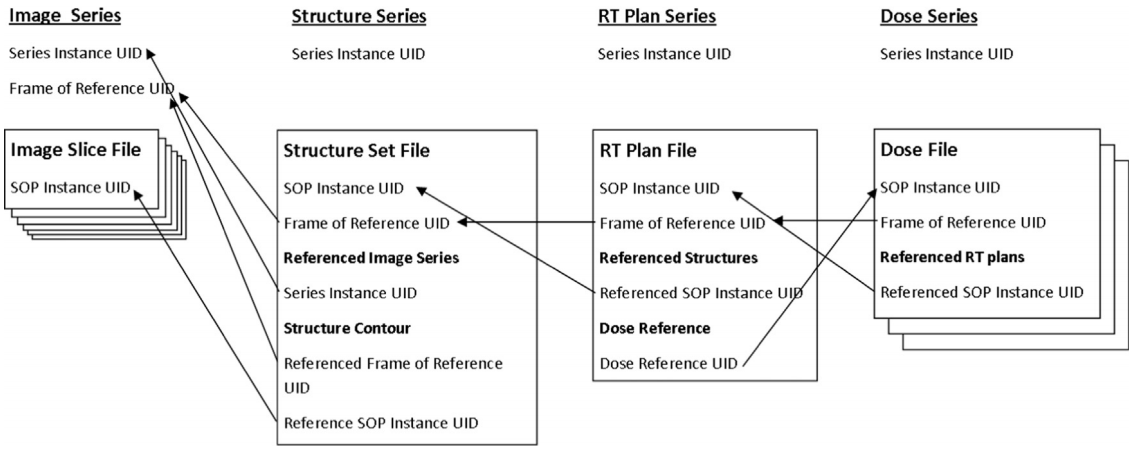
# Reference dataset

This reference dataset has been designed in order to be distributed along with the NCS report on Quality assurance of Treatment Planning Systems and its specific suggested tests concerning the patient and dose modeling. It has been created using MATLAB (R2017b, MathWorks Inc, Natick, MA, USA), especially the DICOM Manipulation Tools developed by Mark Geurts from University of Wisconsin [geurts], and respecting the following procedure for the different UIDs [newhauser].



The figures have been generated using 3D Slicer (v4.8.1, Surgical Planning Laboratory, Harvard Medical School, Boston, MA, USA) [fedorov], and especially its RT module, SlicerRT from Queen’s University (Ontario, Canada) [pinter].

## Patient information

The patient’s information has been designed as follows.

Family name NCS TPS QA

Given name PHANTOM

ID NCSTPSQA2020

Birth date 18/04/2018

Sex M

Institution name NCS

## CT1

The first phantom is a CT of 280 slices of 512x512 voxels. The voxel size is 1x1x1 mm³. The origin is set at the center of the image. The ‘ImagePatientPosition’, which is the position of the center of the upper left voxel, is at (-255.5, -255.5, 139.5) mm for the first image.

Here is a summary of the relevant Dicom tags of this phantom.

Directory phantom1

Files CT1\_xxx.dcm

Modality CT

Series description NCS TPS QA Phantom 1

Patient position HFS

Voxel size [mm³] 1 x 1 x 1

Image size [voxels] 512 x 512 x 280

Image 1 Patient position [mm] (-255.5, -255.5, 139.5)

Some structures have been set to a known Hounsfield unit as the background is set to -1000.

Position Dimensions HU Mimicking tissue

Cylinder Centered H = 240 mm and R = 200 mm 0 Water

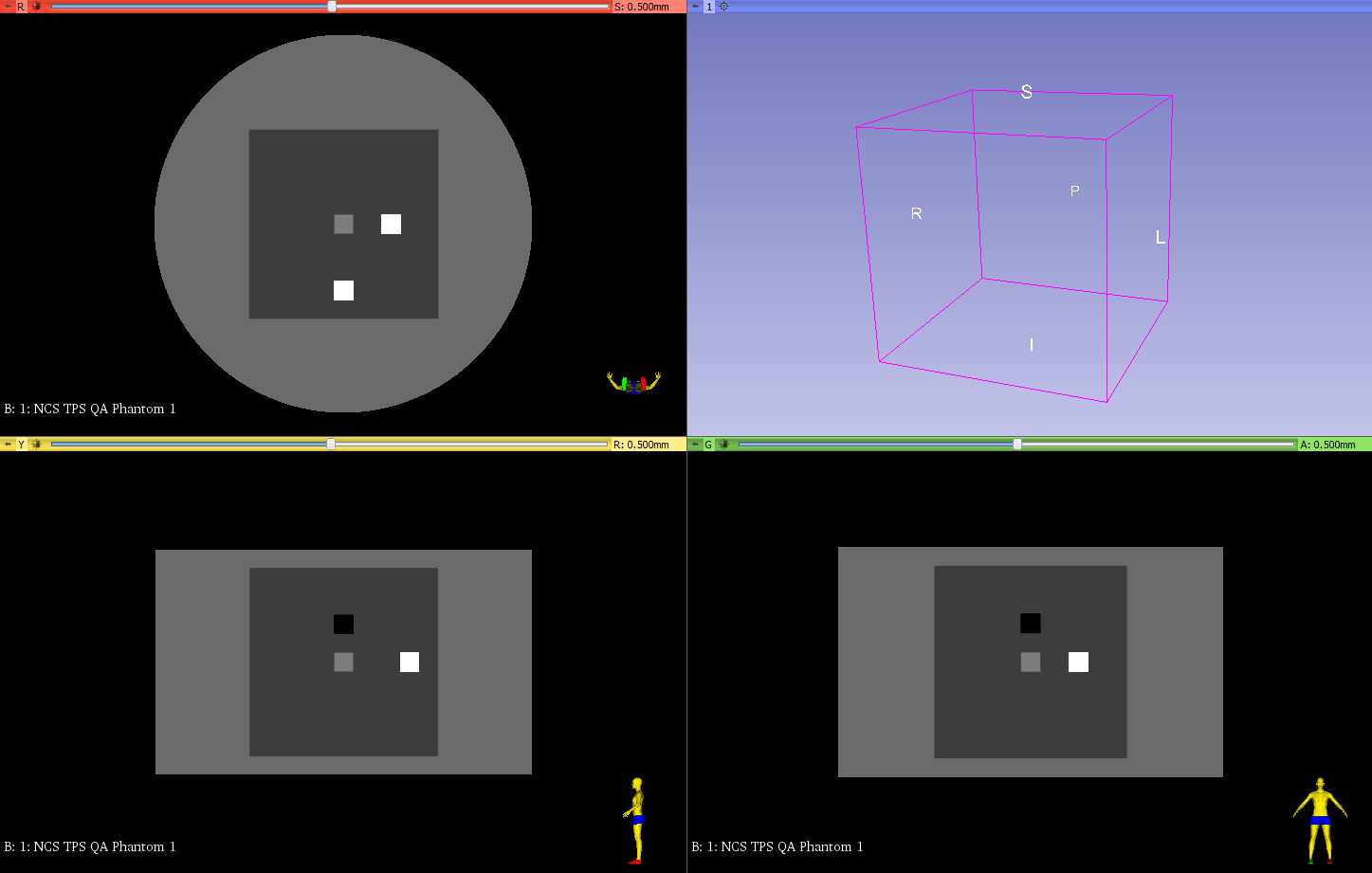
Big cube Centered L= 200 mm -100 Fat

Cube 1 Centered L = 20 mm 40 Soft tissue

Cube 2 50 mm LEFT L = 20 mm 1800 Cortical bone

Cube 3 70 mm POST L = 20 mm 4000 Prosthesis

Cube 4 40 mm SUP L = 20 mm -700 Lung



## RTStruct

Directory phantom1

File RTSS1.dcm

Modality RTSTRUCT

Series description NCS TPS QA RTSS1

Structure set label RTSS1

Manufacturer model name WriteDICOMStructures

A RTStruct file has been generated for all the structures visible in CT1 on every slice. All structures have a geometric type set to ‘CLOSED\_PLANAR’, a contour slab thickness of 1 mm and different Dicom interpreted types, as summarized in the following table.

# Name Type Slices (Top, Bottom) [mm] Points/slice Volume [cm³]

1 ProsthesisCube PTV 20 (9.5, -9.5) 40 8.0

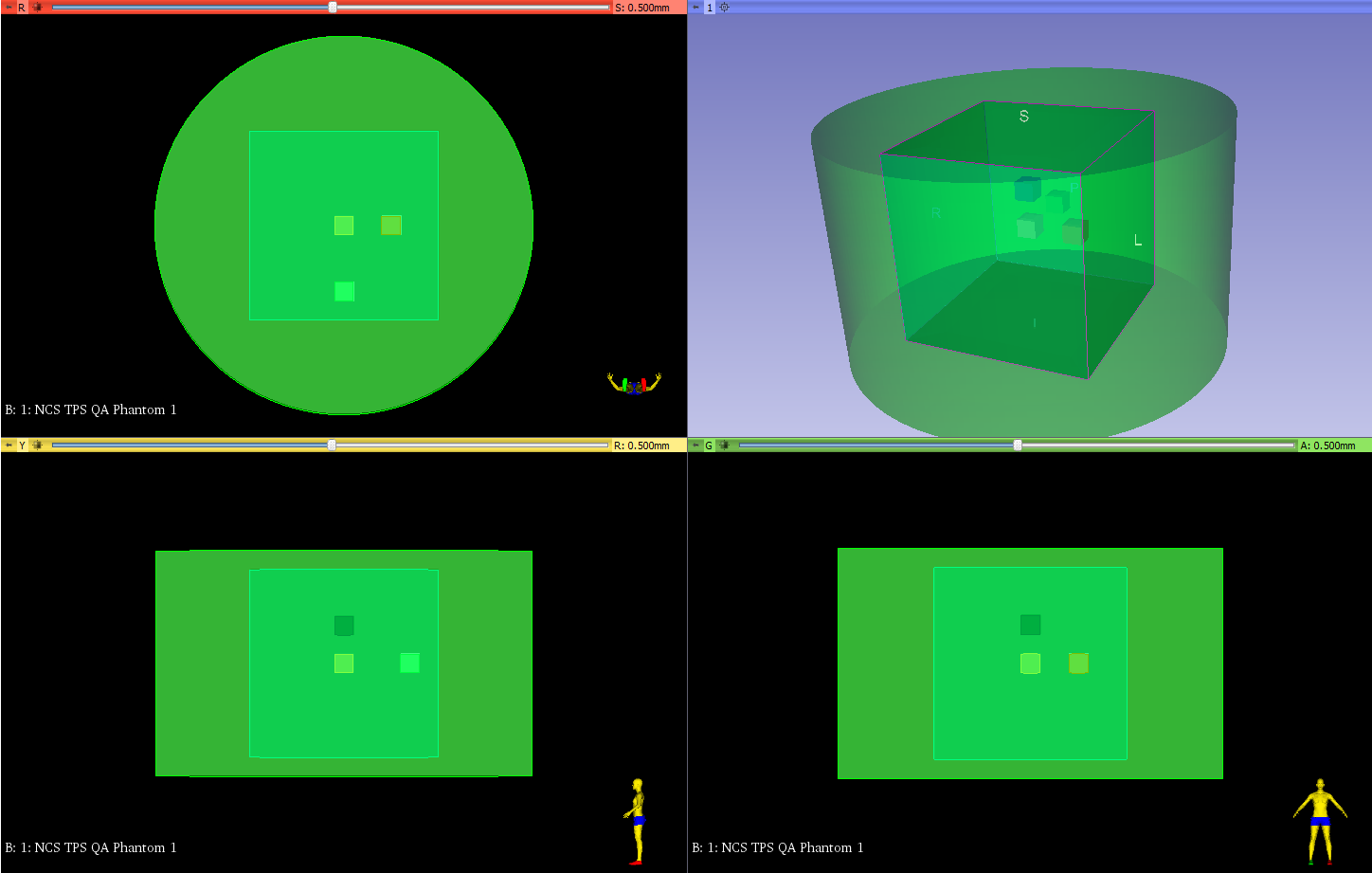
2 FatCube ORGAN 200 (99.5, -99.5) 400 8000.0

3 LungCube GTV 20 (49.5, 30.5) 40 8.0

4 BoneCube PTV 20 (9.5, -9.5) 40 8.0

5 SoftCube AVOIDANCE 20 (9.5, -9.5) 40 8.0

6 WaterCylinder EXTERNAL 240 (119.5, -119.5) 201 30159.3



## RTPlan and RTDose

Directory phantom1 phantom1

Files RTPlan1.dcm RTDose1.dcm

Modality RTPLAN RTDOSE

Series description NCS TPS QA RTPlan NCS TPS QA RTDose

Manufacturer model name WriteDICOMPlan WriteDICOMDose

The RTPlan is composed of 2 opposed static photon beams with open fields of 40x40 cm² for 5 fractions of treatment. Some relevant DICOM tags are summarized in the following table.

Beam name ant post

Beam type STATIC STATIC

Radiation type PHOTON PHOTON

Delivery type TREATMENT TREATMENT

Gantry angle [°] 0 180

Collimator angle [°] 0 180

Beam meterset [MU] 1644.4 1770.7

Dose rate [MU/min] 400 400

The RTDose has been designed to match exactly the matrix of the primary image (CT1). The dose grid size is 1x1x1 mm³ and the ‘ImagePositionPatient’, which is the position of the upper left voxel of the last slice in RTDose files, is (-255.5, -255.5, -139.5) mm. The units and type of dose are set to ‘GY’ and ‘PHYSICAL’ respectively. In this file, the structures have been set a uniform dose as illustrated in the table below.

Structure Dose [Gy]

BoneCube 25

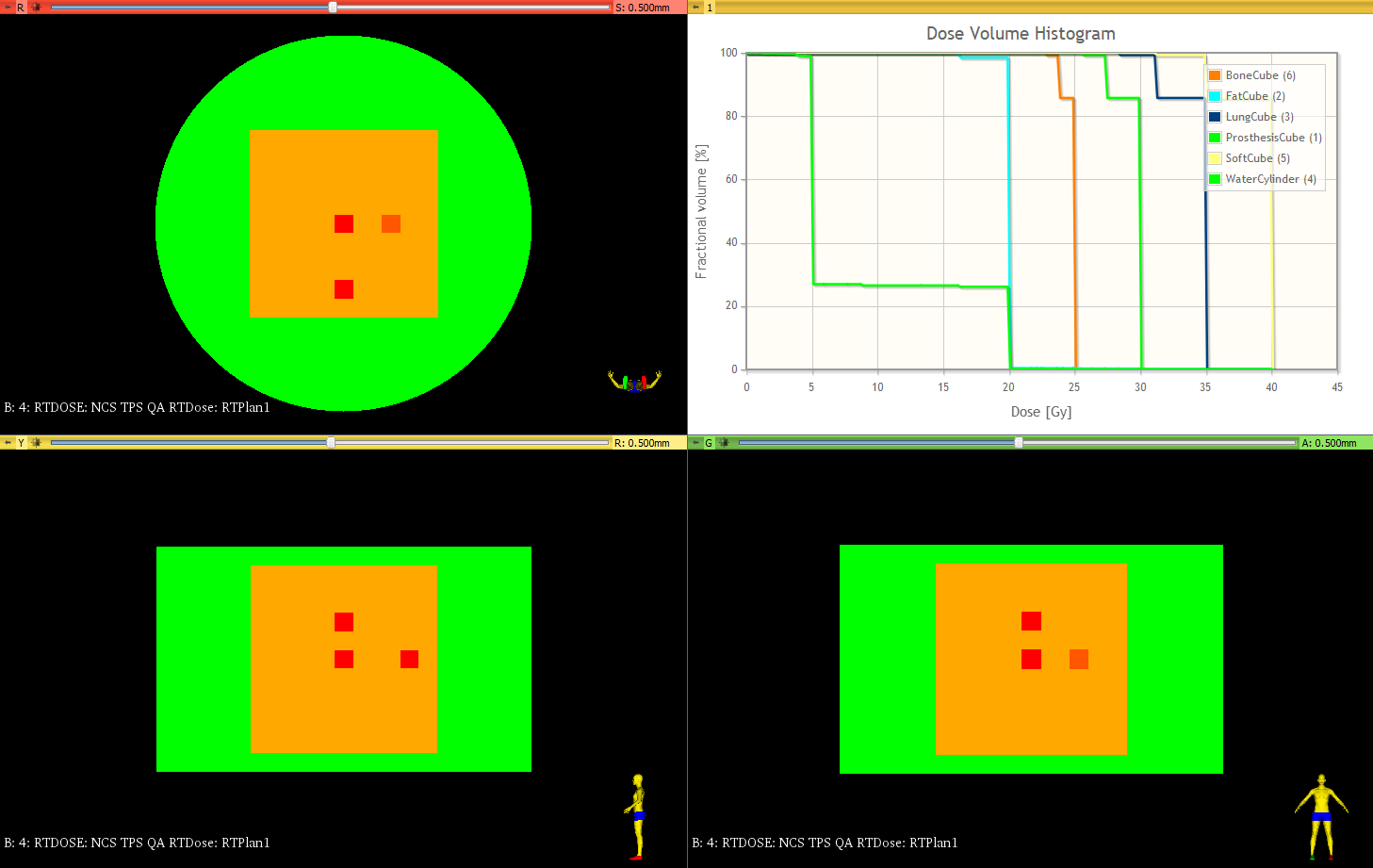
ProsthesisCube 30

LungCube 35

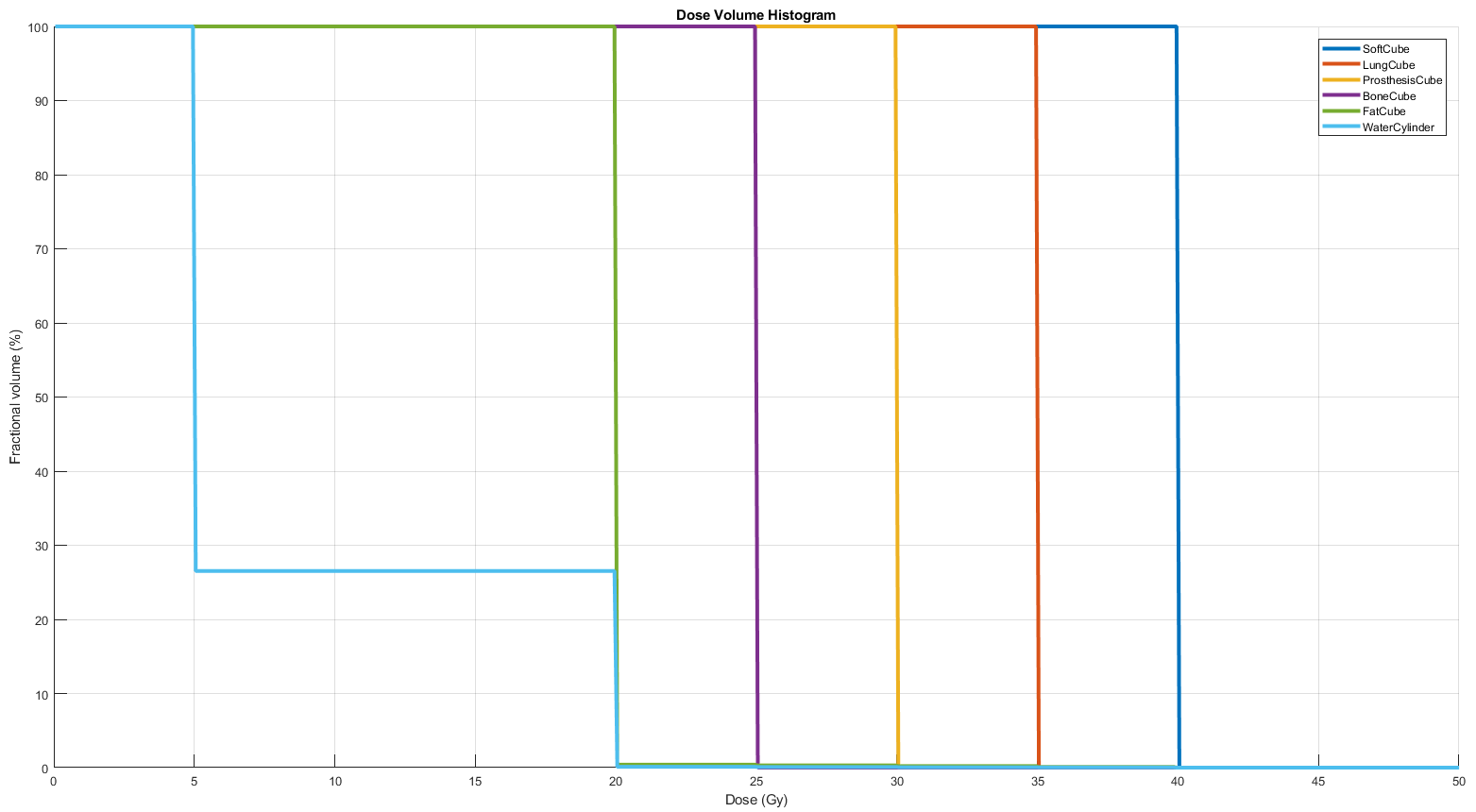
SoftCube 40

FatCube 20

WaterCylinder 5



The dose volume histogram (DVH) does not seem to be perfectly displayed in this viewer. For the 4 little cubes - BoneCube, ProsthesisCube, LungCube and SoftCube - there should only be a perfect step at 25, 30, 35 and 40 Gy respectively, as represented in the following figure. As the FatCube and the WaterCylinder encompass other structures, their DVH should not be a perfect step-like curve. Some dose statistics are summarized in the following table.



Structure Dmin [Gy] Dmax [Gy] Dmean [Gy]

BoneCube 25 25 25

ProsthesisCube 30 30 30

LungCube 35 35 35

SoftCube 40 40 40

FatCube 20 40 20.050

WaterCylinder 5 40 8.992

## MRI

Directory phantom1MRT2

Files MRT2\_xxx.dcm

Modality MR

Series description NCS TPS QA Phantom MR T2

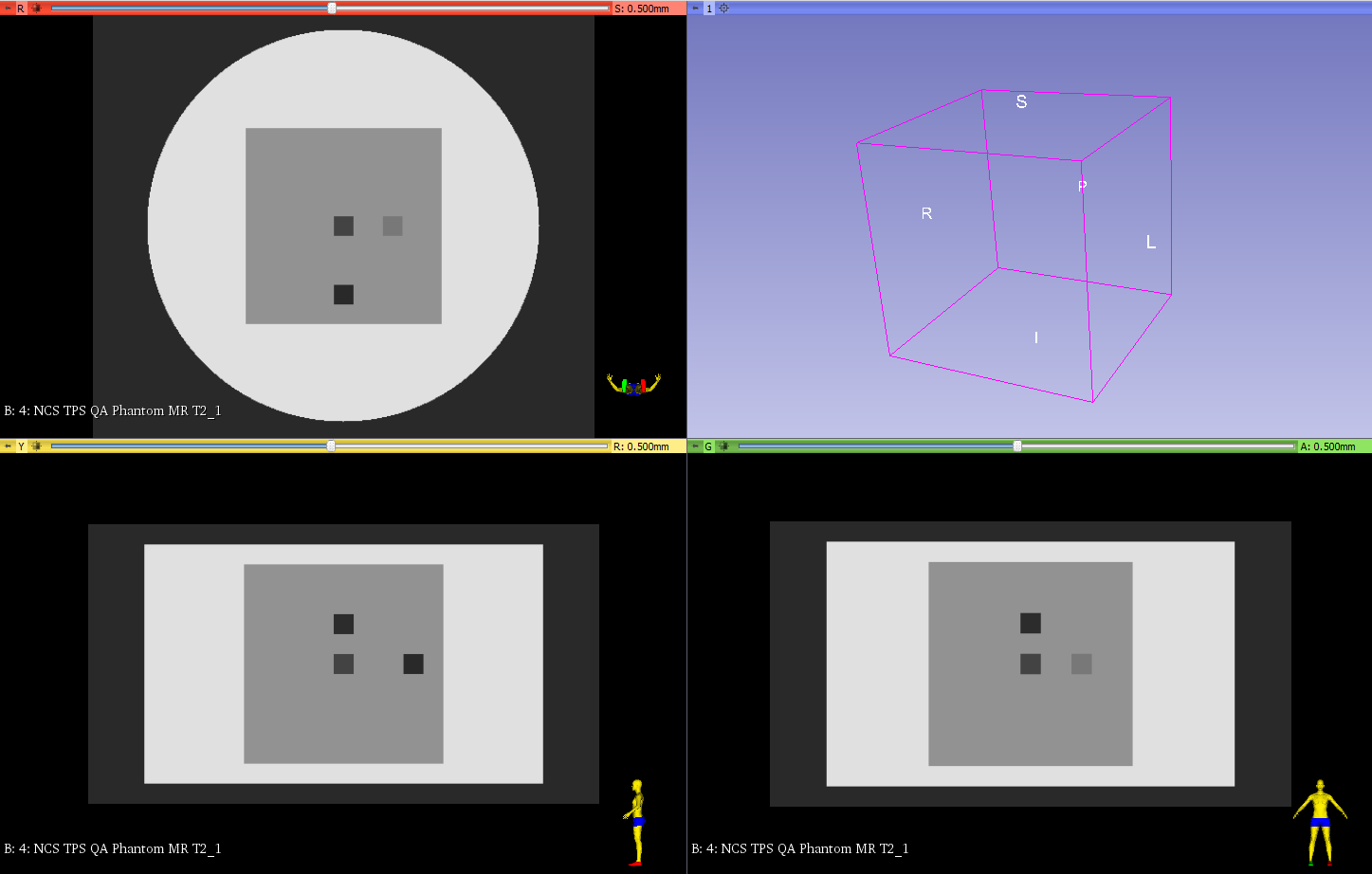
Patient position HFS

Voxel size [mm³] 1 x 1 x 1

Image size [voxels] 512 x 512 x 280

Image 1 Patient position [mm] (-255.5, -255.5, 139.5)

An MR T2-like image has been created, using the same resolution and position as the CT1, on a 3T imager. Signal values have been assigned to the different structures but they do not reflect any physical properties.



Structure Signal value

SoftCube 100

LungCube 10

BoneCube 300

ProsthesisCube 0

FatCube 400

WaterCylinder 700

## PET

Directory phantom1PET

Files PET\_xxx.dcm

Modality PT

Series description NCS TPS QA Phantom PET FDG

Study description 18F-FDG PET

Patient position HFS

Units BQML

Voxel size [mm³] 2.56 x 2.56 x 2.80

Image size [voxels] 200 x 200 x 100

Image 1 Patient position [mm] (-254.72, -254.72, 138.60)

An FDG PET-like image has been created, using first the same resolution and size as CT1 (1x1x1 mm³ and 512x512x280 voxels). Activities have been assigned to the different structures, as shown in the following table, with the background set to 0.

Structure Activity [Bq/ml]

SoftCube 24000

LungCube 8000

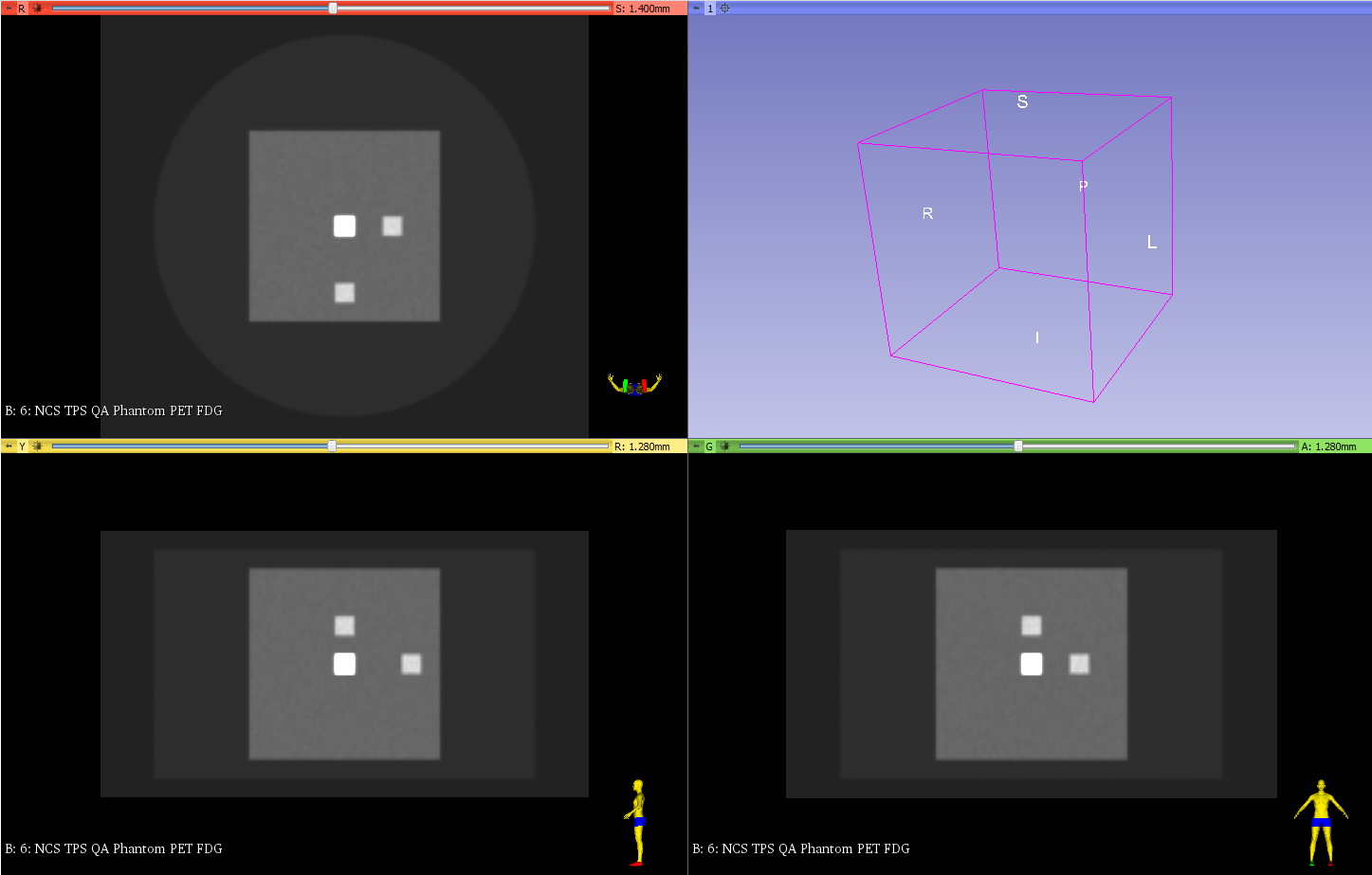
BoneCube 8000

ProsthesisCube 8000

FatCube 3000

WaterCylinder 500

The 3D matrix has then been resampled to 200x200x100 voxels, leading to a new voxel size of 2.56x2.56x2.80 mm³, but keeping the origin in the center of the phantom with a new ‘ImagePositionPatient’ set to (-254.72, -254.72, 138.60) mm.



## Patient position

New CTs have been generated based on CT1 to check for patient position and image orientation. The size and resolution were kept identical.

Directory phantom1FFS phantom1HFP phantom1FFP

Files CT1\_FFS\_xxx.dcm CT1\_HFP\_xxx.dcm CT1\_FFP\_xxx.dcm

Series Description NCS TPS QA Phantom 1 FFS … HFP … FFP

Patient position FFS HFP FFP

Image orientation [-1 0 0 ; 0 1 0] [-1 0 0 ; 0 -1 0] [1 0 0 ; 0 -1 0]

## Shifts and tilts

Directory phantom1Shift

Files CT1\_shift\_xxx.dcm

Modality CT

Series Description NCS TPS QA Phantom 1 Shifted

Voxel size [mm³] 1 x 1 x 1

Image size [voxels] 512 x 512 x 280

Image 1 Patient position [mm] (-255.5, -255.5, 139.5)

A shifted CT has been created based on CT1. The size and the resolution are kept the same. Only the structures in the image were shifted according to the following table. The ‘ImagePositionPatient’ is kept at (-255.5, -255.5, 139.5) mm.

Shift [mm] Direction

AP 20 POST

LR 30 LEFT

SI 10 INF

A rigid registration Dicom file has also been created, bringing back the CT shifted to the space of CT1.

Directory phantom1Shift

File REG\_shift.dcm

Modality REG

Series description NCS TPS QA REG shifts

The transformation matrix is naturally given by

which is a translation vector of (-30, -20, 10) mm and a rotation vector of (0, 0, 0) °.

Directory phantom1Tilt phantom1MRtilt

Files CT1\_tilt\_xxx.dcm MRtilt\_xxx.dcm

Modality CT MR

Series description NCS TPS QA Phantom 1 Tilted NCS TPS QA Phantom MR Tilted

Voxel size [mm³] 1 x 1 x 1 2 x 2 x 4

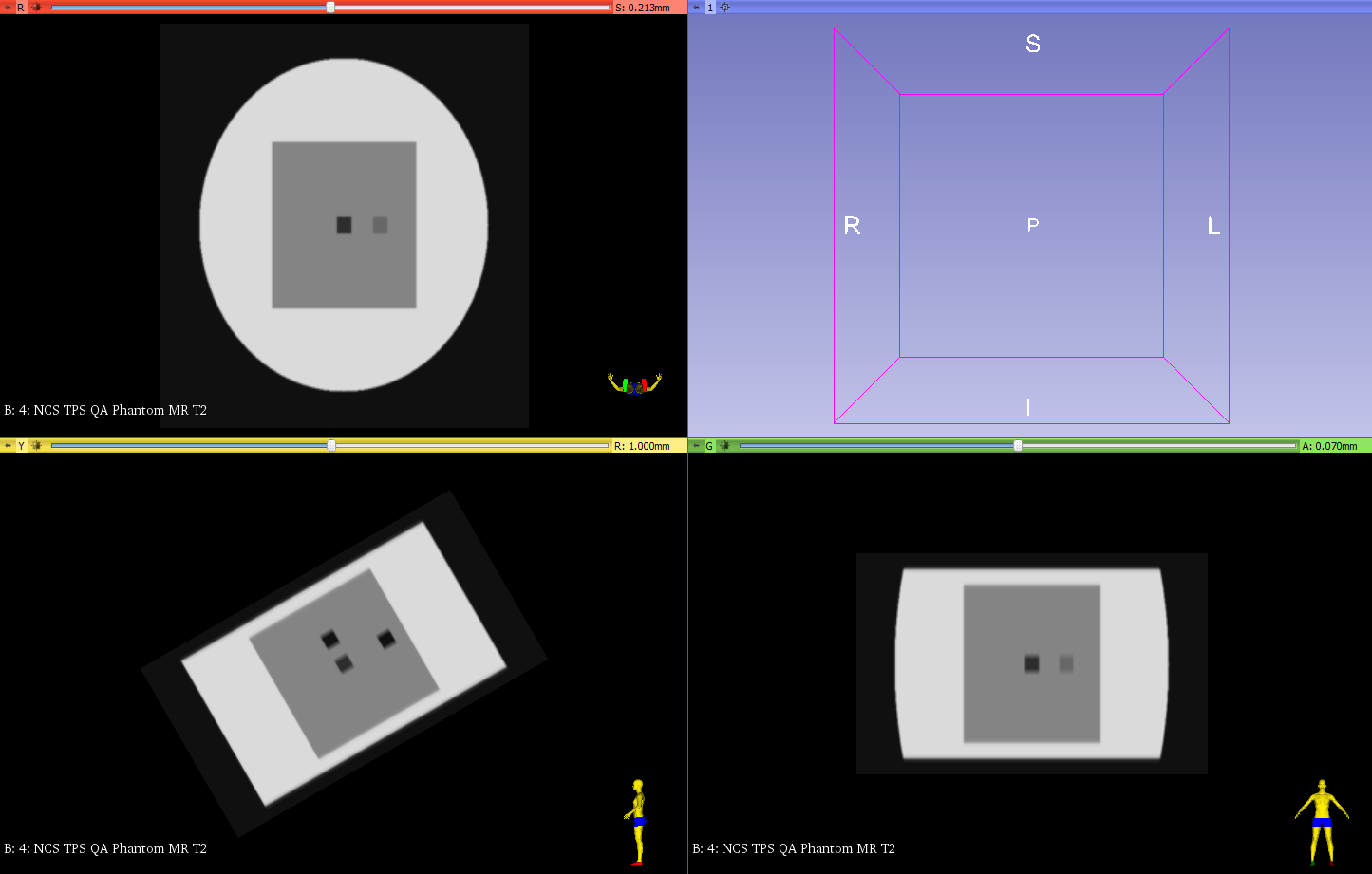
Image size [voxels] 512 x 512 x 280 256 x 256 x 70

Image 1 Patient position [mm] (-255.5, -349.0, 93.5) (-255.0, -347.8, 92.5)

Image n Patient position [mm] (-255.5, -209.5, -148.1) (-255.0, -209.8, -146.6)

A tilted CT has also been created based on CT1, and a tilted MRI as well. The CT kept its original resolution and size while it changed to 256x256x70 voxels and 2x2x4 mm³ for the MRI, without changing the origin of the images.

Both images have been tilted with an angle of 30° along the LR axis. The ‘ImagePositionPatient’ should also vary, not only through its slice location, but taking tilt into account as well.



A rigid registration Dicom file has also been created, bringing back the CT tilted to the space of CT1.

Directory phantom1Tilt

File REG\_tilt.dcm

Modality REG

Series description NCS TPS QA REG tilt

The transformation matrix is naturally given by

which is a translation vector of (0, 0, 0) mm and a rotation vector of (-30, 0, 0) °.

## Dose grid

Other RTPlans and RTDoses were created to test for the dose grid effect. The RTPlans have the same configuration as the original RTPlan.

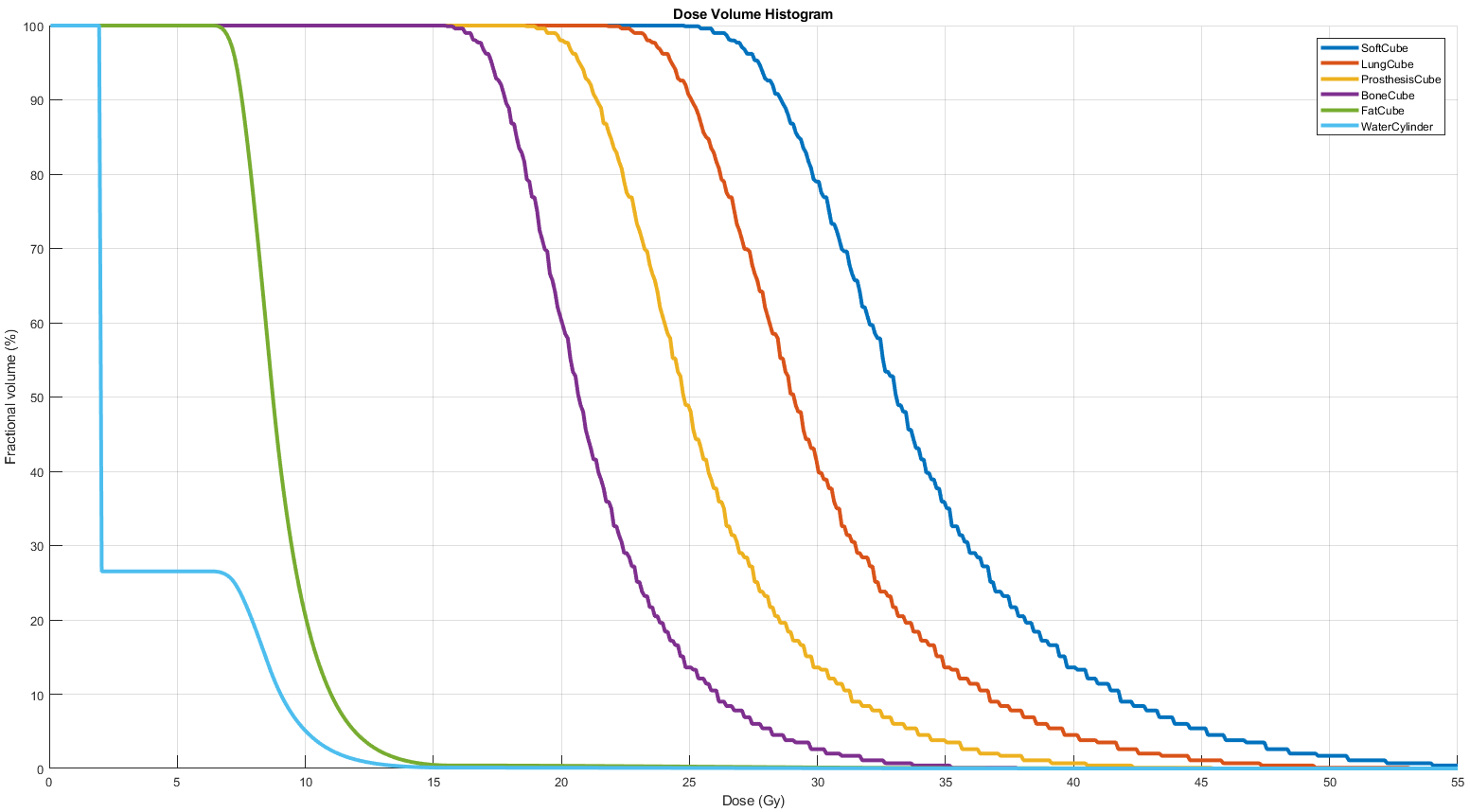
Directory phantom1rt2 phantom1rt3

Files RTPlan2\_3mm.dcm RTPlan3\_1mm.dcm

Modality RTPLAN RTPLAN

Series description NCS TPS QA RTPlan2 3mm NCS TPS QA RTPlan3 1mm

The original RTDose has been designed to match exactly the matrix of the primary image (CT1). The dose grid size is 1x1x1 mm³ and the ‘ImagePositionPatient’, which is the position of the upper left voxel of the last slice in RTDose files, is (-255.5, -255.5, -139.5) mm. The units and type of dose are set to ‘GY’ and ‘PHYSICAL’ respectively. In this file, the doses in the structures have been set to produce the following DVH.



This original RTDose was first resized to a 170x170x92 voxels matrix with a dose grid of 3x3x3 mm³, leading to the RTDose2\_3mm file. This dose was then super-sampled to a 510x510x276 voxels matrix with a dose grid of 1x1x1 mm³, the RTDose3\_1mm file.

Directory phantom1rt2 phantom1rt3

Files RTDose2\_3mm.dcm RTDose3\_1mm.dcm

Modality RTDOSE RTDOSE

Series description NCS TPS QA RTDose2 3mm NCS TPS QA RTDose3 1mm

Voxel size [mm³] 3 x 3 x 3 1 x 1 x 1

Image size [voxels] 170 x 170 x 92 510 x 510 x 276

Image Patient Position [mm] (-253.5, -253.5, -136.5) (-254.5, -254.5, -137.5)

This new dose distribution produces a DVH as illustrated in the following figure. Some dose statistics are summarized in the following table.

Doses (Gy) Min Max Mean D1% D5% D20% D50% D80% D95% D99%

SoftCube 14.89 50.40 31.29 16.02 18.85 20.40 32.88 36.64 43.31 50.40

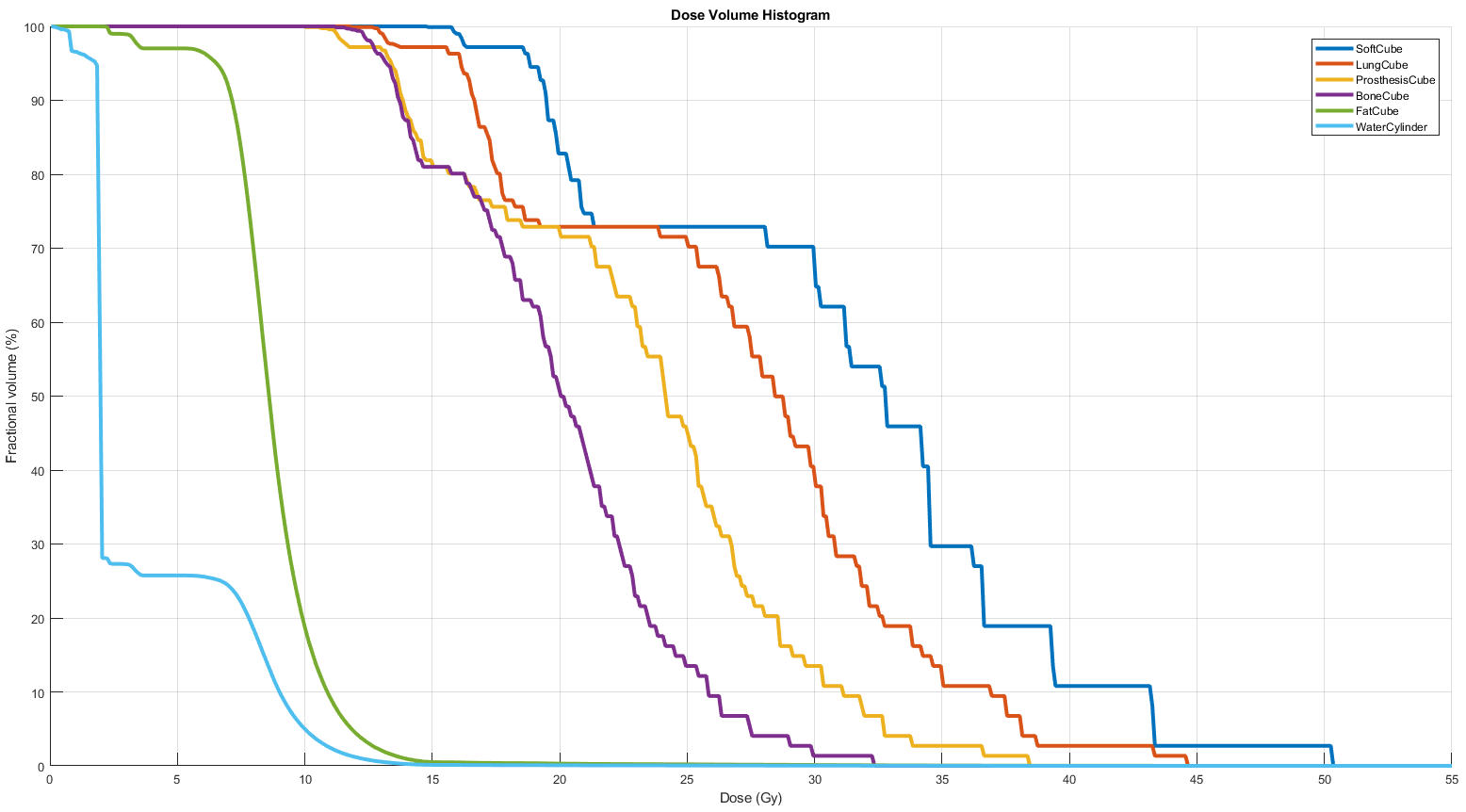
LungCube 11.80 44.61 27.23 13.12 16.11 17.74 28.48 32.77 37.13 44.61

ProsthesisCube 10.04 38.48 23.33 11.30 13.42 16.34 24.15 28.63 32.79 38.48

BoneCube 11.17 32.28 20.03 12.25 13.10 16.21 19.96 23.43 27.42 32.28

FatCube 2.02 50.40 8.83 2.42 6.59 7.69 8.65 9.96 11.87 13.97

WaterCylinder 0.05 50.40 3.78 0.86 1.83 2.00 2.00 7.85 10.04 12.26



## CT2

Another phantom has been designed to test for structure expansion and shrinkage. This phantom is a CT of 300 slices of 512x512 voxels. The voxel size is 1x1x1 mm³. The origin is set at the center of the image. The ‘ImagePatientPosition’ is at (-255.5, -255.5, 149.5) mm for the first image.

Directory phantom2

Files CT2\_xxx.dcm

Modality CT

Series description NCS TPS QA Phantom 2

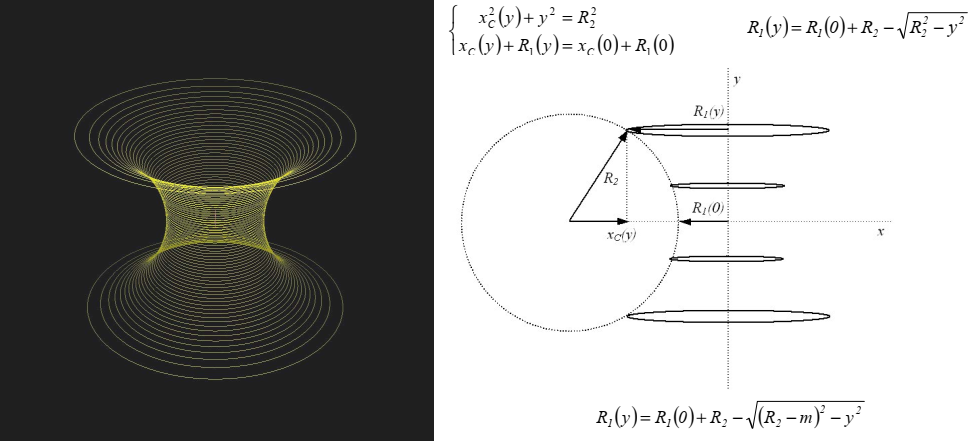
Patient position HFS

Voxel size [mm³] 1 x 1 x 1

Image size [voxels] 512 x 512 x 300

Image 1 Patient position [mm] (-255.5, -255.5, 149.5)

The diabolo structures have been designed following the instructions of the NCS report 15 [ncs15] and are recalled here.



The different structures are centered and have been set to a known Hounsfield unit as the background is set to -1000.

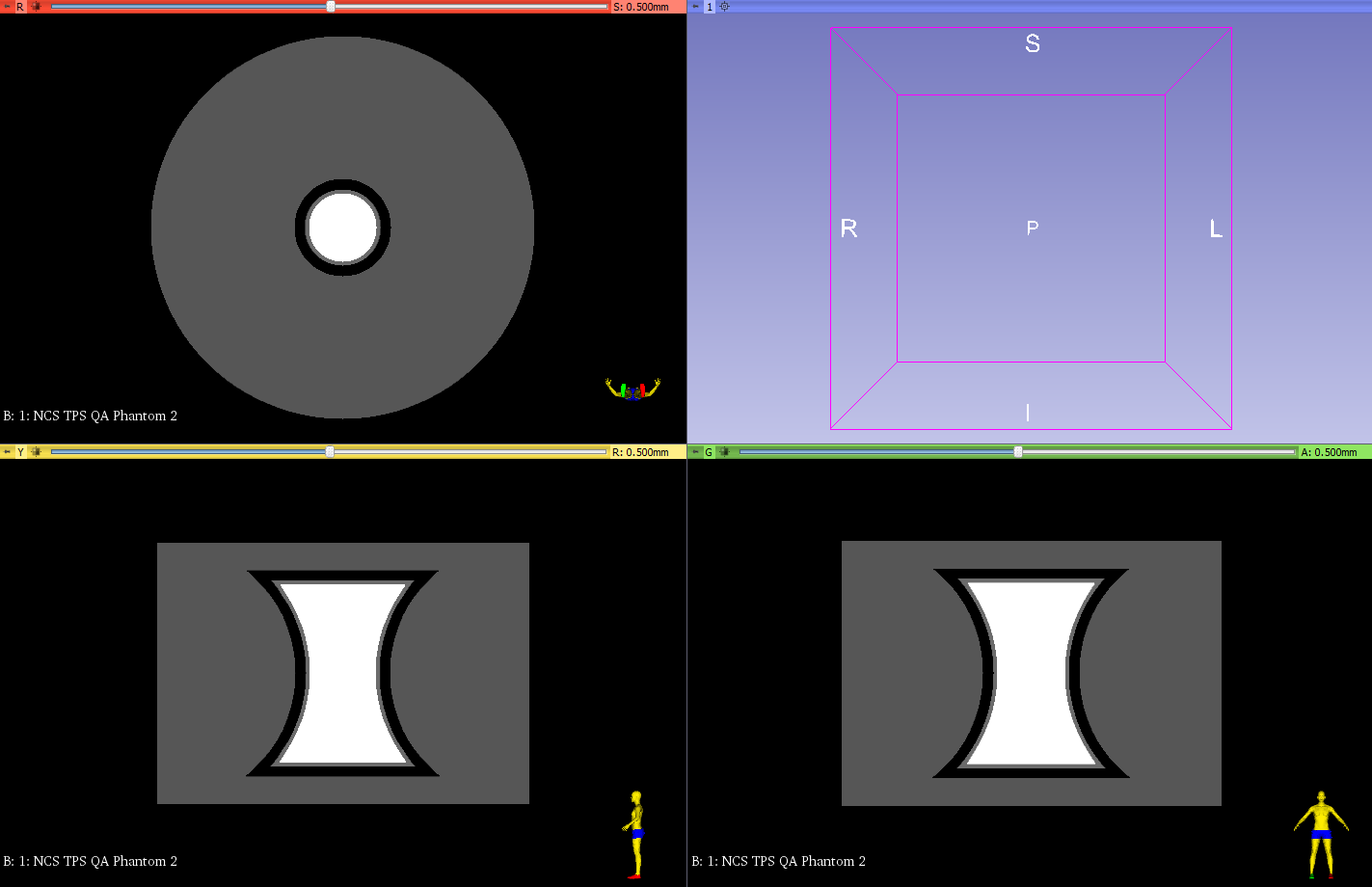
Dimensions (mm) Volume (cm³) HU Mimicking tissue

Cylinder H = 280, R = 200 35175.6 0 Water

Diabolo1 R1(0) = 40, R2 = 150, m = 0 1777.0 40 Soft tissue

Diabolo+ R1(0) = 40, R2 = 150, m = 10 3188.1 -700 Lung

Diabolo- R1(0) = 40, R2 = 150, m = -5 1281.6 1800 Cortical bone



## References

[geurts] Geurts M. DICOM Manipulation Tools. 2018, GitHub Repository, University of Wisconsin, Madison, WI, USA, <https://github.com/mwgeurts/dicom_tools>

[newhauser] Newhauser W, Jones T, Swerdloff S, Newhauser W, Cilia M, Carver R, Halloran A, Zhang R. Anonymization of DICOM electronic medical records for radiation therapy. 2014, Computers in Biology and Medicine 53: 134-140

[fedorov] Fedorov A, Beichel R, Kalpathy-Cramer J, Finet J, Fillion-Robin J-C, Pujol S, Bauer C, Jennings D, Fennessy FM, Sonka M, Buatti J, Aylward SR, Miller JV, Pieper S, Kikinis R. 3D Slicer as an Image Computing Platform for the Quantitative Imaging Network. 2012, Magnetic Resonance Imaging 30(9):1323-1341

[pinter] Pinter C, Lasso A, Wang A, Jaffray D, Fichtinger G. SlicerRT – Radiation therapy research toolkit for 3D Slicer. 2012, Medical Physics 39(10):6332-6338

[ncs15] Bruinvis IAD, Keus RB, Lenglet WJM, Meijer GJ, Mijnheer BJ, van ‘t Veld AA, Venselaar JLM, Welleweerd J, Woudstra E. Quality assurance of 3-D treatment planning systems for external photon and electron beams. Report 15 of the Netherlands Commission on Radiation Dosimetry. 2005