**Introduction**

This document provides most of the information needed to run what I call RITE Dos, which stands for Radiotherapy *In vivo* Two-dimensional EPID Dosimetry.

Essentially, RITE Dos works by correlation ratios between the dose at isocentre, and the intensity of the transit signal (i.e. from image taken *through* the phantom) recorded by the central pixels of the electronic portal (MV) imaging device (EPID). This simple idea was first presented by Piermattei et al. (2006, Med Phys), a research group based in Rome, Italy. Currently (2017), their system records in vivo dose for most of their treatments. Of course, the image is formed by the treatment beam itself – no added dose to the patient. They have published dozens of papers on their work throughout the years (key authors: Piermattei, Fidanzio, Cilla, etc.). Their system provides dose in one point only – the isocentre. That is because the correlation ratios are calculated on the central axis (CAX) and there is no simple way of extending this calculation on 2D or 3D.

My PhD work (myself with Wendy Smith and Derek Brown, at the University of Calgary and Tom Baker Cancer Centre) consisted in extending this dose calculation from 1D to 2D: from the *isocentre* point to the plane perpendicular to the beam, at the depth of isocentre (sometimes called the *isoplane*). A complete presentation, which include all material available in peer review papers, is my PhD thesis “Development and Clinical Application of a New Two-Dimensional in vivo Dosimetry by Electronic Portal Imaging” (© Stefano Peca 2017). Update and simplification of the MATLAB code was facilitated by Zach Whatman and David DeVries at the Cancer Centre of Southeastern Ontario and Queen’s University, Kingston.

**DISCLAIMER**:

This document is meant to help you navigate through the process of implementing RITE Dos. It is not exhaustive, it is a guide only. Often there are references specific to Varian Eclipse (version 13). The experienced user will be able to apply those instructions to other TPS.

The code itself is not of professional quality. No doubt, it may be greatly improved to be made more efficient (faster) and more ‘elegant.’ Also, it has no graphic user interface.

Most importantly the dose calculation has limited accuracy. In addition, the more the test conditions (phantom/patient with inhomogeneities and irregular contours; asymmetrical, irregular fields, etc) differ from the reference conditions (simple slab phantom, square fields), the less accurate the dose calculation. Finally, the dose estimation is based on the (planning) CT. If irradiation conditions are different from CT (e.g. anatomy changes in a patient, setup differences, etc), a systematic error in dose estimation will appear.

This code and these instructions are provided “as is” for the benefit of other clinical researchers. The process is divided into two sections: (1) commissioning, and (2) dose estimation. The instructions are based on a Varian Eclipse TPS, and Varian aSI EPID. Steps in the process and in the code may be changed at the user’s discretion. Further reading is chapter 5 of my thesis. Please improve and share, thank you!

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**Abbreviations, jargon**

Transit image – an EPID image taken through a phantom or patient. If patient, this is an *in vivo* image.

SW – solid water. A slab phantom. Sometimes called plastic water. Can be replaced by sheets of plastic.

w – this symbol refers to thickness of phantom, in terms of water equivalent thickness. If it has no subscripts, it is assumed to be on the CAX. If it is on the ray line going from the source to the imager’s pixel (i,j) it is written as wi,j.

*cine* – or continuous acquisition. this is the imaging modality I used. You may want to make your life easier by using an integrated image instead. It will save you the step I had to do, of summing multiple images

SFS – square field size. Here referred with the symbol l.

TMR – tissue maximum ratio. The TPR with reference to depth of max dose. We used Varian golden data.

Summary:

Note: run all scripts from the main directory **RITE Dos MATLAB package**

1. Required measurements and data
   1. EPID images through vertically centered phantoms. Place in appropriate directory.
   2. EPID images through vertically off-centered phantoms. Place in appropriate directory.
   3. TPS dose maps. Place in appropriate directory.
   4. TMR data. Place in appropriate directory.
2. Commissioning scripts (all scripts should be run while in ‘RITE Dos Matlab package’
   1. make\_F\_big
   2. make\_f\_little
   3. make\_2D\_backscatter\_correction
   4. make\_Gaussian\_weights\_CentralProfiles
   5. make\_Gaussian\_Horns\_Correction
3. Patient calculation
   1. Obtain patient’s CT dicom dataset, and run PROJECTION for each gantry angle (e.g. 0, 90, 180, 270). Place files (e.g. WED000, WED090, WED180, WED270) in appropriate directory.
   2. Obtain patient’s in vivo transit EPID images. Place in appropriate directory.
   3. Run RITE\_Dos\_Calc.

# Commissioning of the isocentre point dose estimation

To calculate dose, you need to produce three lookup tables**: F, f, TMR**. These are energy- and machine-specific. You will obtain measurements from EPID and TPS. Then you will interpolate values, to obtain a finer resolution table.

This section (1) will allow estimation of the dose at the isocentre point, as proposed by Piermattei et al (2006).

Note: if you use different parameter values (phantom thickness **w**, square field size **l**, phantom off-center displacement **d**) or different interpolation, you will have to update the MATLAB code.

Note: In this text I am assuming the water equivalent thickness of the couch to be 0.6 cm.

Note: this procedure refers to ONE energy and ONE rep rate.

Note: these scripts are made to work in *cine* imaging. They may be simplified to work in other imaging modes such as integrated

## Notes on portal imaging

### Imaging Modality (cine vs integrated)

The RITE Dos was developed using *cine*, or continuous acquisition, EPID imaging. This has the added benefits of:

1. For 3D-CRT, providing a ‘movie’ in which intra-fraction patient motion can be visualized
2. For IMRT and VMAT, providing a ‘movie’ in which MLC motion can be visualized
3. Allowing future extension of RITE Dos to gantry-dynamic treatments such as VMAT

On the other hand, cine imaging has some drawbacks:

1. If multiple frames are averaged into one image (f/i >1) then the user may have to account for possible frame loss at beam off (see Peca, Brown, Smith, 2017).
2. Many images are generated, especially if f/i=1. This can take up RAM and storage memory. (it is advisable to set lower resolution, i.e. 512x384, with cine imaging)

The user may choose to switch from *cine* to *integrated* imaging. This produces only one image per beam. Minimal adaptations in the MATLAB code may be required.

### Flood Field

Before you do anything else, make new flood field (FF) and dark field (DF) correction, for the energy, dose rate, and imaging modality you will need. SAVE these images, you may need them.

What I highly suggest is to take your FF correction image through 20 cm of solid water. This approximates patient thickness, and allows the in vivo images to conserve the correct profile. In the Varian EPID system, every imaging modality requires its own FF image. Varian recommends using an empty (unperturbed) beam. I suggest dedicating a modality to in vivo dosimetry (i.e. *cine*), and taking an FF through 20 cm of water for that modality only. **NOTE**: If you use an unperturbed image for your FF, the subsequent EPID images may be too pointy (you would lose the horns) to the point of not being able to approximate the dose profile.

### Beam On Delay

The Varian AM Maintenance has a feature called *BeamOnDelay* which makes the imager wait some time after beam is turned on before acquiring images. I suggest setting this to 0 seconds.

### EPID positioning

Perform all commissioning with the EPID in the location where it will be during in vivo image acquisition, i.e. 50cm downstream of iso.

### The CT and treatment couches

The added attenuation of the CT and treatment couches (beds) is not accounted for in this simplified RITE Dos package.

## Commissioning measurements you need

### EPID images with phantom vertically centered

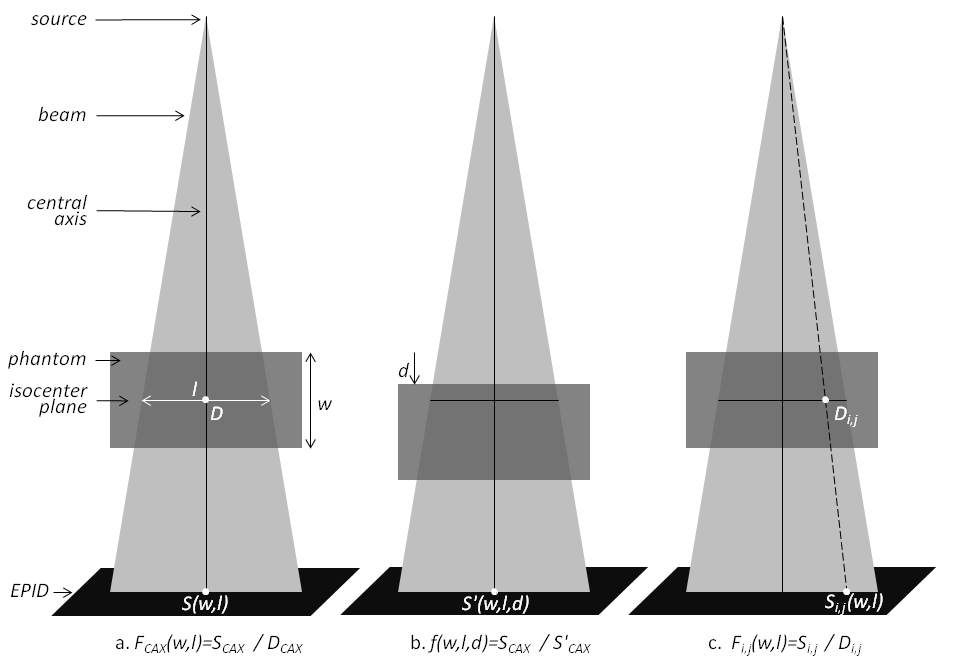
Take EPID images through the couch AND through w=5-40cm of SW. Center (couch+SW) at iso (i.e. if 20cm of SW on couch and w(couch) is 0.6cm, depth should be 20.3cm, and SSD 79.7cm).

Take each image for **100 MU**. I used SAD 100, with the (phantom+couch) radiological thickness centered vertically about the isocentre. You may choose to ignore the couch.

w = phantom thickness = 5, 10, 15, 20, 25, 30, 35, 40

l = square field size = 5, 10, 15, 20

Save images in Commissioning data/EPID images with centered phantoms (F)/wXXlYY where XX is the phantom thickness and YY is the field size.



### EPID images with phantom off-center

Same as above, but moving the couch vertically by

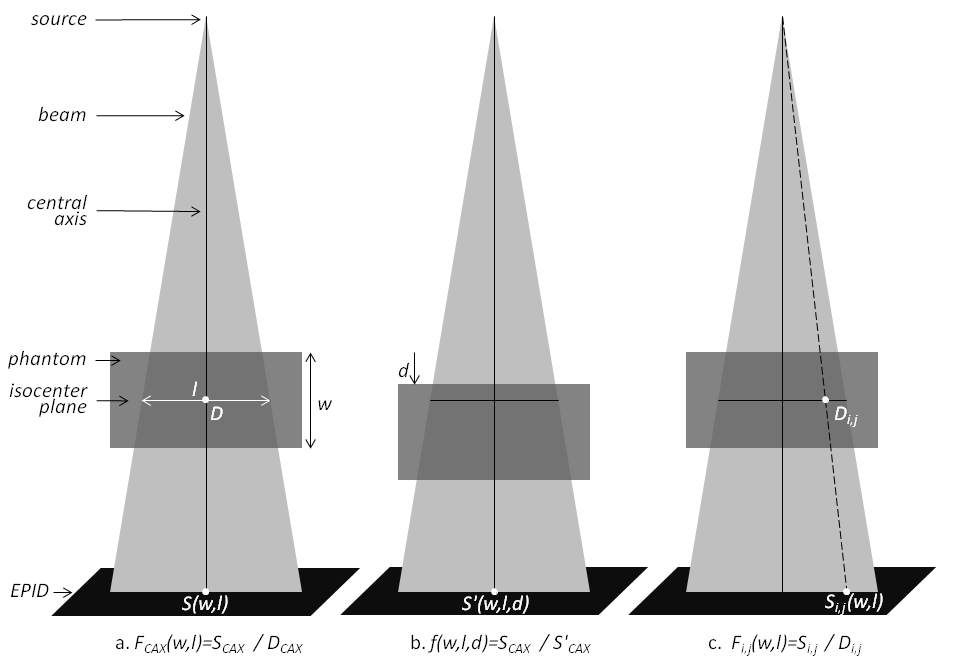
d = -10, -5, 0, 5, 10

For each value of d, acquire images for the 4 field sizes: 5, 10, 15, 20.

(actually, the measurements with d=0 are the same as taken previously)

Place these images in Commissioning data/EPID images with phantoms off-center (f)/fx01 to fx20

Where fx01-04 are for d=0cm, fx05-08 for d=-5cm, fx09-12 for d=-10cm, fx13-16 for d=+5cm, fx17-20 for d=+10cm.



### TPS Dose maps

In your TPS, obtain 2D dose maps which simulate dose at mid-plane of the vertically centered phantoms above, i.e. dose at the plane going through the isocentre.

If you are new to Varian’s Eclipse, the following can help you.

First, create virtual water phantoms of thicknesses w (5, 10, 15, 20, 25, 30, 35, 40 cm).

To the first phantom (w=5cm) create a course, a plan (head-first supine) and apply a 5x5 field. The geometry must be the same as in 2.1.1. Ensure there is only 1 field in the plan. Ensure energy and dose rate are appropriate.

The “Dose/fraction” is unimportant, but the “number of fractions” **MUST** be set to 1. Set MU to 100 and calculate dose. (**NOTE**: it is crucial that the number of MU is the same as the MU delivered to the EPID in the section “EPID images with phantom vertically centered”)

Select the **frontal** view. Right click on dose, choose “export dose plane”

|  |  |
| --- | --- |
| Dose | Absolute |
| Planar Dose Details | X size=**26.7083\***, points=**512** ; Y size=**20.0704\*\***, points=**384** |
| Set ad Default | select for the future exports |
| burn marker pixels in corner | Uncheck |
| Align matrix with field | Field 1 (or what is appropriate) |

\*=0.0784\*511\*(100/150)

\*\*=0.0784\*383\*(100/150)

Rename the dicom file according to the scheme below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **w Solid Water** | **l** | **depth** | **SSD to set in Eclipse** | **filename to use (.dcm)** |
| 5 | 5x5 | 2.5 | 97.5 | **w05l05** |
| 5 | 10x10 | 2.5 | 97.5 | **w05l10** |
| 5 | 15x15 | 2.5 | 97.5 | **w05l15** |
| 5 | 20x20 | 2.5 | 97.5 | **w05l20** |
| 10 | 5x5 | 5 | 95 | **w10l05** |
| 10 | 10x10 | 5 | 95 | **w10l10** |
| 10 | 15x15 | 5 | 95 | **w10l15** |
| 10 | 20x20 | 5 | 95 | **w10l20** |
| … | … | … | … | **…** |
| 40 | 5x5 | 20 | 80 | **w40l05** |
| 40 | 10x10 | 20 | 80 | **w40l10** |
| 40 | 15x15 | 20 | 80 | **w40l15** |
| 40 | 20x20 | 20 | 80 | **w40l20** |

(this takes ~30 minutes per energy)

Place all .dcm files in a directory such as “TPS\_6X\_600RR”

## The F=S/D lookup table, as a function of thickness (w) and (equivalent) square field size (l)

The most important information you need on your system is the capital F correlation ratio. It is defined on the CAX

Use the script **make\_F\_big**

It obtains values for (FCAX) as a function of phantom thickness (w) and field size (l) by FCAX(w,l)=SEPID(w,l)/DTPS(w,l)

These tables will be different for different energies (i.e. 6 MV and 15 MV) and for different linear accelerators, even if of the same model.

## The f=S/S’ lookup table, as a function of (equivalent) square field size (l) and vertical displacement between the isocentre plane and the radiological mid depth (d)

The second important correlation ratio is the lowercase f. Again, this is defined on the CAX .

Run the script **make\_f\_little.**

Piermattei et al. (2006) found that this parameter has very little dependence with w, so that is not further considered. This lookup table is created based on EPID measurements only, no TPS. You should use the same images you obtained to measure F (section 2.1.1). And you will need more images taken with the same SFS (l), and with various values of d. You can do these all with constant thickness w, making it a sensible patient-like thickness like 20cm.

Our center’s results are in

## TMR values

Lastly, you will need a lookup table of TMR values, as a function of thickness (w) and field size. (l).

You are provided with the 6X one from our Varian machines. Please update it to match your machines.

## Optional: correction for frame loss at beam off (*cine* mode only)

If you are using cine mode, and your frames/image (f/i) value is >1, you will likely lose frames at beam off.

Example: f/i=8. You deliver 100 MU to a patient while collecting in vivo images. When the beam turns off, you have produced 12 images (each image is the average of 8 frames) and 4 extra frames. As these extra frames are <8, they do not make an image and get thrown away. When you calculate dose from the images, you are only accounting for 12/12.5=0.96 of the dose, i.e. you underestimate dose by 4%.

You can correct this by a method outlined in the Peca, Brown, Smith 2017 paper. Or you can use an integrated mode rather than *cine*, and you should avoid the problem entirely.

# Commissioning of the 2D isoplane dose estimation

This section (2) allows the dose estimation in the whole plane at isocentre depth.

## Backscatter correction

The EPID backscatter is not uniform. We can account for this with the method proposed by Berry et al (2010). **Run the script make\_2D\_backscatter\_correction.m** to generate a set of corrections for each of the commissioning phantom measurements (the ones with the phantom vertically centered).

## Multi-Gaussian planar dose correction

Dose fall-off at the level of isocentre (inside patient/phantom)is different from image intensity fall-off at the level of the imager. We can account for this by a two step process. (1) convolution in 2D by a linear combination of weighted Gaussians, and (2) correction for the horns by a horn correction matrix (HCM).

The key is to compare profiles along the radial axes of the EPID image (“image profiles”) with profiles of the TPS dose estimation, along the same radial axes (“dose profiles”). For a number of reasons (see especially my thesis, chapter 4) these two profiles differ. Which is of course to be expected, as the image profile is a set of pixel values of an image taken through a block of water, while the dose profile is a set of dose values in the middle of that block of water.

The strategy we use is described in Chapters 4 and 5 of my thesis. In short, we use the TPS dose profile as a reference. Then, we take the empirical EPID image profile and convolve it iteratively with various linear combinations of four pre-set Gaussian smoothing kernels, so that the product of the convolution is as close as possible to the reference.

# Calculating delivered dose to patient from *in vivo* EPID images

Open the patient plan in **Eclipse**

### Exporting the CT and plan data

In the context window, select and open (drag into viewing window) the appropriate plan.

“File” – “Export” – “Wizard” – “Plan”. Check “Include image slices of 3D volume”. Uncheck every other option. “Dose” – “None”.

“Finish”: This will export all CT dicom slices (“CT… .dcm”) and one plan file (“RP… .dcm”). Place files in a directory dedicated to the patient (e.g. “Patient001”).

In Matlab workspace, type “CTdata=Import\_CT\_2;”. This script takes all .dcm files which start with CT and puts them together in a variable (a 3D array) which you called CTdata.

Save the variable “CTdata” as file CTdata.mat in the same directory

Open the script “PROJECTION\_2015\_A”. Verify the gantry angle (ImAng) is correct. Run it. (approx 4.5 hours).

Select the three WED variables, save them with a filename that denotes the gantry angle (e.g. “WEDs-GA090.mat”).

### Exporting a dose plane image for each beam

Make a note (on paper) of the **MU** of each field you wish to verify. (Note: if you hover with the mouse over the MU value, it provides a decimal value)

Create a **new course**, name it “Physics\_RITE\_Dos”

Copy the plan you wish to verify from the treatment approved course into the new course.

Set **weights of all fields except the one you wish to verify =0**. This will cause MU of the field to be verified to increase, while all the others go to zero.

For the field you wish to verify, **manually set the MU value equal to what it was initially**. This will change the weighting factor, but that is not a problem.

Click on the window which gives you a **beam’s eye view**. Normally, this translates into:

|  |  |
| --- | --- |
| ***Gantry angle*** | ***Beam’s eye view*** |
| 0° | “Frontal”, “move viewing planes to isocenter”, |
| 270° | “Sagittal”, “move viewing planes to isocenter”, |
| 90° | Rotate “Transversal” by 180°, “move viewing planes to isocenter”, select “Sagittal” window. |
| 180° | Rotate “Transversal” by 180°, “move viewing planes to isocenter”, select “Frontal” window. |
| other | Rotate “Transversal” by the appropriate gantry angle, “move viewing planes to isocenter”, select either “Sagittal” or “Frontal” window as appropriate. |

*(ensure you are actually in a view that coincides with beam’s eye view before proceeding)*

RMC on Dose, choose “**Export dose plane**”.

|  |  |
| --- | --- |
| Dose | absolute |
| Planar Dose Details | **Xsize=26.76053**, points=512 ; **Ysize=20.0704**, points=384 |
| Align matrix with field | choose the appropriate field |
| burn marker pixels in corner | Uncheck |

Export the image into your working directory; **name** it in a recognizable way, e.g. “tpsGA180.dcm”.

Repeat for all fields you wish to verify.