

OrthoChromic Film Dosimetry Protocol

Highly Efficient Use of OrthoChromic Film (OC-1) and OrthoChrome Pro Software (OC Pro)

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1 Scope

To define a highly efficient protocol to calibrate and evaluate film dose measurements with minimum resources and effort. The protocol covers OrthoChromic film OC-1 application in a dose range of below 0.1 Gy up to 100 Gy involving only two pieces of film and a single scan for the entire measurement. Calibration data are generated by a continuous dose field and the calibration is carried out separately for structured fields of scanner sensors. Calibration and dose evaluation are done together in a plain procedure. The OrthoChromic films are usually scanned 1 h after exposure.

The protocol is based on correlation of multi-dimensional data for each sensor field and also determines the quality of the calibration data and the resulting dose conversion accurately.

2 Introduction

Calibration in film dosimetry is usually carried out by using a sequence of known flat field exposures. Such flat fields can be overlaid forming a multi-level step wedge. An example dose plan with rectangular shape and maximum dimensions of 13 cm x 20 cm is shown in Fig. 1. There are 8 dose levels with a cumulative maximum dose of about 8 Gy.

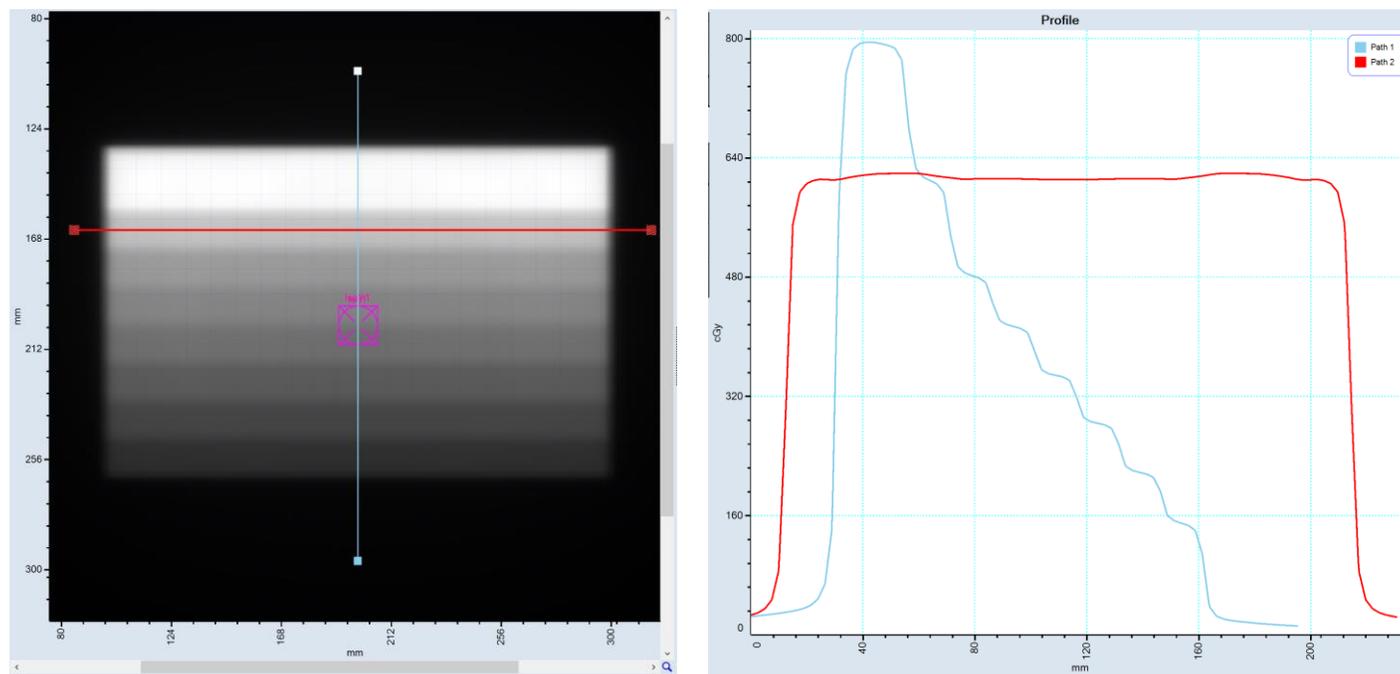


Figure 1: Dose plan consisting of 8 overlaid rectangular flat fields with total size of 20 x 13 cm and maximum dose level at 8 Gy.

The dose plan was delivered to OC-1 film. Fig. 2 shows a scan of the exposed film on an Epson 12000XL-GA photo scanner. Although the 20 cm wide field covers two thirds of the lateral scan area, the profile of the red channel at about 6 Gy in lateral direction (cyan) does not exhibit any systematic lateral dependency as observed with other radiochromic films. However, since every scanner sensor carries its own calibration and measurement characteristics, the scanner itself introduces lateral variations (sensor to sensor variations) into the measurement results.

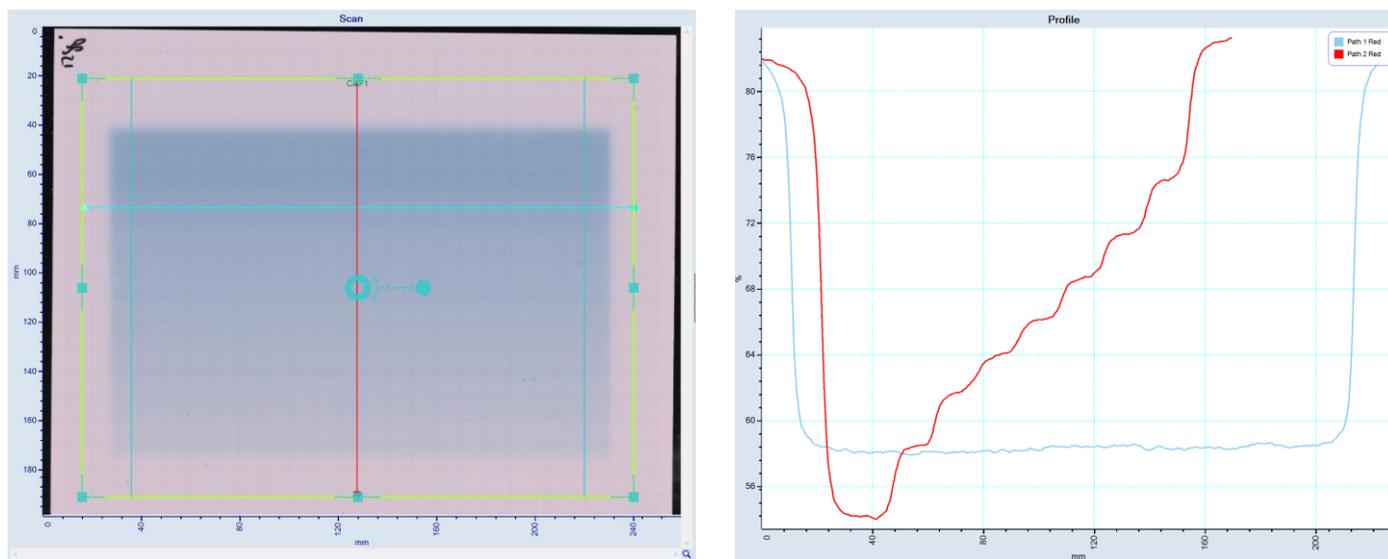


Figure 2: Scan of the dose field delivered to OC-1 using Epson 12000XL-GA and profiles of red channel in lateral (cyan) and scan direction (red). The lateral profile at ~6 Gy does Not show a lateral artifact like other radiochromic films. Frame and vertical limit lines (cyan) restraint the plan and film pixel locations utilized for calibration.

Determining the plan registration vs. film image (protocol description will explain how to carry out such registration) both images are overlaid to chart the scanned RGB values vs. the dose values of the plan at same locations as shown in Fig. 3.

Traditionally such data are used to correlate parameterized RGB vs dose dependencies – in case of separated flat fields and plan regions restricted to the flat part of the fields, this describes the most commonly used calibration approach in film dosimetry.

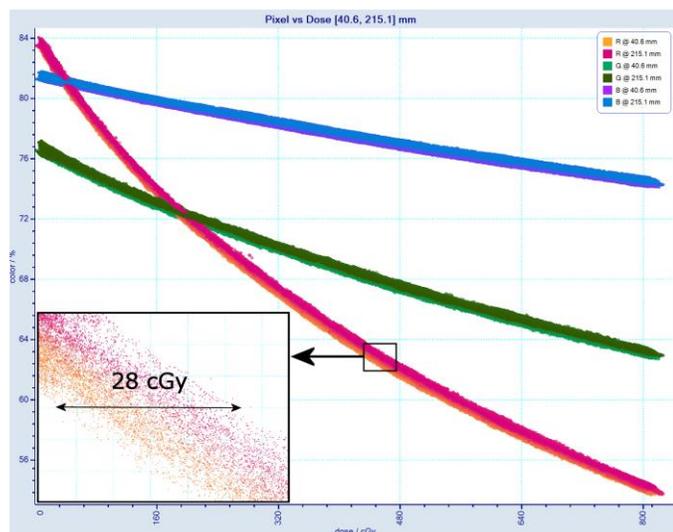


Figure 3: RGB data of scanned OC-1 image vs dose of the registered plan image for all plan pixels. Magnified area shows dose variations up to 28 cGy (> 6 %).

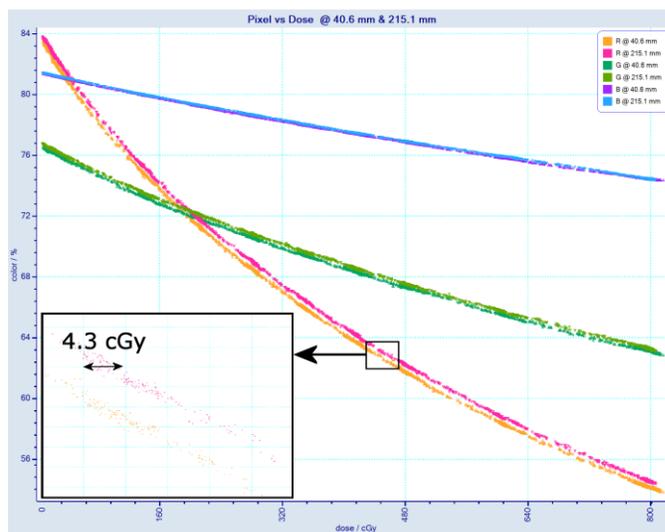


Figure 4: RGB data vs plan dose for single lateral positions at edges of pixel range. Magnified area shows dose variations < 4.3 cGy (< 1 %) for both lateral positions.

However, as the magnified area in the chart illustrates, the data show statistical variations which amount up to 28 cGy or > 6 % for the given example. One has to expect a calibration error to be at this observed level of variation or higher.

Those variations stem from

1. Sensor to sensor variations of the scanner,
2. Scanner sensor noise,
3. Non-uniformities of the film,
4. Offset between plan data and delivered dose.

When considering the data for each lateral pixel location separately, the dose variation will reduce – in the example shown in Fig. 4 it reduces substantially by more than factor 6, i.e. discretizing the lateral (scanner) dimension and calibrating those pixel lanes independently has a clear benefit. Any sensor to sensor variation can be compensated this way too. To apply a lateral calibration discretization, the calibration field must cover the lateral range that should be compensated – an example is shown in Fig 2 using a 20 cm wide step wedge.

Sensor noise can be addressed by active, non-linear filtering like ‘Median filter’ (uses median value of surrounding area of a pixel) or ‘Least square plane’ filter (uses least square fit of the plane through the surrounding pixel values).

To correct uncertainties of plan vs delivered dose field, e.g. plateau and penumbral pixels have different uncertainty, notorious pixel locations should have a reduced statistical weight to minimize distortions. Plateau and penumbral locations can be identified by the gradient of the corresponding plan position which allows to reduce the statistical weight of the penumbra regions.

Film non-uniformities can be redressed by using measurements of a field of sensors that allows to determine thickness based distortions.

3 Dosimetry Equipment and Materials

To carry out dose measurement the following equipment and materials are needed:

- OrthoChromic OC-1 film,
- OrthoChrome Pro software,

- 48-bit flatbed scanner with 64-bit Twain driver, recommended is Epson 12000XL-GA (transparency adapter is Not needed),
- Heavy glass plate 5 - 10 mm thick and size of the scan area 31.5 x 44.5 cm to flatten film at scanner platen to ensure the flatness of the films on scanner, preferred opaque glass (mirror or one side painted black) to minimize the ambient light interference,
- Optional scissors or paper trimmer to cut film,
- Recommended use of powder free rubber gloves to avoid marks on films.

4 OC-1 Film Handling

- **Storing:** OrthoChrome OC-1 film is delivered in a re-sealable plastic bag packed in a black, light safe box. Leave the film in the bag and box until use. The film can be stored at ambient condition for the period before expiration date.
- **Light:** The film darkens very slowly when exposed to indoor ambient light – i.e. multiple scanning or indoor working with the film causes little to no additional darkening. Do Not expose it to direct sun light. Do not leave films outside for any unnecessary period. Keep the film dark when Not in use.
- **Surface:** Soiling and smudging of the active film side must be avoided. Do Not touch the active side with your bare hands. Wearing powder free gloves is recommended. Dusts can be cleaned with a soft cloth using water only. Solvents such as alcohol will damage the film surface! When cleaning the scanner platen with solvent, one should ensure that the scanning surface is completely dry before putting the film on the scanner. Permanent marker can be used to mark or write on the film.
- **Cutting:** When film cutting is necessary use a pair of sharp scissors or paper cutter without damaging or smearing the active side of the film. The ~5 mm along the cutting edge may have some degree of degradation in terms of measurement accuracy.
- **Scanning:** After exposure, the optical density of the film will grow slowly over time. The OrthoChromic protocol compensates this effect by using only a single scan for the measurement evaluation and involves only two pieces of films – one for calibration and one for the treatment field. Scan the films after a minimum four times the time difference between first and second exposure. To achieve best accuracy, scan the film no later than 48 hours after exposure.

5 Scanner Setup

Install your scanner by following the instructions of the manufacture – make sure the **64-bit Twain** driver is installed. Test the scanner using the native software supplied with the scanner.

The OC-1 film dosimetry was validated using Epson 10000XL, 11000XL and 12000XL scanners. The later uses LED light source and delivered the most stable results during the tests.

Select a scanner at the Twain 'Select Source' panel as shown in Figure 5 – the selection can be done either using the scanners native software or via OC Pro software.

Note: Twain might have both 32 and 64 bit driver versions - make sure the 64-bit selection is used.

The OrthoChromic protocol allows a wide range of scan resolution, most common are 70 – 150 dpi (recommended 75 dpi). For the Epson 12000XL select the 'Main Settings' and the 'Advanced Settings' as shown in Figure 5 and 6.

From the 'Main Settings' the 'Color Management' panel shown in Figure 7 can be reached to turn Off the color management.

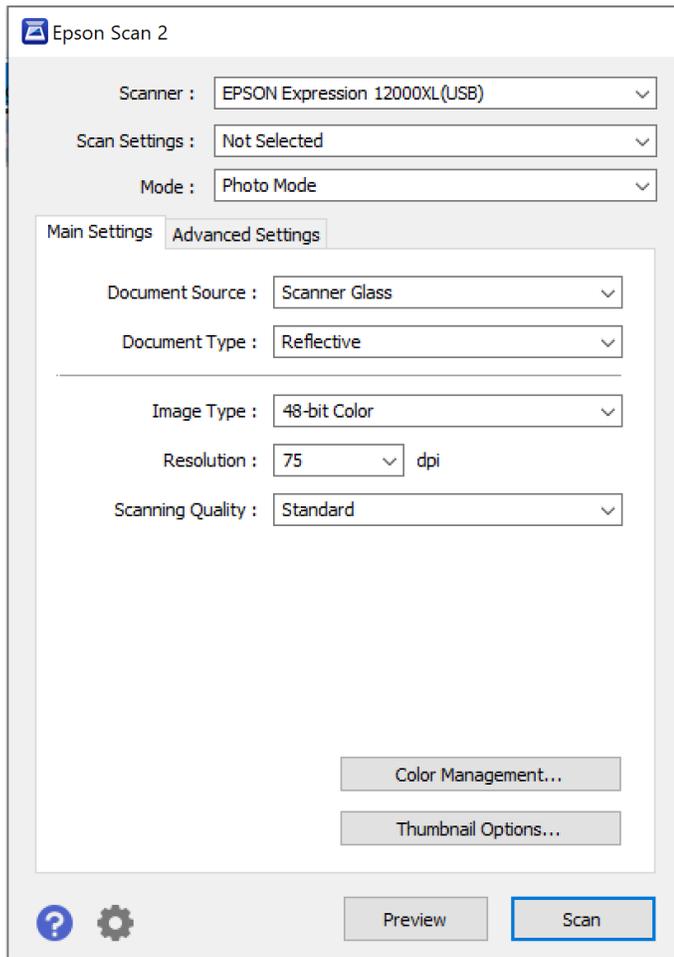


Figure6: Epson Scan 'Main Settings'.

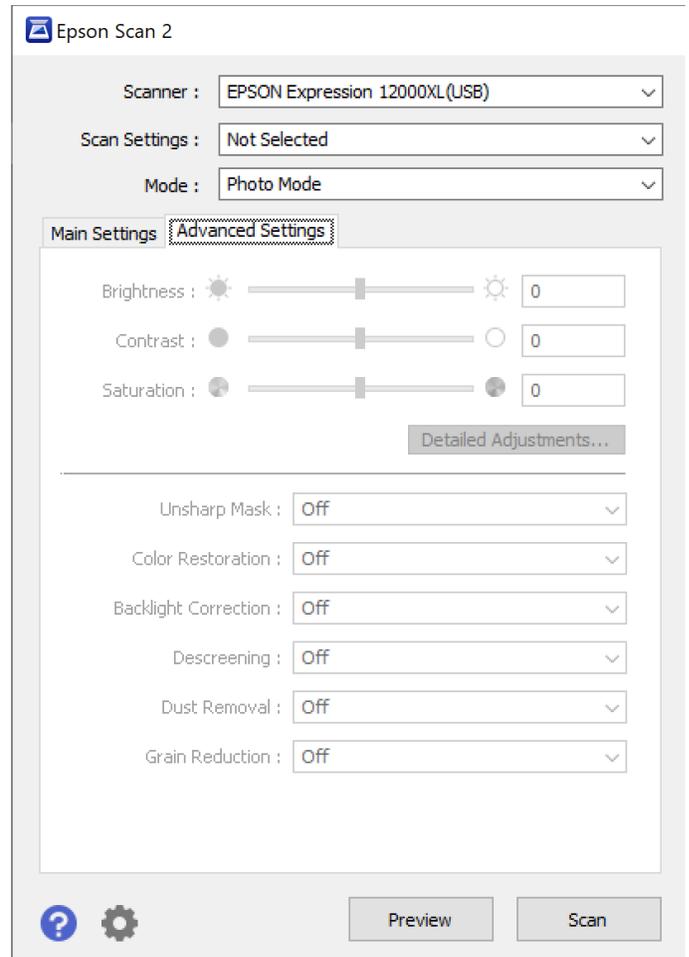


Figure 7: Epson Scan 'Advanced Settings'.

Note: The Twain driver can only be accessed by one application at the time, i.e. close any native scanner software before accessing the Twain driver using OC Pro.

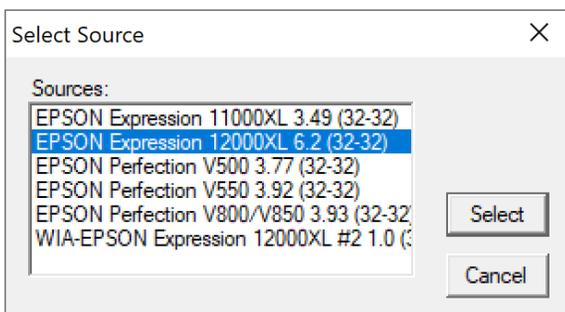


Figure8: Twain 'Select Source' panel choose Epson Expression 12000XL.

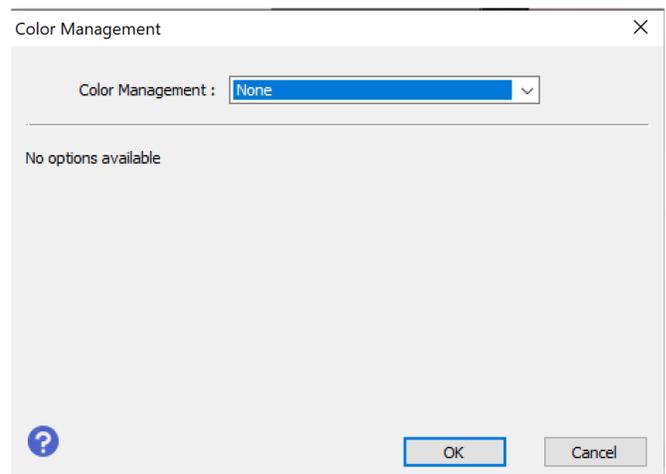


Figure 9: Epson Scan 'Color Management'.

6 OC-1 Film Basic Properties

OrthoChromic film was designed to be the most robust and user friendly dosimetry tool. The special single layer coating is water proof and can be safely immersed into water - see structure in Fig. 10.

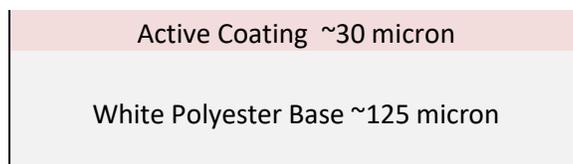


Figure10: Structure of OrthoChromic Film OC-1

OC-1 film is opaque and its reflective nature is designed to eliminate most of the interfaces that can create artifacts during scanning process with commonly used flatbed scanner.

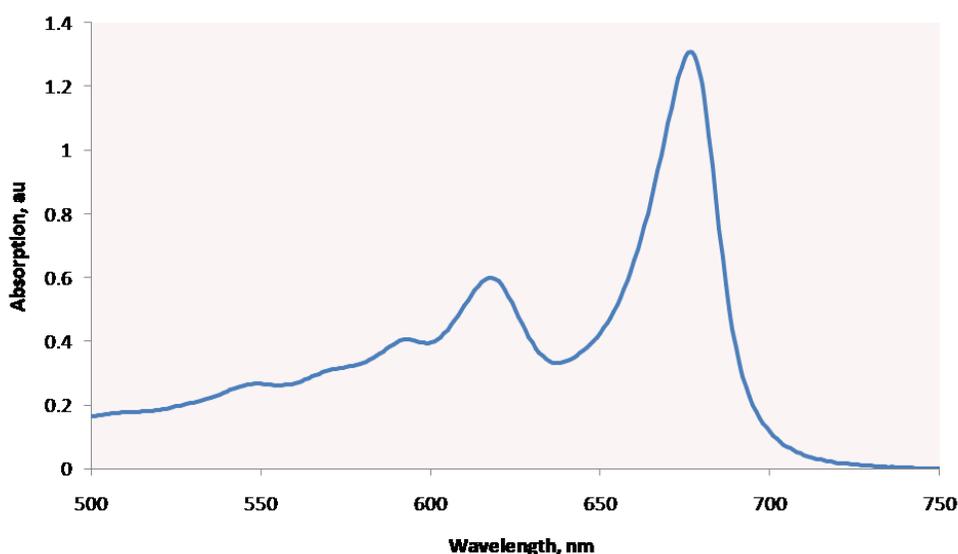


Figure11: Absorption Spectrum of the OrthoChrome Film

The flexible nature of the film also enables the use of the film in phantoms of all shapes and curvatures. The active component has an absorption peak at 670 nm – see Fig. 11).

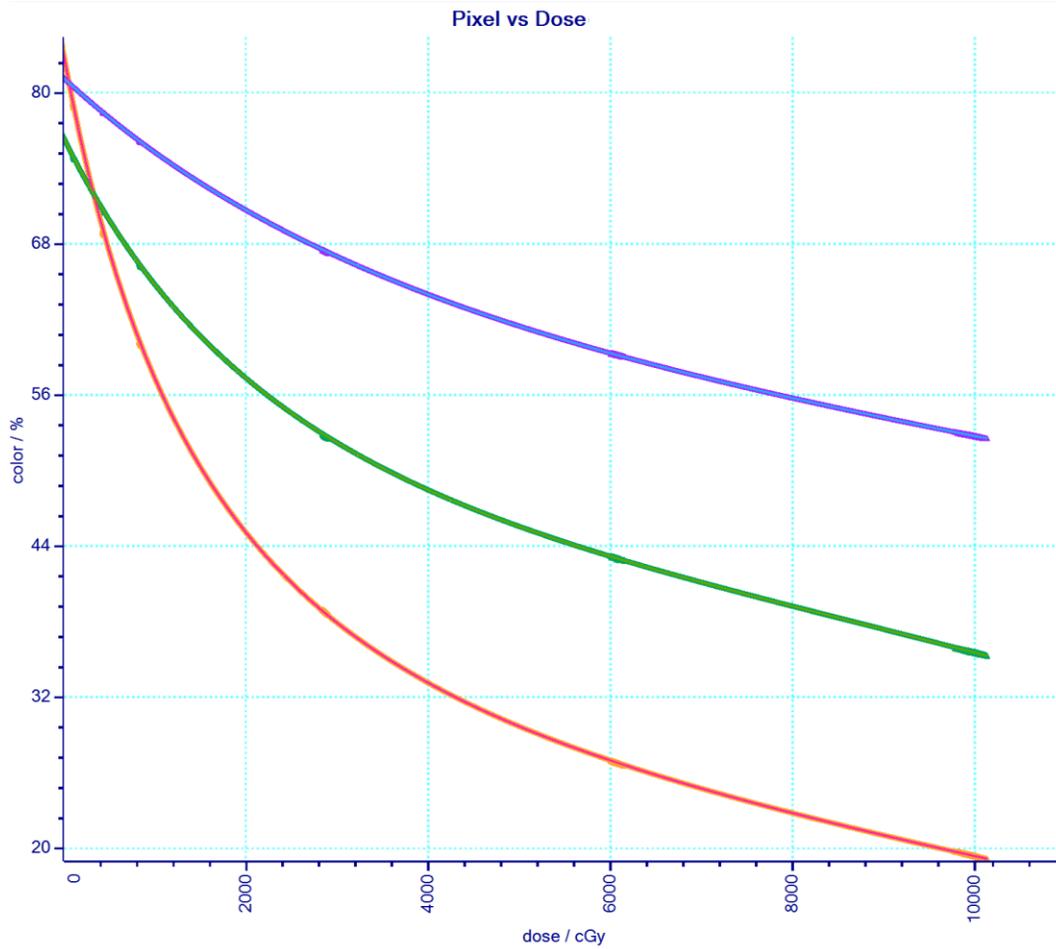


Figure12: Color Density Response Curves of OC-1 Film.

OC-1 film has an extremely wide usable dynamic range as shown in Figure12, the usable dose range extends from 10 cGy to 100 Gy.

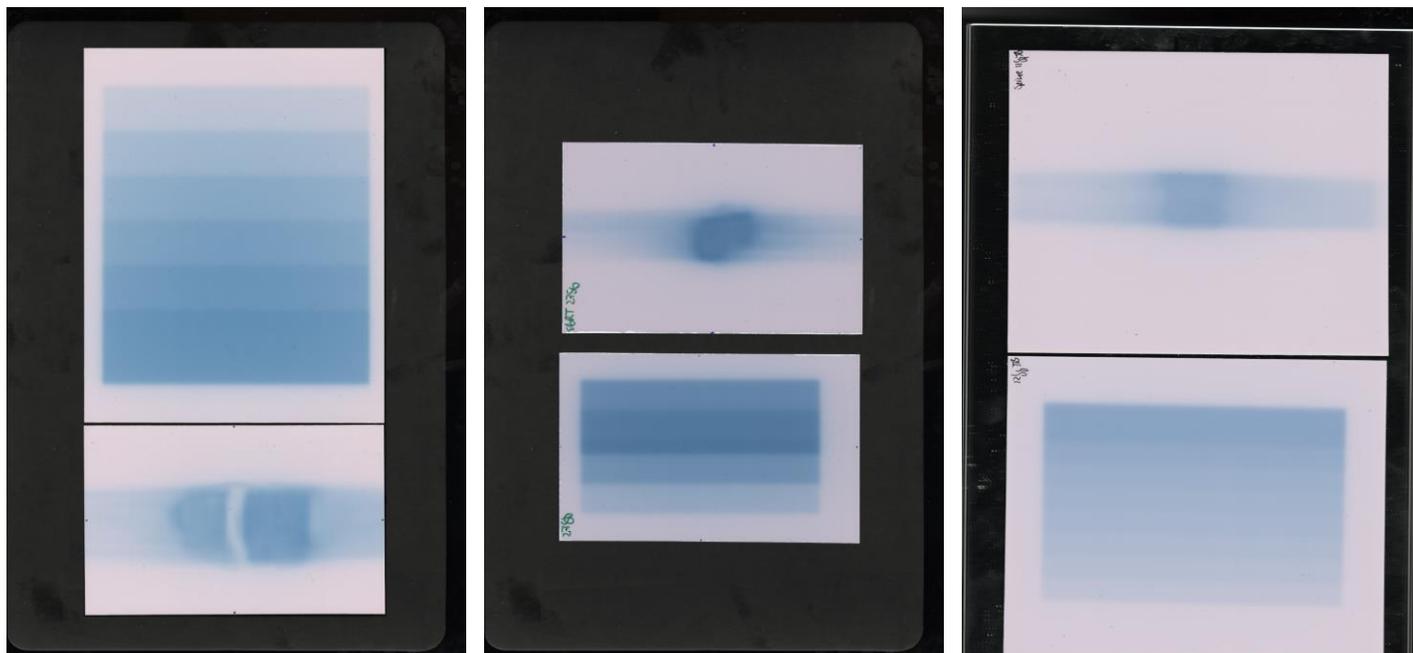
7 OrthoChromic Protocol

This protocol allows reliable and accurate verification of any radiotherapy and radiosurgery plans.

7.1 Film and calibration data

The measurement requires two pieces of OC-1 film – one to be exposed to the calibration field (calibration film) and one for the delivered treatment plan (measurement film). The calibration field area should not fall below a size of 100000 pixels (this corresponds approximately of 10 cm x 10 cm @ 75 dpi) to provide enough statistical pixel mass for the calibration process.

To compensate the lateral variations the calibration film must cover the approximately the same lateral dimension as measurement film. Using a quarter, a half or a full film sheet for calibration depending on the dimensions of the field to be measured. The quality of the calibrations stipulates the achievable accuracy for the entire measurement the measurement error is very rarely better than the calibration error. To target reliably best results the calibration field (film) must Not be undersized. The cardinality of calibration pixels should always exceed that of the treatment field pixels. Fig. 13 shows examples of different size combinations of calibration and measurement films.



Figur 13: Examples of full and half sheet calibration film configurations.

In principle, any dose field that is reliably delivered with high accuracy can be used for calibration. The use of flat or flattening-filter-free (FFF) rectangular fields allows to produce calibration fields with high certainty. To compact the total calibration area and to increase the ratio of plateau vs penumbra pixels, those rectangular fields can be superimposed forming a step wedge.

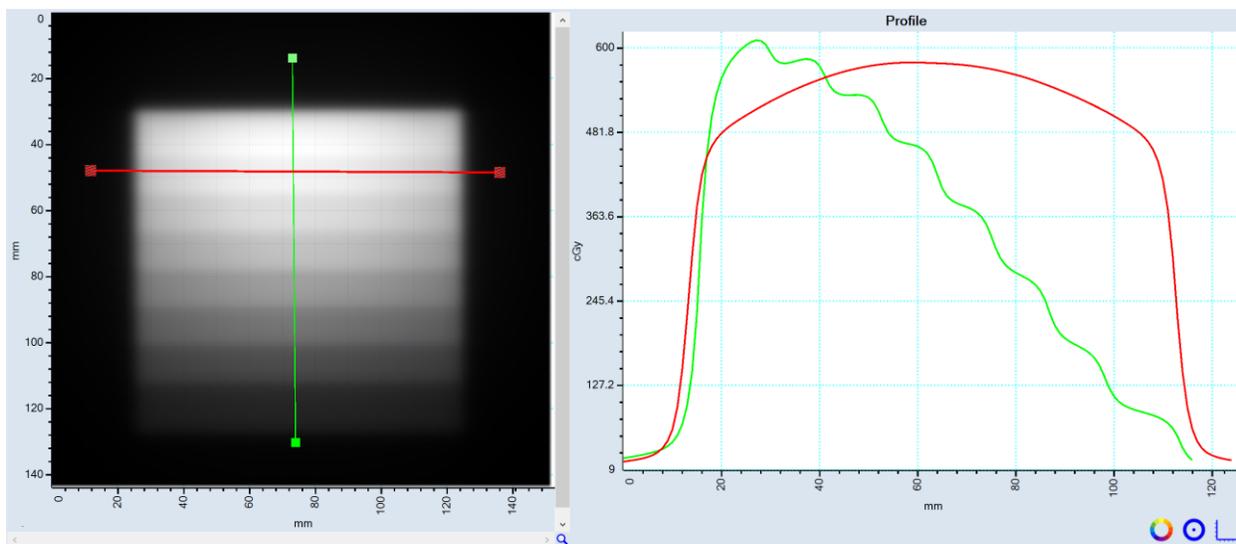


Figure 14: CyberKnife™ 10 cm x 10 cm calibration field consisting of eight overlaid FFF rectangular fields.

Example of FFF calibration field with minimum size of 10 cm x 10 cm generated by CyberKnife™ is shown in Fig. 14. A wide calibration field of 20 cm x 13 cm covering 2/3 of the lateral scanner range created by a TrueBeam™ using rectangular flat field is shown in in Fig. 15. Note in both examples that the plateau area of the highest dose level is ~60 % greater than the other levels to overweight the highest dose and to compensate the two downwardly directed penumbra edges. Both measures support to minimize the error at the top of the dose range.

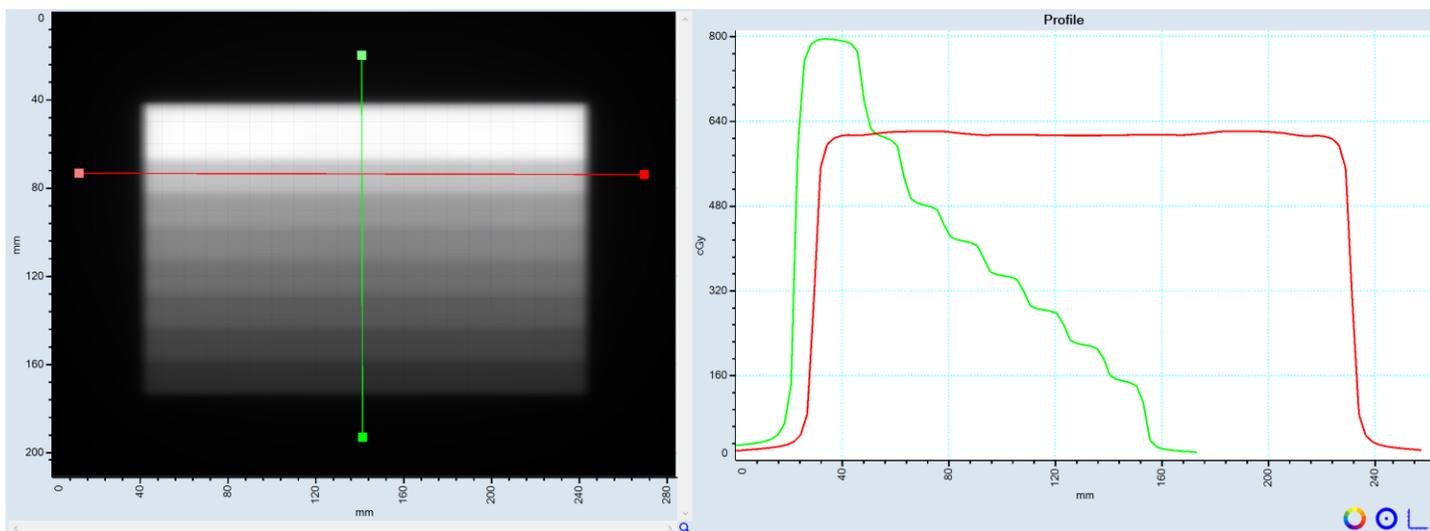


Figure 15: TrueBeam™ 20 cm x 13 cm calibration field consisting of eight overlaid rectangular flat fields.

The ability to deliver certain dose field shapes with best accuracy is machine dependent. The application of the OrthoChromic Protocol does Not depend on any specific shape of the calibration field and the quality verification of the calibration data (approximation error and passing rate) is part of the protocol as described later.

The following calibration data settings are recommended:

- Calibration field is superposition of rectangular fields (flat or FFF)shaping step wedge,
- Calibration wedge should have 6 to 8 dose levels, the number of dose level must Not be below 4,
- Highest dose level has an area ~50 % larger than other dose levels,
- Width of calibration wedge matches lateral dimension of treatment field.

7.2 Exposure vs Scanning Timing

The OC-1 film is a self-developing film. The developing process is triggered by the exposure (post exposure growth) and slows down exponentially after it started.

The OrthoChromic protocol requires two exposed films. The time delay between measurement film exposure (treatment field) exposure and calibration film exposure (calibration field) causes an offset between the post exposure growth of both films. Due to the exponential slow down this offset can be neglected approximately after waiting four times the delay time between the exposures, i.e.

$$\begin{aligned}
 t_{wait} &= t_{end\ 2nd\ exposure} - t_{scan\ start} \\
 &\geq 4\{t_{end\ 2nd\ exposure} - t_{start\ 1st\ exposure}\} \\
 &= 4t_{exposure\ delay}
 \end{aligned}
 \tag{1}$$

For example, if both exposures are within a 7.5 minute time window, scanning should be delayed by at least 30 minutes.

7.3 Protocol Procedure

Description of the protocol is based on the OC Pro installation example 'Example Spine 11Gy TB' using an 8 level 20 cm wide step wedge for calibration and a Spine treatment field with 11 Gy maximum dose delivered by a TrueBeam™.

7.3.1 Scan films with treatment and calibration fields.

Start: After starting OC Pro software the panel should look as shown in Fig. 16 below.

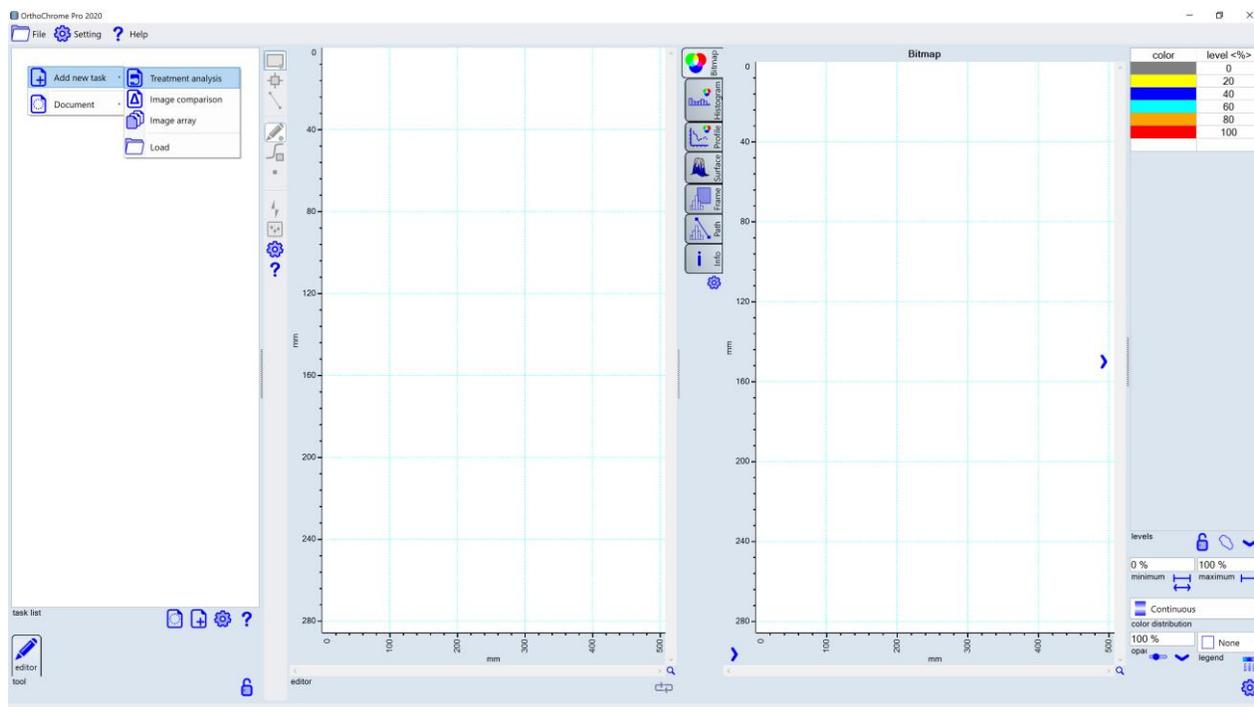


Figure 16: Adding 'Treatment analysis' task

Right click the  icon of the task row as shown in Fig. 17 and select  to scan the radiated films.

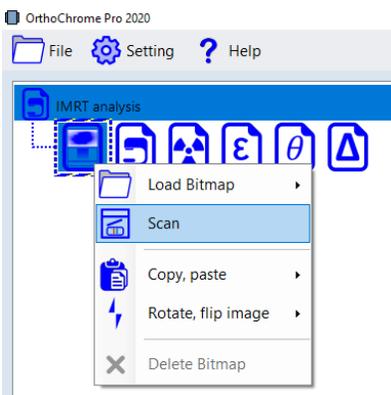


Figure 17: Scanning calibration and measurement films.

The twin scanner panel parameters should be assigned as displayed in Fig. 6.

Film alignment: Place the calibration film in the middle at the very end of scanner platen with the highest dose level of the calibration step wedge towards the center of the scan area as shown in Fig. 18. The measurement film (treatment field) should be located next to the calibration film minimizing the distance between areas with highest dose exposures of both film pieces, i.e. the preferred field alignment on the measurement film is usually along the lateral scanner direction. Lateral sensor to sensor variations are compensated with the OrthoChromic protocol whereas any scanner variation in scan direction directly contributes to the dose error.

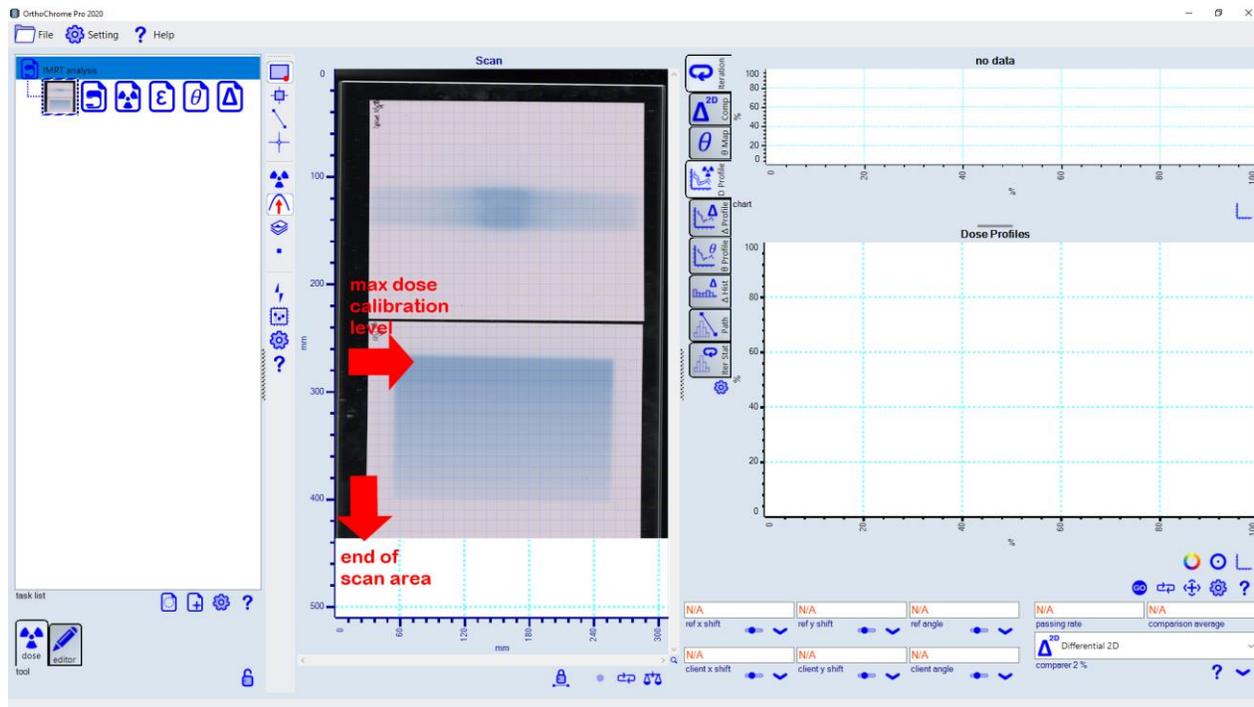


Figure 18: Scanned calibration and measurement films.

Resolution: Preferred image scan resolution is

75 dpi

(2)

(70 dpi – 150 dpi range) for half to full sheet film pieces. For smaller film pieces, as required for some special phantoms, higher resolution might be used.

7.3.2 Assign calibration plan to calibration field area (auto registration).

Settings: Both calibration and treatment **plans** should have the **same resolution** as the scanned image (OC Pro is multi-threaded 64 bit software and able to handle large data with ease).

Make sure the '2D matching' tool,  button, as well as the 'frame' tool,  button, are both selected-see  in Fig. 20.

By default, newly created frames have the type 'Calibration field' – the 'frame' tool menu allows to verify or set the frame type as shown below.

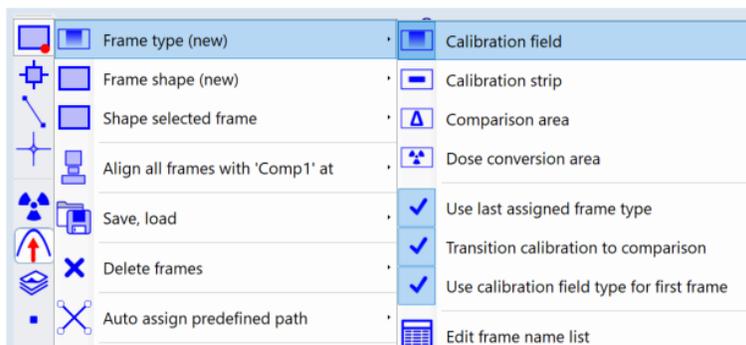


Figure 19: Selection of type for new frames at 'frame' tool menu.

Calibration frame: Click and drag to draw a frame around the calibration field starting at upper left corner as depicted in Fig. 20.

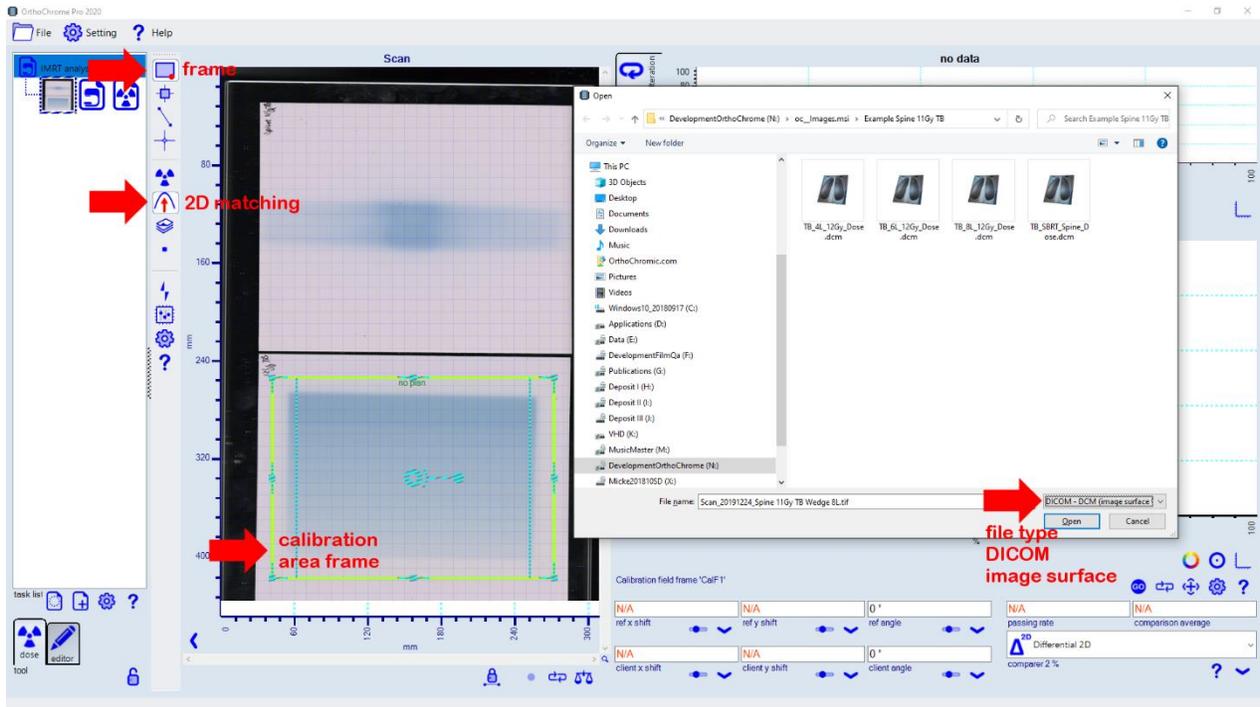


Figure 20: Loading calibration plan.

Select data file:By default, a file opening panel will pop up to select the file to extract the plan data from. In most cases the plan data are provided as DICOM file either as single image or as 3D cube from which the plan surface (plane) must be extracted. The later allows to control the plan resolution when reading the plan data to match the mage resolution. For the demonstration example the data are provided as 3D cube, i.e. file type must be 'DCM image surface' (see marker in Fig. 20).If the plan is provided as single image in a RT_DOSE file select 'DCM (single image)' and skip next paragraph.

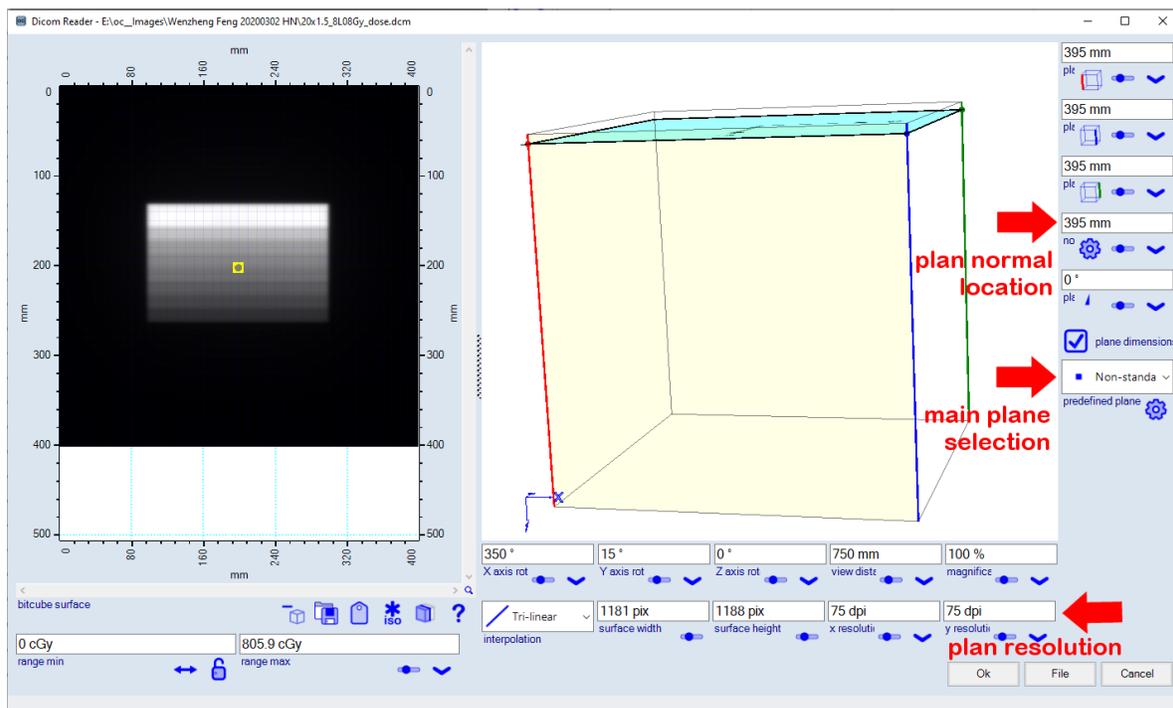


Figure 21: Extracting calibration plan from 3D cube.

Extract plan from 3D cube: For this example the 3D cube file is 'TB_8L_12Gy_Dose.dcm' and the plan is the XY-plane at normal position (position along normal direction of the plane) at 395 mm. Select main plane orientation at 'predefined plane' selector as marked by  in Fig. 21, then select the position of the plane at normal direction (this example 1 cm below the top, i.e. at 395 mm). Lastly enter the target resolution for the plan plane 75 dpi.

After reading the plan data, the plan image is overlaid to scanned film using green coloring – see Fig. 26.

Note: After plan data are assigned, one may or may not assign a weight map to underweight pixels at penumbra area vs. pixel at calibration field plateaus (right click inside calibration and select 'Assign plan weight via dialog panel', see below).

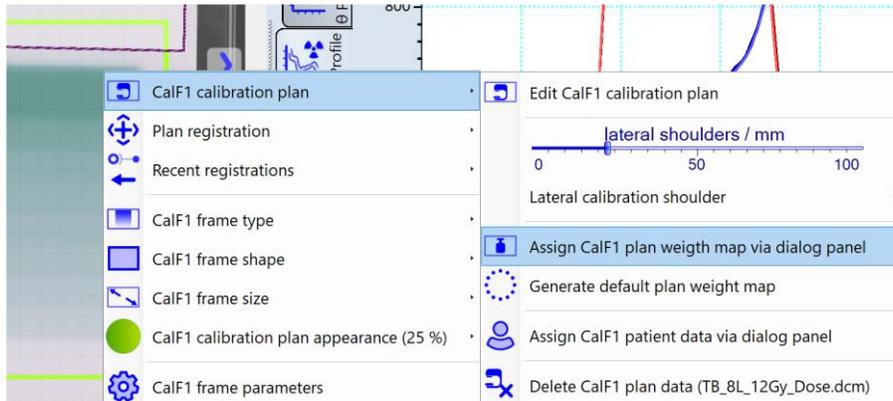


Figure 22: Select dialog to generate or edit weight map underweight pixels at penumbra area vs. pixels at calibration field plateaus.

Figure 23 shows an example how penumbra pixels are weighted vs pixels at flat areas using weights that are reciprocally proportional to the gradient at calibration plan location.

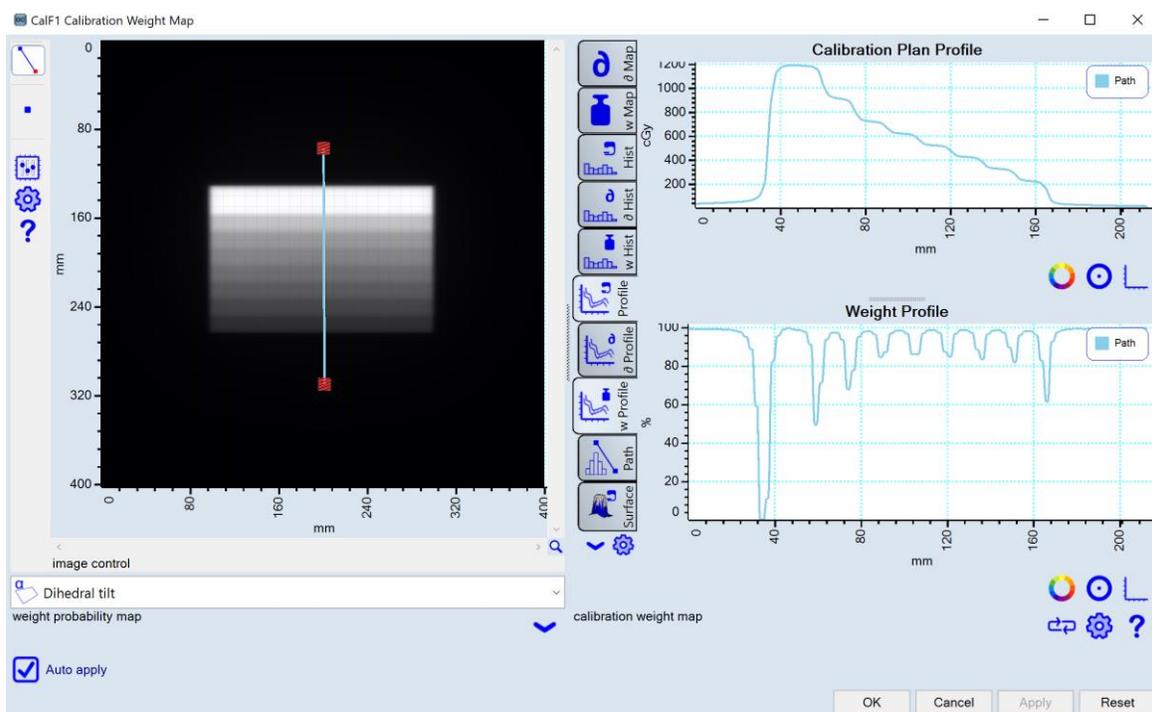


Figure 23: Profile path at calibration plan, calibration plan profile and profile at resulting weight map.

Registration of calibration plan: For plan registration the film image must be converted into a dose map what requires an (approximate) initial calibration – use  button to switch to predefined ‘Calibration for initial registration’ as shown in figure below.

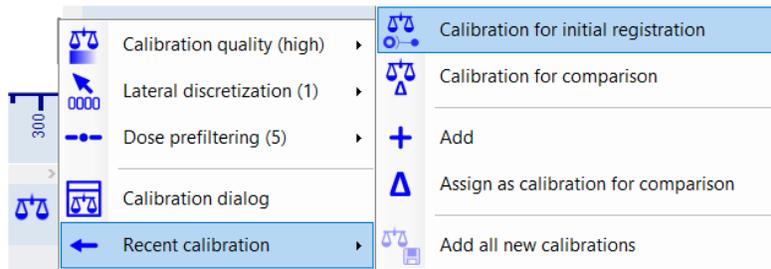


Figure 24: Toggle between predefined calibration settings.

After selecting predefined calibration setting, the calibration calculation starts (wait until  changes back to ). If no paths to profile are assigned yet, just double click inside the calibration to auto-generate default path cross as shown in Fig. 26. The profiles exhibit both an offset in calibration plan registration and calculated dose.

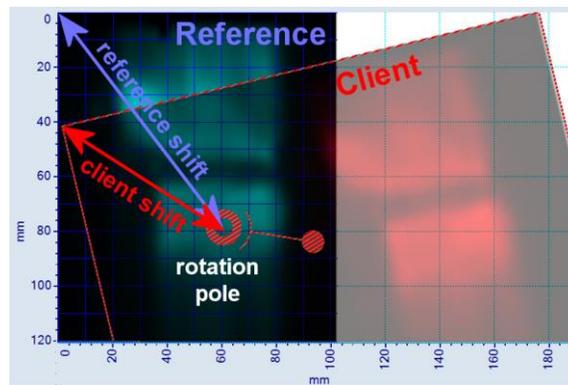


Figure 25: Frame registration data scheme: ‘Reference’ is measured or scanned image displayed as fixed background, ‘Client’ is corresponding plan image which shifted and rotated.

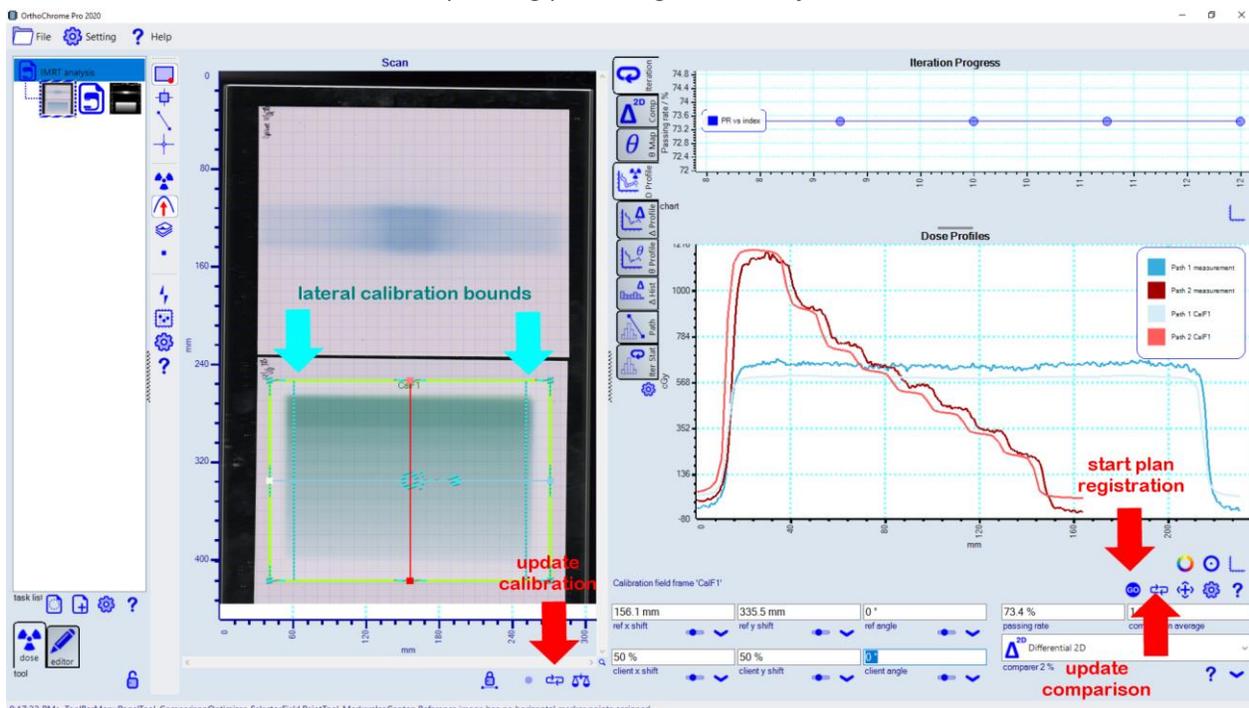


Figure 26: Initial calibration after loading calibration plan. For registration data meaning see Fig. 25.

The comparison data at lower right corner (passing rate and average comparison value) are a measure for the quality of current calibration and registration. To update the comparison data, click the  button underneath the profile chart. The meaning of the registration data (reference shift, client shift, and rotation) is explained in the schematic shown in Fig. 25.

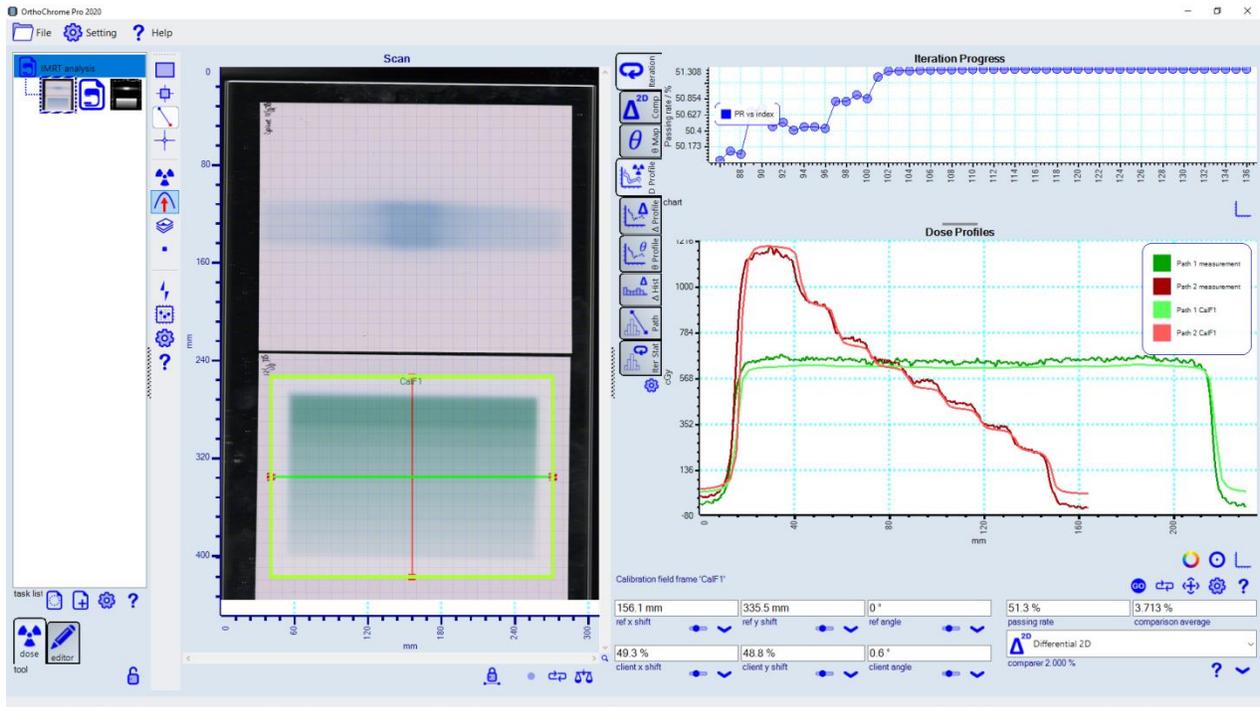


Figure 27: Registration optimized, but calibration Not yet updated.

To start the optimization of the calibration plan registration press the  button. This optimization minimizes the registration offset, but it is carried out using the same initial calibration. The optimization time depends on the speed of used processor.

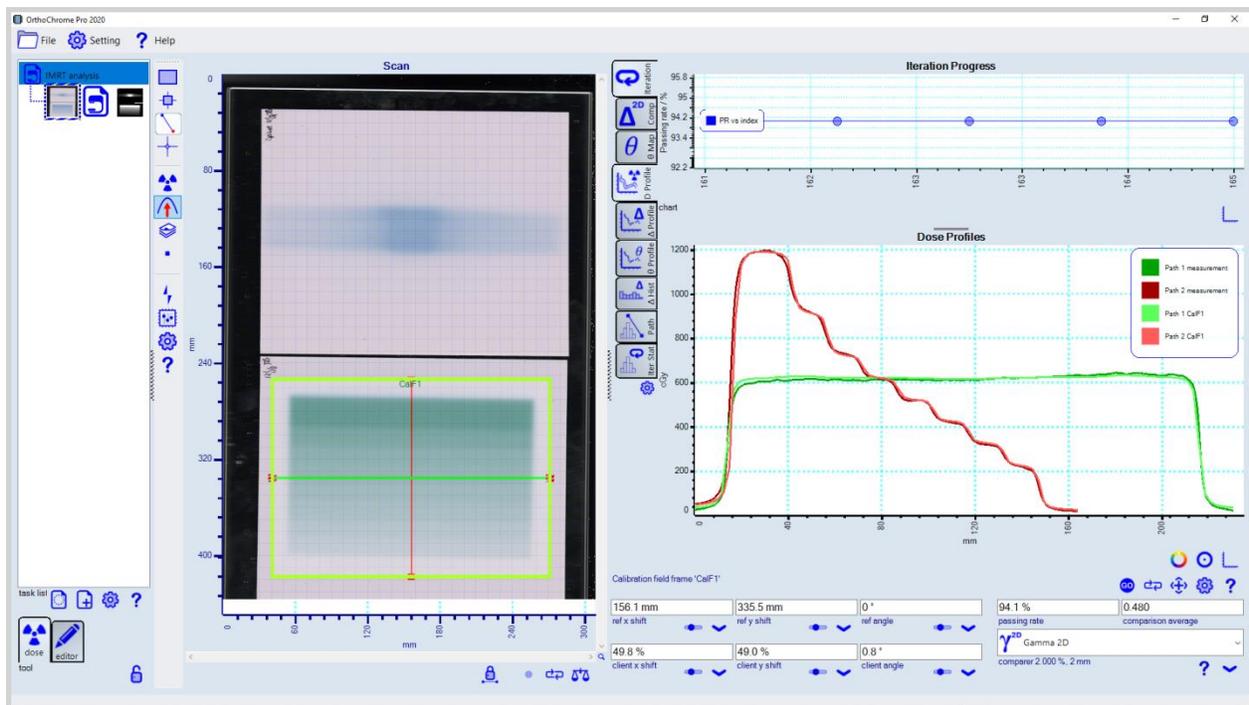


Figure 28: Same registration as in Fig. 27 but 'calibration for comparison' configuration.

To carry out 200 - 300 iterations (upper iteration chart) may take up to several minutes. Press  button to stop optimization - e.g. when average error reaches ~2 %.

Refinement of registration and calibration: Although the comparison data have improved after registration optimization, the dose calculation (calibration) is still based on the initial registration (see Fig. 27). Now the ‘Calibration for comparison’ configuration can be used since the calibration plan registration is optimized and coarse plan mismatches are already removed. This recalibration steps generates a significant improvement of the calibration comparison – see also Fig. 28 and Table 1.

Registration ¹ step	Calibration configuration	Differential comparison		Gamma comparison	
		Average	Passing rate @ 2 %	Average @ 2 %/2 mm	Passing rate @ 2 %/2 mm
No optimization, after plan reading	Calibration for Initial configuration	5.622 %	19.2 %	1.039	73.4 %
After 1 st optimization		3.713 %	51.3 %	0.657	90.4 %
After 2 nd optimization	Calibration for comparison	2.917 %	71.3 %	0.480	94.1 %
		0.769 %	93.7 %	0.314	99.1 %

¹ Registration optimized by minimizing average comparison value.

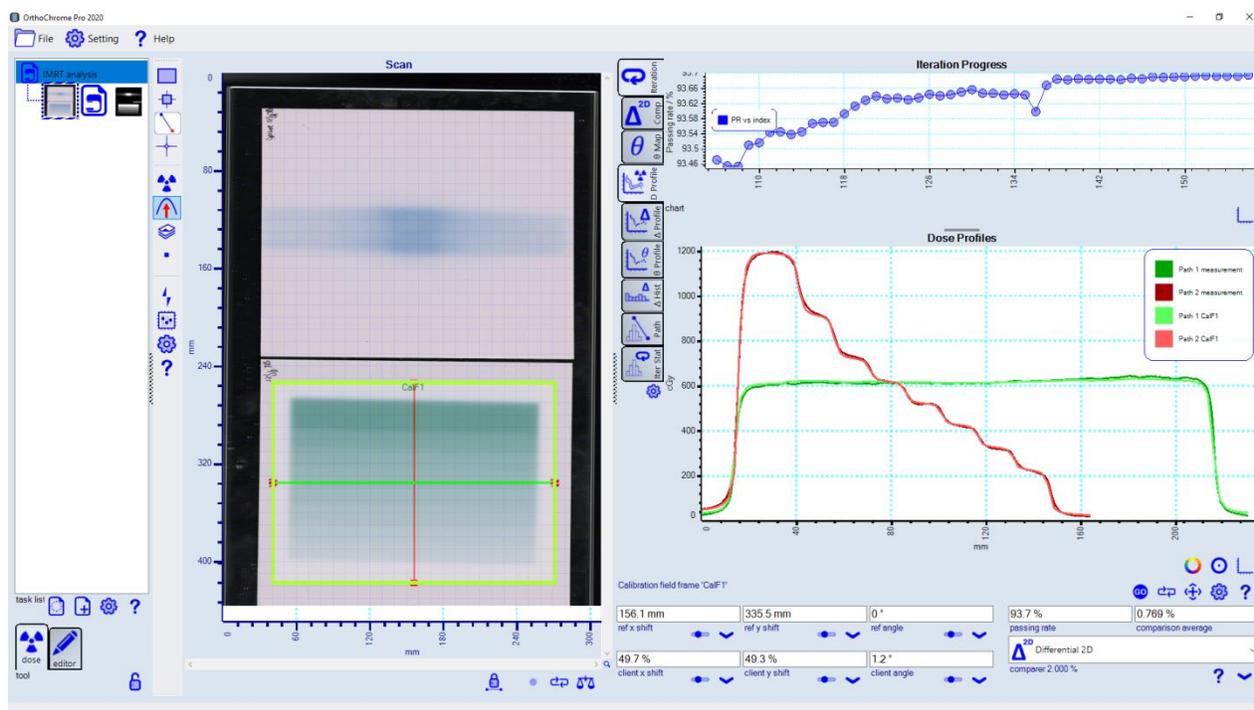


Figure 29: ‘calibration for comparison’ configuration after 2nd registration optimization.

Second optimization: A second optimization of the calibration plan registration adjust for the improved dose accuracy (just click the  button again). Final improvement is shown in Fig. 29 in the last row of Table 1. This completes calibration and dose conversion of the scanned film image.

Reduction of the algorithm: In many cases the calibration configuration ‘Calibration for comparison’ is robust enough and can be used from the very beginning instead of ‘Initial configuration’ – this allows to skip the ‘Refinement of registration and calibration’ step.

7.3.3 Assign treatment plan to treatment field area (auto registration).

Settings: Make sure the  button (‘2D matching’ tool) as well as the  button (‘frame’ tool) are both selected. By default, after assigning the first calibration field the frame type changes to ‘Comparison area’. The ‘frame’ tool menu allows to verify or set the type ‘Comparison area’ as shown in figure below.

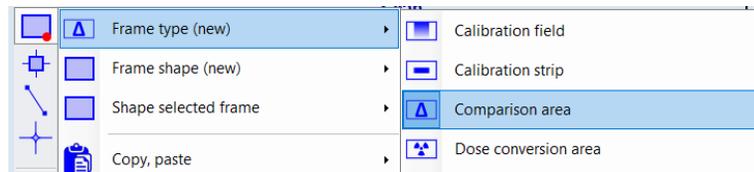


Figure 30: Selection of type for new frames at ‘frame’ tool menu.

Click and draw a frame around the treatment field starting at upper left corner as depicted in Fig. 31.

Select data file: By default, a file opening panel will pop up to select the file to extract the plan from. The plan can be provided as DICOM file either as single image or as 3D cube from which the plan is extracted. Note, the plan resolution should to match the image resolution. For the demonstration example the data are provided as 3D cube, *i.e.* file type must be ‘DCM image surface’ (see marker in Fig. 31). If the plan is provided as single image in a RT_DOSE file select ‘DCM (single image)’ and skip the next paragraph.

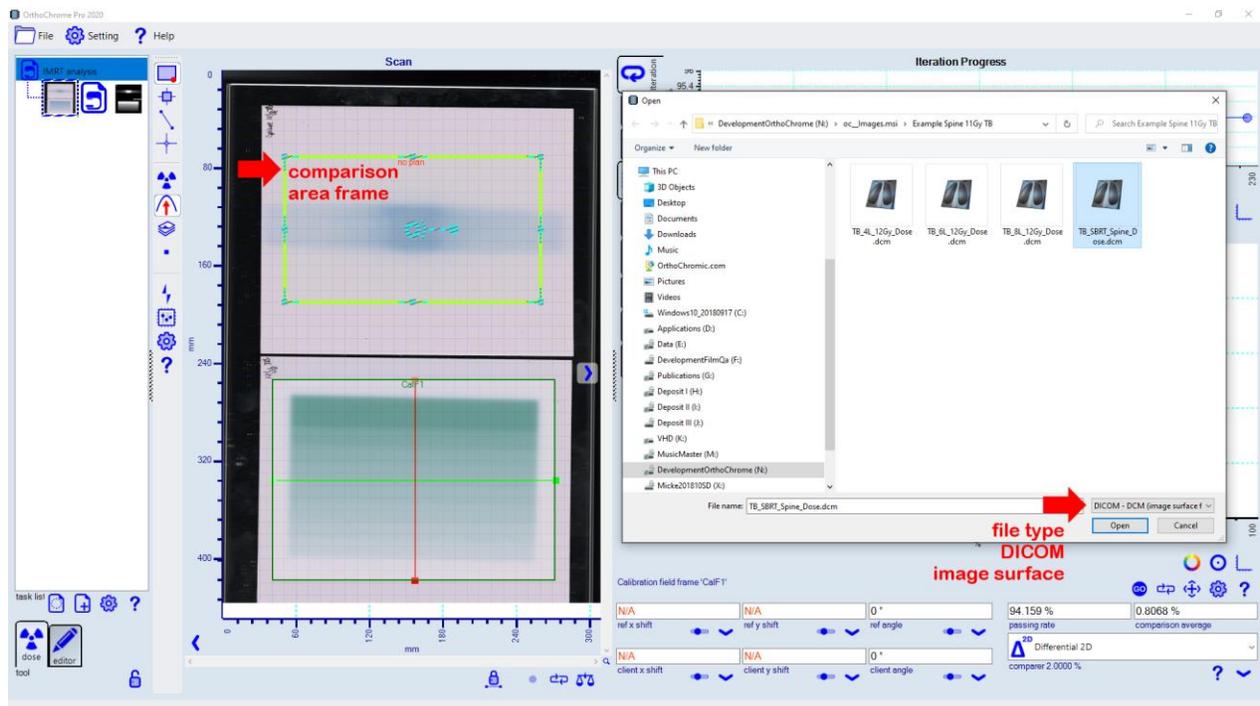


Figure 31: Loading treatment plan.

Extract plan from 3D cube: For this example the 3D cube file is ‘TB_8L_12Gy_Dose.dcm’. The plan data are given by the XY-plane at center of normal position (position along normal direction of the plane). Select main plane orientation at ‘predefined plane’ selector as marked by  in Fig. 32. Lastly enter the target resolution for the plan plane 75 dpi.

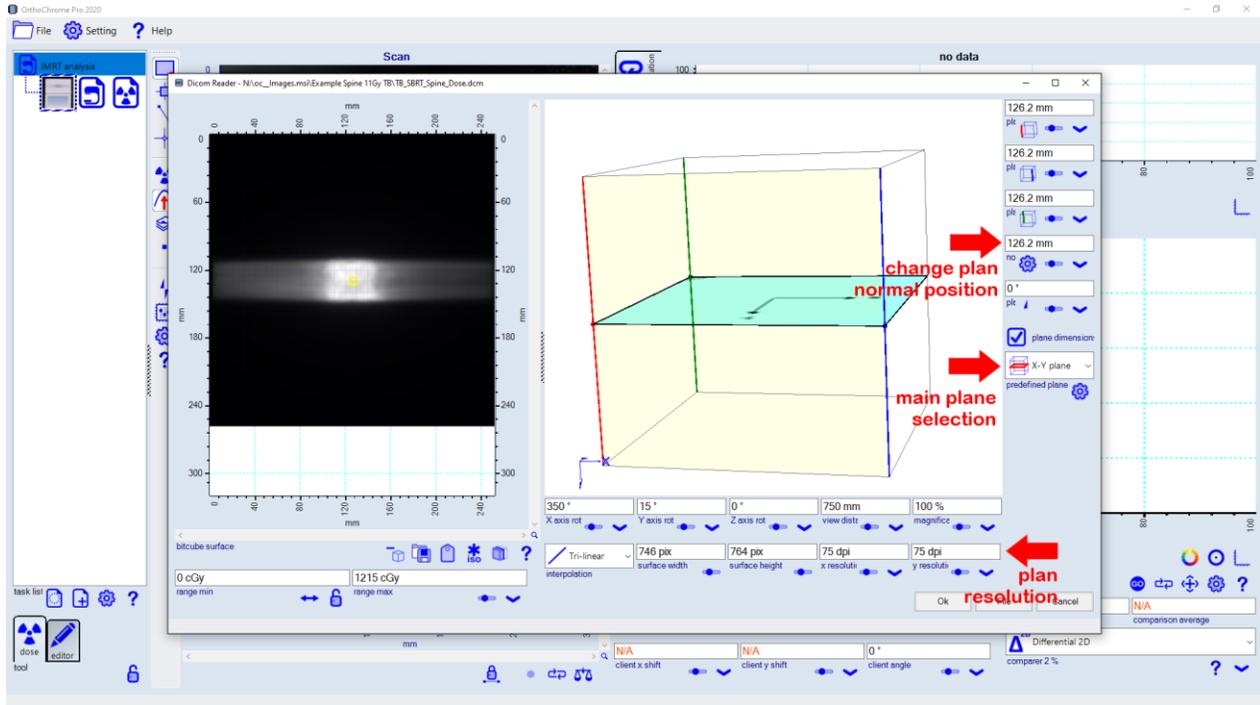


Figure 32: Extracting treatment plan from 3D cube.

After reading the plan data, the plan image is overlaid to scanned film using red coloring as shown in Fig. 33.

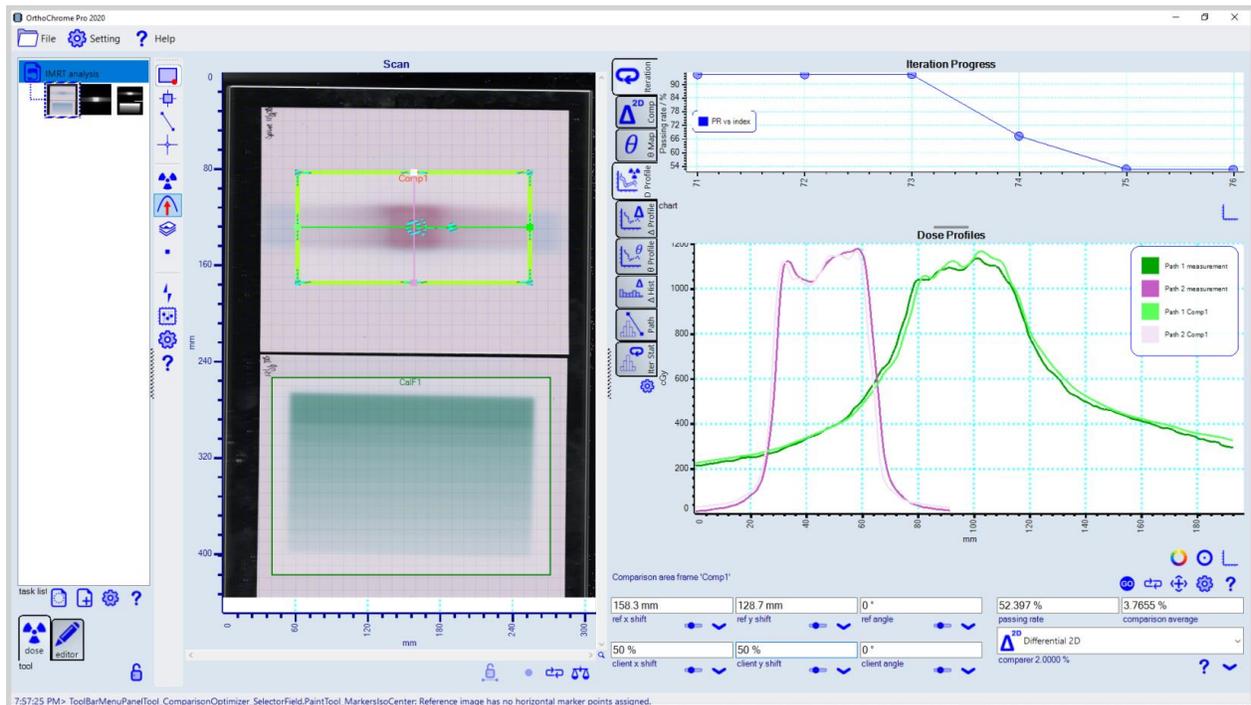


Figure 33: Profile and comparison across comparison frame after assigning treatment plan.

Registration of treatment plan: To start the optimization of the treatment plan registration press the **GO** button. The optimization time depends on used processor type (e.g. number of CPU cores). To carry out 100 iterations (upper iteration chart) may take more than a minute. Press **STOP** button to stop optimization - e.g. when error falls below 2 %.

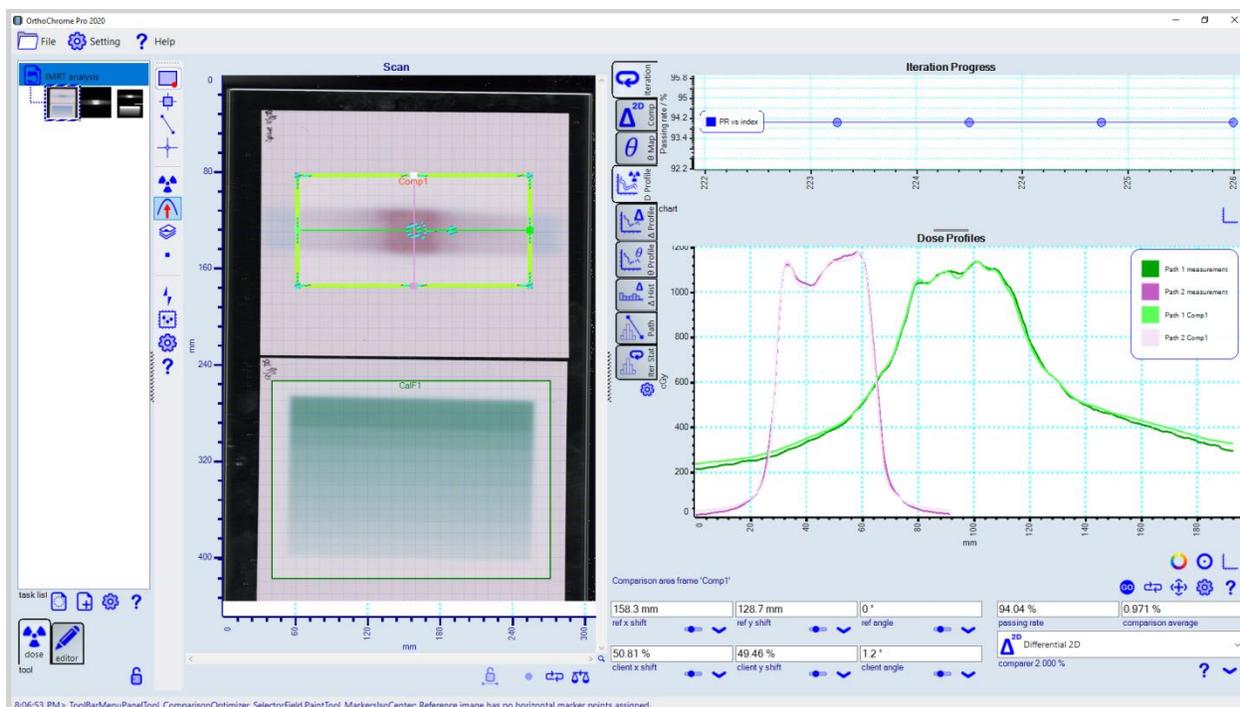


Figure 34: Profile and comparison across comparison frame after optimizing treatment plan registration.

The resulting profiles and comparison data after optimizing the treatment plan registration is shown in Fig. 34. Table below summarizes comparison before and after optimizing registration.

	Differential comparison		Gamma comparison	
	Average	Passing rate @ 2 %	Average @ 2 %/2 mm	Passing rate @ 2 %/2 mm
After plan reading	3.765 %	52.40 %	0.823	69.13 %
After optimization	0.968 %	94.41 %	0.463	98.20 %

This completes the analysis using OrthoChromic Protocol.

Variations: Variation of the calibration configuration parameters (calibration quality, resolution of lateral discretization) can easily assigned using  button menu as exemplified in the figure below to find best configuration to evaluate dose measurement. After parameter modification calibration and comparison steps are executed and the results are displayed in real time.

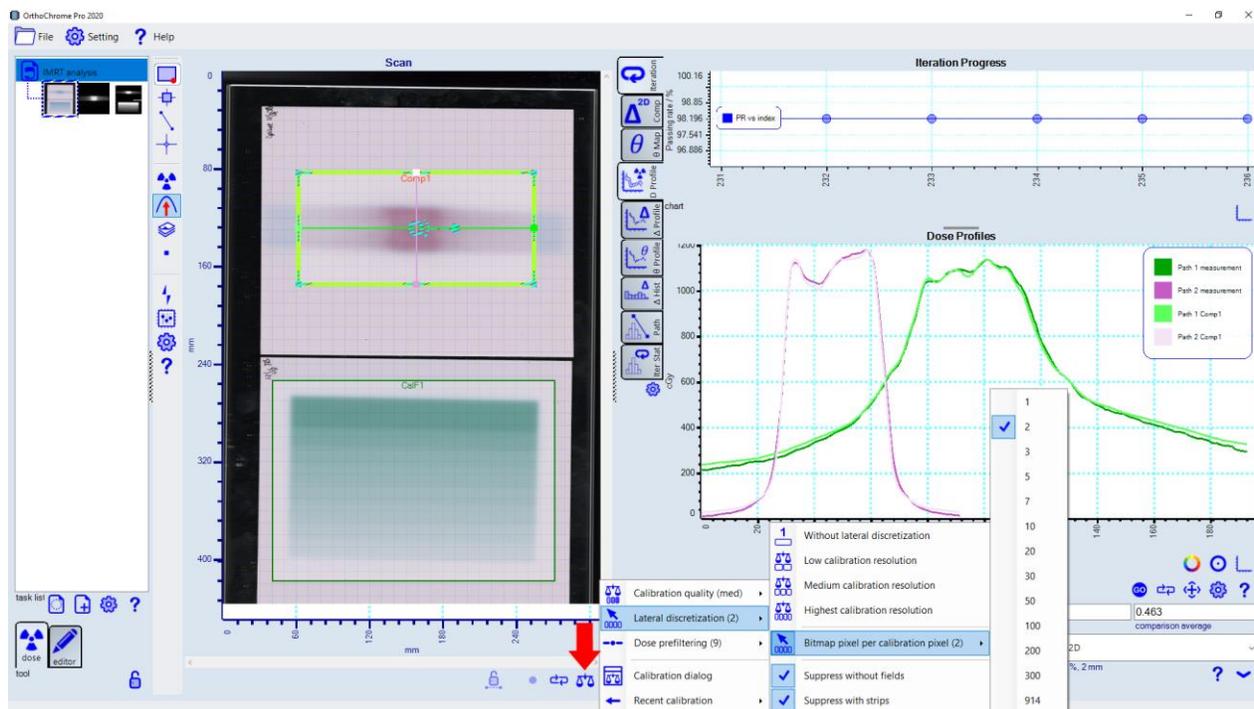


Figure 35: Varying calibration parameters.

8 Advantages ‘Field Calibration’ vs. ‘Strip Calibration’ A Comparative Case Example

This chapter compares OC protocol using ‘Calibration Field’ with and without lateral discretization to traditional calibration approach.

An OC-1 film exposed to a prostate treatment field with maximum dose of 250 cGy is evaluated using both ‘field calibration’ as described in the previous chapter and traditional film strip based calibration. Exposure were doe using an Eclipse. Both approaches requiring a single scan, those scans are shown in Figs. (36) and (37).

Exposing multiple film strips with flat fields (usually 10 x 10 cm) of known dose is a long-standing approach to determine the dose vs. scanner value dependency (calibration). This strip calibration approach can be considered as the special case of using multiple calibration fields that have the trivial plan shape of constant dose. Often the pixels values are averaged per calibration frame to simply data handling.

	Strip Calibration	Field Calibration
Active calibration area	53.0 cm ² 45 kpix	285.5 cm ² 242.4 kpix
Number of exposures	3	1
Major dose levels	4	6
Dose distribution	discrete	continuous

Although the total film size used for calibration is roughly similar (see examples in Figs. 36, 37), the area actively used for calibration differ substantially. The area quantities for the considered examples as shown in Table 3 vary by factor > 5, e.g. a calibration field is more compact and provides extra statistical mass for analysis.

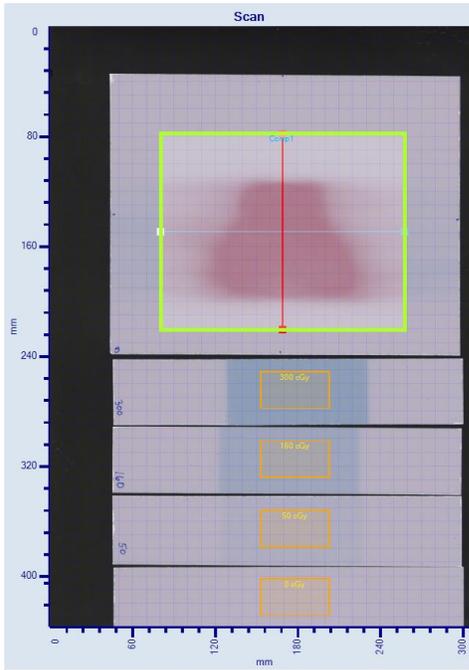


Figure 36: 250 cGy prostate case with 4 strip calibration.

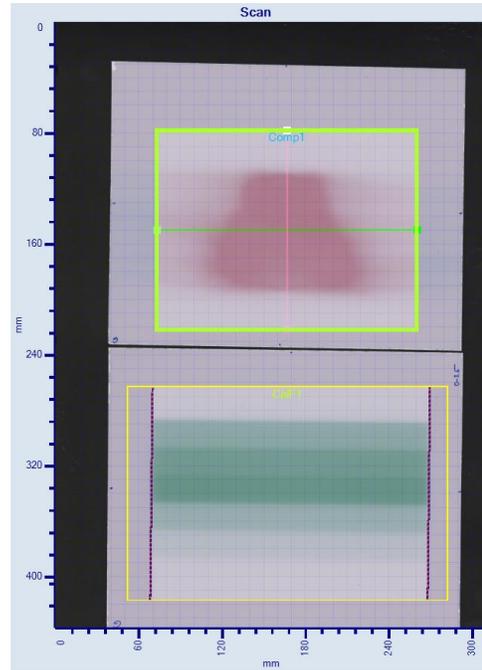


Figure 37: 250 cGy prostate case with 5 level calibration field

Despite having a reduced number of active calibration pixels, the strip calibration requires multiple exposures, *i.e.* it requires more time between first and last exposure what also results into longer waiting time to equilibrate post exposure growth (see also equ. (1)).

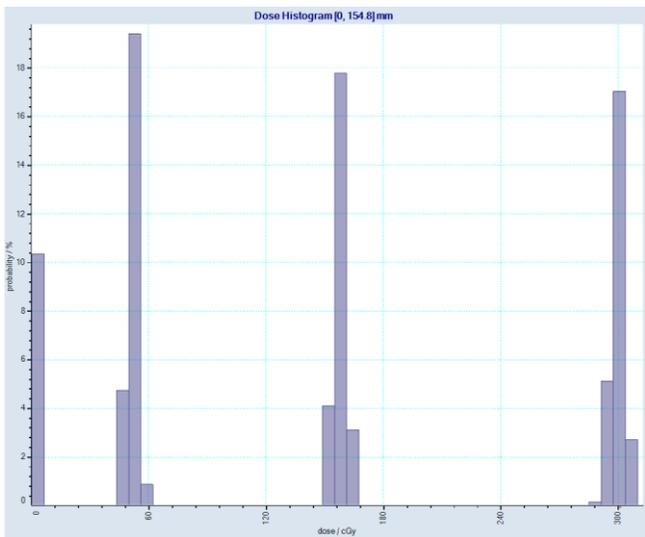


Figure 38: Dose distribution histogram of calibration pixels for 250 cGy prostate case with 4 strip calibration.

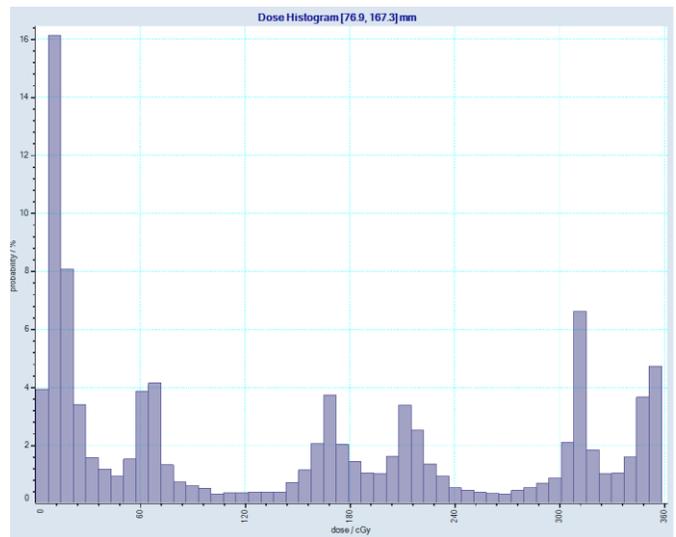


Figure 39: Dose distribution histogram of calibration pixels for 250 cGy prostate case with 5 level calibration field and close to zero level data.

To allow a minimization of the approximation error for all dose values of the calibration dose range, pixel data which are equally distributed across this range would be required. A continuous wedge covering the entire dose range could deliver calibration data with such dose distribution. However, wider dose ranges are hard to realize this way and in many cases

a realization is not feasible. Step shaped fields can approximately generated a calibration field with equi-distributed dose. The dose histogram of the calibration field used in this example (see Fig. 39) is closer to an equi-distributed than the discrete dose distribution of a strip calibration (see Fig. 38).

Step shaped fields can easily composed from overlaid rectangular fields (flat or FFF) which can be delivered with similar certainty as the flat fields used for strip calibration.

The dose histogram of the calibration strips in Fig. 38 shows clearly a dose distributions for all exposures. Note, the dose distribution at zero dose is insignificant compared to that of the exposed strips, implying deviations of the delivered field from the assumed dose constancy across the selected region for each exposure.

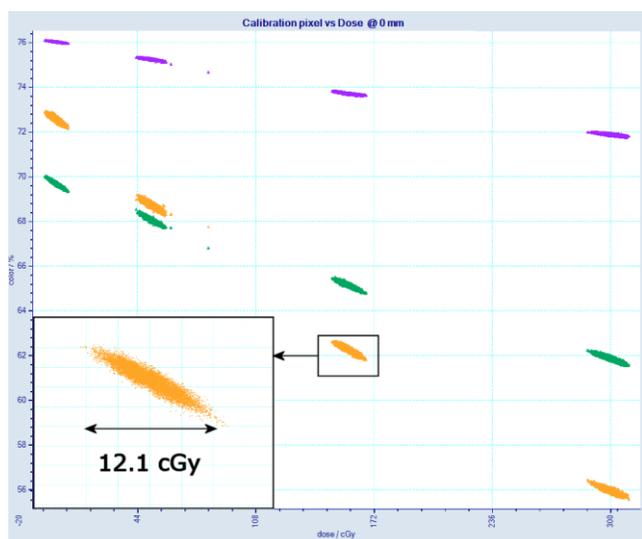


Figure 40: 250 cGy prostate case all (strip) calibration pixels vs. (correlated) dose data of strip calibration. Magnified area of 150 cGy exposure has variation width 12 cGy (> 8 %) – see also Fig. 3.

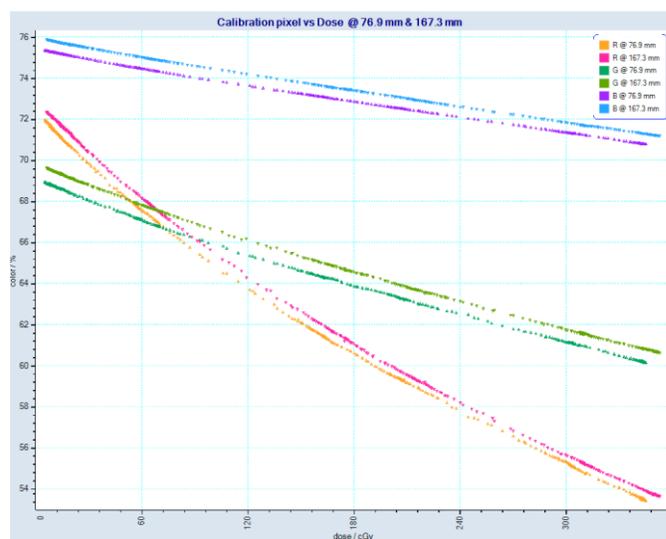


Figure 41: 250 cGy prostate case very left and center pixel lane vs. (correlated) dose data of calibration field – see also Fig. 4.

Table 4: Accuracy strips calibration at calibration pixel.				
frame	calibration dose <cGy>	D(ave RGB) <cGy>	ϵ ave error ¹ <cGy>	δ std dev ² <cGy>
strip 1	0	0.0	1.3	1.0
strip 2	50	50.0	1.8	1.4
strip 3	160	160.0	2.4	1.7
strip 4	300	300.0	2.2	1.6

¹ $\epsilon = \text{average } |D_{\text{calibration}} - D(\text{RGB})|$
² $\delta = \text{standard deviation } |D_{\text{calibration}} - D(\text{RGB})|$

The chart of calibration RGB pixel data vs. correlated dose in Fig. 40 shows both the RGB and dose variation per calibration strip which is produced at constant dose. The dose variation are Not only caused by offset between delivered vs. (constant) plan dose, but by lateral sensor to sensor variations as well as by non-uniformities of the used calibration films.

Any estimate for the calibration error can only be localized to the exposure dose values as shown in Table 4. There are no data available to verify the quality of the strip calibration over the entire targeted calibration dose range. Most approximation with sufficient number of parameters can approximate discrete set of values exactly (*e.g.* high order polynomials), but lacks any verifiable accuracy in the part of the dose range that is not covered by calibration data. Furthermore any lateral variation can only be compensated in average across the strip calibration regions but not at pixel location level.

In case of calibration field an accuracy comparison of the full dose range can be performed using same comparison analysis methods used to verify the treatment field (*e.g.* gamma analysis).

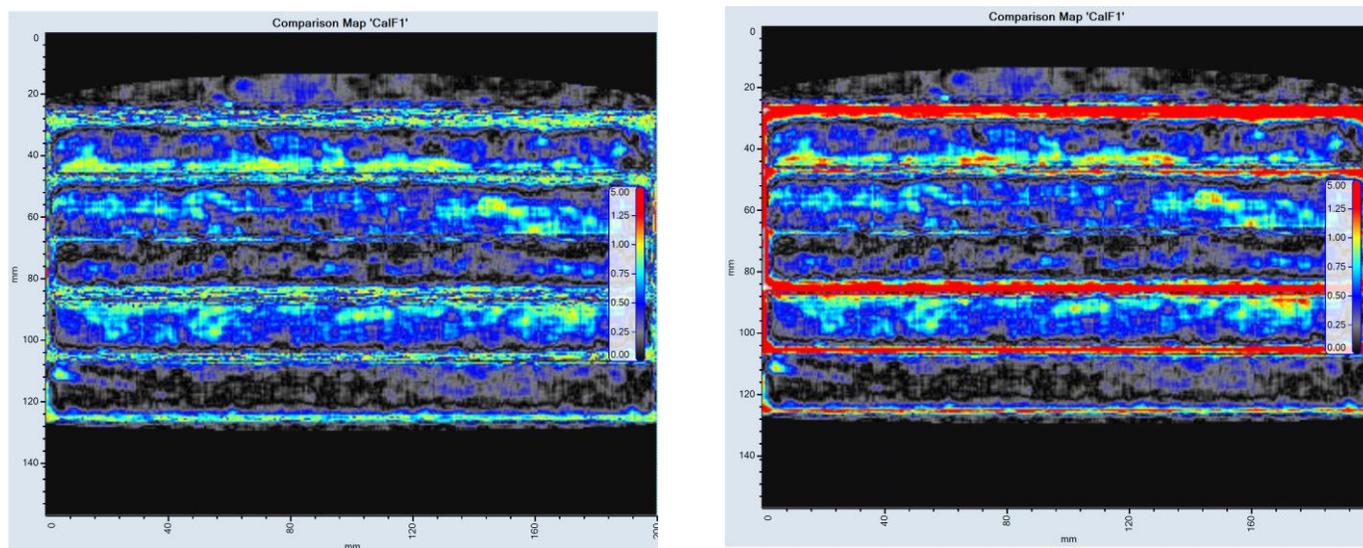


Figure 42: Gamma map @ 2 %/2 mm (left) and more strict @ 2%/0 mm (right) of calibration field for 250 cGy prostate case reaching passing rate of 99.2 % @ 2 %/2 m and 87.6% @ 2%/0 mm.

The gamma map for the calibration field is presented in Fig 42. At the left the comparison for the standard gamma analysis using 2 %/2 mm for verification – producing almost perfect passing rate of 99.2%. The limiting case using 2%/0 mm for gamma (*e.g.* differential comparison), as depicted at the right, makes the regions with the largest deviations visible (red). Those are the penumbra regions of the overlaid flat fields. This information might be used to underweight such regions with high deviations as exemplified in Fig. 23 generating a weight map penalizing the penumbra pixels.

On the other side this comparison data analysis also opens up an optimization of the calibration field shape by finding fields that deliver highest passing rates at sufficiently strict testing conditions (*e.g.* gamma parameters).

When converting the pixel data into dose, one can estimate how much each sensor contributing to the dose conversion deviates from the correlated calibration behavior, *i.e.* how much a sensor must be corrected to match the calculated dose. The OC Pro software presents those data as ‘Variation Map’ in arbitrary units. A variation value $\theta=0$ stands for perfect agreement and negative or positive values for under- or overdetermined dose values.

The variation map using strip calibration shown in Fig. 43 indicates only good agreement at vertical scan center region with non-zero dose (black and gray areas). The calibration quality deteriorate quickly outside this center region (often referred to as lateral effect). Vertical streaks indicating lateral variations of the scanner (sensor to sensor variation, LED light source variations). Each film piece exhibits local distortion close to the cutting edge. The unexposed zero strip at the very bottom has both scanner related distortion (cyan) and edge related aberrations at the upper border – this might explain the bad agreement of the treatment field film at zero dose even in the central scan area.

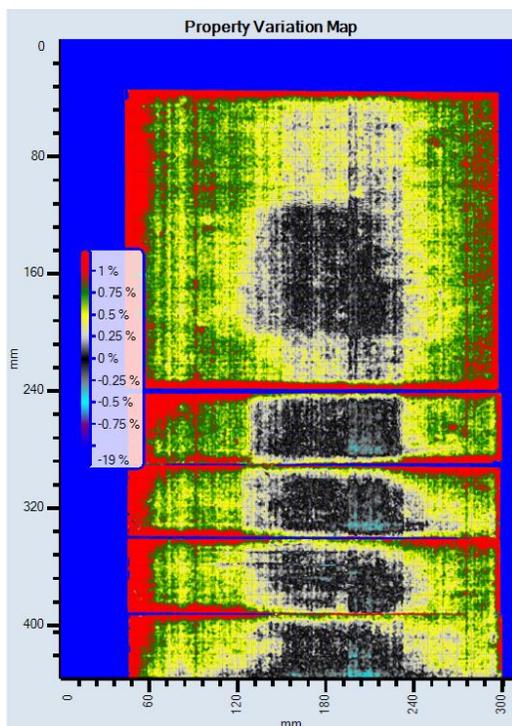


Figure 43: Variation map - strip calibration without lateral discretization, i.e. one calibration only. . Black/gray areas are regions with good agreement.

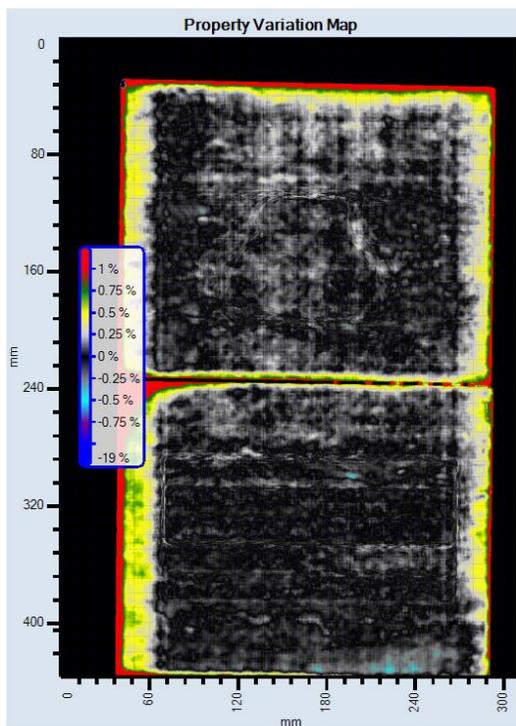


Figure 44: Variation map -calibration field using lateral discretization of 1 pixel, i.e. 914 calibrations. This calibration is used for final treatment field comparison. . Black/gray areas are regions with good agreement.

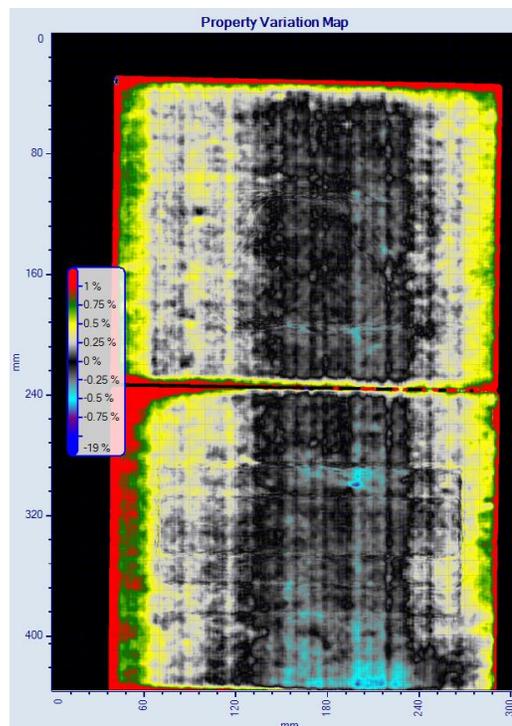


Figure 45: Variation map - calibration field without lateral discretization i.e. using one calibration only. . Black/gray areas are regions with good agreement.

The variation map using field calibration using maximum lateral discretization with 1 pixel per calibration (*i.e.* 914 calibrations are correlated) is shown in Fig. 44. The full width of the used calibration field (914 pixels) is in good agreement (black and gray area) except the film edges. Outside the calibration range where calibration at lateral calibration bound is used (see Fig. 26) the calibration quality declines due to lateral variations.

To show how much the results depend on lateral discretization, the scan with calibration field was converted into dose without lateral discretization (*i.e.* one calibration only was used). The corresponding variation map (see Fig. 45) shows how the calibration quality suffers because of lateral variation.

Comparing strip calibration (Fig. 43) to calibration field (Fig. 45) without lateral discretization the superiority of calibration fields over calibration strips becomes evident (due to the wider lateral dimension of the calibration data and larger statistical mass).

Profiles in vertical and horizontal direction through the treatment field are shown in Figs. 46, 47 – even with such simple verification tool the deviation at high and close to zero dose are clear visible when using strip calibration instead of field calibration.

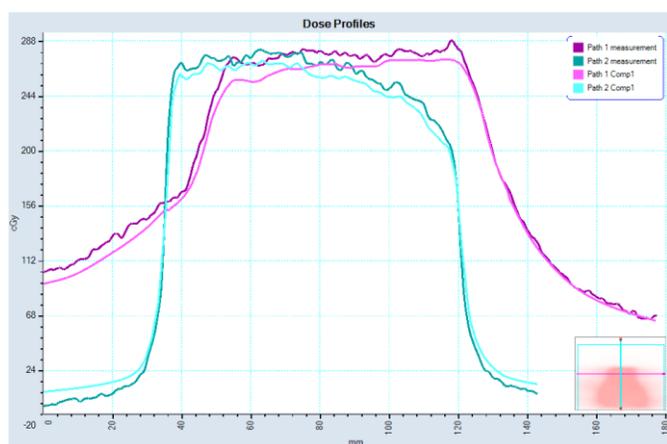


Figure 46: Vertical and horizontal profiles of prostate treatment field using strip calibration with noticeable deviations both at low and high dose areas. Gamma passing rate of 90.2 % @ 3 %/3 mm.

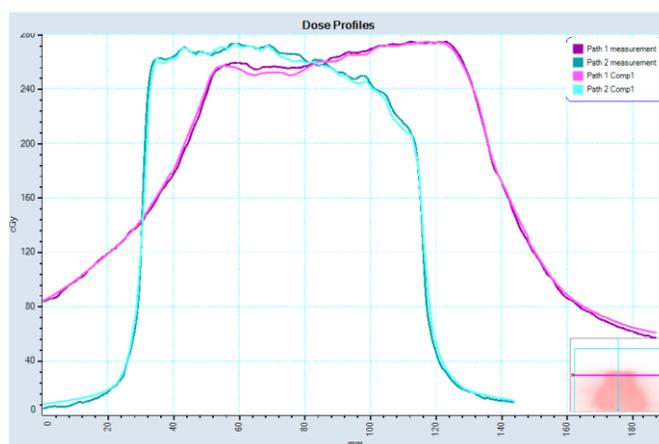


Figure 47: Vertical and horizontal profiles of prostate treatment field using calibration field exhibiting good agreement both at low and high dose areas. Gamma passing rate of 99.1 % @ 2 %/2 mm.

High emphasis is on the gamma analysis for the treatment field. When using calibration fields, the a-priori information of the gamma analysis for the calibration data can be used as upper bound for possible results of the gamma analysis for the treatment field. Furthermore the variation map is indicating areas which are less reliable for dose conversion and where elevated error levels should be expected.

The gamma map @ 2 %/2 mm for the prostate case with strip calibration is shown in Fig. 48 – as already observable in the variation map, the calibration accuracy deteriorates outside the lateral center used to calibrate and since the prostate field exceeds the width of the lateral calibration range noticeably (see frame selections in Fig. 36) the overall measurement accuracy suffers and a passing rate @ 2 %/2 mm of 75 % is not acceptable even if the passing rate @ 3 %/3 mm exceeds 90 %. This becomes fully evident when comparing the results using calibration field.

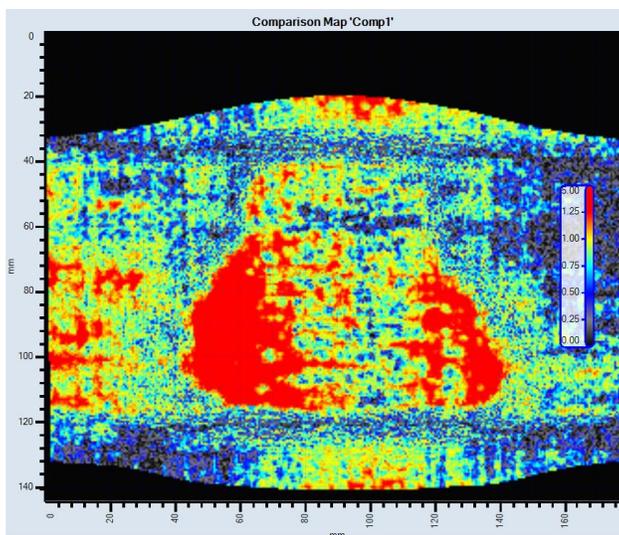


Figure 48: Gamma map @ 2 %/2 mm for 250 cGy prostate case with strip calibration reaching passing rate of only 75% (90.2 % @ 3 %/3 mm).

The gamma map @ 2 %/2 mm for the prostate case using calibration field and full lateral discretization (1 pixel) is shown in Fig. 48. Deviations are only noticeable at penumbral region of the prostate field and in a small region at the lower right. All together a gamma passing rate of 99.1 @ 2 %/2 mm is near perfect considering that the calibration field passes with 99.2 (see Fig 42). Also the variation map does Not show any non-regularities in the area of the treatment field (see Fig. 44). Both calibration analysis and variation map confirm the treatment field analysis and provide additional certainty.

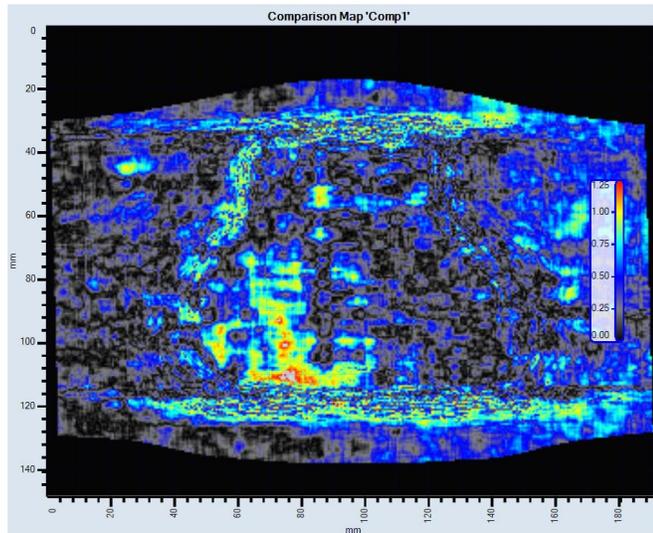


Figure 49: Gamma map @ 2 %/2 mm for prostate case with calibration field and full lateral discretization reaching passing rate of 99.1 % (99.9 % @ 3 %/3 mm).

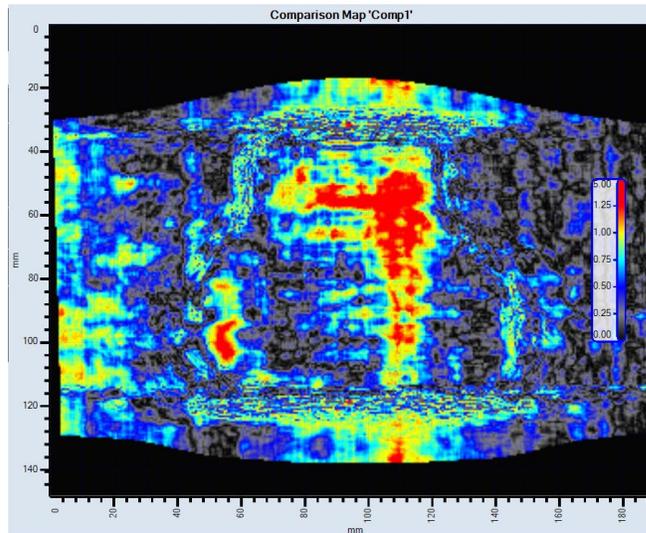


Figure 50: Gamma map @ 2 %/2 mm for prostate case with calibration field but without lateral discretization reaching passing rate of 93.7 % (99.3 % @ 3 %/3 mm).

To emphasize the importance of the lateral discretization, the gamma analysis was also carried out for the dose map using calibration field without lateral discretization (*i.e.* one calibration only was used). The corresponding gamma map @ 2 %/2 mm is depicted in Fig. 50. The accuracy is substantially distorted due to a streak artifact caused by lateral scanner variation which was already recognizable in the variation map (cyan streak, see Fig. 45).

This example shows how essential lateral discretization is for proper treatment field analysis and leaves no doubt that strip calibration is inferior.

9 OrthoChrome Pro Software

Download OC Pro to install or update at <http://www.orthochromic.com/OC/installation.html>.

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