself, when visible, is appropriate.
Humerus_Ipsi	Proximal articular surface of the humerus, consists of the bone's large, rounded head.
Liver	Includes the right, left, caudate, and quadrate lobes. Includes the superior dome of the surface of the liver up to the diaphragm. Excludes the gallbladder.
Lung_Contra	This may be contoured with auto0segmentation with manual verification.
Lung_Ipsi	This may be contoured with auto0segmentation with manual verification.
Lungs	Low density structures, contoured together.
Scar_Marker	Wire marker should be placed at the time of simulation and contoured to delineate mastectomy scar CTV.
SpinalCord	Begins at the cranial-cervical junction (i.e., the top of the C1 vertebral body). Superior to this is brainstem and inferior to this is cord. The inferior border of the spinal cord volume will be defined at approximately L2.
Stomach	Begins at the GE Junction, with overlap with the esophagus, through the gastroduodenal junction inferiorly
Trachea	Begins at the bottom of the larynx and continues until the carina inferiorly
External	External border of the patient

The planning target volumes (PTV) and the organs at risk (OARs) are contoured on the planning CT.

Optimization structure guidelines:

<table>
<tr><th>Model Structure</th><th>Derived Boolean/Expansion</th></tr>
<tr><td>PTV_Combined</td><td>{<PTV_CW> OR <PTVn_Ax> OR <PTVn_IMN> OR <PTVn_SCL> OR <PTV_Scar>}</td></tr>
<tr><td>PTV_CW_Eval</td><td>{<PTV_CW> CROP _Outer <BODY|+3mm>}</td></tr>
<tr><td>zPTV_CW_Opt</td><td>{<PTV_CW> SUB <Lungs>}</td></tr>
<tr><td>PTV_Scar_Eval</td><td>{<PTV_Scar> CROP _Outer <BODY|+3mm>}</td></tr>
<tr><td>Flash</td><td>{<PTV_CW>|+15mm (ANT/POST/L/R only) SUB <BODY>} + HU Threshold -400</td></tr>
<tr><td>External</td><td>{<Body> OR <Flash>}</td></tr>
<tr><td>Lungs</td><td>{<Lung_L> OR <Lung_R>}</td></tr>
<tr><td>zLung_Contra_OPT</td><td>{<Lung_Contra> SUB <PTV_Combined>|+70mm}</td></tr>
<tr><td>zLung_OPT3cm</td><td>{<Lung_Ipsi> SUB <PTV_Combined>|+30mm}</td></tr>
<tr><td>zLung_OPT5cm</td><td>{<Lung_Ipsi> SUB <PTV_Combined>|+50mm}</td></tr>
<tr><td>zHeart_OPT</td><td>{<Heart> SUB <PTV_Combined>|+30mm}</td></tr>
<tr><td>zBody-PTV2</td><td>{<Body>|+20mm SUB <PTV_Combined>}</td></tr>
<tr><td>Body-PTVs</td><td>{<Body> SUB <PTV_Combined>}</td></tr>
<tr><td>zBreast_Contra_Opt</td><td>{<Breast_Contra> SUB <PTV_Combined>|+80mm}</td></tr>
<tr><td>z_Ring_2cm</td><td>{<PTV_Combined>|+20mm SUB <{PTV_Combined>|+2mm AND <BODY>}</td></tr>
<tr><td>z_Ring_2_4cm</td><td>{<PTV_Combined>|+40mm SUB <{PTV_Combined>|+20mm AND <BODY>}</td></tr>
<tr><td>GreatVes</td><td>{<A_Aorta> OR <A_Pulmonary> OR <V_VenaCava_S>}</td></tr>
</table>

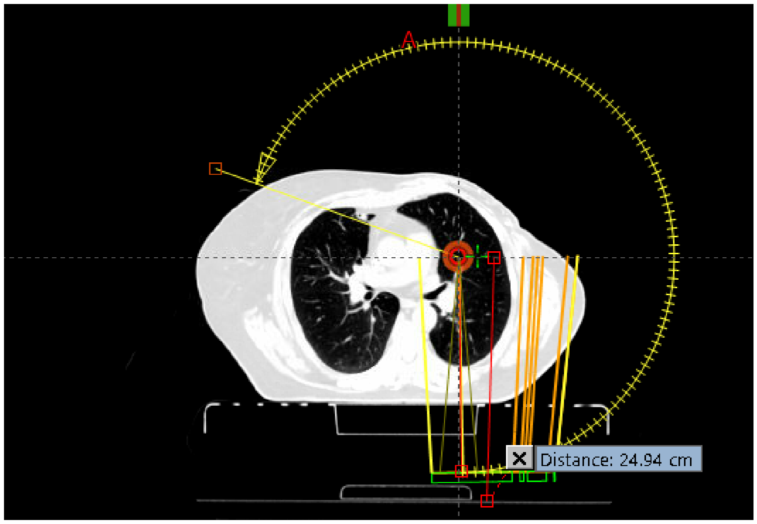


Treatment planning guidelines:

All cases used to train and validate the model were planned using head-first supine positioning with chin neutral or slightly rotated to contralateral side. All patients were immobilized with wingboard with arms over head.

All plans used a Virtual Bolus technique to generate flash for VMAT plans. Plans should be generated on a copy of the treatment planning CT, with the Flash (Virtual Bolus) structure Booleaned into the BODY structure to ensure MLCs will extend beyond the CT-designated external structure. All plans used a HU override of -400 for the Flash structure. The model is trained from plans calculated on virtual data sets. Once optimized, copy the plan and calculate on the treatment planning CT for clinical use.

A six arc VMAT technique was utilized with six partial coplanar arcs on TrueBeam with Millenium-MLC. Arc combinations include two sets of partial 50-60 degree “tangent arcs” on the lateral and medial sides with collimators rotated ±5-10 to match the posterior edge of the patient’s chest wall contours. This method helps reduce the field in the x-dimension, potentially reducing leakage and low dose spray to nearby OARs. Two long partial arcs rotated to 90±10 degrees were used to provide extra coverage for the lower and upper PTVs and improve dose conformity; each partial arc was skewed to treat either the upper or lower, with about 2cm overlap between them. The split arc apertures should overlap, but always ensure that total X jaw does not exceed 15.0cm.



Isocenter and arc selection is rather important in these cases. Collisions should be avoided at all costs. The distance from the isocenter to the tabletop should be kept to 25cm or less (seen above). Isocenter should be placed at mid chest wall. Moving the isocenter medial could further reduce collisions and allow the user to pull the gantry farther to the contralateral side, thus potentially improving chest wall coverage and limiting dose to ipsilateral lung and heart dose (left-sided). If the user has collision check software, it is prudent to run prior to optimization. Care should be taken to avoid entering through contralateral breast or chest wall.

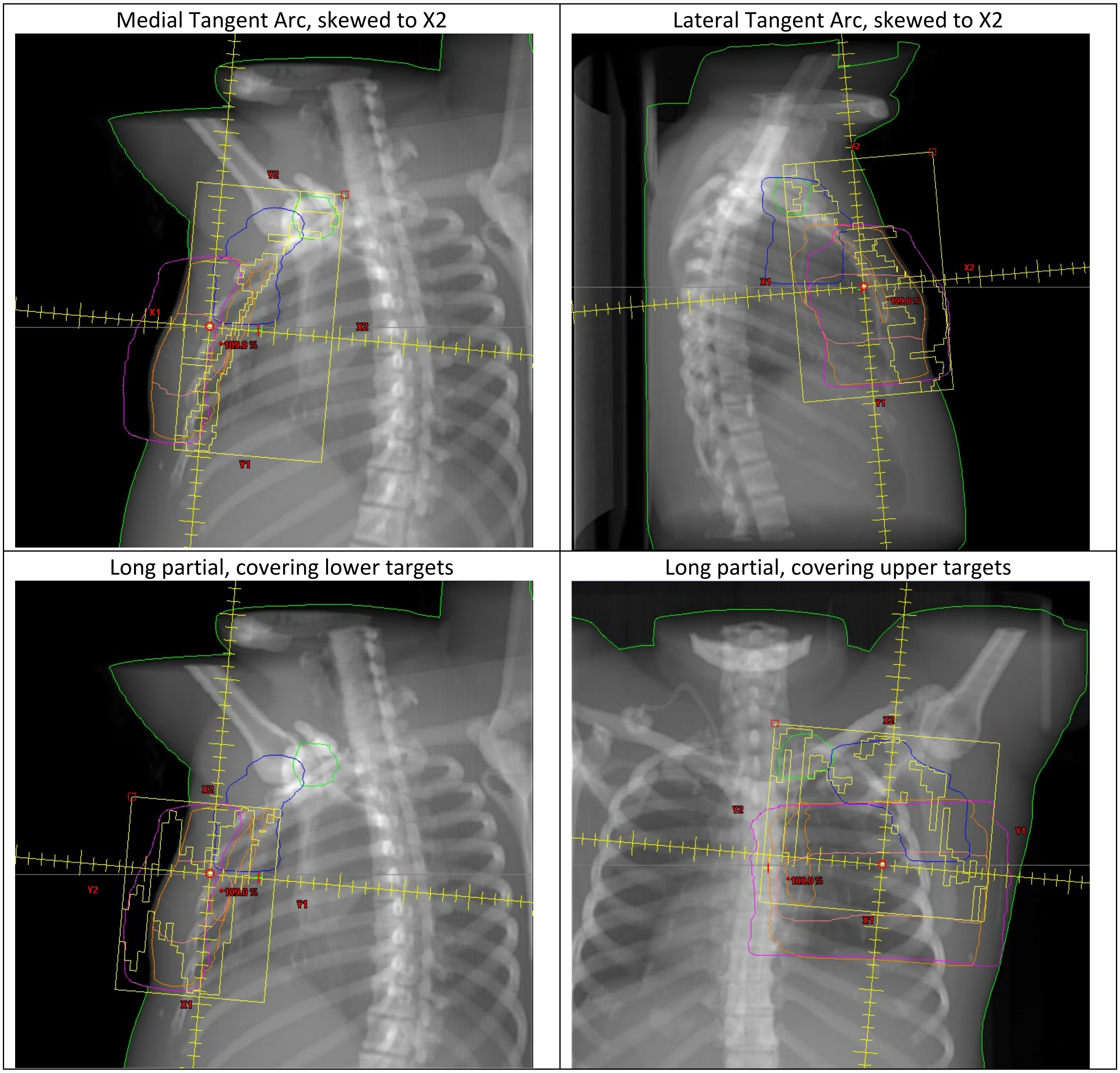
Arc setups for a typical left-sided PMRT case would include:

1) G295-350 (CW), C5 – Medial tangent arc (skew wider X1)
2) G350-295 (CCW), C5 – Medial tangent arc (skew wider X2)
3) G295-179 (CW), C95 – Lower Partial
4) G160-100 (CCW), C355 – Lateral tangent arc (skew wider X1)
5) G100-160 (CW), C355 – Lateral tangent arc (skew wider X2)
6) G179-295 (CCW), C95 – Upper Partial

Arc setups for a typical right-sided PMRT case would include:

1) G60-5 (CCW), C355 – Medial tangent arc (skew wider X1)
2) G5-60 (CW), C355 – Medial tangent arc (skew wider X2)
3) G60-181 (CCW), C85 – Lower Partial
4) G200-260 (CW), C5 – Lateral tangent arc (skew wider X1)
5) G260-200 (CCW), C5 – Lateral tangent arc (skew wider X2)
6) G181-60 (CCW), C85 – Upper Partial

The following should result in a plan that provides adequate PTV coverage, minimizes OAR dose, and provides flash. Below are fields for a right-sided PMRT case showing how the collimators are rotated for the following arcs to maximize coverage, attain flash, and minimize OARs.


Medial Tangent Arc, skewed to X2
Lateral Tangent Arc, skewed to X2
Long partial, covering lower targets
Long partial, covering upper targets

Target Clinical Goals

The following dose prescription and planning guidelines were used for the cases to train and validate the model.

Standard Target Name	Dose [Gy]	Fraction Size [Gy]	# of fractions	Dose specification technique
PTV_CW_Eval	42.56	2.66	16	>=95% of PTV should receive >=95% Rx
PTVn_Ax	42.56	2.66	16	>=95% of PTV should receive >=95% Rx
PTVn_SCL	42.56	2.66	16	>=95% of PTV should receive >=95% Rx
PTVn_IMN	42.56	2.66	16	>=90% of PTV should receive >=90% Rx

This model is compatible (trained and validated) with the above fractionation scheme. Other fractionation regimens may work; this model has successfully been tested on 50Gy in 25 fractions. However, this model has not been tested at other prescriptions. Use caution if scaling this model by a significant amount.

PTV and OAR Clinical Goals:

Name of Structure	Dosimetric parameter	Goal	Variation Acceptable
PTV_CW_Eval	V95%(%)	>= 95%	>=90%
	D50%[%]	<= 108%	<= 112%
	D0.03cc[%]	<= 112%	<= 115%
PTV_Scar_Eval	V95%(%)	>= 100%	> = 95%
PTVn_Ax	V95%(%)	>= 95%	>= 90%
PTVn_SCL	V95%(%)	>= 95%	>= 90%
	D3.0cc(%)	<= 105%	<= 108%
	D0.03cc(%)	<= 108%	<= 110%
PTVn_IMN	V95%(%)	>= 95%	>= 90%
	V90%(%)	>= 90%	>= 80%
	D0.03cc(%)	<= 110%	<= 120%
Lung_Ipsi	V16Gy(%)	< = 30%	< = 35%
	V10Gy(%)	< = 50%	< = 55%
	V5Gy(%)	< = 65%	< = 75%
Lungs	Mean(Gy)	<= 8.5Gy	<= 9.4Gy
Lung_Contra	V4.3Gy	< 15%	
Breast_Contra	D5%	<= 3Gy	<= 4.1Gy
	V5Gy(%)	<= 5%	<= 10% (IMRT only)
Heart (Left)	Mean(Gy)	<= 3.2Gy	<= 4.0Gy
	D0.03cc(Gy)	<= 38Gy	<= 41Gy
Heart (Right)	Mean(Gy)	<= 1.6Gy	<= 3.2Gy
	D0.03cc(Gy)	<= 26Gy	<= 38Gy
SpinalCord	D0.03cc[Gy]	< = 45Gy	< = 48Gy
Esophagus	Mean [Gy]	< = 9.3Gy	
	V10Gy [%]	< = 27%	
	V30Gy [%]	< = 10%	IMRT only
	D0.03cc(Gy)	< = 50Gy	IMRT only
Liver	Mean(Gy)	<= 8Gy	
Body	V110%(%)	<= 10cc	<= 15cc
	D0.03cc(%)	< = 112%	<= 115%

Dosimetric Scorecard overview-points only:

Summary of 36 metric, 200-point dosimetric scorecard, based on various clinical goal sets, guided this work.

Left-sided PMRT			
Metric Id	**StructureId**	**Metric Text**	**Max Score**
1	PTV_CW_Eval	Volume at 95% [%]	12
2	PTV_CW_Eval	Dose at 95% [%]	7
3	PTV_CW_Eval	Dose at 50% [%]	5
4	PTV_CW_Eval	Dose at 0.03CC [%]	5
5	PTVn_SCL	Volume at 95% [%]	10
6	PTVn_SCL	Dose at 95% [%]	6
7	PTVn_SCL	Dose at 3CC [%]	5
8	PTVn_SCL	Dose at 0.03CC [%]	5
9	PTVn_Ax	Volume at 95% [%]	10
10	PTVn_Ax	Dose at 95% [%]	6
11	PTVn_Ax	Dose at 50% [%]	5
12	PTVn_Ax	Dose at 0.03CC [%]	5
13	PTVn_IMN	Dose at 90% [%]	6
14	PTVn_IMN	Volume at 90% [%]	10
15	PTVn_IMN	Dose at 0.03CC [%]	5
16	PTV_Scar_Eval	Volume at 95% [%]	7
17	Heart	MeanDose [Gy]	9
18	Heart	Dose at 5% [Gy]	6
19	Heart	Dose at 0.03CC [Gy]	6
20	Lung_Ipsi	Volume at 16Gy [%]	8
21	Lung_Ipsi	Volume at 10Gy [%]	6
22	Lung_Ipsi	Volume at 5Gy [%]	7
23	Lung_Contra	Volume at 4.3Gy [%]	5
24	Breast_Contra	Dose at 5% [Gy]	2
25	Breast_Contra	Dose at 10% [Gy]	2
26	Breast_Contra	Volume at 5Gy [%]	8
27	BODY	Dose at 0.03CC [%]	5
28	BODY	Volume at 110% [CC]	5
29	SpinalCord	Dose at 0.03CC [Gy]	3
30	GreatVes	Dose at 0.03CC [Gy]	2
31	Humerus_Ipsi	Dose at 0.03CC [Gy]	2
32	Trachea	Dose at 0.03CC [Gy]	3
33	Esophagus	Dose at 0.03CC [Gy]	4
34	Esophagus	Volume at 30Gy [%]	4
35	Esophagus	Volume at 10Gy [%]	2
36	Esophagus	MeanDose [Gy]	2
			200

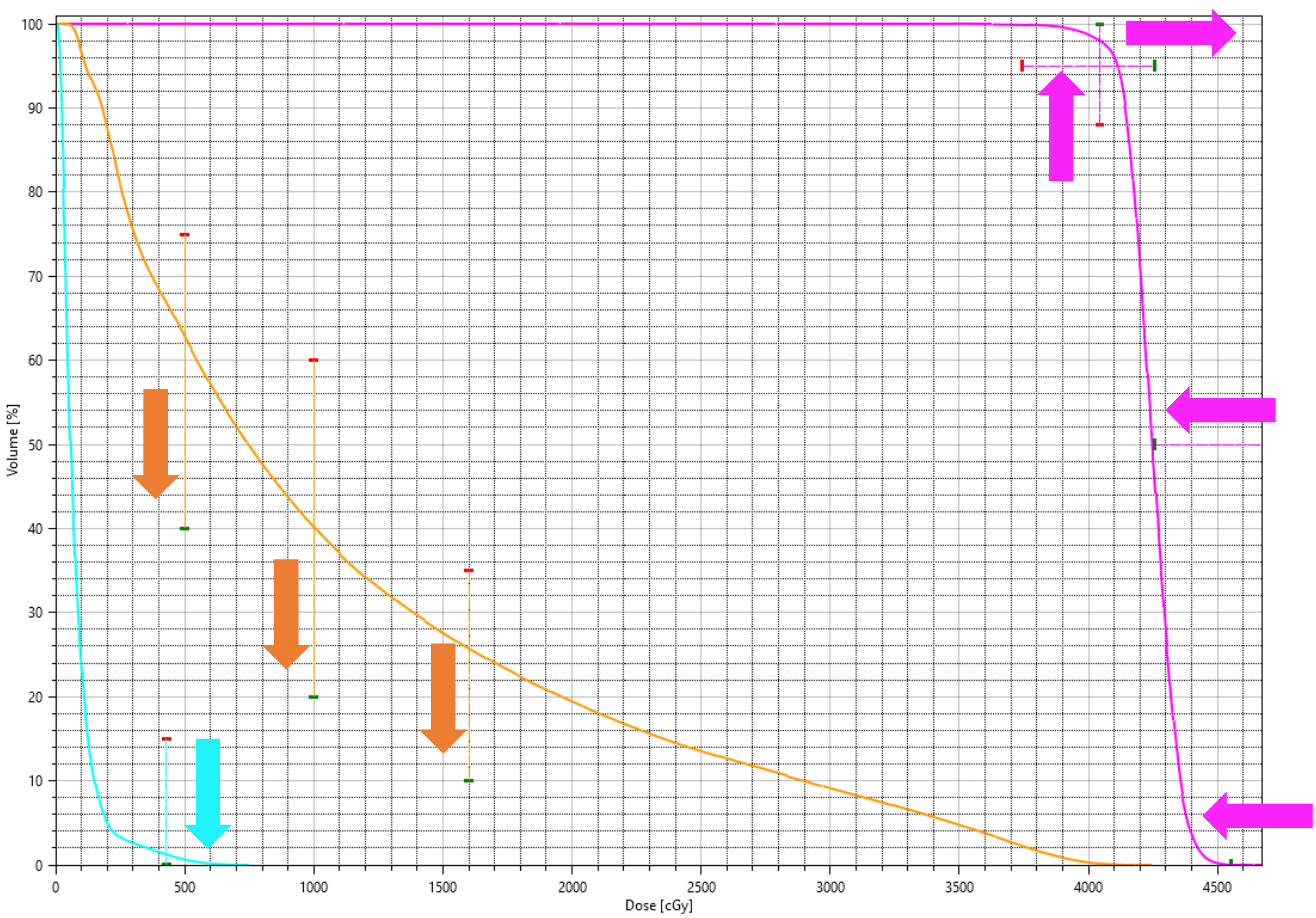
Right-sided PMRT			
Metric Id	**StructureId**	**Metric Text**	**Max Score**
1	PTV_CW_Eval	Volume at 95% [%]	12
2	PTV_CW_Eval	Dose at 95% [%]	7
3	PTV_CW_Eval	Dose at 50% [%]	5
4	PTV_CW_Eval	Dose at 0.03CC [%]	5
5	PTVn_SCL	Volume at 95% [%]	10
6	PTVn_SCL	Dose at 95% [%]	6
7	PTVn_SCL	Dose at 3CC [%]	5
8	PTVn_SCL	Dose at 0.03CC [%]	5
9	PTVn_Ax	Volume at 95% [%]	10
10	PTVn_Ax	Dose at 95% [%]	6
11	PTVn_Ax	Dose at 50% [%]	5
12	PTVn_Ax	Dose at 0.03CC [%]	5
13	PTVn_IMN	Dose at 90% [%]	6
14	PTVn_IMN	Volume at 90% [%]	10
15	PTVn_IMN	Dose at 0.03CC [%]	5
16	PTV_Scar_Eval	Volume at 95% [%]	7
17	Heart	MeanDose [Gy]	9
18	Heart	Dose at 2% [Gy]	6
19	Heart	Dose at 0.03CC [Gy]	6
20	Lung_Ipsi	Volume at 16Gy [%]	8
21	Lung_Ipsi	Volume at 10Gy [%]	6
22	Lung_Ipsi	Volume at 5Gy [%]	7
23	Lung_Contra	Volume at 4.3Gy [%]	5
24	Breast_Contra	Dose at 5% [Gy]	2
25	Breast_Contra	Dose at 10% [Gy]	2
26	Breast_Contra	Volume at 5Gy [%]	8
27	BODY	Dose at 0.03CC [%]	5
28	BODY	Volume at 110% [CC]	5
29	SpinalCord	Dose at 0.03CC [Gy]	3
30	GreatVes	Dose at 0.03CC [Gy]	2
31	Humerus_Ipsi	Dose at 0.03CC [Gy]	2
32	Trachea	Dose at 0.03CC [Gy]	3
33	Esophagus	Dose at 0.03CC [Gy]	4
34	Esophagus	Volume at 30Gy [%]	4
35	Esophagus	Volume at 10Gy [%]	2
36	Esophagus	MeanDose [Gy]	2
			200

In general, how points are assigned between the various competing metrics on a dosimetric scorecard represents the physician's preference insofar as relative weighting. Each function spans a DVH value range of two or more values (ranges not pictured, see Annex A1-A2); each range consists of a starting, failing value (0 points) through the maximum achievable point value. The zero value represents a failure and is the first order priority. Depending on the metric, intermediate point values were added in between the failing point and the maximum achievable point value, covering the piecewise linear function shape and providing multiple levels of reasonably expected DVH values; metrics that contain ideal and acceptable goals typically have 3 or more points. Ideally, most maximum values are not achievable as to continue to quantify additional improvement in already "very good" treatment plans. Care must be taken when attempting such a precise articulation of clinical intent. The full dosimetric scorecard provides a singular objective measure of dosimetric plan quality for a specific intent from which the RapidPlan optimization objective tuning can be manually iterated upon. This laborious model tuning process can prove worthwhile when such a RapidPlan model is deployed in a clinic and works as a single button press auto planning solution of high quality (as defined by its associated dosimetric scorecard).

Example metrics for three structures – PTV_CW_Eval (pink), Lung_Ipsi (orange), and Lung_Contra (cyan) are shown below.

Dosimetric Scorecard selected piecewise linear metrics plotted on DVH:

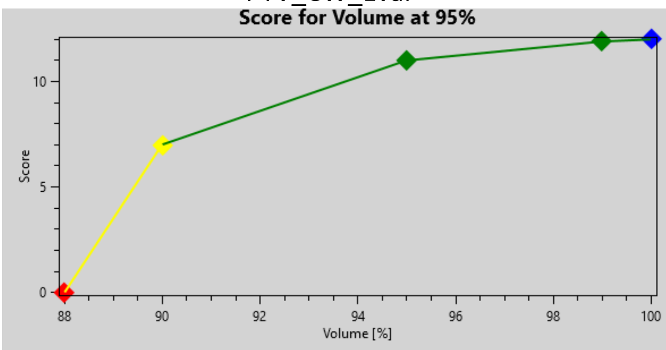
Volume at Dose (vertical) and Dose at Volume (horizontal) lines *with arrows to represent increasing score*



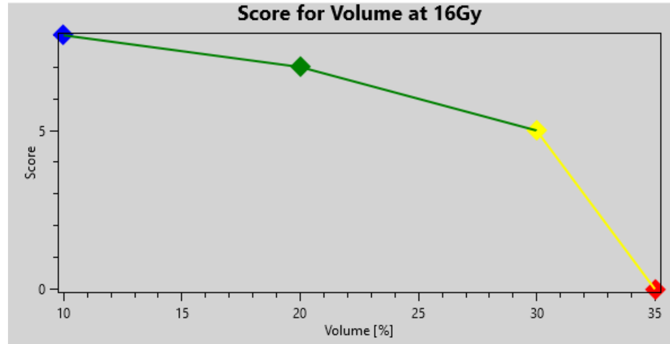
DVH for a clinical PMRT case. PTV_CW_Eval (pink), Lung_Ipsi (orange), and Lung_Contra (cyan) are shown here in the DVH, with arrows pointing in the direction to improve the plan scorecard.

Below, metric plots for PTV_CW_Eval and ipsilateral and contralateral lungs are included:

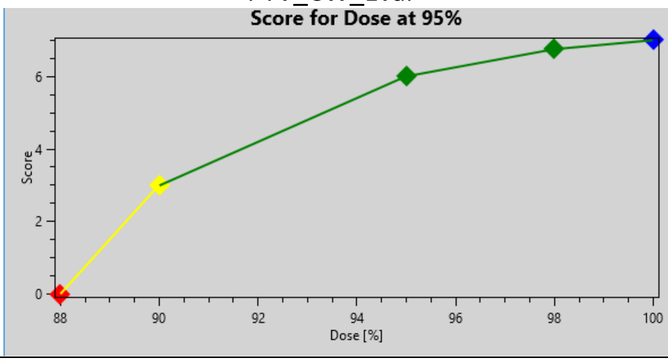
PTV_CW_Eval



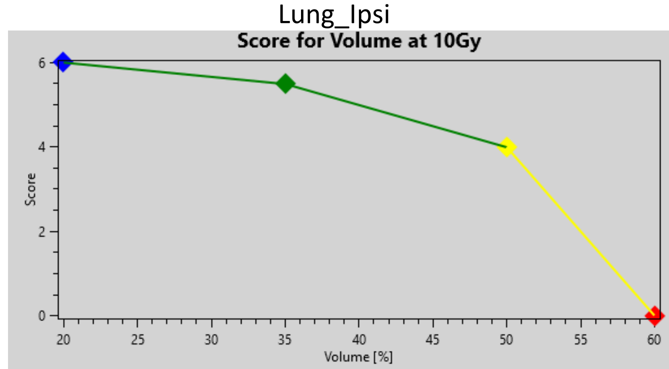
Lung_Ipsi



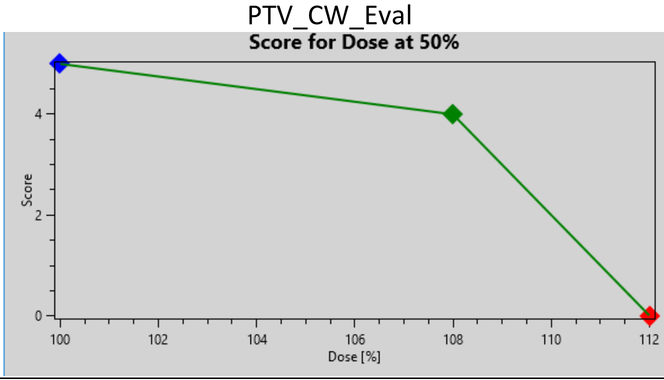
PTV_CW_Eval



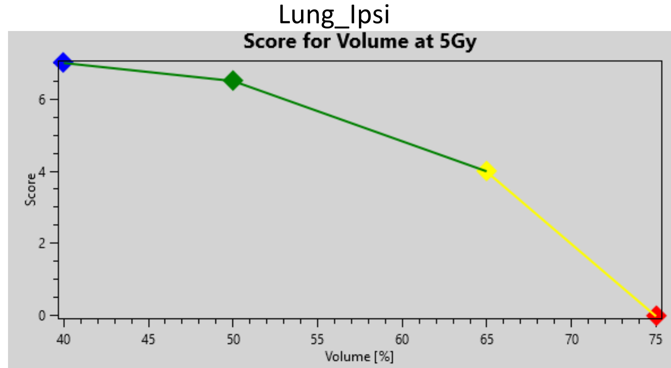
Lung_Ipsi



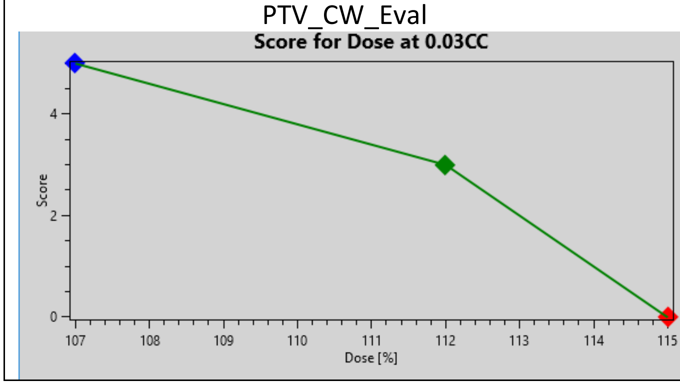
PTV_CW_Eval



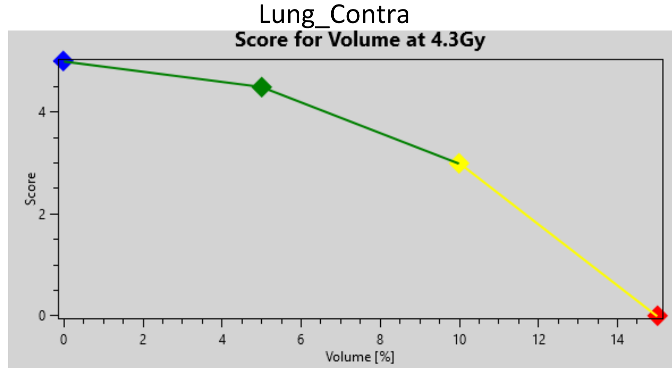
Lung_Ipsi



PTV_CW_Eval



Lung_Contra



Structure codes:

Recommended structure code assignment:

CTVn_IMN	CTV_High (99VMS_STRUCTCODE)
Flash	PTV_Low (99VMS_STRUCTCODE)
PTV_CW_Eval	PTV_High (99VMS_STRUCTCODE)
PTV_Scar_Eval	PTV_High (99VMS_STRUCTCODE)
PTVn_Ax	PTV_High (99VMS_STRUCTCODE)
PTVn_IMN	PTV_High (99VMS_STRUCTCODE)
PTVn_Scl	PTV_High (99VMS_STRUCTCODE)
zPTV_CW_Opt	PTV_High (99VMS_STRUCTCODE)
Breast_Contra	19910, 19908 (FMA)
Esophagus	7131 (FMA)
GreatVes	GreatVessels (FMA)
Heart	7088 (FMA)
Humerus_Ipsi	25929, 25927 (FMA)
Liver	7197 (FMA)
Lung_Contra	7309, 7310 (FMA)
Lung_Ipsi	7309, 7310 (FMA)
SpinalCord	7647 (FMA)
Stomach	7148 (FMA)
Trachea	7394 (FMA)
z_Ring_2_4cm	Ring (99VMS_STRUCTCODE)
z_Ring_2cm	Ring (99VMS_STRUCTCODE)
zBody-PTV2	NormalTissue (99VMS STRUCTCODE)
zLung_OPT3cm	7309, 7310 (FMA)
zLung_OPT5cm	7309, 7310 (FMA)

Optimization objectives:

The following optimization objectives were defined in the model and will be generated when the model is applied to a new case (v18.0):

Model Structures and Objectives

Add Objectives to S

Target	ID	Vol [%]	Dose	Priority	gEUD a
Yes	CTVn_IMN (CTV_High)				
	Lower	99.0	97.0 %	175	
Yes	Flash (PTV_Low)				
	Upper	0.0	104.0 %	300	
	Lower	80.0	80.0 %	80	
Yes	PTV_CW_Eval (PTV_High)				
	Lower	99.0	97.0 %	250	
	Lower	99.9	98.0 %	250	
Yes	PTV_Scar_Eval (PTV_High)				
	Upper	0.0	104.0 %	300	
	Lower	100.0	95.0 %	200	
Yes	PTVn_Ax (PTV_High)				
	Upper	2.0	102.0 %	300	
	Upper	0.0	104.0 %	300	
	Lower	98.0	98.0 %	250	
	Lower	99.0	97.0 %	250	
Yes	PTVn_IMN (PTV_Low)				
	Upper	0.0	104.0 %	300	
	Upper	2.0	102.0 %	250	
	Lower	97.0	95.0 %	200	
	Lower	99.0	90.0 %	200	
Yes	PTVn_Scl (PTV_High)				
	Upper	2.0	102.0 %	300	
	Upper	0.0	104.0 %	300	
	Lower	98.0	98.0 %	250	
	Lower	99.0	97.0 %	250	
Yes	zPTV_CW_Opt (PTV_High)				
	Upper	2.0	102.0 %	300	
	Upper	0.0	104.0 %	300	
	Lower	98.0	98.0 %	250	
	Lower	99.0	97.0 %	250	
	Breast_Contra (19910, 19908)				
	Upper (fixed dose, generated vol.)	Generated	300.0 cG	150	
	Upper gEUD		Generated	175	1.0
	Line (preferring target)	Generated	Generated	175	
	Esophagus (7131)				
	Upper	0.0	100.0 %	100	
	Upper (fixed dose, generated vol.)	Generated	1000.0 cG	100	
	Upper gEUD		Generated	100	12.0
	Upper gEUD		Generated	100	1.0
	Line (preferring target)	Generated	Generated	85	
	GreatVes (GreatVessels)				
	Upper gEUD		Generated	100	1.0
	Line (preferring target)	Generated	Generated	70	
	Heart (7088)				
	Upper (fixed vol., generated dose)	0.0	Generated	100	
	Upper gEUD		Generated	175	1.0
	Upper gEUD		Generated	150	40.0
	Line (preferring target)	Generated	Generated	175	
	Humerus_Ipsi (25929, 25927)				
	Upper gEUD		Generated	70	1.0
	Upper gEUD		Generated	70	12.0
	Line (preferring target)	Generated	Generated	70	
	Liver (7197)				
	Upper gEUD		Generated	100	1.0
	Upper gEUD		Generated	100	40.0
	Line (preferring target)	Generated	Generated	75	
	Lung_Contra (7310, 7309, 68877)				
	Upper (fixed dose, generated vol.)	Generated	430.0 cG	100	
	Line (preferring target)	Generated	Generated	100	
	Lung_Ipsi (7309, 7310, 68877)				
	Upper (fixed dose, generated vol.)	Generated	1600.0 cG	150	
	Upper (fixed dose, generated vol.)	Generated	1000.0 cG	150	
	Upper (fixed dose, generated vol.)	Generated	500.0 cG	150	
	Upper (fixed dose, generated vol.)	Generated	50.0 %	150	
	Upper gEUD		Generated	100	1.0
	Line (preferring target)	Generated	Generated	125	
	SpinalCord (7647)				
	Upper (fixed vol., generated dose)	0.0	Generated	100	
	Line (preferring target)	Generated	Generated	85	
	Stomach (7148)				
	Upper gEUD		Generated	100	1.0
	Upper gEUD		Generated	100	40.0
	Line (preferring target)	Generated	Generated	75	
	Trachea (7394)				
	Upper gEUD		Generated	50	1.0
	Line (preferring target)	Generated	Generated	50	
	Z_Ring_2_4cm (Ring)				
	Line (preferring target)	Generated	Generated	85	
	Z_Ring_2cm (Ring)				
	Upper	0.0	102.0 %	250	
	Upper gEUD		98.0 %	100	40.0
	zBody-PTV2 (NormalTissue)				
	Upper gEUD		60.0 %	100	40.0
	zLung_OPT3cm (7310, 7309)				
	Upper gEUD		Generated	75	1.0
	Line (preferring target)	Generated	Generated	80	
	zLung_OPT5cm (7310, 7309)				
	Upper gEUD		Generated	90	1.0
	Line (preferring target)	Generated	Generated	95	

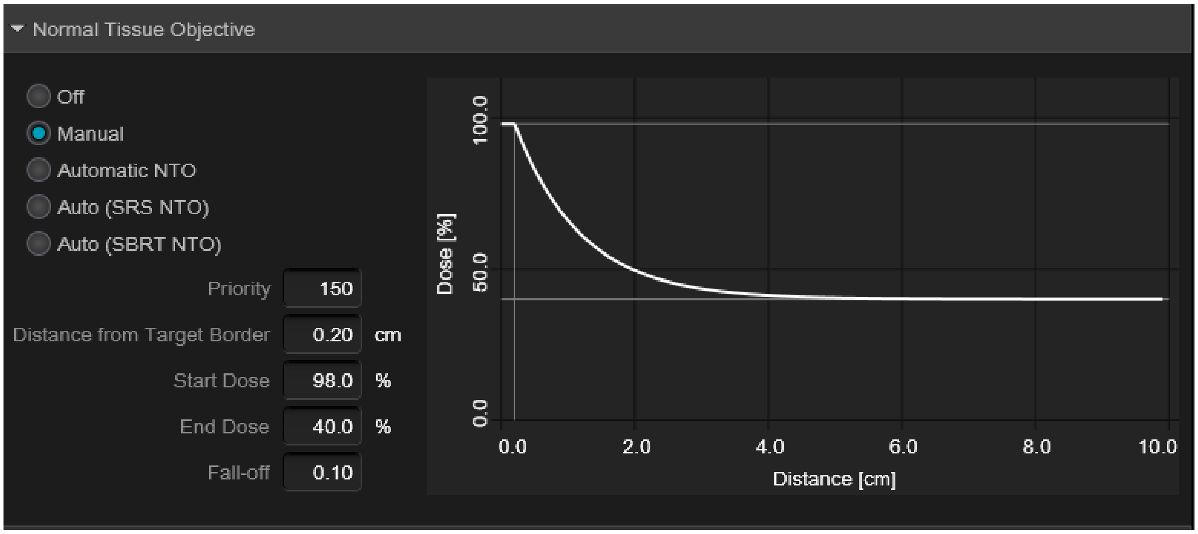
With v15.6, generated gEUD values are not available. For those constraints, we have left the priority set to 0 and the gEUD dose set to a default value of 3000cGy. Please adjust these values during optimization to push the plan to your liking. The following optimization objectives were defined in the model and will be generated when the model is applied to a new case (v15.6):

Model Structures and Objectives

Add Objectives to S

Target	ID	Vol [%]	Dose	Priority	gEUD a
Yes	CTVn_IMN (CTV_High)				
	Lower	99.0	97.0 %	175	
Yes	Flash (PTV_Low)				
	Upper	0.0	104.0 %	300	
	Lower	80.0	80.0 %	80	
Yes	PTV_CW_Eval (PTV_High)				
	Lower	99.0	97.0 %	250	
	Lower	99.9	98.0 %	250	
Yes	PTV_Scar_Eval (PTV_High)				
	Upper	0.0	104.0 %	300	
	Lower	100.0	95.0 %	200	
Yes	PTVn_Ax (PTV_High)				
	Upper	2.0	102.0 %	300	
	Upper	0.0	104.0 %	300	
	Lower	98.0	98.0 %	250	
	Lower	99.0	97.0 %	250	
Yes	PTVn_IMN (PTV_Low)				
	Upper	0.0	104.0 %	300	
	Upper	2.0	102.0 %	250	
	Lower	97.0	95.0 %	200	
	Lower	99.0	90.0 %	200	
Yes	PTVn_Scl (PTV_High)				
	Upper	2.0	102.0 %	300	
	Upper	0.0	104.0 %	300	
	Lower	98.0	98.0 %	250	
	Lower	99.0	97.0 %	250	
Yes	zPTV_CW_Opt (PTV_High)				
	Upper	2.0	102.0 %	300	
	Upper	0.0	104.0 %	300	
	Lower	98.0	98.0 %	250	
	Lower	99.0	97.0 %	250	
	Breast_Contra (19910, 19908)				
	Upper (fixed dose, generated vol.)	Generated	300.0 cGy	150	
	Mean		Generated	200	
	Line (preferring target)	Generated	Generated	175	
	Esophagus (7131)				
	Upper	0.0	100.0 %	100	
	Upper (fixed dose, generated vol.)	Generated	1000.0 cGy	100	
	Mean		Generated	125	
	Upper gEUD		3000.0 cGy	0	12.0
	Line (preferring target)	Generated	Generated	85	
	GreatVes (GreatVessels)				
	Mean		Generated	125	
	Line (preferring target)	Generated	Generated	70	
	Heart (7088)				
	Upper (fixed vol., generated dose)	0.0	Generated	100	
	Mean		Generated	200	
	Upper gEUD		3000.0 cGy	0	40.0
	Line (preferring target)	Generated	Generated	175	
	Humerus_Ipsi (25929, 25927)				
	Mean		Generated	95	
	Upper gEUD		3000.0 cGy	0	12.0
	Line (preferring target)	Generated	Generated	70	
	Liver (7197)				
	Mean		Generated	125	
	Upper gEUD		3000.0 cGy	0	40.0
	Line (preferring target)	Generated	Generated	75	
	Lung_Contra (7310, 7309, 68877)				
	Upper (fixed dose, generated vol.)	Generated	430.0 cGy	100	
	Line (preferring target)	Generated	Generated	100	
	Lung_Ipsi (7309, 7310)				
	Upper (fixed dose, generated vol.)	Generated	1600.0 cGy	150	
	Upper (fixed dose, generated vol.)	Generated	1000.0 cGy	150	
	Upper (fixed dose, generated vol.)	Generated	500.0 cGy	150	
	Upper (fixed dose, generated vol.)	Generated	50.0 %	150	
	Mean		Generated	125	
	Line (preferring target)	Generated	Generated	125	
	SpinalCord (7647)				
	Upper (fixed vol., generated dose)	0.0	Generated	100	
	Line (preferring target)	Generated	Generated	85	
	Stomach (7148)				
	Mean		Generated	125	
	Upper gEUD		3000.0 cGy	0	40.0
	Line (preferring target)	Generated	Generated	75	
	Trachea (7394)				
	Mean		Generated	75	
	Line (preferring target)	Generated	Generated	50	
	z_Ring_2_4cm (Ring)				
	Line (preferring target)	Generated	Generated	85	
	z_Ring_2cm (Ring)				
	Upper	0.0	102.0 %	250	
	Upper (fixed dose, generated vol.)	Generated	98.0 %	100	
	zBody-PTV2 (NormalTissue)				
	Upper (fixed dose, generated vol.)	Generated	60.0 %	100	
	zLung_OPT3cm (7309, 7310)				
	Mean		Generated	100	
	Line (preferring target)	Generated	Generated	80	
	zLung_OPT5cm (7309, 7310)				
	Mean		Generated	115	
	Line (preferring target)	Generated	Generated	95	

The default manual NTO settings for both v18.0 and v15.6:



Optimization Tips and Tricks

Contouring:

It helps to create all structures on the nominal treatment planning CT (TXCT) then duplicate the structure set in Eclipse. Call this structure set VB for Virtual Bolus. Then, Boolean the BODY with Flash, incorporating the Flash structure into the BODY for optimization purposes.

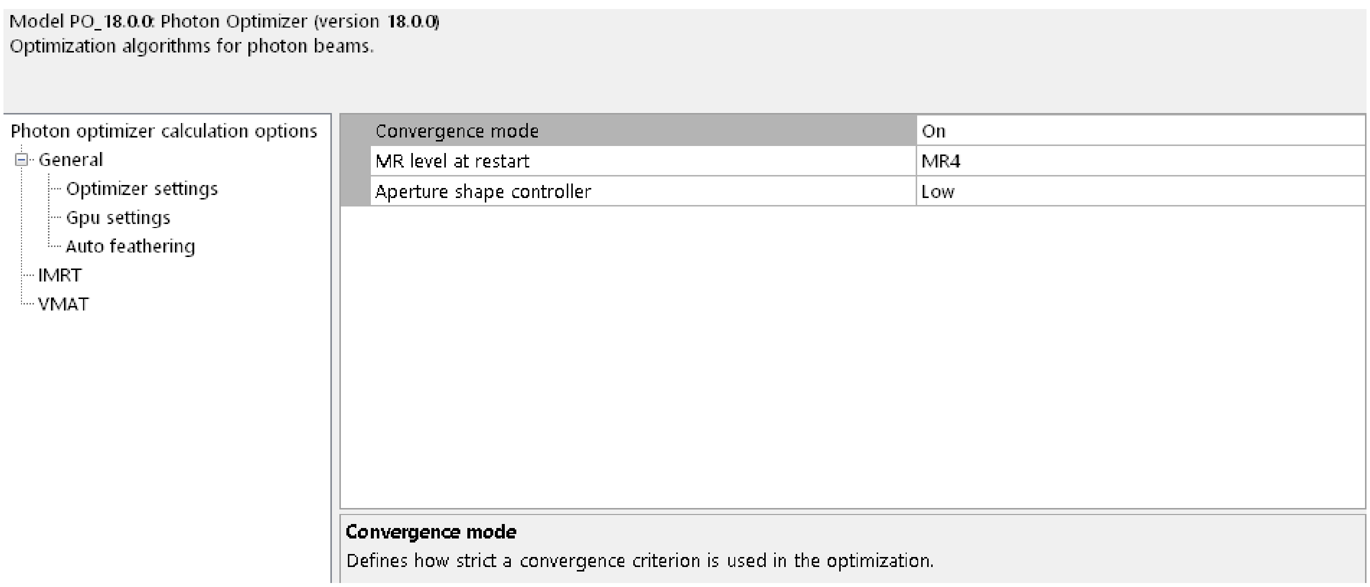
Flash Hounsfield Unit override is based on the findings from Maria Lizondo *et. al*. (Physica Medica, July 2019, https://doi.org/10.1016/j.ejmp.2019.05.010). We settled on HU = -400 based on similar testing.

All planning structures are automated using AutoContour. Our template has been including with the RapidPlan models.

Optimization:

Optimization Parameters

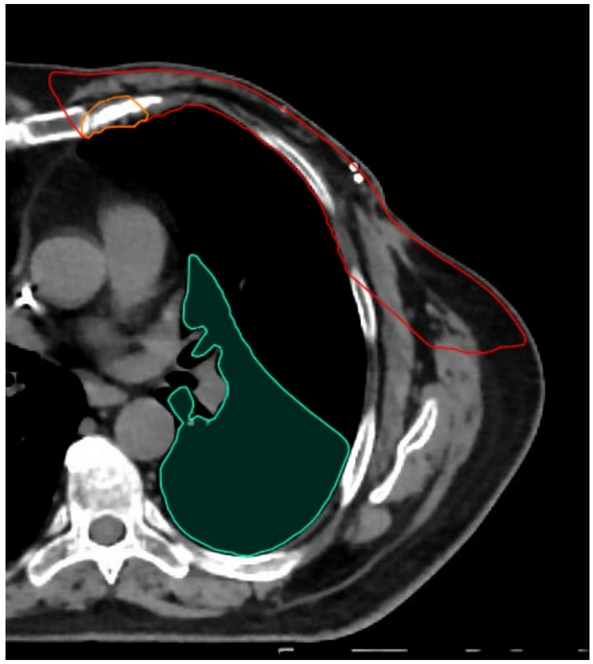
We suggest turning Convergence Mode ON for all plans. To reduce MLC modulation, a LOW or MODERATE setting for Aperture Shape Controller can be added. Further modulation reduction can be achieved with MU limits in the optimizer. We suggest waiting until MR Level 2 before adjusting MU limits during plan optimization.



Avoidance Structures

Beyond the model, there are some relevant tips worth sharing. We suggest the use of No Entry/No Exit for the following structures to reduce low dose spray:

- zLung_Contra_OPT (not included in model)
- zLung_OPT5cm (pictured below)



Use No Entry/No Exit to keep the 10% isodose line our of the posterior and medial portions of the ipsilateral lung (cyan).

Depending on patient geometry, the following structure could also employ either No Entry/No Exit or No Entry avoidance:

- zBreast_Contra_OPT

We've found it helpful to not use the contralateral breast and lung structures as the Avoidance Structures during optimization as they could be bordering the PTVs and could thus worsen target coverage and/or unnecessarily increase plan modulation. Using the cropped planning structures should improve the optimization and yield the desired reduction of the low dose bath, pushing it away from the lower/medial ipsilateral lung, contralateral lung, and contralateral breast.

For cases that involve the PTV_CW or PTV_Scar extending medially towards the contralateral breast, the user can reduce the medial expansion of Flash to achieve clinical goals this OAR.

Weights/Priorities

The model provides constraints and weights. The user is encouraged to adjust weights to their liking.

Flash is set to PTV_Low and has fairly relaxed constraints in order to allow the MLCs to extend beyond the body.

For difficult cases where the heart or contralateral breast may need extra sparing to meet clinical tolerances, the planning structures zHeart_OPT and zBreast_Contra_OPT can be matched when loading the RapidPlan Model. We've seen additional benefit from using this technique in difficult cases needing extra TLC.

For cases that end up with hot spots of 105-108% in the chest wall after calculating the plan on the TXCT, one suggestion would be to lower the goals for PTV_CW_Eval and zPTV_CW_Opt by about 2%.

This might leave your virtual plan slightly cold, but once calculated on the TXCT, you should maintain your coverage with fewer hot spots.

Normal Tissue Optimizer

For plans with excess modulation or lack of coverage, the NTO can be turned off and the user can rely on the ring structures to provide adequate falloff. The default weighting is 150; in verification planning, there have been cases that benefit from reducing the weighting or removing NTO from the optimization altogether and simply relying on rings for dose falloff.

Hot Spots

If your plan has hot spots after optimization and the plan is close to completion, we recommend contouring the 105%, 107%, and 110% (if applicable) isodose lines and rerunning the optimizer from MR4. We suggest to add mean dose constraints to each level and upper of 0% and pull these isodose contours down with the optimizer paused. This should help reduce hot spots on the virtual and TXCT data sets.

Dose Calculation on TXCT

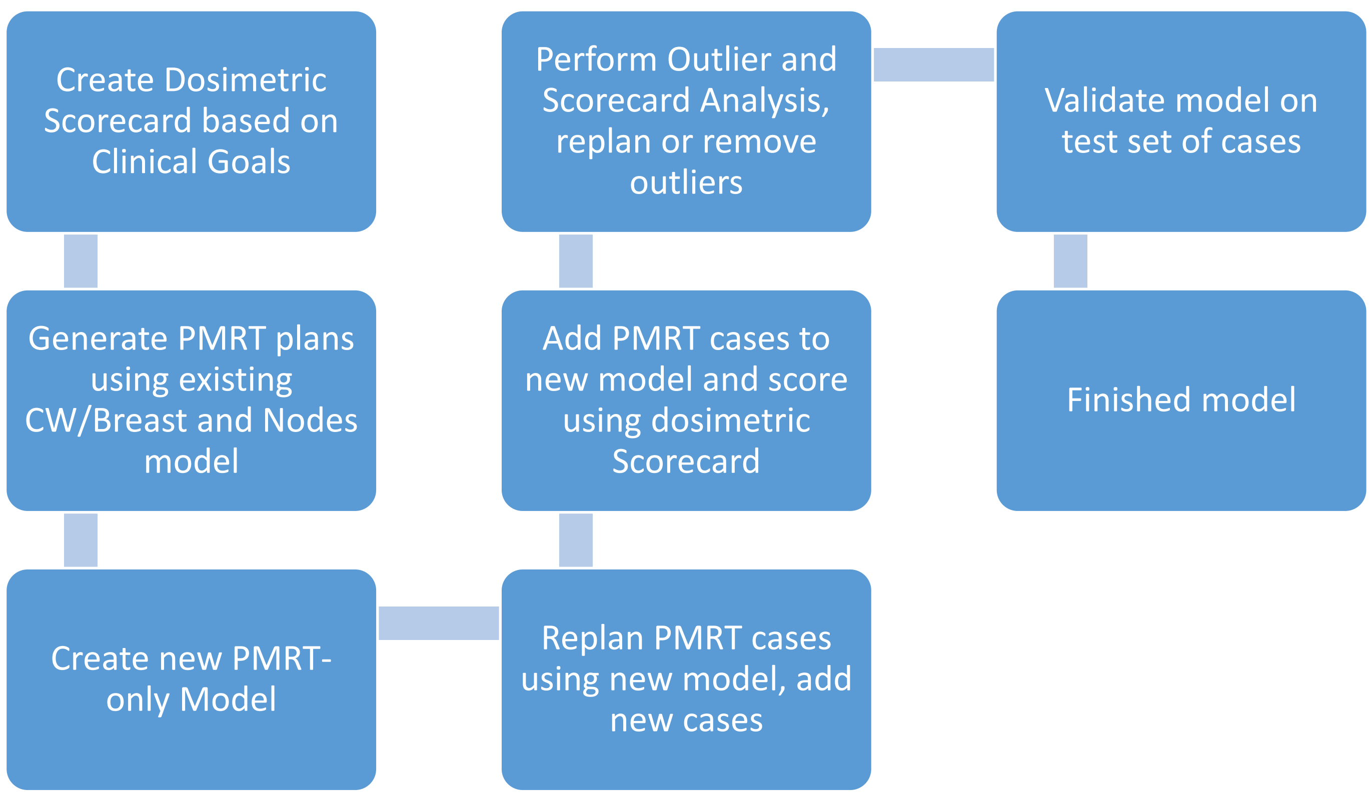
Copy your plan from the Virtual data set so you don't lose your optimization and assign it to the TXCT. Recalculate using your photon algorithm of choice. Plans can be normalized to achieve desired dosimetric goals.

For plans that need bolus attached, copy the plan (if bolus QOD) and attach bolus to all fields.

Model Training:

This PMRT model was originally trained with a set of 35 VMAT plans to aid in planning difficult cases. Structures that were initially modeled included heart, ipsilateral and contralateral lung, and contralateral breast. Over time, this model separated into intact and post-mastectomy cases only. For this updated PMRT model, more OARs and tuning structures were added to aid planners during optimization. All cases come from our institution and were planned to our clinical standards, which are largely based on established tolerances from clinical trials. Cases used for modeling include a near 50-50 split of left and right-sided cases.

Initial plans for the model were generated via our initial PMRT model. More plans were generated and added, taking the total to 57, to generate the latest PMRT model. In actuality, over 75 cases were initially in the model, but through outlier and dosimetric scorecard analyses, the total was reduced to 58 in the final model. A dosimetric scorecard, based on clinical goals and constraints, was utilized to assess all plans added to the model. Plans with low scores, by our clinical standards, were heavily scrutinized and were re-optimized to improve the score. A scorecard threshold of 78% was enacted to remove low quality plans and further tune the model. The final yielded an average plan score of 86.5±5.3%. A validation subset of 16 plans (8 left, 8 right) not included were used for testing the model.



Model Validation:

In addition to the initial 58 case training set, model tuning and validation shown above, this PMRT model was validated using 15 validation cases: eight left-sided and seven right-sided PMRT cases. Scorecard analysis on the validation set yielded an average composite score of 91.9±3.4%.

Annex Directory

Annex A: **Scorecard Details**

A1-2 PMRT **Scorecards (Left and Right)**

A3 PlanScoreCard ESAPI tool: **where to find**

Annex B: **Acknowledgements**

Annex C: **Distribution and compatibility**

Annex A: **Dosimetric scorecard** details and **PlansScoreCard** ESAPI tool

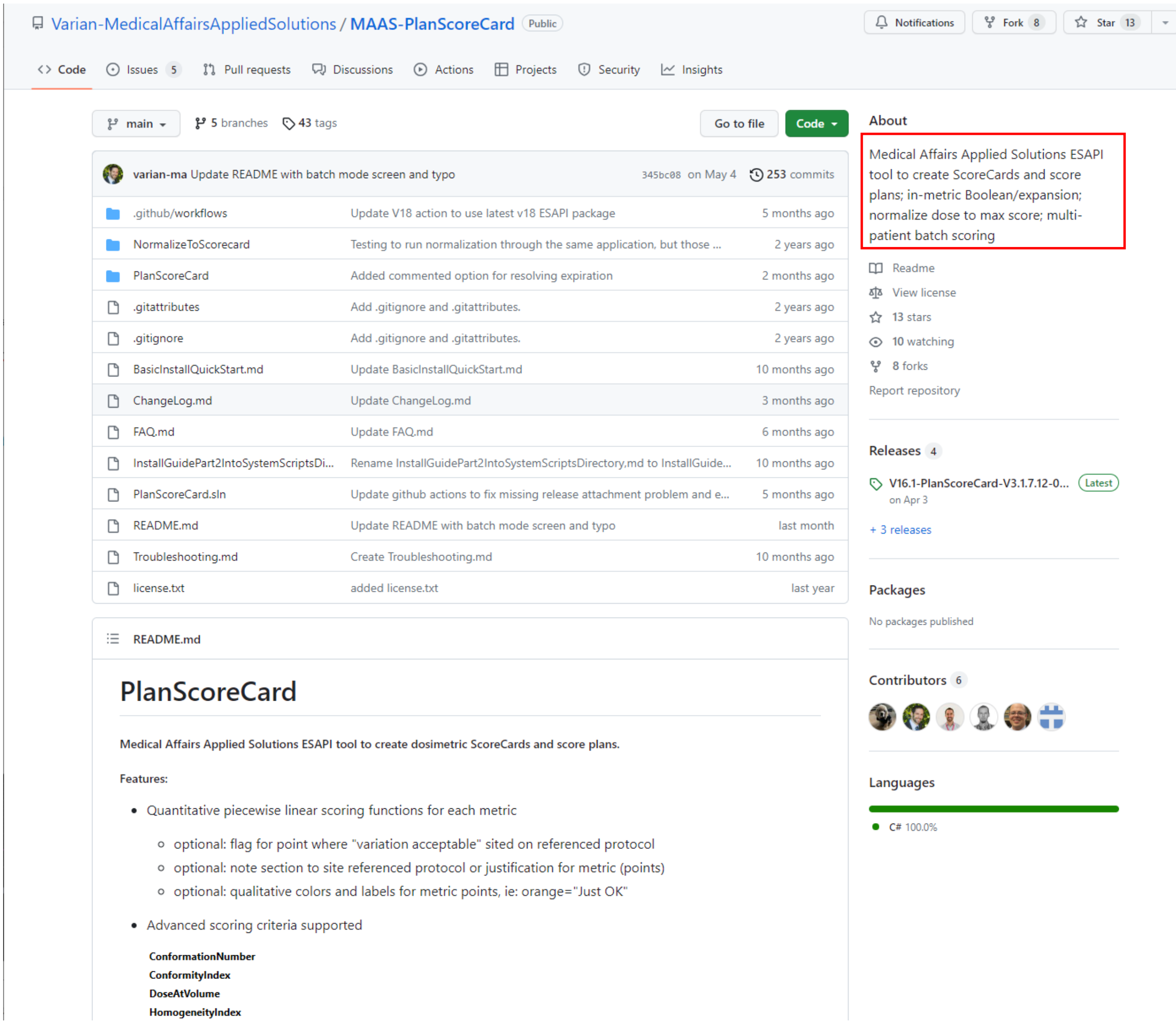
A1 Full Scorecard for PMRT Left-sided - 200 point total

A2 Full Scorecard for PMRT Right-sided - 200 point total

Download full Scorecard(json), DICOM case example and this RapidPlan model: link

A3 PlanScoreCard ESAPI tool: where to find

[Varian-MedicalAffairsAppliedSolutions](https://github.com/Varian-MedicalAffairsAppliedSolutions/MAAS-PlanScoreCard) (https://github.com/Varian-MedicalAffairsAppliedSolutions/MAAS-PlanScoreCard)



Currently, the source code is shared on the Varian Medical Affairs Applied Solutions GitHub where it can be downloaded and complied with Visual Studio 2022 (including with the free community edition), now in the releases section users can find precompiled binaries ready to run in all compatible versions of Eclipse (v15.6+). PlanScoreCard is made available under the Varian Limited Use Software License Agreement.

Annex B: Acknowledgements

Initial Plans created from KU CW/Breast VMAT model by Kenny Guida, DMP, DABR and KU Dosimetry Team

KBP-Optimized plans created by Kenny Guida, DMP, DABR

All data generated and complied by Kenny Guida, DMP, DABR

Model generation and editing by Kenny Guida, DMP, DABR; Lesley Rosa, CMD; Ryan Clark, MS, CMD

Dosimetric Scorecard PMRT (L/R) and derived structures designed by Kenny Guida, DMP, DABR; Ryan Smith, MS, CMD; Anthony Magliari, MS, CMD

Model generated validation plans created by Kenny Guida, DMP, DABR; Jonathan Cornelisse, MS, CMD; Megan Smith, MS, CMD; Ryan Clark, MS, CMD

Clinical Description document created by Kenny Guida, DMP, DABR; Jonathan Cornelisse, MS, CMD; Megan Smith, MS, CMD; Shane Stecklein, MD, PhD

Special thanks to Anthony Magliari, Ryan Clark, and Lesley Rosa of Varian Medical Affairs

Please reference future publication: **TBD**

Annex C: Distribution and compatibility

This RapidPlan model is to be distributed exclusively via the links found on Varian Medical Affairs:

Enter new link

Please do not re-distribute this model as number of downloads will be tracked (strictly to judge the success of this project).

This RapidPlan model was built with Eclipse v18.0 and rebuilt and validated from Eclipse v15.6 RapidPlan for maximal compatibility.