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Performance of the Vidar® Red LED Dosimetry Pro Advantage™: A scanner optimized for use with GAFCHROMIC® EBT Dosimetry Film.

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Abstract

The Vidar® Red LED Dosimetry Pro Advantage™ scanner is a new digitizer designed for use with radiochromic film. The Red LED light source in the scanner is specifically designed to deliver optimum response with GAFCHROMIC® EBT dosimetry film. This work in this report evaluates the improvements provided by the Red LED scanner as compared to the earlier Vidar® VXR-16 scanner. Measurement and evaluation are reported for the improved sensitometric response, the noise characteristics and the dose resolution provided by the red LED light source. In addition, the effects of light scattering have been significantly reduced in the Red LED scanner and a banding artifact often seen in digitized images of EBT in the VXR-16 scanner have been eliminated. Results show that EBT film is preferably scanned in landscape orientation on the Red LED scanner. Optimal results are provided by digitizing the film at the center of the available scan area. Used in this manner, it is shown that EBT film and the Red LED scanner yield high quality results in measuring the flatness of open exposure fields in a linear accelerator and in evaluating dosimetry for patient IMRT treatment plans.

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1.0 Introduction

Film dosimetry is frequently used as a means for measuring 2-dimensional distributions of radiation dose. In the practice of medical radiotherapy, film dosimetry measurements are made for the quality assurance of radiation producing equipment as well as for the validation of therapeutic treatment plans prior to exposure of human patients to radiation sources.

A silver halide based dosimetry film responds to radiation exposure by developing a latent image. Upon development of the latent image a visual image is produced wherein the optical density at any point in the image is representative of the dose of radiation absorbed by the film.

A radiochromic dosimetry film responds to radiation exposure by immediately developing a visible image wherein the optical density at any point in the image is representative of the dose of radiation absorbed by the film. One advantage of radiochromic film over silver halide film is that the radiochromic film does not require post-exposure processing to develop a visible image. Another advantage is that it can be used and handled in room light. A third advantage is that radiochromic film is composed almost entirely of carbon, hydrogen, nitrogen and oxygen. For this reason the radiochromic film has an energy independent dose response from the keV to the MeV range whereas the response of a silver film is highly energy dependent. The energy dependence of a radiochromic film, GAFCHROMIC® EBT, and a silver film, Kodak EDR-2, is shown in Appendix 1.

One particular aspect of film dosimetry involves the measurement of a radiation-produced image in a film scanner. The film scanner produces a digital image of the dosimetry film. The digital image essentially describes the lightness or darkness of the film over an array of points and the film scanner is able to digitize the film image at high spatial resolution. While measurements of the film could be made with a manual densitometer, a scanner is the preferred method because it is able to measure many points over a large area in a short time period.

Film scanners of two basic types are in common usage. The first type employs a small beam of light to scan the film in a raster pattern. This type of scanner frequently uses a laser light source. The second type of scanner employs a long, diffuse light source such as a fluorescent tube to broadly illuminate the film and project an image of the film on a linear or a 2-dimensional CCD array. Scanners of this second type are referred to as CCD scanners.

The Vidar® VXR-16 and Vidar® Dosimetry Pro Advantage™ are CCD scanners widely used for film dosimetry. They are designed to work with the black-and-white images produced by silver based films. Because silver-based films absorb light across the entire visible spectrum both Vidar® scanners used broadband white-light sources. The VXR-16 has a fluorescent tube and the Dosimetry Pro uses light emitting diodes (LED) to illuminate a long strip of translucent plastic diffuser material.

However, radiochromic films such as GAFCHROMIC® EBT and HS produce blue-colored images when exposure to radiation with the greatest absorption in the red part of the spectrum. This is shown in Figure 1-1. Since even a heavily exposed radiochromic film transmits blue light, the white-light sources in CCD scanners are poorly suited to the measurement of radiochromic films. While this drawback can be addressed by using color filters or color CCDs, until now none of the Vidar® scanners have had a spectral product optimized for radiochromic film.

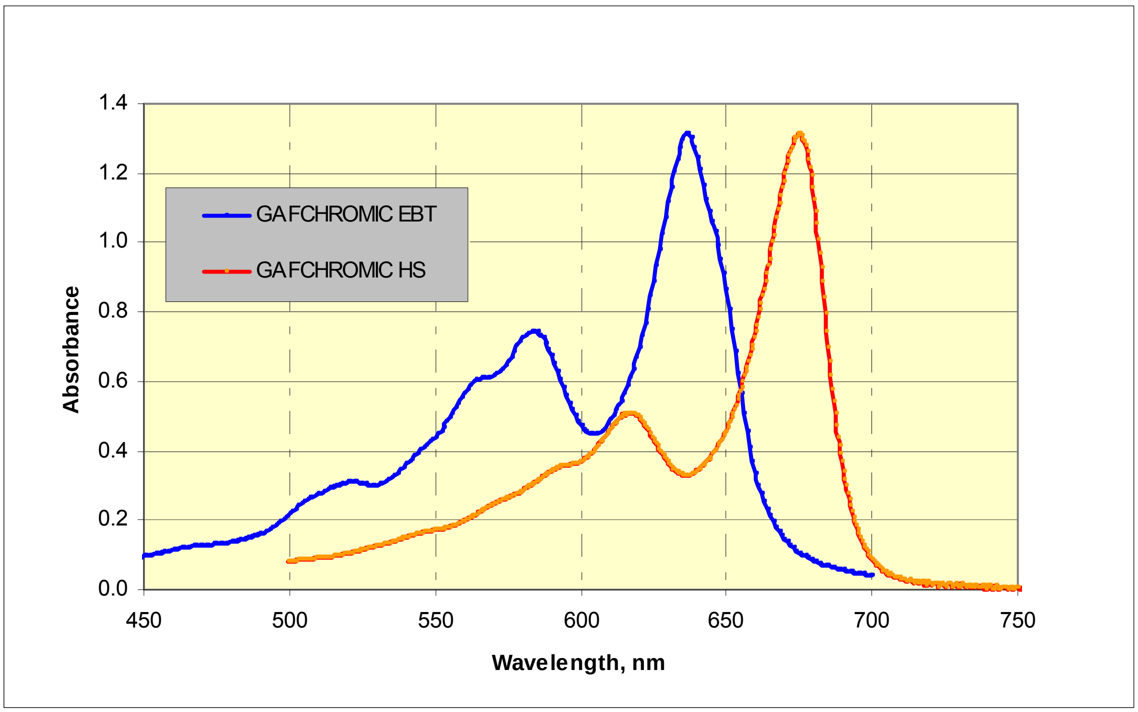


Figure 1-1: Absorption Spectra of Two Radiochromic Films

2.0 Vidar® scanners

Vidar® film scanners have served the oncology market for film dosimetry for 20 years. The design of Vidar® scanners has consistently progressed from the original 8-bit digitizer to 12-bit and 16-bit models. The 16-bit, VXR-16 scanner used in the majority of US radiotherapy departments for many years has been superseded by the Dosimetry Pro Advantage™. The revolutionary design of this scanner incorporated self-calibration before every film scan, highest reliability and lifetime through the use of LED light sources and minimization of the effects of light scattering by bringing the light source very close to the film.

Until recently all Vidar® scanners have used light sources with broad emission in the visible wavelengths. When used to digitize colored media such as radiochromic films these scanners produce images with less than optimum contrast. This results in diminished dose resolution and increased noise in a scanned image of radiochromic media such as the EBT film.

Now Vidar® has developed a version of the Dosimetry Pro Advantage™ with features specifically designed to produce optimum results when digitizing GAFCHROMIC® EBT film images. The Red LED Dosimetry Pro Advantage™ employs an LED light source with nominal maximum emission at 627nm and FWHM bandwidth of 20nm. This light source is very closely matched to the peak absorption of EBT film at 635nm. The red emitters in the Red LED scanner illuminate a translucent diffuser located within a few millimeters of the film thereby minimizing the effects of light scattering by the film-digitizer measurement system. Finally the Red LED scanner has been provided with rollers attached to the LED lamp cartridge to reduce flexing of film in the transport system that can lead to the appearance of artifacts in digitized images.

3.0 Radiochromic Film

Radiochromic films contain a microcrystalline active component dispersed in a binder matrix coated as a thin layer on a polyester substrate. Because there is a small difference between the refractive indices of the active component and the binder matrix, radiochromic films appear slightly hazy and scatter light. This phenomenon causes the response of the scanner to differ by position relative to the center of the light source. The effect can be compensated by scanning an unexposed radiochromic film or a uniformly exposed film and using that image to calculate a scanner flatness correction. This correction is subsequently applied to all images. The magnitude of the non-uniformity is dependent in part on the geometric arrangement of optical components in the scanner. In the VXR-16 scanner the light source is long and situated several centimeters away from the film. As described in Appendix 2 both characteristics heighten the effects of light scattering.

3.0 Objective

This work reported herein was undertaken to evaluate the improvements provided by the Red LED Dosimetry Pro Advantage™ digitizer. Vidar Systems Corporation has recently designed and developed this evolutionary film scanner to have optimum performance with GAFCHROMIC® EBT dosimetry film. This scanner employs a red light LED with output in a narrow band of wavelengths centered close to 635nm. The use of this light source in this scanner provides several performance advantages with EBT film when compared to the VXR-16.

A second objective was to provide guidance to users who wish to take advantage of the benefits of radiochromic film and to develop protocols to help users to maximize the performance of the Red LED scanner.

4.0 Evaluation Plan

The performance of the Red LED and VXR-16 scanners were compared by digitizing several sets of GAFCHROMIC® EBT test films. In some cases a set of Kodak EDR-2 films was also scanned with the Red LED scanner and the results compared with those with the EBT films.

The film sets included EBT and EDR-2 calibration films, films of the same type exposed uniform open fields of various sizes as well as EBT films that had been exposed to the seven individual fields of an IMRT treatment plan.

The data were used to evaluate the improvement in the dose response of EBT film on the Red LED scanner as compared to the VXR-16. Further analysis was used to contrast the noise characteristic of the two scanners. The effect of light scattering by EBT film and the Red LED and VXR-16 scanners was determined. This included investigation of the effect of EBT film orientation during scanning as well as the position of the film in the scanners. It also included the evaluation of a simple protocol for characterizing light scattering by an EBT film and applying a correction procedure. Finally, scan data from measurement of IMRT treatment fields were also analyzed and compared with the IMRT treatment plans to compare the performance of the Red LED and VXR-16 scanners and demonstrate the preferred orientation for scanning EBT film in the Red LED Dosimetry Pro Advantage™.

Films were placed between 5cm slabs of solid water and exposed to 6MV photons in a Varian 21EX linear accelerator at an SSD of 95cm. Where EBT and EDR-2 films were used they were placed together in the solid water phantom and exposed simultaneously. Films were scanned in the Red LED and VXR-16 scanners to provide 16-bit grayscale images at a spatial resolution of 71dpi.

The digitized films were evaluated with a number of image analysis software packages including Mira AP (www.mirametrics.com), ImageJ (http://rsb.info.nih.gov/ij/), and FilmQA™ (www.3Cognition.com).

5.0 Results

5.1 Scanner response: Red LED vs. VXR-16

The GAFCHROMIC® EBT calibration films were scanned on a Vidar® VXR-16 and a Red LED Dosimetry Pro Advantage™. The film images were evaluated by defining an area of interest about 1.5cm x 1.5cm at the center of each of the areas exposed to the calibrated doses and measuring the scanner response. The results are plotted in Figure 5.1-1. The values have been scaled to give the same response values for the unexposed film on the two scanners. The data show that the response of the Red LED scanner is greatly enhanced in comparison to the response of the VXR-16. For a dose of 250cGy the net response, compared to zero dose, for the VXR-16 is about 24000. At the same dose the net response for the Red LED is approximately 46000, almost 2X the response of the VXR-16. At lesser doses the net response of the Red LED scanner is between 2X and 3X greater than the response with the VXR-16.

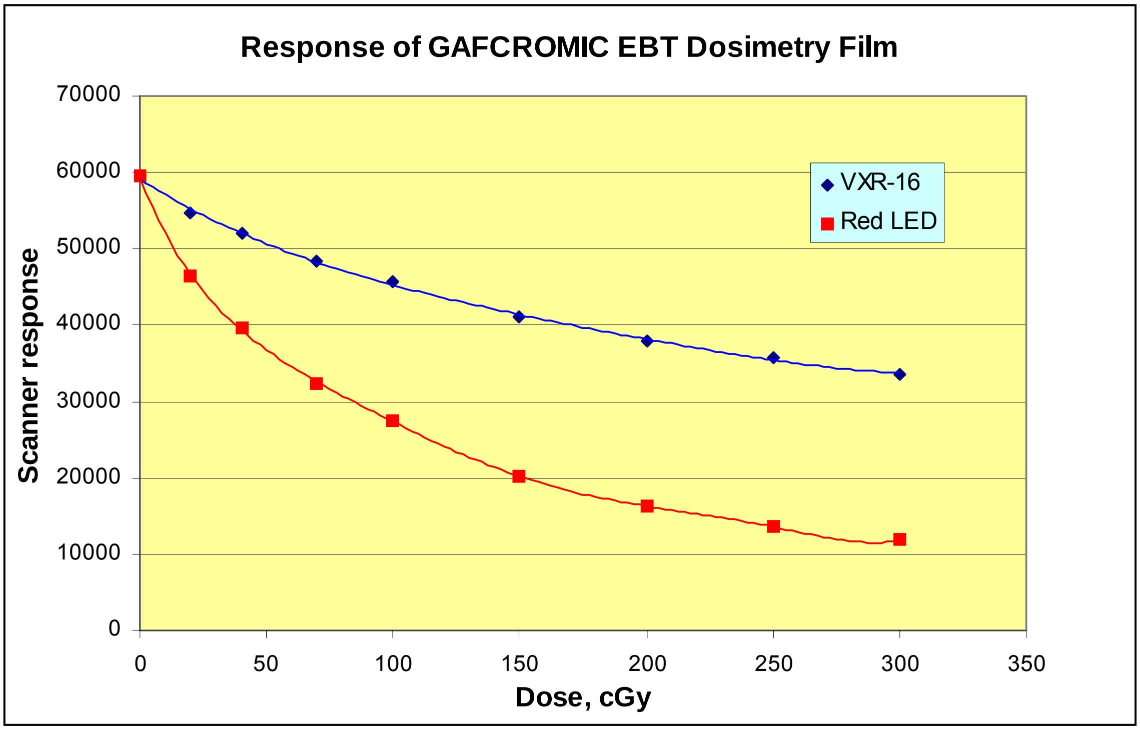


Figure 5.1-1: Dose Response of Radiochromic Film in the Red LED and VXR-16 Digitizers

5.2 Noise and Dose Resolution

A film scanner measuring a transparency determines the amount of light transmitted by the film. A scanner with 16 bit resolution assesses the transmission on a scale from 0 (no transmission) to 65535 (high transmission). The intensity of the transmitted light is reported as the pixel value (PV).

The dose resolution, Δd, of a film-digitizer system depends upon the slope ($\Delta d/\Delta PV$) of the dose response curve and the standard deviation of the measurement of the pixel value $\sigma_{PV,d}$. This is depicted in Figure 5.2-1. Assume that the variability in the response measurements is normally distributed and that the dose of a pixel is to be known at a confidence level of 90%. Then the dose resolution at dose d is given by the slope of the response curve at that point multiplied by 1.65. $\sigma_{PV,d}$.

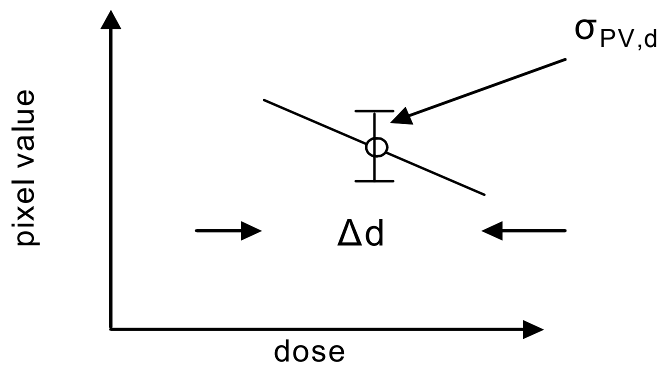


Figure 5.2-1: Effect of the Standard Deviation of Scanner Response on Dose Uncertainty

Sheets of EBT and EDR-2 film were simultaneously exposed to eight doses of 6MV radiation between about 20cGy and 300cGy. The exposed areas were approximately 4cm x 4cm in size. These EBT calibration tablets were digitized on a Vidar® VXR-16 and Red LED scanner. After development, the EDR-2 films were scanned on the Red LED digitizer. All scans were obtained at a spatial resolution of 71 dpi.

The scanned images were processed with a de-speckling filter (3x3 median filter) yielding images with an effective spatial resolution of approximately 1 pixel/mm spatial resolution (71 dpi/3). These images were then evaluated by measuring the mean pixel value and standard deviation over an area of interest approximately 1cm x 1cm in size at the center of each exposed area. The data for each scanned image were plotted and fit to a polynomial function.

The slopes of the response curves vary with dose. The slope of the response curve at each of the doses on the step tablet was determined from the dose and the first derivative of the polynomial fitting function. Using the calculated slope at each step and each scanner and the corresponding standard deviation for the single pixel response value, the effect of noise in the single pixel measurements was determined by calculating the absolute value of the OD error divided by OD:

$$ABS(\sigma_n/S_n)*100/R_n$$

where:
σ = average standard deviation for a single pixel measurement at the n^{th} step
S = slope of pixel value-dose response at the n^{th} step
R = scanner response of the n^{th} step
ABS = absolute value

Figure 5.2-2 shows the results plotted as (dose error x 100)/dose vs. dose. Characteristically the dose error/ dose is greater at lower doses and relatively flat at doses of 100cGy, or more for each scanner-film combination.

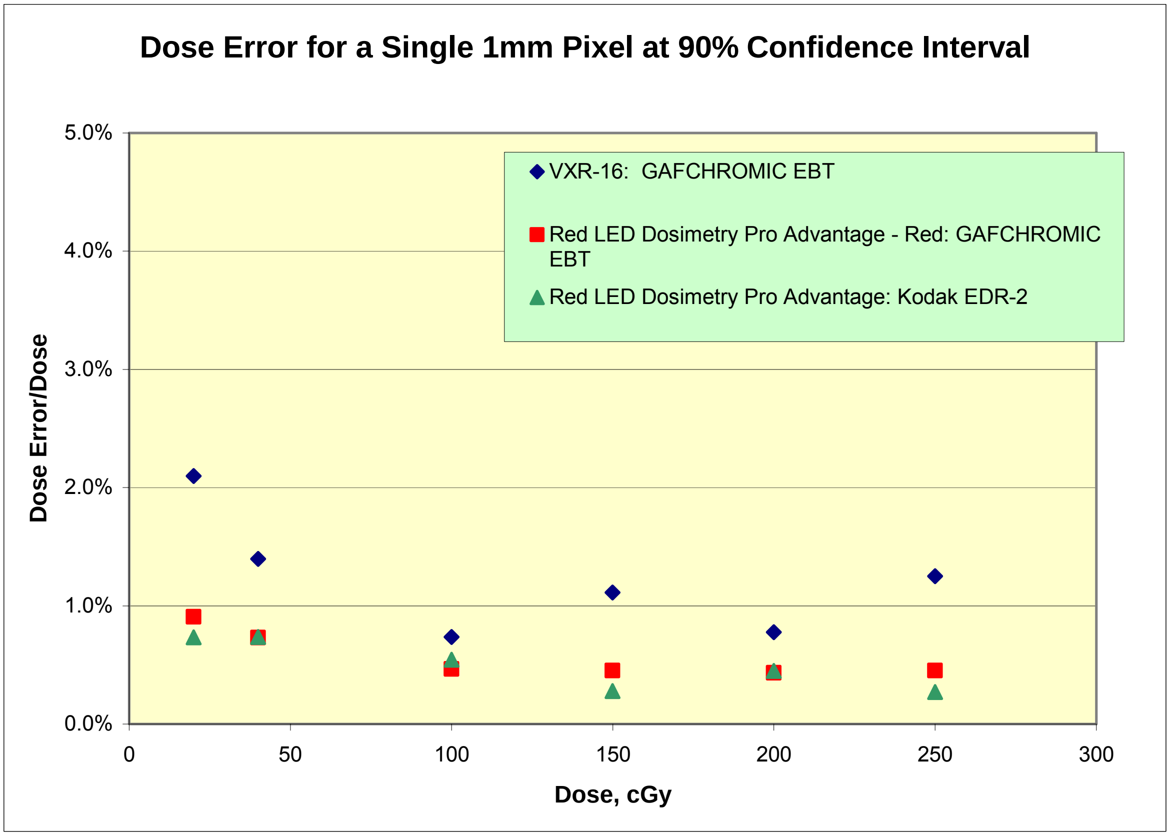


Figure 5.2-2: Dose Resolution of GAFCHROMIC® EBT Dosimetry Film with Film-Scanners

It is evident that the Red LED scanner provides superior dose resolution with EBT film. This presumably results from the greater net response of the Red LED scanner with EBT as shown in Figure 5.1-1. The data in Figure 5.2-2 also show that the dose resolution of EBT film on the Red LED scanner is similar to that for EDR-2 film.

5.3 Light scattering

Vidar® digitizers have long, diffuse light sources – a fluorescent tube for the VXR-16 and a translucent plastic diffuser illuminated by red light-emitting diodes in the Red LED Dosimetry Pro. The effects of light scattering by films when digitized in scanners with extended, diffuse light sources are described in Appendix 2.

Films composed of particles dispersed in a binder will scatter incident light depending on the difference between the refractive indices of the two components. The contribution of light scattering to the magnitude of the scanner response at a point in the digitized image depends on the position of that point relative to the center of the light source, as well as the distance between the light source and the film. When GAFCHROMIC® EBT is digitized in a VXR-16 scanner the effects of light scattering cause the scanner response to be greater for film locations closer to the center of the light source. The contribution caused by light scattering diminishes the greater the distance from the center of the light source.

Figure 5.3-1 shows the response profile across the image of a 10" wide unexposed EBT film scanned in the center of the scan window of a VXR-16 digitizer, i.e. the scan is conducted with the center of the film located at the center of the light source. The response values at the center of the image are approximately 38800. The values are about 34400 at the edges, i.e. the values are >10% lower at the edges than at the center.

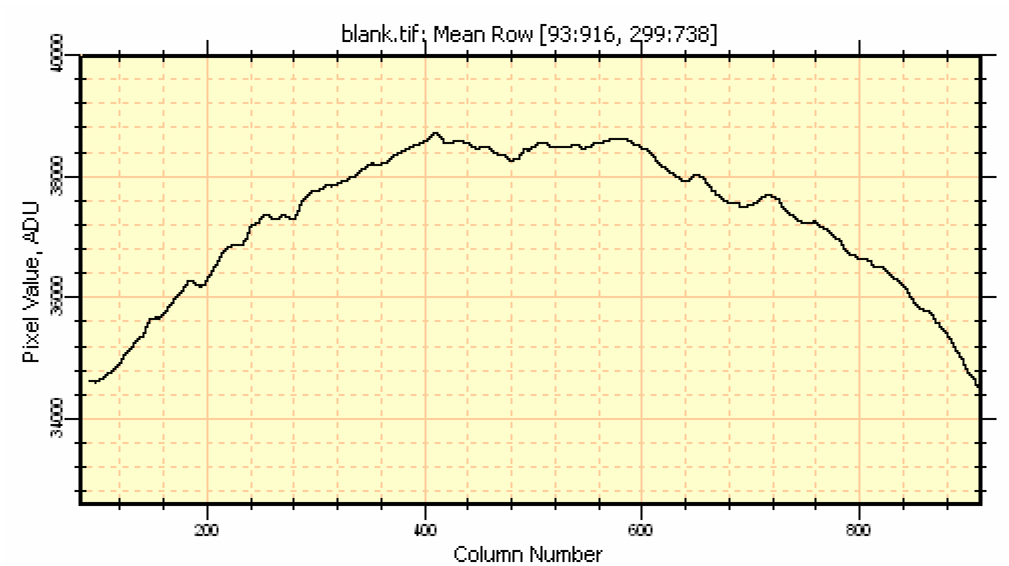


Figure 5.3-1: Profile of EBT Film in VXR-16 – Film is Centered in the Scan Window

The design of the Red LED Dosimetry Pro Advantage™ has improvements that reduce the effect of light scattering. The light source is a translucent diffuser illuminated by the Red LED's and it is located within a few millimeters of the film. By comparison, the fluorescent tube in the VXR-16 is several centimeters from the film.

Figure 5.3-2 depicts the response profile of the same unexposed EBT film digitized in the Red LED Dosimetry Pro. The difference in response between the center and the edges is about 800, i.e. <2% difference. This represents a very significant improvement.

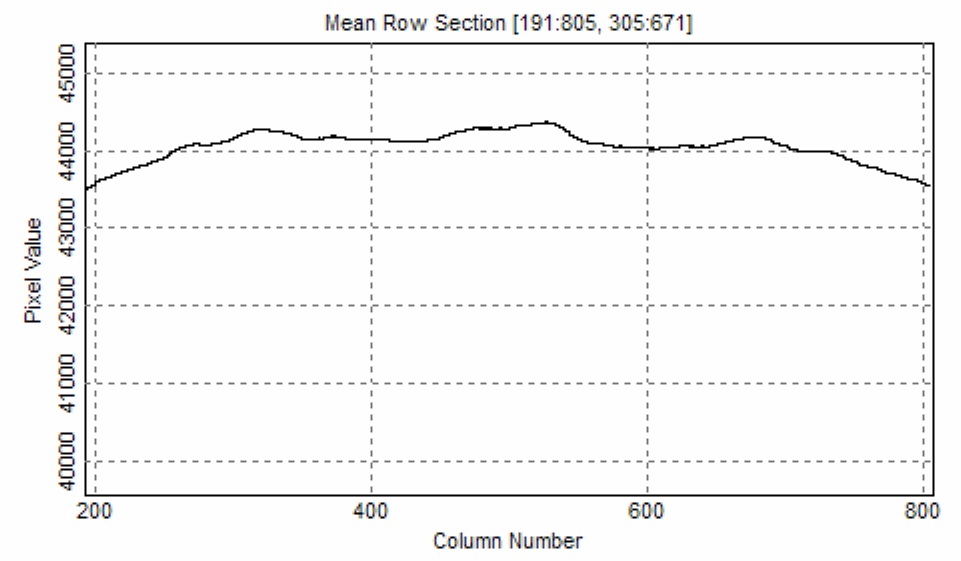


Figure 5.3-2: Profile of EBT Film in Red LED Scanner – Film is Centered in the Scan Window

Figure 5.3-3 shows the profile of an image of the same film digitized in the Red LED Dosimetry Pro, but with film moved to the left of the scan window. Since the scan window in the Red LED Dosimetry pro is 14" wide and the film is 10" wide, the film was moved 2" to the left of center in the scan window. When the film is scanned in this position the response rolls off at the left edge. The scanner response is about 2300 less (~5%) at the left edge than at the center. However, even in this extreme position the performance of the Red LED scanner is superior to the VXR-16. The roll-off in the Red LED scanner images is less than half of the roll-off in the VXR-16.

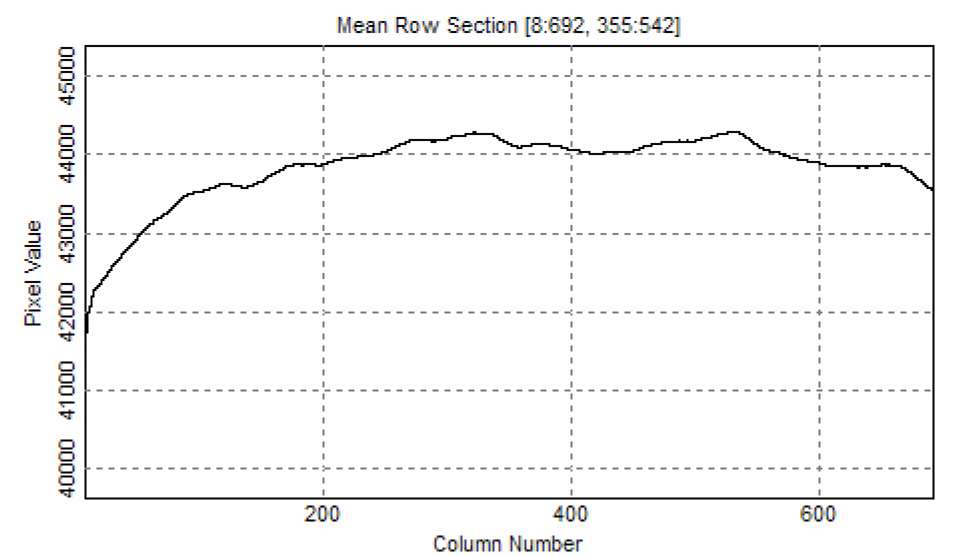


Figure 5.3-3: Profile of EBT Film in Red LED Scanner – Film Positioned to the Left of the Scan Window

A simple correction for the effects of light scattering in EBT film images can be made by employing an unexposed film. Thus an image of an unexposed film is obtained and the image is normalized by dividing the response values for every pixel by the mean response value. An EBT film image is then corrected by dividing the response values for each of the pixels in the image by the response value of the corresponding pixel in the normalized image of the unexposed film. The image arithmetic functions to do this are available in image analysis software such as FilmQA™ (www.3Cognition.com), Mira AP (www.mirametrics.com) and ImageJ (at http//rsb.info.nih.gov/ij/).

5.3.1 Banding

Effects of Light Scattering on Image Profiles Perpendicular to the Light Source

Figure 5.3.1-1 shows another artifact that frequently occurs when EBT film is canned on a Vidar® VXR-16. Distinct bands may appear across the VXR-16 images about 3cm from the start and/or end of the scan. The bands may be darker or lighter than adjacent areas

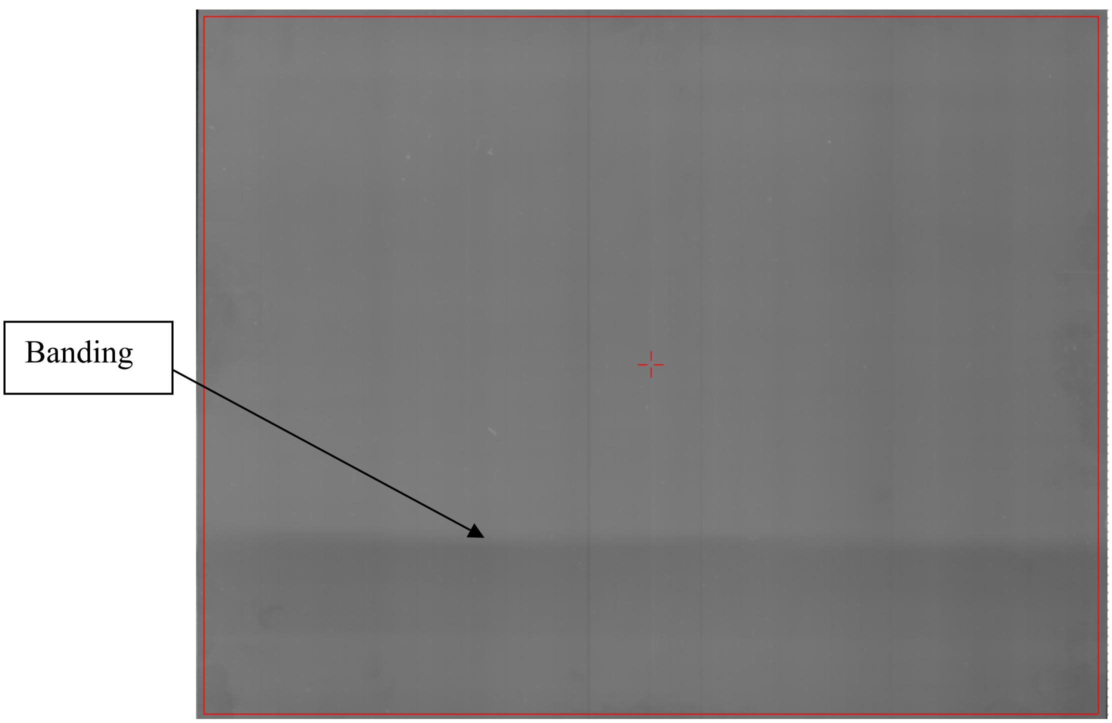


Figure 5.3.1-1: Banding in the Image of an EBT Film Digitized on a Vidar® VXR-16

of the image. Figure 5.3.1-2 shows the profile across a band in the image of an unexposed sheet of EBT film digitized on a VXR-16 scanner. The pixel values in the image were normalized by dividing by the mean pixel value. The profile exhibits an abrupt 3% change in scanner response close to row number 600. The bands are often less prominent, but when present usually have a response at least 1% different than adjacent image areas.

The fact that the band is not physically present on the film can be seen by visual inspection, or inspecting an image of the film turned 90° and scanned in that orientation. While the artifact may be unimportant if the ends of the film do not have areas of dosimetric interest, they will often interfere with the utility of an image.

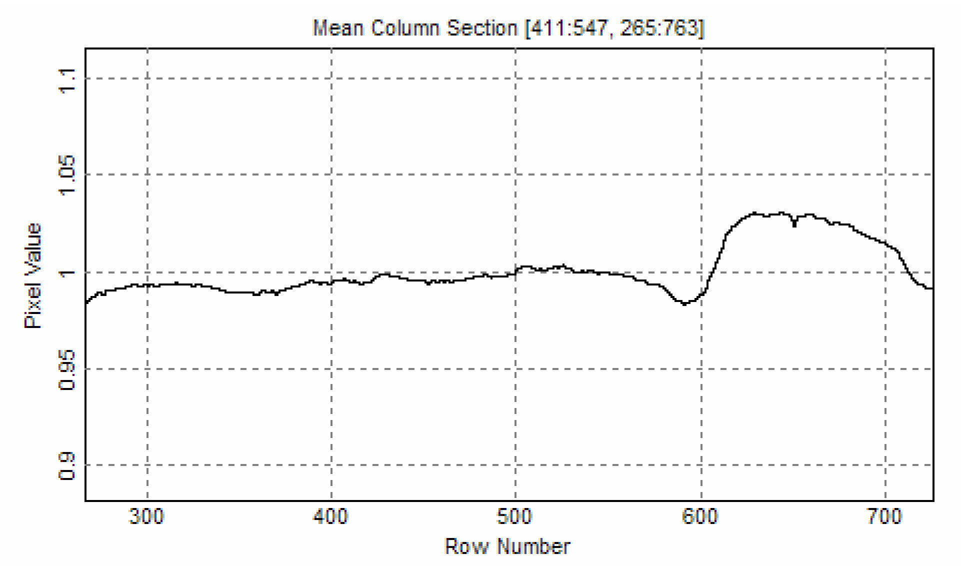


Figure 5.3.1-2: Profile of a Band in the Image of an EBT Film Digitized on a VXR-16

The artifact is caused by a change in the location of the film plane as the film is transported through the scanner. In the middle of a scan in the VXR-16 the film is supported on both sides as it passes a slit in the optical system. However at the start and end of a scan the film is supported from only one side. If the plane of the film moves when support from one side is not present, a band appears in the scan image.

The film transport system in the Red LED Dosimetry Pro Advantage™ has been improved by the addition of guide features to the film transport system. This has been accomplished by integrating guide rollers into the construction of the lamp cartridge of the digitizer. This improvement eliminates the banding artifact with EBT film. The benefit is shown in Figure 5.3.1-3, depicting the profile across an image of an unexposed EBT film digitized in the Red LED scanner. The profile is uniform to better than 0.5%.

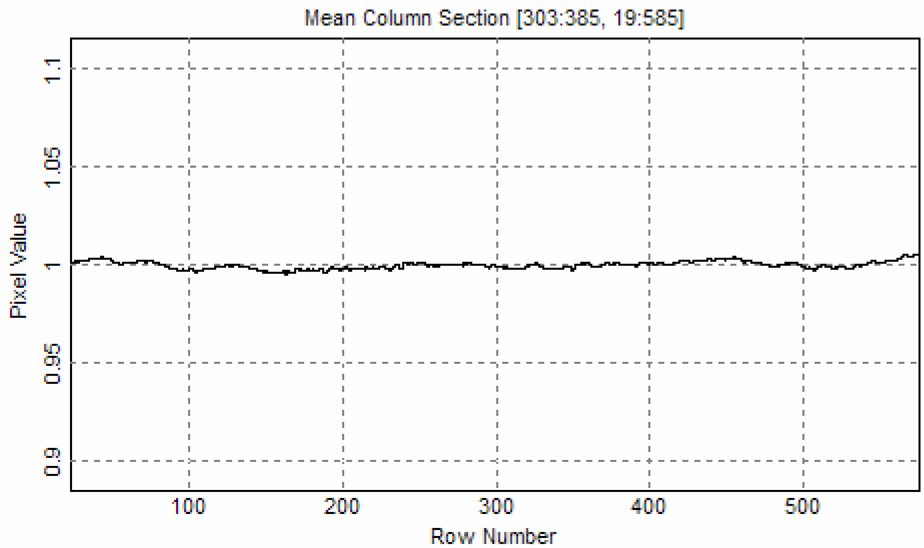


Figure 5.3.1-3: Profile of an EBT Film Digitized on the Red LED Dosimetry Pro Advantage™

5.3.2 Recommendation for Film Positioning

Even though the effects of light scattering can be corrected as described above, it is recommended that EBT films be scanned in the center of the scan window of the Red LED Dosimetry Pro digitizer. When EBT films are scanned in this fashion, the performance of the Red LED Dosimetry Pro is much superior to the VXR-16.

5.4 Film Orientation

The response of EBT films scanned on the Red LED Dosimetry Pro is dependent on the film orientation during digitization. This effect arises owing to anisotropic light scattering by EBT film. EBT films are 8"x10" or 14"x17" and may be scanned in either landscape mode (short edge of the film parallel to the scan direction), or the portrait mode (long edge of the film parallel to the scan direction). Since the light scattering of EBT film is greater in the direction parallel to the short edge of the film, it is preferable to scan EBT film in the landscape mode.

Squares of EBT film about 1.2cm in size were exposed to several doses from a linear accelerator. The orientation of the film squares with respect to the sheet of film from which they were cut was recorded. A carrier sheet was fabricated with small open windows at various locations. The exposed squares were then fit into the windows and the carrier sheet with attached films was scanned. In this manner each film was digitized in landscape and portrait orientations at a number of locations in the scan window. These positions covered locations from about 1" to the right of center to about 6" to the left of center. The scan window in the Red LED Dosimetry Pro is 14" wide.

Measurements of the scanner response values in the film images were made. For each of the film orientations the response values were normalized to the average value at the three locations closest to the center of the scan window.

The normalized response values for the landscape and portrait orientations are shown in Figures 5.4-1 and 5.4-2 respectively. The data show that in the landscape orientation, while the scanner response is greater at the center (7" location) than close to the edge (1" location), the behavior is similar for all doses (0cGy to 189cGy). However, for the

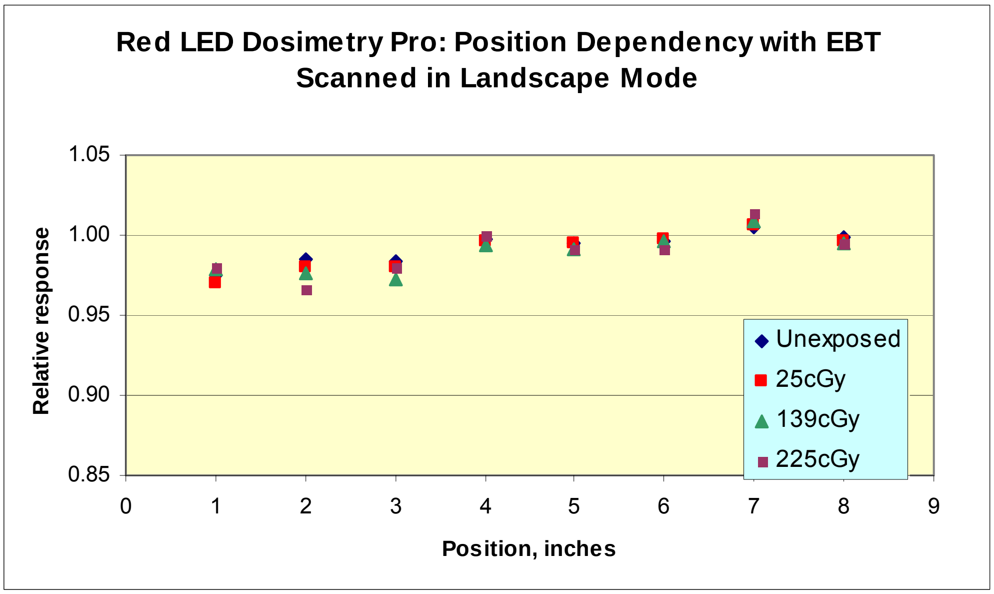


Figure 5.4-1: Response of EBT Film in Landscape Mode on the Red LED Scanner

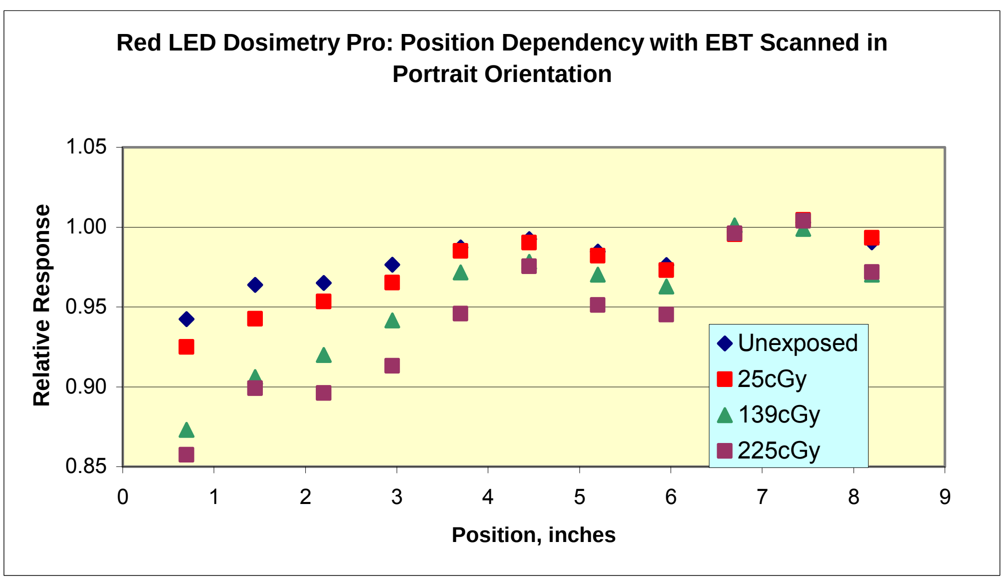


Figure 5.4-2: Response of EBT Film in Portrait Mode on the Red LED Scanner

portrait orientation the scanner response is dependent on position and dose. It is evident that a simple procedure relying on the response of a large sheet of unexposed film, or any uniformly exposed film, could be used for correcting for the effects of light scattering in landscape mode. Correction for the position-dependent and dose-dependent effects in the portrait orientation would be more complex, though not impossible.

A simple correction procedure is based on the image of an unexposed film. To illustrate the process, an 8”x10” unexposed EBT film and one film uniformly exposed to about 120cGy were scanned in landscape and portrait orientations. In addition a calibration film was exposed to a number of doses between about 25cGy and 225cGy.

Image measurement and arithmetic operations were performed with Mira AP. The digitized images of the unexposed films were normalized by dividing the pixel values in an image by the mean pixel response value in the same image. These normalized images were then used to correct the position-dependency of the pixel values in the images of corresponding uniformly exposed film. By this procedure, each pixel value in the image of a uniformly exposed film was divided by the value of the corresponding pixel in the normalized image of the unexposed film.

Scanner response data from the calibration films scanned in both orientations was plotted and fit to polynomial functions. Using the coefficients of the polynomial each of the corresponding corrected images was then converted from scanner response values to dose values. The values in the dose images were normalized to the values at the center of the scan window.

Figure 5.4-3 shows the profiles across the normalized dose images. It is evident that the dose profile of the landscape image is flat to within ±1%. The dose profile of the portrait

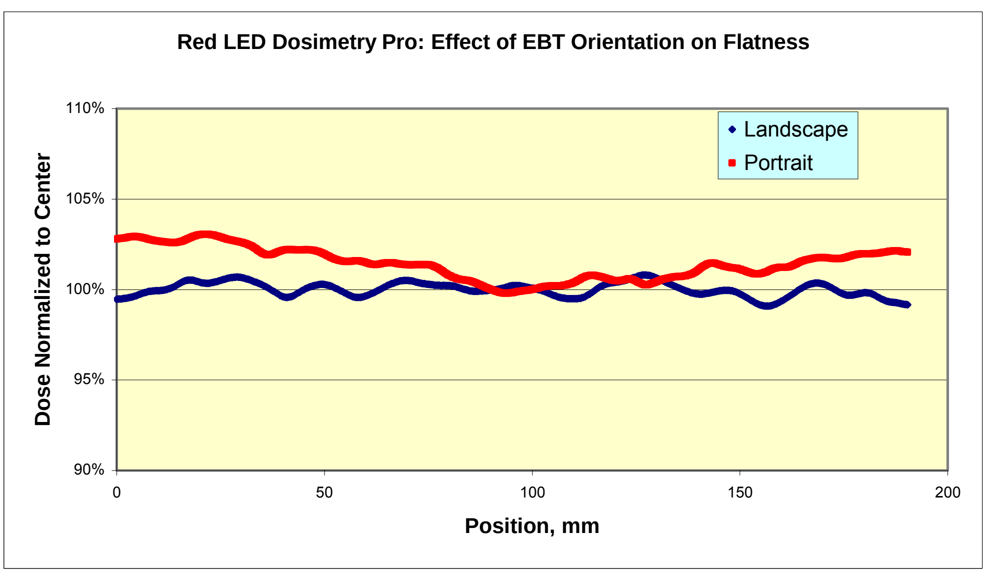


Figure 5.4-3: Profiles of a Uniformly Exposed EBT Film Scanned in Landscape and Portrait Mode on a Red LED Digitizer.

image shows about 3% greater values at the edges than at the center. This qualitative behavior is predictable given the dose-dependent characteristic of the portrait-mode scan data in Figure 5.4-3.

5.4.2 Recommendation for Film Orientation

In addition to scanning in the center of the scan window, it is recommended that EBT be scanned in landscape mode (relative to the 8"x10" dimension of EBT film) on the Red LED scanner. With the scans in this central position and the film in landscape orientation, a correction for the effects of light scattering can be made using a scan of an unexposed film and simple image arithmetic.

5.5 Evaluation of Flatfield Images

Open fields of 5x5cm, 10x10cm and 15x15cm were exposed on film at doses of about 150cGy. GAFCHROMIC® EBT films (8"x10") and Kodak EDR-2 films (10"x12") were placed together between 5cm sheets of solid water and exposed simultaneously. After the EDR-2 films had been processed, all films were scanned on a Red LED Dosimetry Pro Advantage™. The EBT films were also digitized with a VXR-16 scanner. Unexposed EBT film and an unexposed and processed EDR-2 film were also scanned. The spatial resolution was set at 71dpi. As recommended in Sections 5.3.1 and 5.4.1 the films were centered in the scan window and scanned in landscape mode.

Film images were processed to correct for the effects of light scattering. Image measurement and arithmetic operations were performed with Mira AP (www.mirametrics.com). Digitized images of the unexposed films were normalized by dividing the pixel values in an image by the mean pixel response value in the same image. The normalized images were used to apply the corrections for scanner response. By this procedure, all pixel values in the images of the flatfield films were divided by the value of the corresponding pixel in the normalized image of the unexposed film.

EBT and EDR-2 calibration films were also provided, each having separate areas exposed to nine discrete doses between 25cGy and 225cGy. The calibration films were scanned in the same way as the flatfield films. Scanner response values were measured in the exposed areas and the calibration data was plotted and fit to a polynomial function. The coefficients of the fitting function were used to convert the corrected flatfield images from scanner value space to dose space. The dose images were smoothed with a 10x10 median filter. Finally the horizontal and vertical profiles across the flatfield dose images were measured and the flatness values were determined using the convention of AAPM Task Group 55 (www.aapm.org).

Horizontal profiles for the three field sizes are displayed in Figures 5.5-1 to 5.5-3. Numerical values for flatness are given in Tables 5.5-1 and 5.5-2. These data demonstrate that the Red LED scanner provides significantly better flatness results with EBT film than the VXR-16 scanner. It is believed that this is due to a combination of factors including:

- The higher response contrast of the Red LED scanner as compared to the VXR-16
- Closer proximity of the light source/film in the Red LED scanner versus the VXR-16
- Improved film transport in the Red LED scanner due to the additional guide rollers

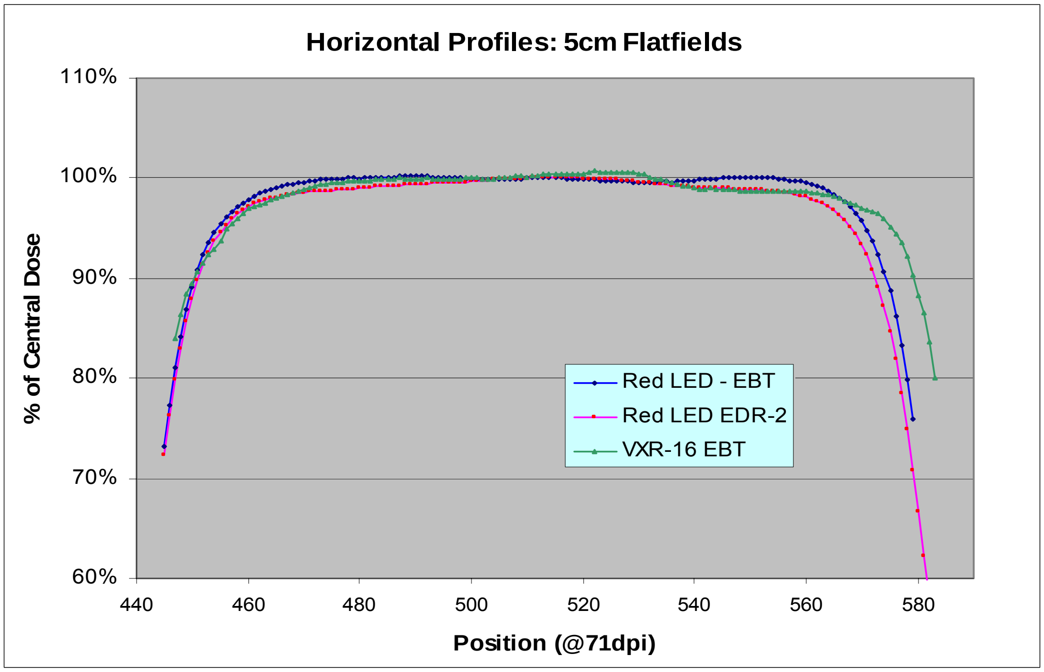


Figure 5.5-1: Profiles of 5x5cm Fields Digitized with Red LED and VXR-16 Scanners

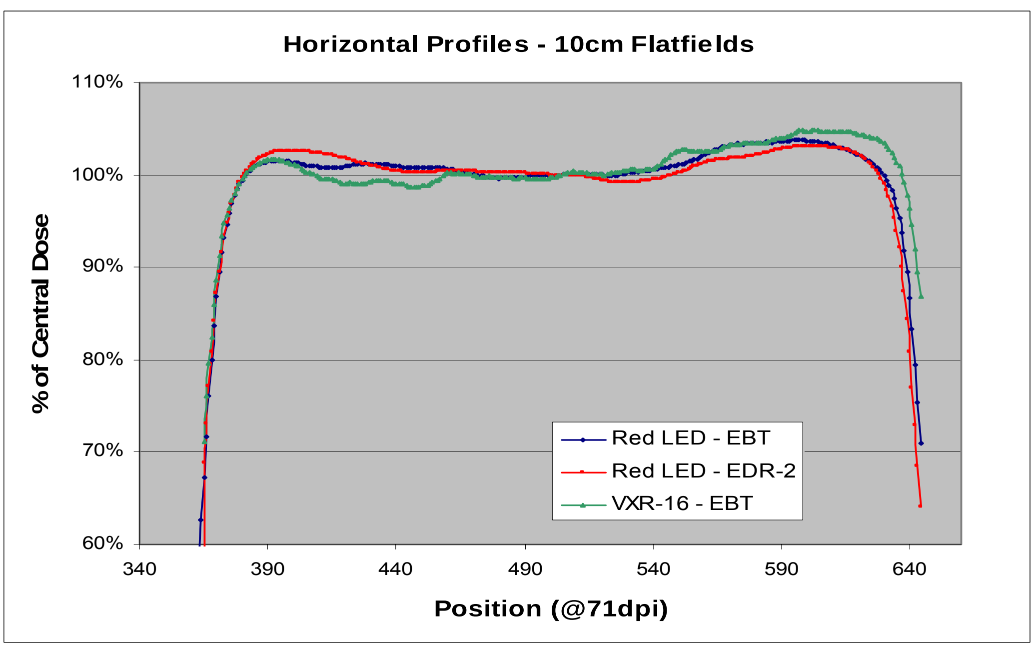


Figure 5.5-2: Profiles of 10x10cm Fields Digitized with Red LED and VXR-16 Scanners

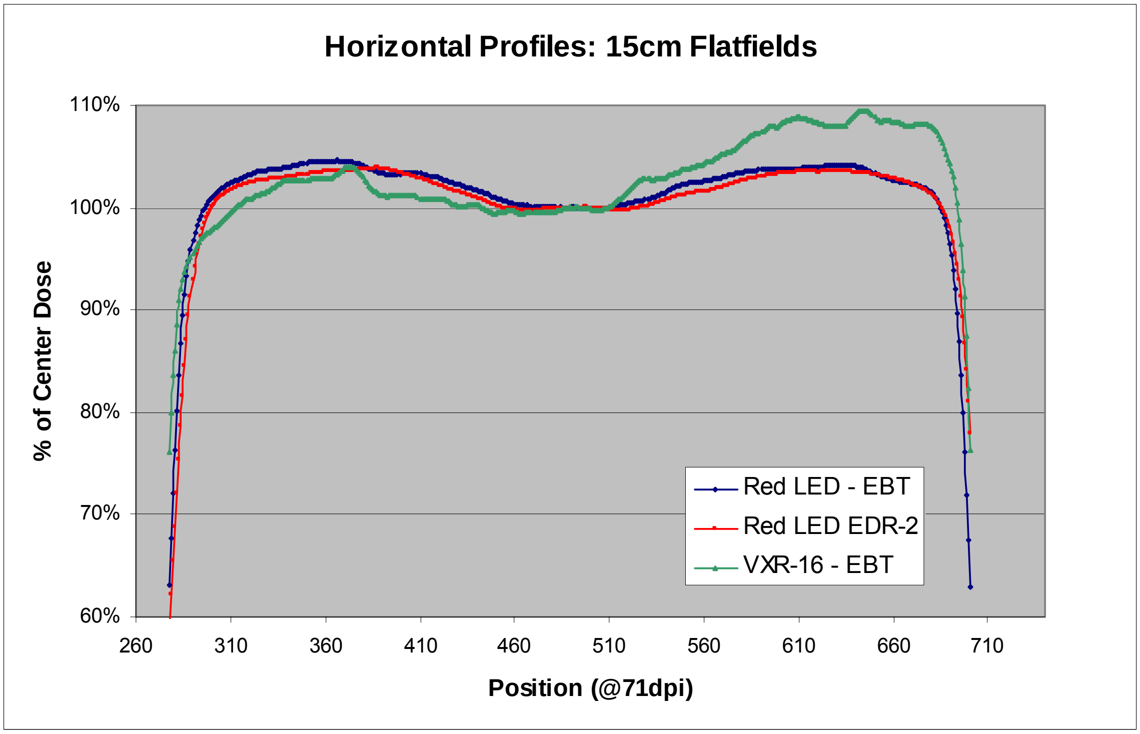


Figure 5.5-3: Profiles of 15x15cm Fields Digitized with Red LED and VXR-16 Scanners

A review of the profiles in the Figures and the data in the Tables also demonstrates that the flatness results provided by the EBT film and EDR-2 films are almost identical when the films are scanned with the Red LED scanner.

Field Flatness – Horizontal profiles				
Scanner Type	**Film Type**	**Field Size**		
		5cm x 5cm	**10cm x 10cm**	**15cm x 15cm**
Red LED	**EBT**	**1.9%**	**2.1%**	**2.3%**
VXR-16	**EBT**	**2.1%**	**3.1%**	**4.8%**
Red LED	**EDR-2**	**2.5%**	**2.0%**	**2.0%**

Table 5.5-1: Flatness of Horizontal Profiles of Fields Scanned with Red LED and VXR-16 Digitizers

Field Flatness – Vertical profiles				
Scanner Type	**Film Type**	**Field Size**		
		5cm x 5cm	**10cm x 10cm**	**15cm x 15cm**
Red LED	**EBT**	**3.7%**	**1.9%**	**2.6%**
VXR-16	**EBT**	**3.8%**	**3.4%**	**3.8%**
Red LED	**EDR-2**	**3.8%**	**2.4%**	**2.5%**

Table 5.5-2: Flatness of Vertical Profiles of Fields Scanned with Red LED and VXR-16 Digitizers

5.6 Analyses of IMRT Treatment Fields

A number of 10x10cm treatment fields from a multi-field IMRT treatment plan were exposed on film. The exposures were made at an SSD of 95cm and depth of 5cm using 6MV photons from a Varian linear accelerator. GAFCHROMIC® EBT films (8"x10") were placed between 5cm sheets of solid water and exposed to the treatment fields. EBT calibration films were created by exposing films to 25 discrete, known doses up to about 250cGy. The films were scanned on a Red LED Dosimetry Pro Advantage™ and a VXR-16 scanner. An unexposed EBT film was also scanned. The spatial resolution was set at 71dpi. The films were centered in the scan window and scanned in landscape mode on the Red LED and VXR-16 scanners. To illustrate the benefit of scanning in landscape mode the films were also scanned in portrait mode on the Red LED digitizer.

All analyses were performed using FilmQA™ (www.3Cognition.com). This software corrects images for the effects of light scattering, measures and plots calibration data and converts images of the treatment fields into dose images. Using dose images imported from the treatment plan the software then evaluates the fit between the measurements and the plan for each of the fields. FilmQA™ employs a variety of qualitative and quantitative evaluation tools including dose contours; horizontal, vertical and user-selected dose profiles; and dose-difference, gamma and distance-to-agreement functions.

Figures 5.6-1, 5.6-2 and 5.6-3 show report pages from the FilmQA™ evaluation of the EBT images obtained respectively:

1. in landscape mode on the Red LED scanner;
2. in portrait mode on the Red LED scanner;
3. in landscape mode on the VXR-16.

Evaluation maps and histograms of the gamma function showing the correspondence between measurements and treatment plan are shown in the top right section of each

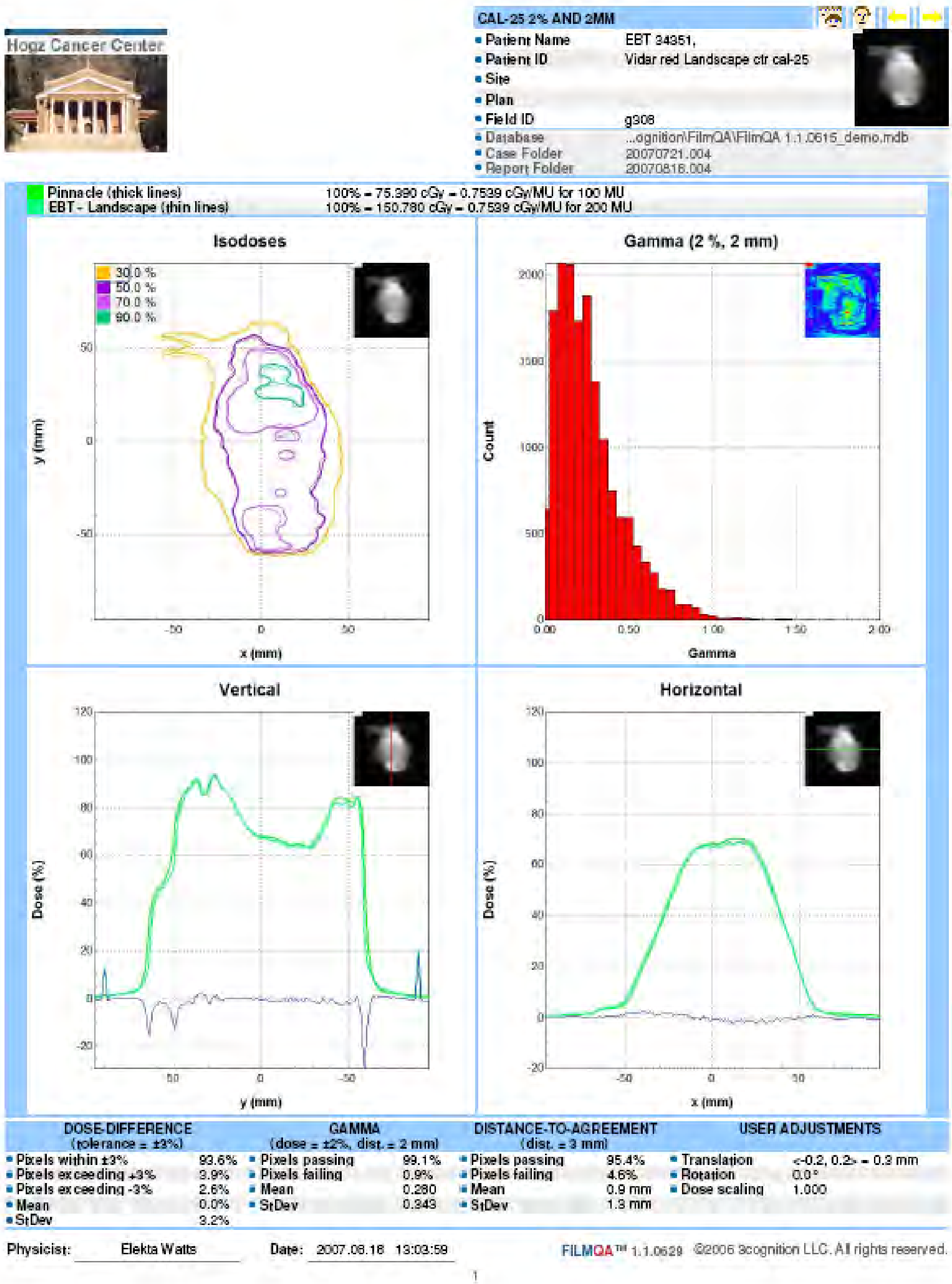


Figure 5.6-1: Evaluation of Measurement vs. Plan - EBT Film Digitized with the Red LED Scanner in Landscape Orientation

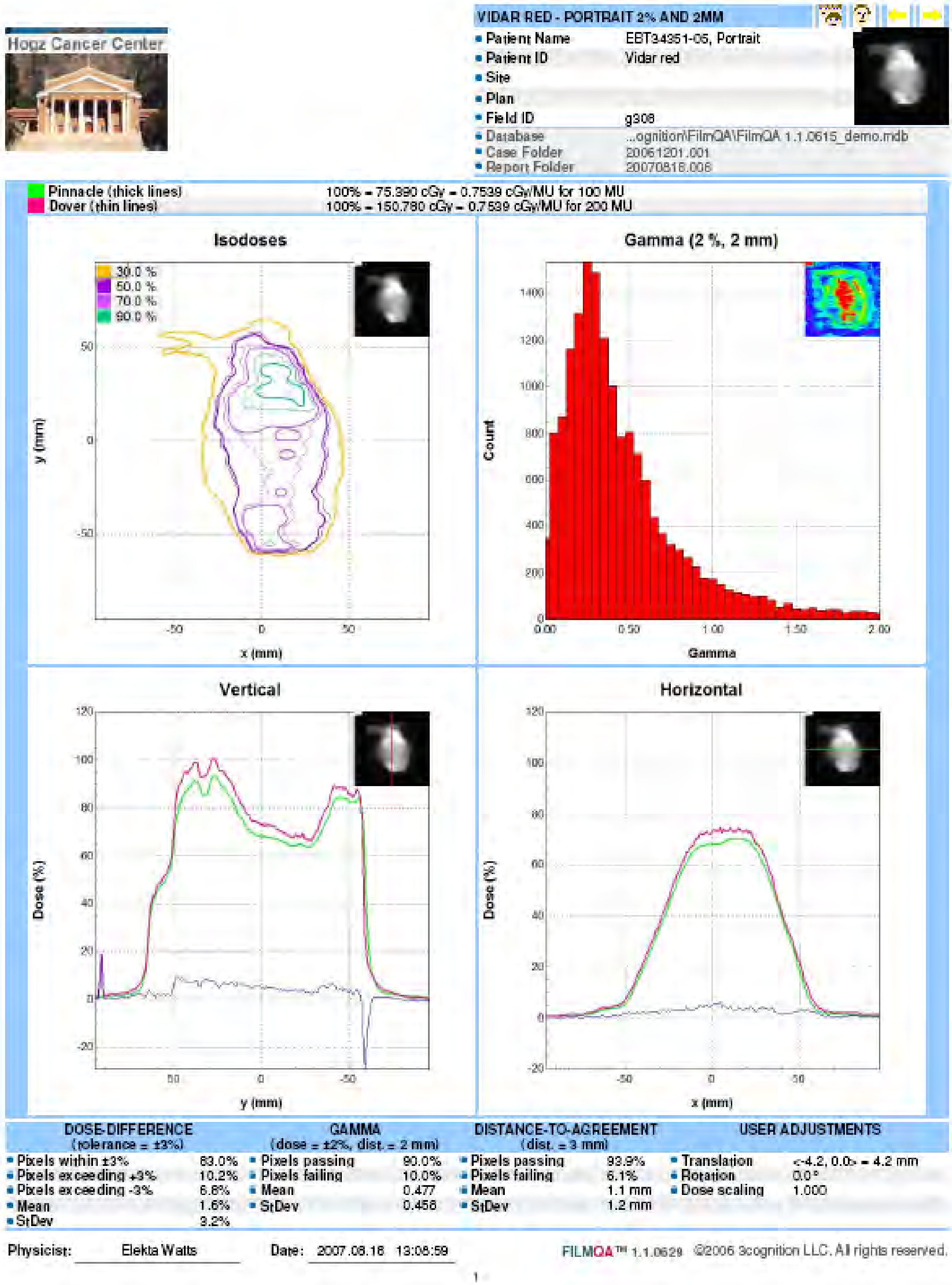


Figure 5.6-2: Evaluation of Measurement vs. Plan - EBT Film Digitized with the Red LED Scanner in Portrait Orientation

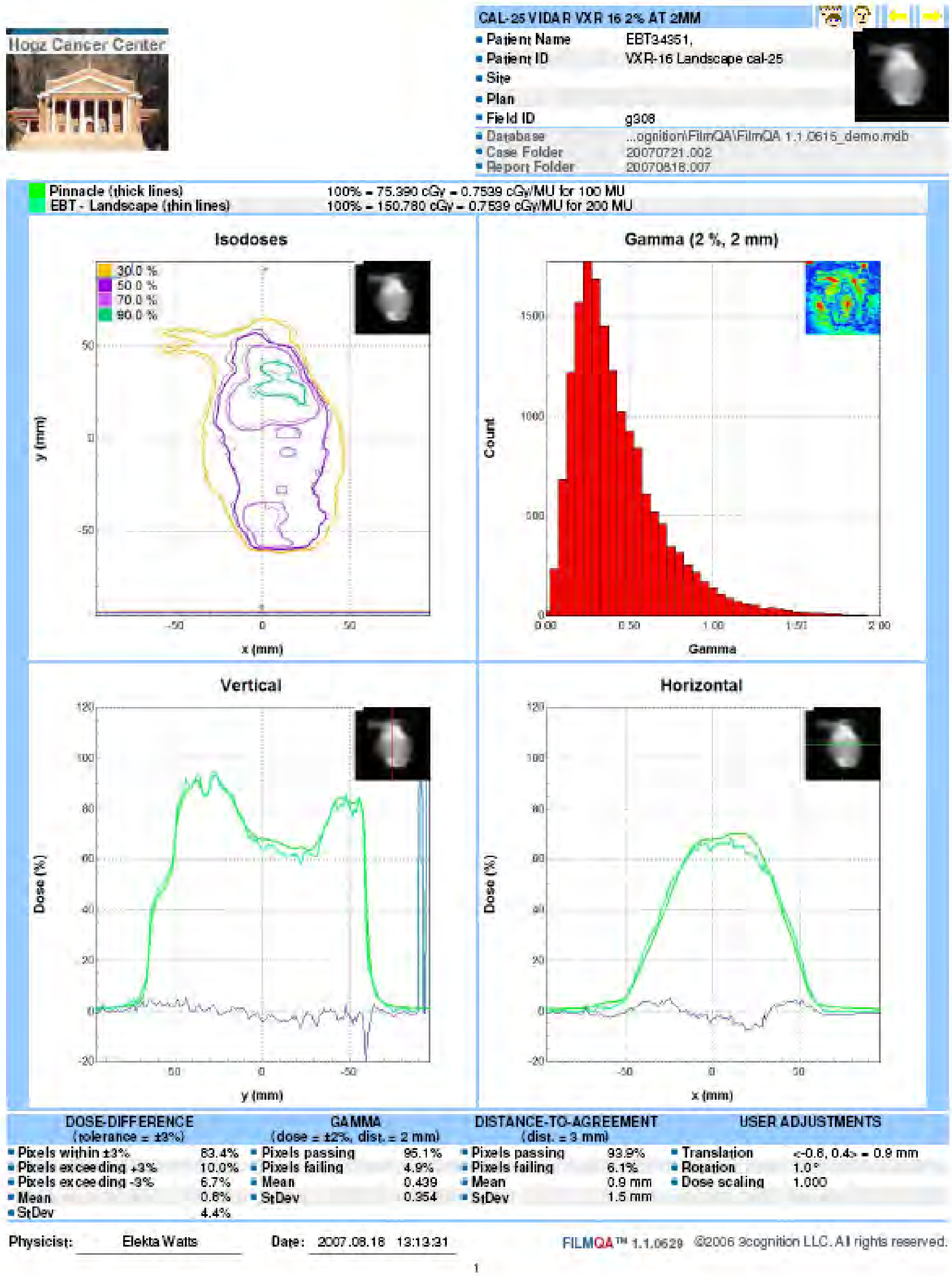


Figure 5.6-3: Evaluation of Measurement vs. Plan - EBT Film Digitized with the VXR-16 Scanner in Landscape Orientation

report page. The histograms show the distribution of pixels in an image with values <1. Any pixel with a value <1 passes the evaluation criteria of 2% at 2mm. The gamma value will be <1 if, within a 2mm radius of a measured pixel, there is a plan dose that is within 2% of the measured value. For the treatment field shown in the figures, the landscape scan on the Red LED digitizer provides superior performance. For the Red LED digitizer and landscape orientation, 99.1% of pixels meet or exceed the gamma evaluation criteria. By contrast, landscape scan on the VXR-16 had 95.1% of pixels passing, while only 90.0% of pixels in the portrait scan on the Red LED digitizer met the evaluation criteria. These results demonstrate that the Red LED scanner is superior to the VXR-16. They also show that with EBT film scanning in landscape orientation yields better results than scanning in portrait mode.

These findings are also supported by inspection of the contour plots and dose profiles in the evaluation reports. It can be seen that the Red LED/landscape scans provide a significantly closer correspondence between the measurements and the treatment plan. Report pages from FilmQA evaluations of the other six fields are provided in Appendices 3A, 3B and 3C.

Table 5.6-1 compares the performance of the Red LED scanner and VXR-16 scanner for scans of EBT film in landscape mode. The data summarizes the % of pixels meeting the gamma evaluation criteria of 2% dose-difference within 2mm. Data in this table clearly demonstrate that digitized EBT images from the Red LED scanner have a significantly higher proportion of pixels surpassing the performance criteria than the scans from the VXR-16. The results support the conclusion that the Red LED is superior to the VXR-16 for scanning EBT film.

Percentage of Pixels Meeting Gamma Function Evaluation Criteria of 2% and 2mm		
Treatment Field	**Red LED/Landscape**	**VXR-16/Landscape**
1	99.1	95.1
2	97.3	94.4
3	98.2	93.8
4	96.6	94.3
5	99.0	97.1
6	98.9	95.7
7	97.9	89.0

Table 5.6-1: Gamma Function Evaluation of Treatment Field Measurements vs. Plan

Table 5.6-2 contains data demonstrating that scanning in landscape orientation is superior to scanning in portrait mode. The values in the table show the % of pixels from the scanner measurements of EBT film in the two orientations that are within 3% of the plan values.

Percentage of Pixels Meeting Dose Difference of 3%		
Treatment Field	**Red LED/Landscape**	**Red LED/Portrait**
1	93.6	83.0
2	89.7	84.9
3	92.4	93.5
4	92.2	91.2
5	94.5	88.6
6	94.6	79.5
7	90.6	87.8

Table 5.6-2: Dose Difference Evaluation of Treatment Field Measurements vs. Plan

The combination of the Red LED digitizer and the EBT film provides a reliable measurement system and yields consistently superior results in the evaluation of IMRT treatment plans.

6.0 Conclusion

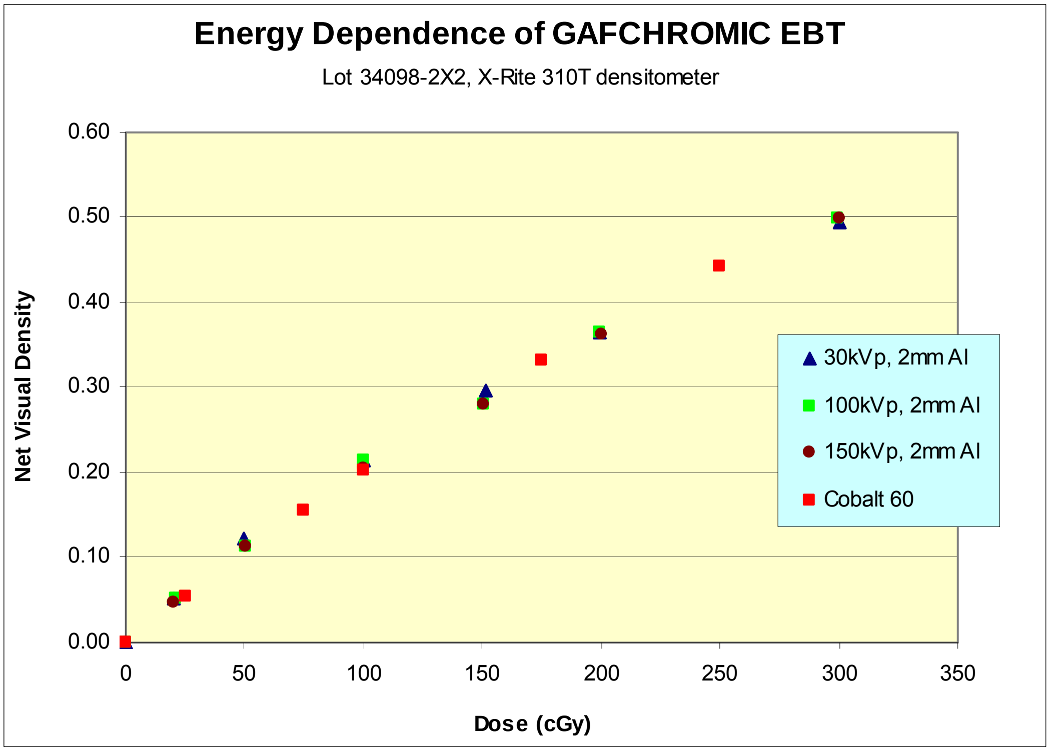
The performance of the Vidar® Red LED Dosimetry Pro Advantage™ scanner in digitizing images on GAFCHROMIC® EBT dosimetry film has been evaluated and compared to the performance of the Vidar® VXR-16 scanner. In each of the four analytical test categories – dose response, noise and dose resolution, light scattering and banding – as well as in the two practical test categories – profiling of flatfields and evaluation/analysis of IMRT treatment fields - the performance of the Red LED scanner was significantly better than the VXR-16. The Vidar® Red LED Dosimetry Pro Advantage™ scanner is an excellent tool for digitizing radiochromic film images.

The investigation has shown that it is preferable to scan GAFCHROMIC® EBT film in landscape mode and to position the film in the center of the scan area when digitizing film with Red LED Dosimetry Pro Advantage™.

The Red LED Dosimetry Pro Advantage™ scanner used in combination with GAFCHROMIC® EBT dosimetry film form a high quality dosimetry measurement system ideal for applications in radiotherapy.

APPENDIX 1

Energy Dependence of GAFCHROMIC® EBT and Kodak EDR-2 Dosimetry Films



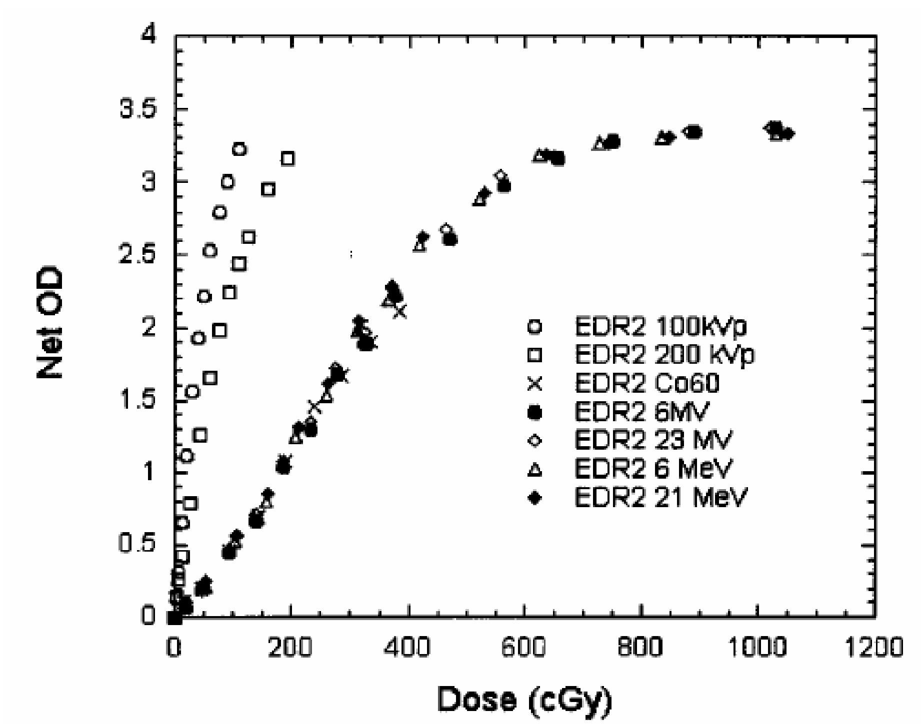


Figure A1-1: Energy Dependence of Kodak EDR-2 Dosimetry Film

APPENDIX 2

Effects of Light Scattering on the Performance of CCD Scanners

Introduction

Film scanners having long diffuse light sources and a CCD detector are susceptible to artifacts that can affect the performance. In particular, when scanners of this type undergo a process to calibrate the intensity of the light source along its length, significant inaccuracies can occur if measurements are made later on films that scatter light. Images in conventional radiographic films and radiochromic films are comprised of particles dispersed in a matrix. Such films will scatter light if the refractive indices of the components differ. The effects of light scattering are seen in digitized images as apparent variations in response in a direction parallel to the light source. The magnitude depends on a number of factors, including the geometric arrangement of the scanner components. Thus the effect of light scattering will generally be proportional to the length of the light source and its distance from the film and the distance between the film and the detector.

FilmQA™ software is a fast, efficient film dosimetry and image analysis software that contains unique features for correcting for the effects of light scattering by CCD scanners. FilmQA™ is unique in this feature and the use of FilmQA software is essential to providing optimum results with EBT film on the Vidar® Red LED Dosimetry Pro Advantage™, the Vidar® VXR-16, as well as on flatbed scanners.

Scanners of the type described above include the Vidar® Dosimetry Pro Advantage™, the VXR-12 and VXR-16, as well as many flatbed photographic film scanners. Of these, the VXR-12 and VXR-16 have very long light sources (an 18” fluorescent tube) placed relatively far away from the film. In the VXR scanners the light source is about 2” from film. The Vidar® Dosimetry Pro and most flatbed scanners have shorter light sources that are within a few millimeters of the film. For these reasons the Vidar® VXR-12 and VXR-16 scanners generally exhibit considerably greater effects due to light scattering than do the other scanners scanners. Figures A2-1 and A2-2 are profiles across the image of an unexposed GAFCHROMIC® EBT film from an Epson 1680 and a Vidar® VXR-16 scanner respectively. The profiles are parallel to the light sources. In both cases the scanner response is a function of position on the film, but the VXR-16 shows considerably greater variation in response. An explanation of the effect will be given later.

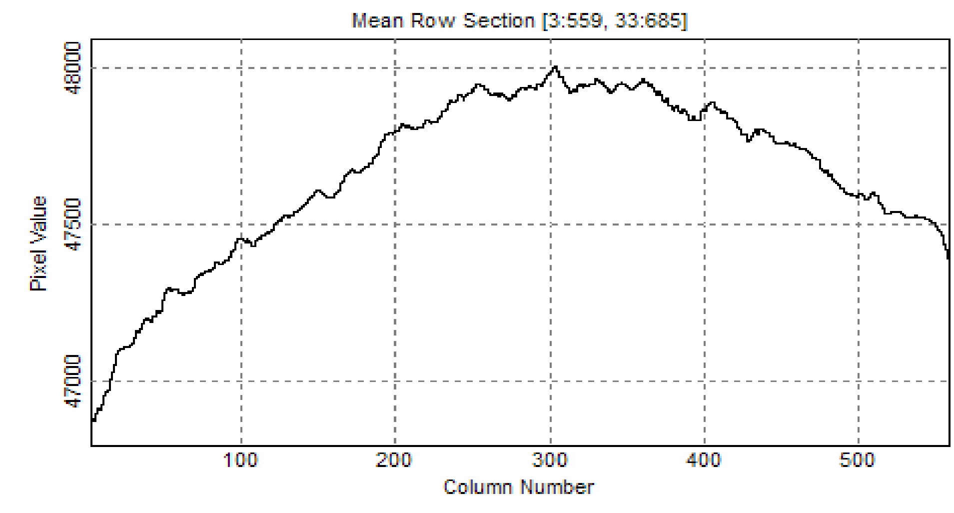


Figure A2-1: Profile across Unexposed EBT film on an Epson 1680 Scanner

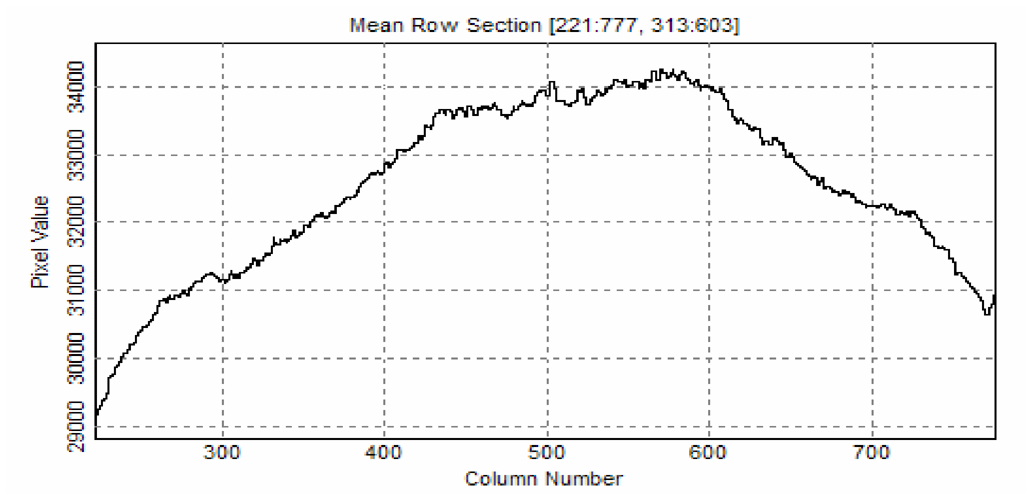


Figure A2-2: Profile across Unexposed EBT film on a Vidar® VXR-16 Scanner

Light scattering is caused by particles in the active layer of the film. The magnitude is proportional to the size and concentration of particles and the refractive index difference between the particles and the film matrix in which they are contained. Nevertheless, the effects of light scattering by GAFCHROMIC® radiochromic films in all these scanners can be easily measured and corrected.

In silver halide films light scattering is caused by grains of silver in the image. The number of particle in the silver image is proportional to dose. Since light scattering increases with dose it becomes difficult and complex to compensate for the effects of light scattering in conventional silver film. In GAFCHROMIC® radiochromic films light scattering is caused by particles of the active component. However the number and size of these particles is independent of exposure.

Figure A2-3 is a schematic of a CCD scanner such as the Dosimetry Pro Advantage™, the Vidar® VXR-16 or Epson flatbed scanner. It shows elements important the calibration of intensity along the length of the light source In the VXR-16 this type of calibration occurs at time intervals of a few minutes. In the Dosimetry Pro Advantage™ and in Epson flatbed scanners this calibration immediately precedes every scan. In none of these scanners is there film in the optical path during calibration. Rather the calibration occurs through a transparent, non light scattering medium: air in the case of the Vidar® digitizers and glass in the Epson flatbed scanners.

All these scanners have long diffuse light sources. But only certain rays passing through the calibration plane will be refracted by the optical components and focused on the detector. The signal that is received at the detector essentially maps the light intensity along the length of the source. When a film is scanned the signal recorded during calibration is then be used to correct intensity differences assuming that the intensity does not change between calibrations, or during a scan. The calibration will be valid so long as the film does not scatter light.

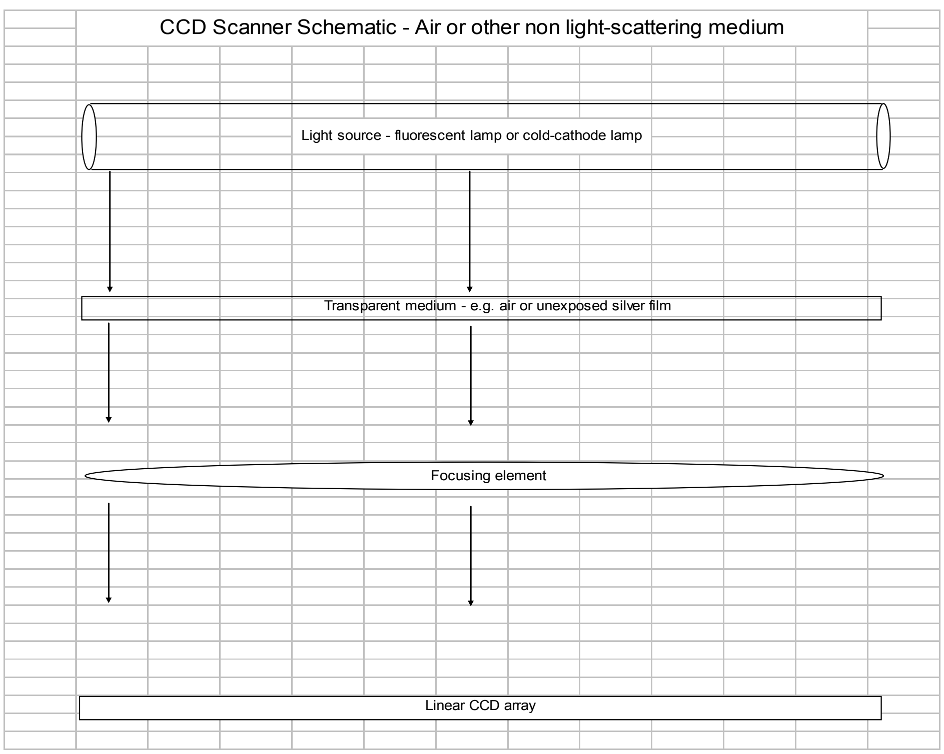


Figure A2-3

Figure A2-4 is a schematic depicting features important to the scanning of a film that scatters light. Because the light source is diffuse, a small proportion of the off-axis illumination at the film plane will be fortuitously scattered by the film and contribute to the signal received at the detector. However, because the light source has a finite

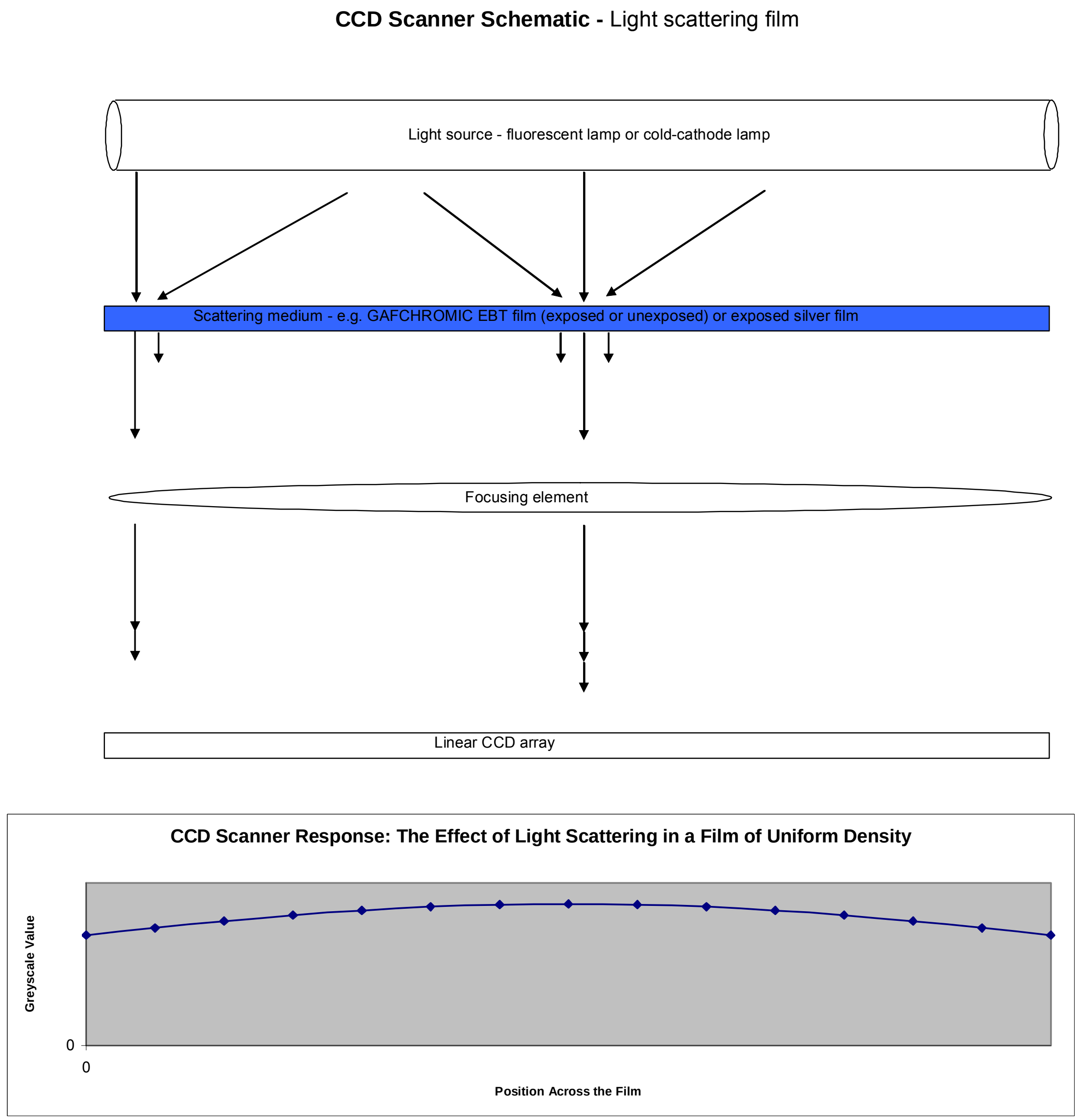


Figure A2-4

length, the off-axis illumination at the center of the film will be greater than at the ends. Consequently the amount of light registering at the detector will be greater in the center and less at the ends. The plot at the foot of Figure A2-4 shows an idealized response profile across a film that has a uniform absorbance, but scatters light.

The effects of light scattering by silver film are shown in Figure A2-5. This figure shows profiles across a 7.5" film uniformly exposed to a net densities of about 0.1. The silver film profile on the left of the figure is from a VXR-16 scan while the right hand profile is from a scan on an Epson 1680. The Vidar® scan was made with the left edge of the film registered against the left edge of the scanner. On the Epson 1680, the left edge of the film was registered against the left edge of the scan window. The scanner response values (pixel values) have been normalized by dividing by the mean scanner response value for the area.

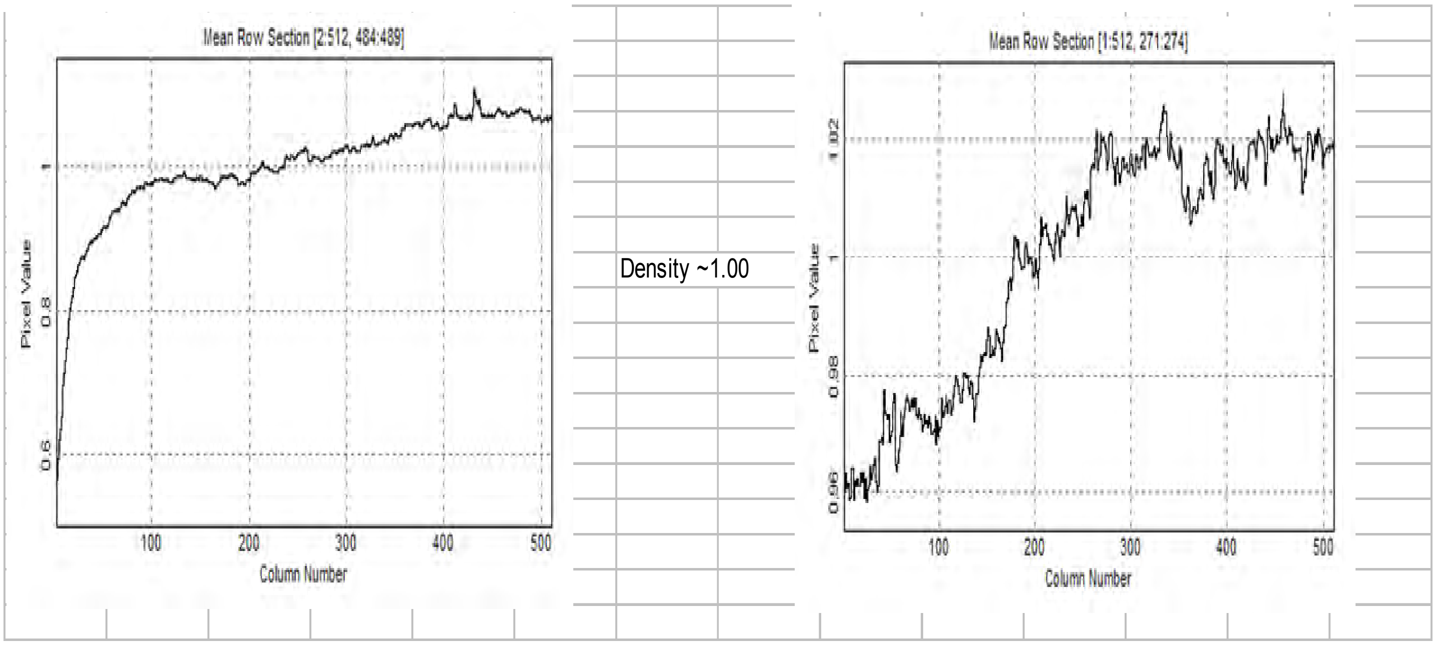


Figure A2-5: Profiles showing normalized scanner response across a silver film at net density ~1.0. Vidar® VXR-16 data is on the left and Epson 1680 data is on the right.

The source of the steep fall-off at the far left side of the silver film profile is unknown, but it is not believed to result from light scattering. However, the effect of light scattering on the measurement can be seen by the slope from approximately columns number 90 to 500. This shows that light scattering by a silver film can result in a 5-10% change in scanner response near the ends of the light source. The results on the right of Figure A2-5 are for the Epson scanner and they show about a 5% difference between the center and the edge. It is believed that the lower contribution from light scattering exhibited by the Epson scanner is due to two factors – a) the light source in the Epson is shorter than the Vidar® (about 11" vs. 18") and; b) the light source in the Epson scanner is closer to the film (about 1cm vs. 2").

The effects of light scattering by EBT film for the Vidar® VXR-16 and Epson 1680 are shown in Figures A2-1 and -2. Light scattering in EBT film is due to refractive index difference between particles of the active component and the gelatin matrix in which they are embedded. The refractive indices of these materials are essentially unchanged and the size of the active material particles is unchanged by irradiation of the film. Thus it is easy to correct for the effects of light scattering using the following four steps.

1. Scanning an unexposed EBT film
2. Measuring the mean pixel value (i.e. scanner response value) of the unexposed film
3. Creating a "Flat Field Correction Image" by dividing all pixel values in the unexposed film image by the mean pixel value. This is referred to as pixel-by-pixel arithmetic. Figure A2-6 shows a profile across a Flat Field Correction Image on an Epson 1680 scanner. A correction image for the VXR-16 will be qualitatively similar, but the correction factors span a wider range of values. Although the profile in Figure A2-6 has not been smoothed, it would be beneficial to apply a smoothing filter to the Flat Field Correction Image to remove scanner and film noise before the Correction Image is used.
4. Flattening all images in a set of images using pixel-by-pixel division of the image by the Flattening Correction Image to correct for the effect of light scattering.

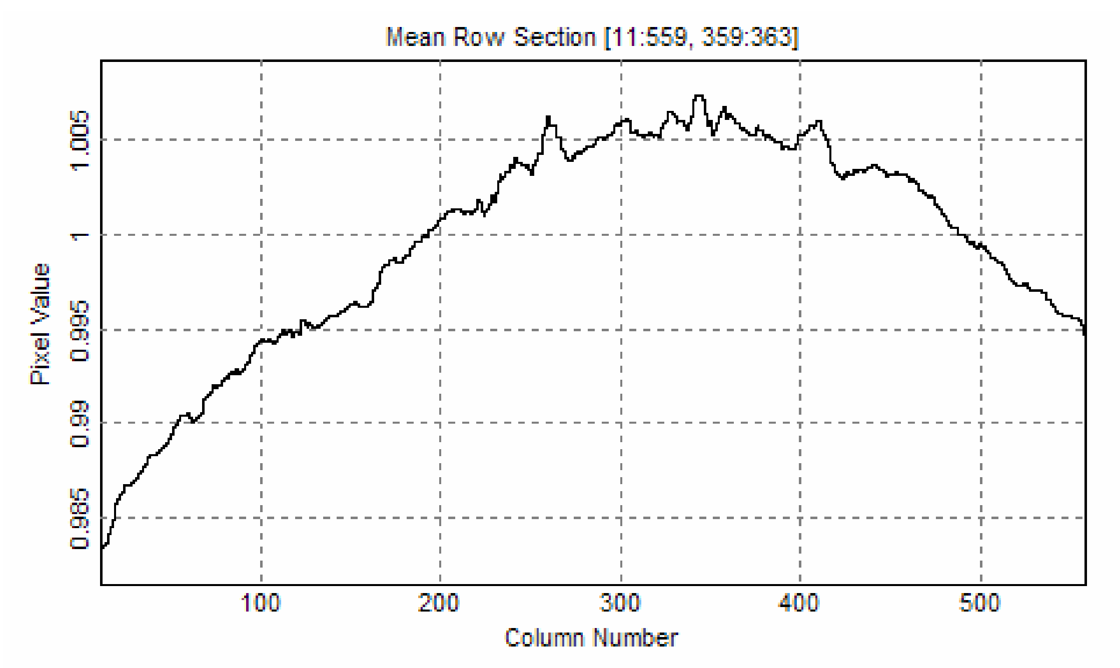


Figure A2-6: Profile across a Flat Field Correction Image

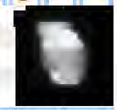
These steps are seamlessly performed by FilmQA™ software. FilmQA™ is unique in this feature and the use of FilmQA software is essential to providing optimum results with all CCD scanners.

APPENDIX 3A

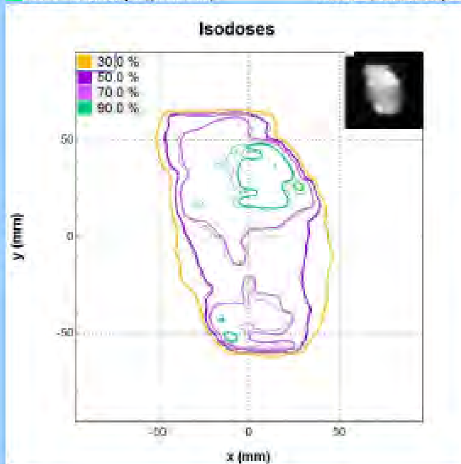
Evaluation of Measurement vs. Plan for EBT Films Digitized with the Red LED Scanner in Landscape Orientation

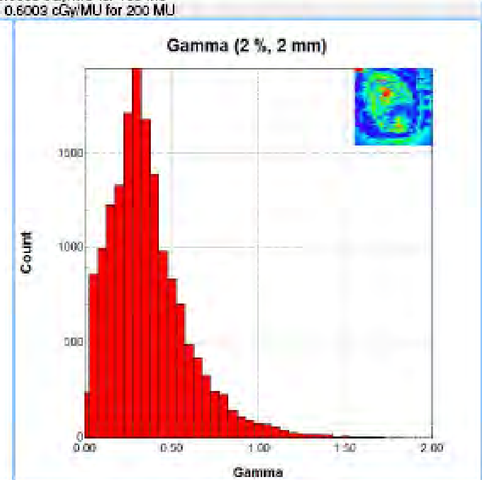
CAL-25 2% AND 2MM

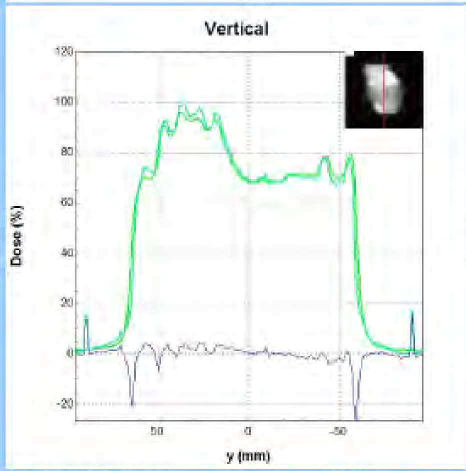
Patient Name	EBT 34351,
Patient ID	Vidar red Landscape ctr cal-25
Site	
Plan	
Field ID	g257
Database	...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
Case Folder	20070721.004
Report Folder	20070816.004

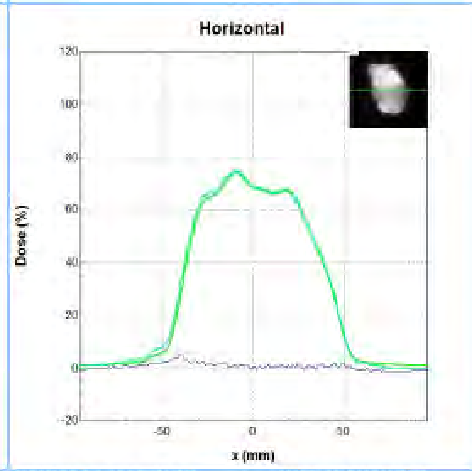


Pinnacle (thick lines)	100% = 60.030 cGy = 0.6003 cGy/MU for 100 MU
EBT - Landscape (thin lines)	100% = 120.060 cGy = 0.6003 cGy/MU for 200 MU









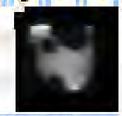
DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	89.7%	Pixels passing	97.3%	Pixels passing	90.2%	Translation	<-0.6, 0.4> = 0.9 mm
Pixels exceeding +3%	6.2%	Pixels failing	2.7%	Pixels failing	9.8%	Rotation	0.0°
Pixels exceeding -3%	4.1%	Mean	0.379	Mean	1.3 mm	Dose scaling	1.000
Mean	0.2%	StDev	0.362	StDev	1.8 mm		
StDev	3.3%						

Physicist: Elekta Watts   Date: 2007.08.16 13:03:59

FILMQA™ 1.1.0629

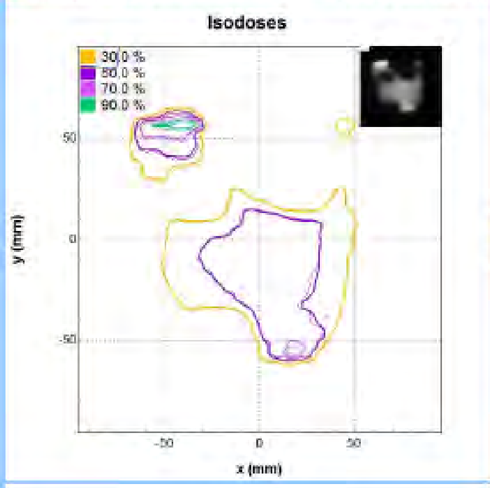
Hogz Cancer Center

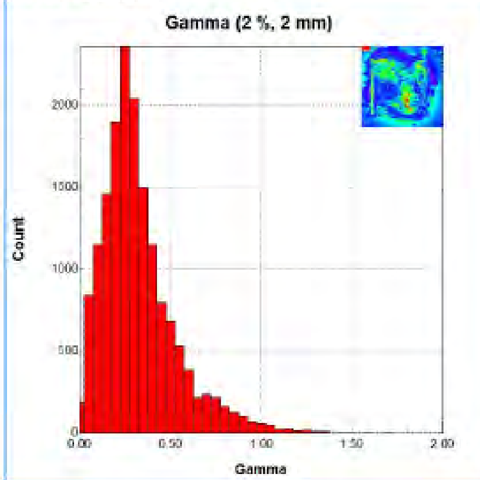
CAL-25 2% AND 2MM

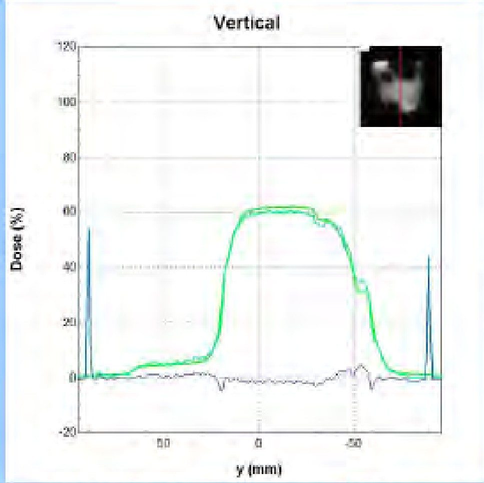


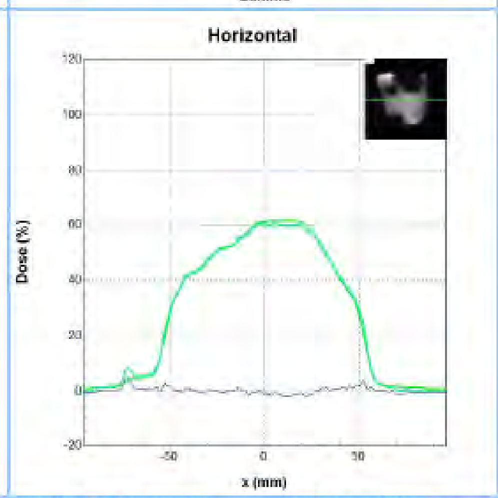
Patient Name	EBT 34351,
Patient ID	Vidar red Landscape ctr cal-25
Site	
Plan	
Field ID	g206
Database	...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
Case Folder	20070721.004
Report Folder	20070818.004

Pinnacle (thick lines)	100% = 48.630 cGy = 0.4863 cGy/MU for 100 MU
EBT - Landscape (thin lines)	100% = 97.260 cGy = 0.4863 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	92.4%	Pixels passing	98.3%	Pixels passing	87.1%	Translation	<0.0, -0.2> = 0.2 mm
Pixels exceeding +3%	4.5%	Pixels failing	1.7%	Pixels failing	12.9%	Rotation	0.0°
Pixels exceeding -3%	3.0%	Mean	0.341	Mean	1.5 mm	Dose scaling	1.000
Mean	0.1%	StDev	0.252	StDev	2.5 mm		
StDev	3.3%						

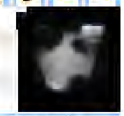
Physicist: Elekta Watts Date: 2007.08.18 13:03:59

FILMQA™ 1.1.0629

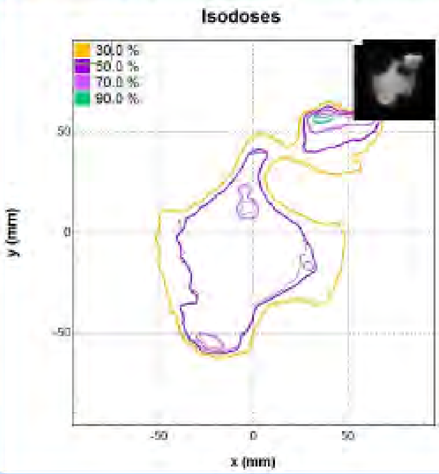
Hogz Cancer Center

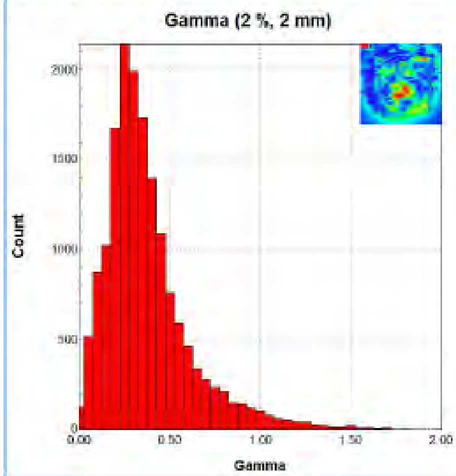
CAL-25 2% AND 2MM

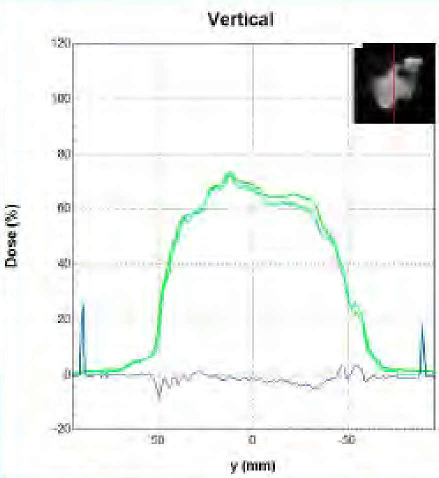
Patient Name	EBT 34351,
Patient ID	Vidar red Landscape ctr cal-25
Site	
Plan	
Field ID	g154
Database	...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
Case Folder	20070721.004
Report Folder	20070818.004

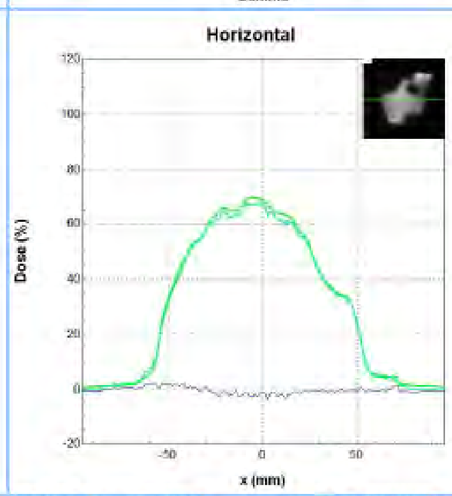


Pinnacle (thick lines) 100% = 47.200 cGy = 0.4720 cGy/MU for 100 MU
EBT - Landscape (thin lines) 100% = 94.400 cGy = 0.4720 cGy/MU for 200 MU









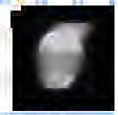
DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	92.2%	Pixels passing	96.6%	Pixels passing	81.0%	Translation	<-0.6, -0.4> = 0.7 mm
Pixels exceeding +3%	4.7%	Pixels failing	3.4%	Pixels failing	19.0%	Rotation	0.0°
Pixels exceeding -3%	3.1%	Mean	0.387	Mean	2.1 mm	Dose scaling	1.000
Mean	-0.5%	StDev	0.341	StDev	3.0 mm		
StDev	3.3%						

Physicist: Elekta Watts Date: 2007.08.18 13:03:59

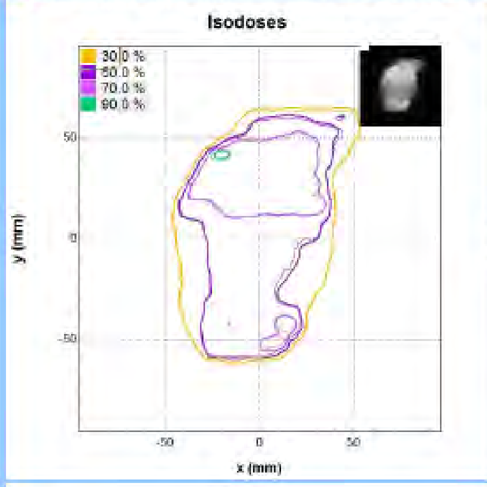
FILMQA™ 1.1.0629

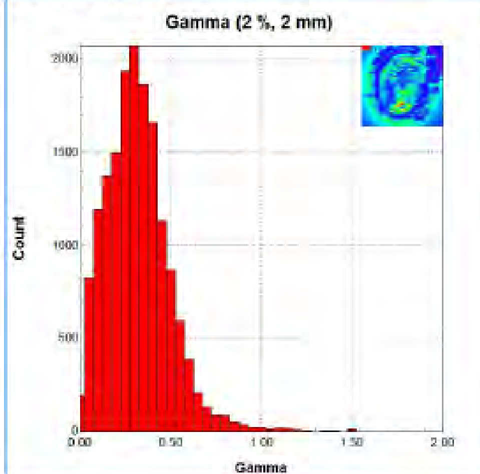
CAL-25 2% AND 2MM

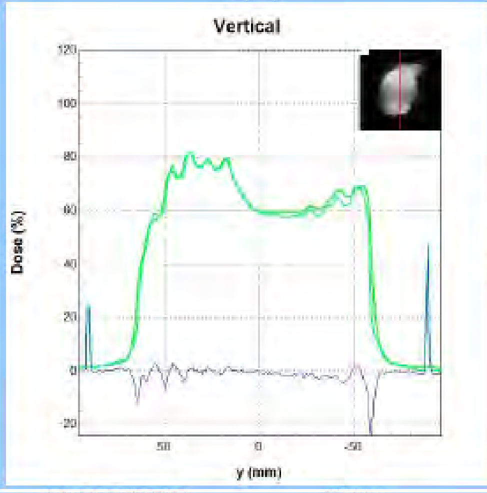
Patient Name	EBT 34351,
Patient ID	Vidar red Landscape ctr cal-25
Site	
Plan	
Field ID	g103
Database	...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
Case Folder	20070721.004
Report Folder	20070818.004

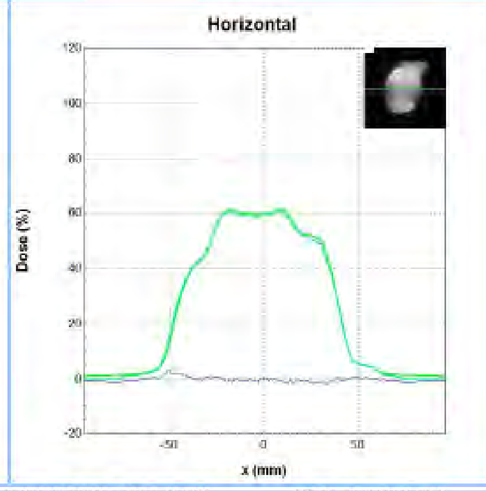


Pinnacle (thick lines)	100% = 60.180 cGy = 0.6018 cGy/MU for 100 MU
EBT - Landscape (thin lines)	100% = 120.360 cGy = 0.6018 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	94.5%	Pixels passing	99.0%	Pixels passing	81.2%	Translation	<0.0, -0.4> = 0.4 mm
Pixels exceeding +3%	3.3%	Pixels failing	1.0%	Pixels failing	18.8%	Rotation	0.0°
Pixels exceeding -3%	2.2%	Mean	0.332	Mean	2.1 mm	Dose scaling	1.000
Mean	-0.3%	StDev	0.306	StDev	3.2 mm		
StDev	3.2%						

Physicist: Elekta Watts Date: 2007.08.18 13:03:59

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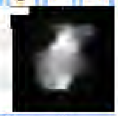
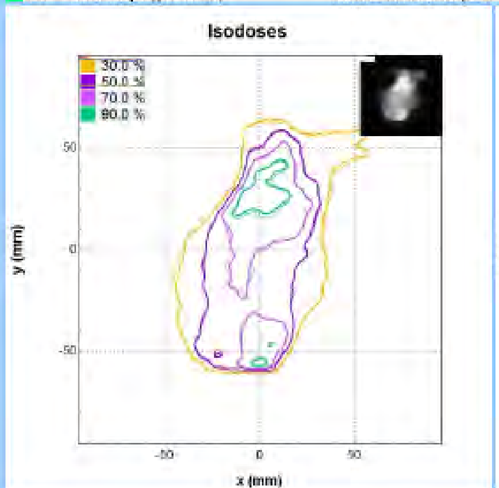
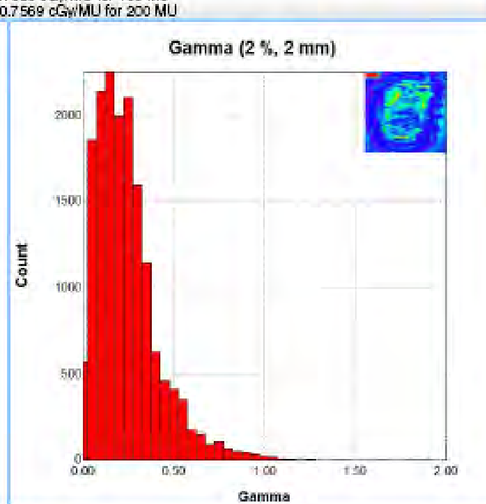
CAL-25 2% AND 2MM

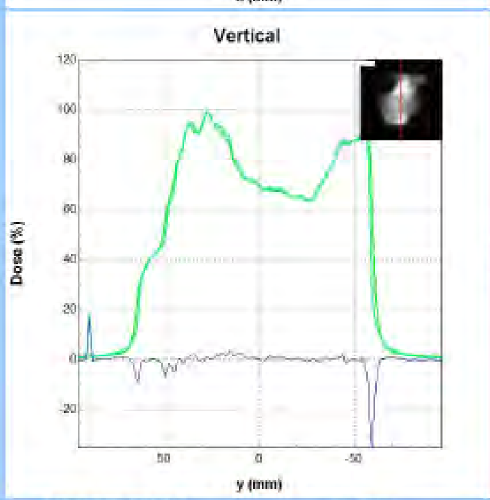


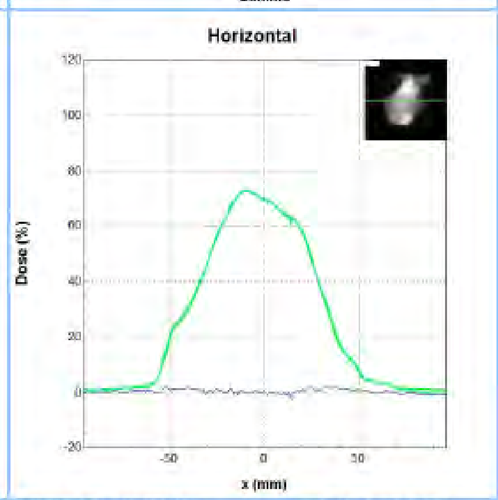
- Patient Name: EBT 34351,
- Patient ID: Vidar red Landscape ctr cal-25
- Site:
- Plan:
- Field ID: g52
- Database: ...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
- Case Folder: 20070721.004
- Report Folder: 20070816.004

Pinnacle (thick lines)	100% = 75.690 cGy = 0.7569 cGy/MU for 100 MU
EBT - Landscape (thin lines)	100% = 151.380 cGy = 0.7569 cGy/MU for 200 MU







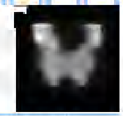


DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	94.6%	Pixels passing	98.9%	Pixels passing	94.1%	Translation	<-1.0, 0.0> = 1.0 mm
Pixels exceeding +3%	3.2%	Pixels failing	1.1%	Pixels failing	5.9%	Rotation	-0.4°
Pixels exceeding -3%	2.1%	Mean	0.269	Mean	1.0 mm	Dose scaling	1.000
Mean	0.5%	StDev	0.402	StDev	1.7 mm		
StDev	3.8%						

Physicist: Elekta Watts   Date: 2007.08.16 13:03:59

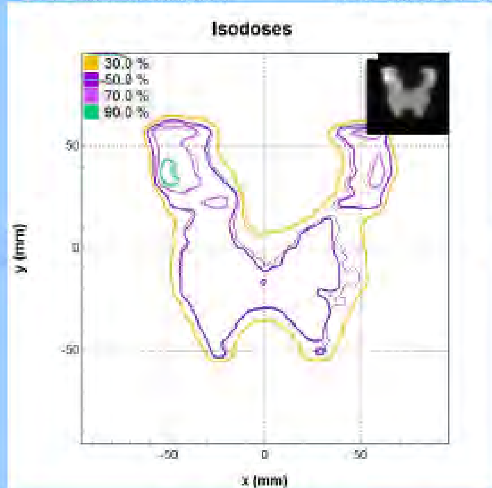
Hogg Cancer Center

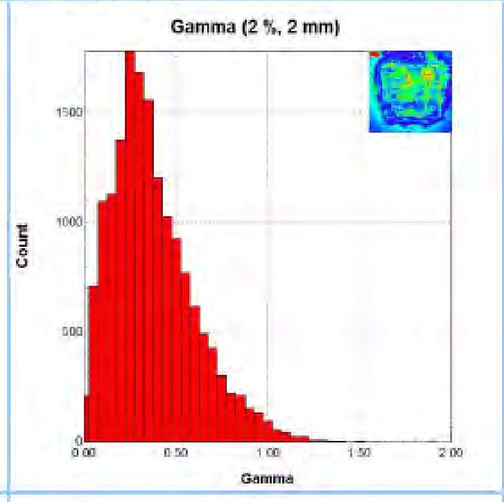
CAL-25 2% AND 2MM

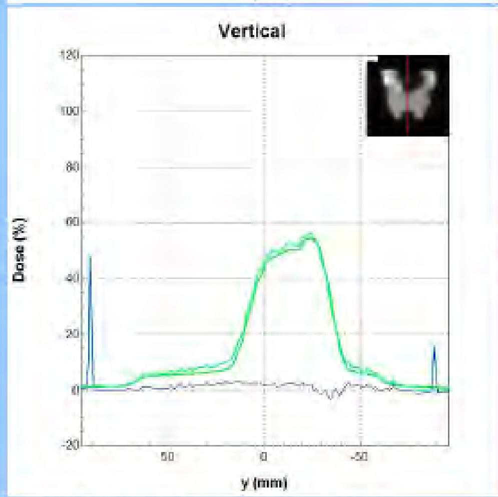


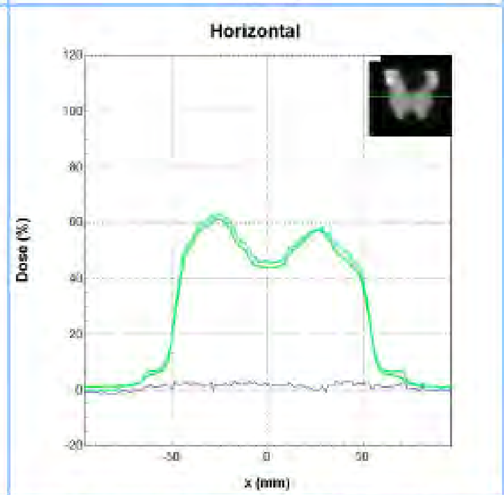
Patient Name	EBT 24351,
Patient ID	Vidar red Landscape ctr cal-25
Site	
Plan	
Field ID	g0
Database	...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
Case Folder	20070721.004
Report Folder	20070518.004

Pinnacle (thick lines)	100% = 43.770 cGy = 0.4377 cGy/MU for 100 MU
EBT - Landscape (thin lines)	100% = 87.540 cGy = 0.4377 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	90.6%	Pixels passing	97.9%	Pixels passing	88.9%	Translation	<-0.4, -1.0> = 1.1 mm
Pixels exceeding +3%	5.6%	Pixels failing	2.1%	Pixels failing	11.1%	Rotation	0.0°
Pixels exceeding -3%	3.7%	Mean	0.390	Mean	1.4 mm	Dose scaling	1.000
Mean	0.7%	StDev	0.362	StDev	2.4 mm		
StDev	3.6%						

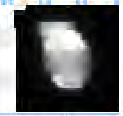
Physicist: Elekta Watts   Date: 2007.08.16 13:03:59

APPENDIX 3B

Evaluation of Measurement vs. Plan for EBT Films Digitized with the Red LED Scanner in Portrait Orientation

Hogg Cancer Center

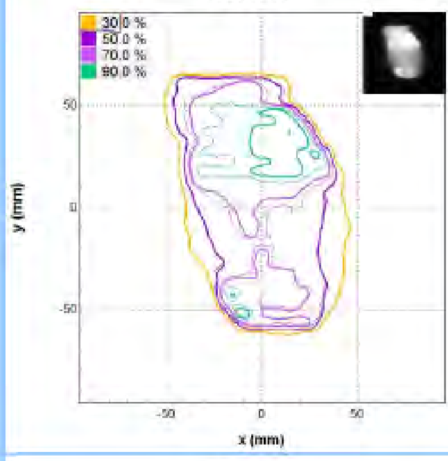
VIDAR RED - PORTRAIT 2% AND 2MM



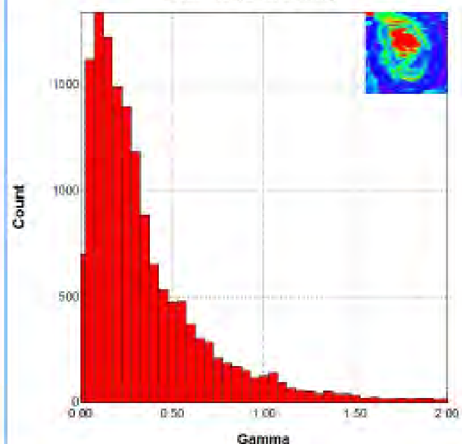
Patient Name	EBT34351-06, Portrait
Patient ID	Vidar red
Site	
Plan	
Field ID	g257
Database	...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
Case Folder	20061201.001
Report Folder	20070818.006

Pinnacle (thick lines)	100% = 60.030 cGy = 0.6003 cGy/MU for 100 MU
Dover (thin lines)	100% = 120.060 cGy = 0.6003 cGy/MU for 200 MU

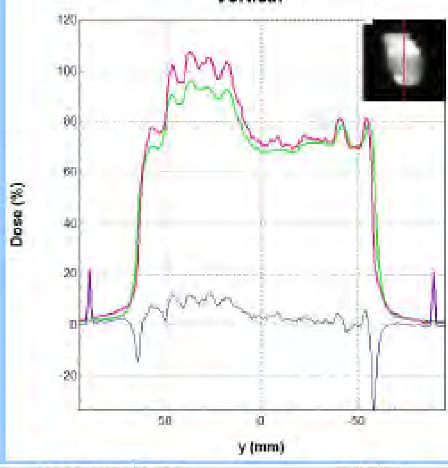
Isodoses



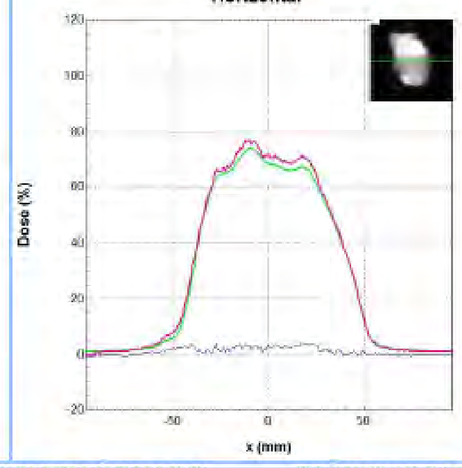
Gamma (2 %, 2 mm)



Vertical



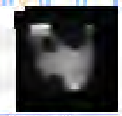
Horizontal



DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	84.9%	Pixels passing	90.1%	Pixels passing	91.8%	Translation	<-0.6, 0.0> = 0.6 mm
Pixels exceeding +3%	9.1%	Pixels failing	9.9%	Pixels failing	8.2%	Rotation	0.0°
Pixels exceeding -3%	6.1%	Mean	0.461	Mean	1.2 mm	Dose scaling	1.000
Mean	1.1%	StDev	0.676	StDev	1.5 mm		
StDev	4.0%						

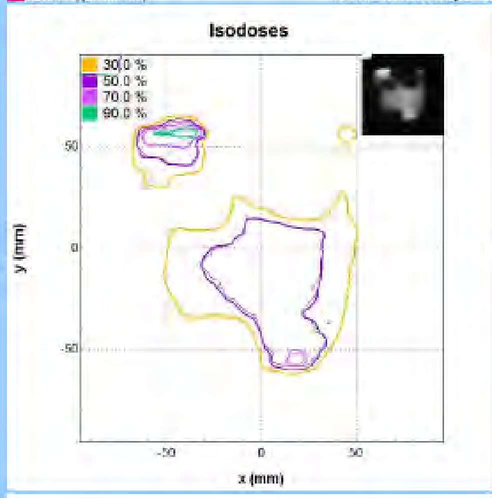
Physicist: Elekta Watts Date: 2007.08.18 13:08:59 FILMQA™ 1.1.0628

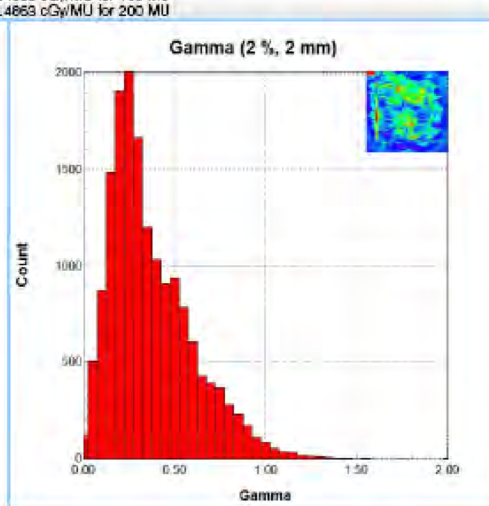
VIDAR RED - PORTRAIT 2% AND 2MM

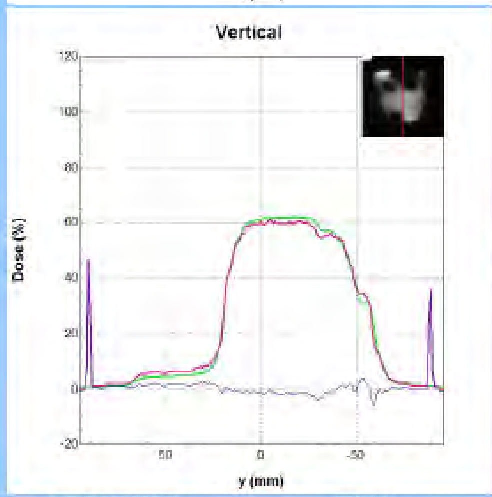


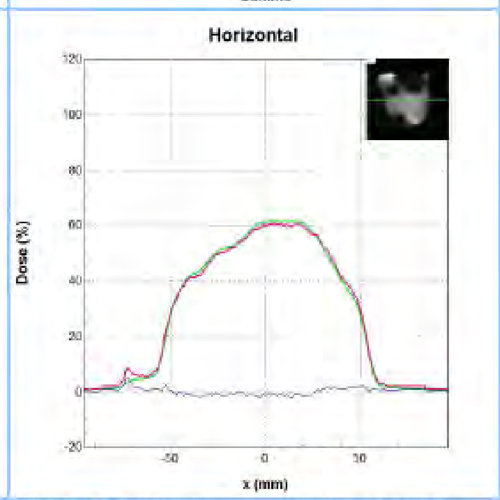
Patient Name	EBT34351-05, Portrait
Patient ID	Vidar red
Site	
Plan	
Field ID	g206
Database	...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
Case Folder	20061201.001
Report Folder	20070816.006

Pinnacle (thick lines)	100% = 48.630 cGy = 0.4863 cGy/MU for 100 MU
Dover (thin lines)	100% = 97.260 cGy = 0.4863 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	93.5%	Pixels passing	97.9%	Pixels passing	94.9%	Translation	<0.0, -0.6> = 0.6 mm
Pixels exceeding +3%	3.9%	Pixels failing	2.1%	Pixels failing	5.1%	Rotation	0.0°
Pixels exceeding -3%	2.6%	Mean	0.389	Mean	1.0 mm	Dose scaling	1.000
Mean	0.5%	StDev	0.262	StDev	1.1 mm		
StDev	3.2%						

Physicist: Elekta Watts Date: 2007.08.16 13:08:59

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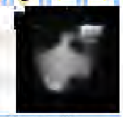
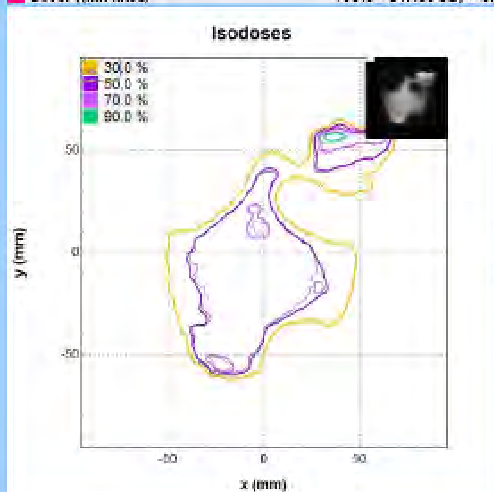
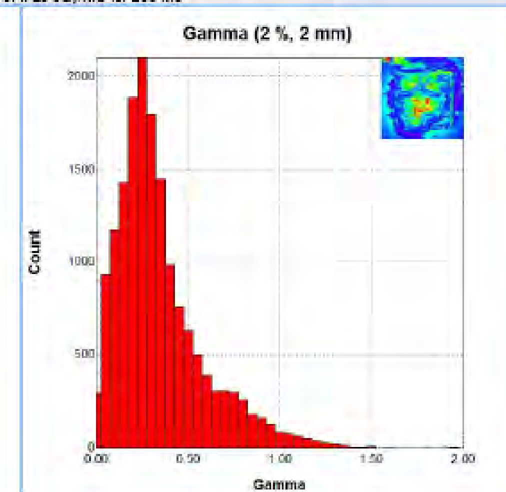
VIDAR RED - PORTRAIT 2% AND 2MM

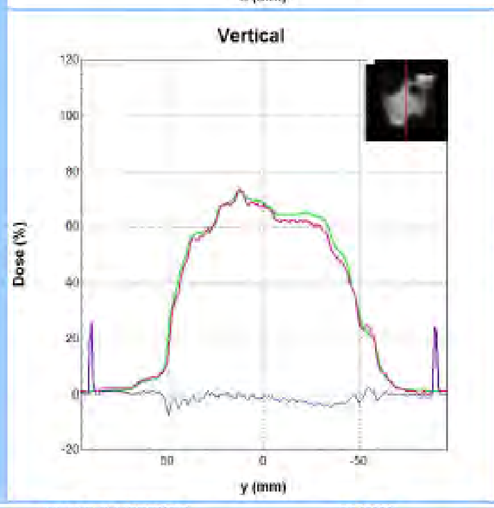
- **Patient Name** EBT34351-05, Portrait
- **Patient ID** Vidar red
- **Site**
- **Plan**
- **Field ID** g154
- Database ...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
- Case Folder 20061201.001
- Report Folder 20070816.006

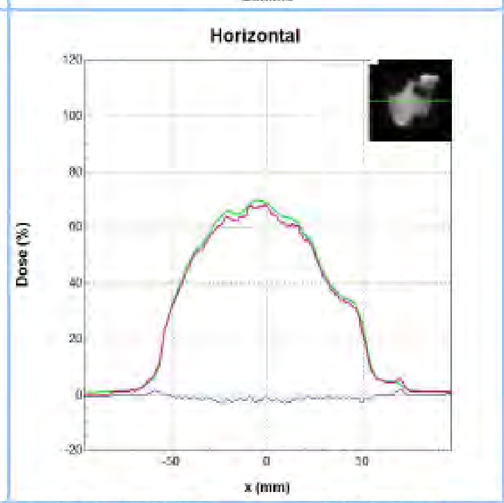


Pinnacle (thick lines) 100% = 47.200 cGy = 0.4720 cGy/MU for 100 MU
Dover (thin lines) 100% = 94.400 cGy = 0.4720 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	91.2%	Pixels passing	97.4%	Pixels passing	88.8%	Translation	<-0.3, -0.3> = 0.4 mm
Pixels exceeding +3%	5.3%	Pixels failing	2.6%	Pixels failing	11.2%	Rotation	0.0°
Pixels exceeding -3%	3.5%	Mean	0.349	Mean	1.4 mm	Dose scaling	1.000
Mean	-0.2%	StDev	0.287	StDev	2.0 mm		
StDev	3.2%						

Physicist: Elekta Watts **Date:** 2007.08.16 13:08:59

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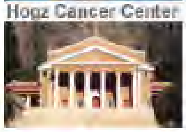
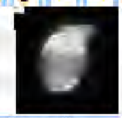
Hogz Cancer Center



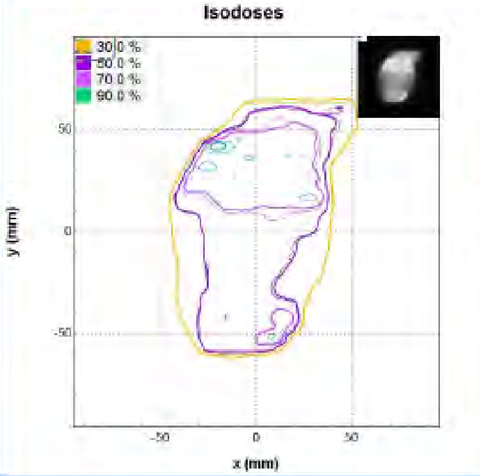
VIDAR RED - PORTRAIT 2% AND 2MM

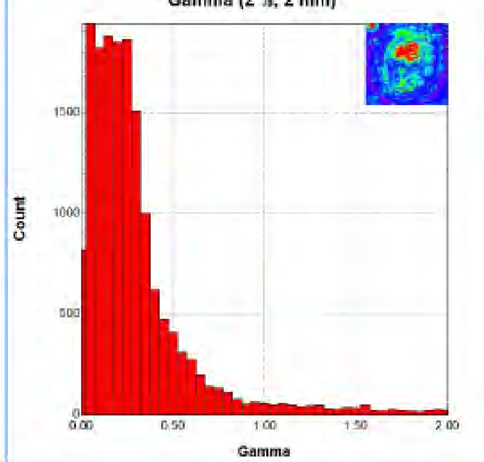
- Patient Name: EBT34351-05, Portrait
- Patient ID: Vidar red
- Site:
- Plan:
- Field ID: g103

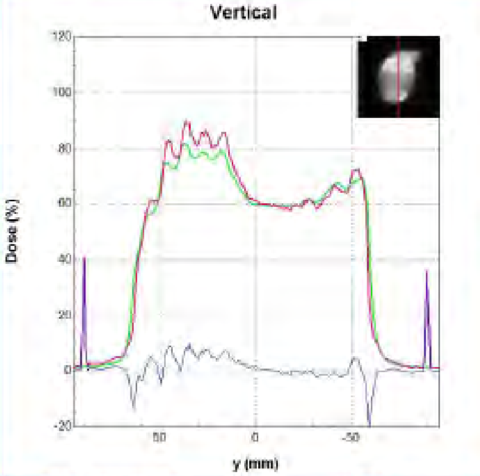


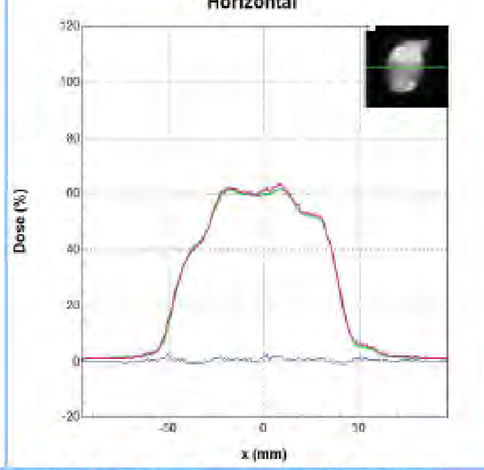
- Database: ...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
- Case Folder: 20061201.001
- Report Folder: 20070816.006

Pinnacle (thick lines)	100% = 60.180 cGy = 0.6018 cGy/MU for 100 MU
Dover (thin lines)	100% = 120.360 cGy = 0.6018 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	88.6%	Pixels passing	94.9%	Pixels passing	94.0%	Translation	<0.0, 0.0> = 0.0 mm
Pixels exceeding +3%	6.9%	Pixels failing	5.1%	Pixels failing	6.0%	Rotation	0.0°
Pixels exceeding -3%	4.6%	Mean	0.312	Mean	1.0 mm	Dose scaling	1.000
Mean	0.6%	StDev	0.372	StDev	1.3 mm		
StDev	3.4%						

Physicist: Elekta Watts Date: 2007.08.16 13:08:59

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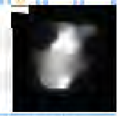
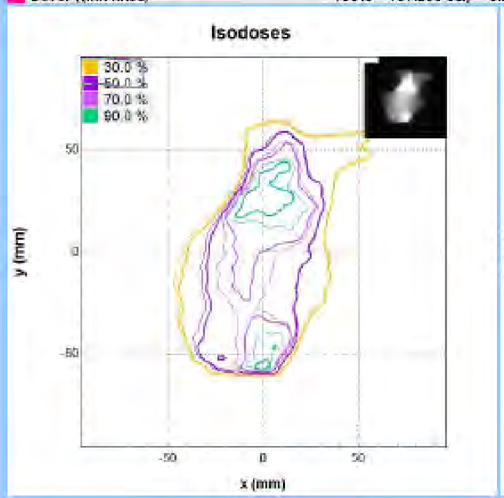
Hogg Cancer Center

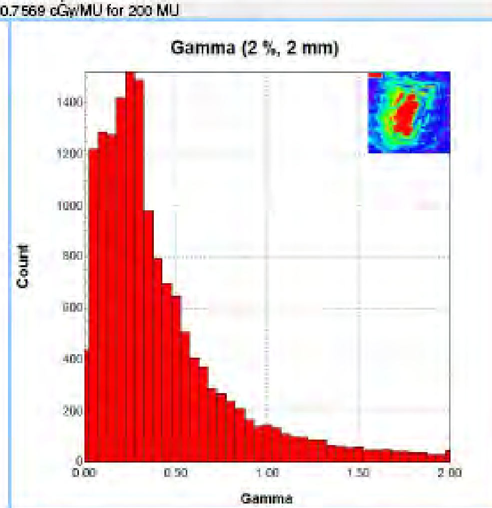
VIDAR RED - PORTRAIT 2% AND 2MM

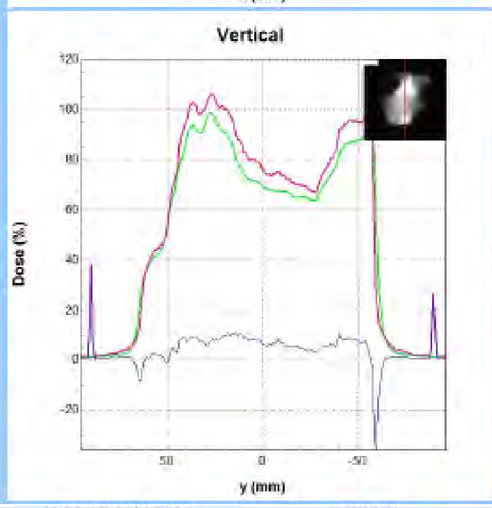


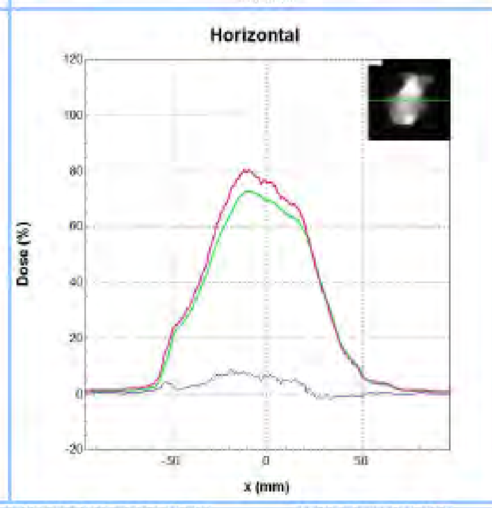
Patient Name	EBT34351-05, Portrait
Patient ID	Vidar red
Site	
Plan	
Field ID	g52
Database	...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
Case Folder	20061201.001
Report Folder	20070816.006

Pinnacle (thick lines)	100% = 75.690 cGy = 0.7569 cGy/MU for 100 MU
Dover (thin lines)	100% = 151.380 cGy = 0.7569 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	79.6%	Pixels passing	87.5%	Pixels passing	92.1%	Translation	<0.0, 0.0> = 0.0 mm
Pixels exceeding +3%	12.3%	Pixels failing	12.5%	Pixels failing	7.9%	Rotation	0.0°
Pixels exceeding -3%	8.2%	Mean	0.509	Mean	1.2 mm	Dose scaling	1.000
Mean	1.7%	StDev	0.623	StDev	1.3 mm		
StDev	4.4%						

Physicist: Elekta Watts Date: 2007.08.16 13:08:59

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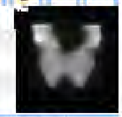
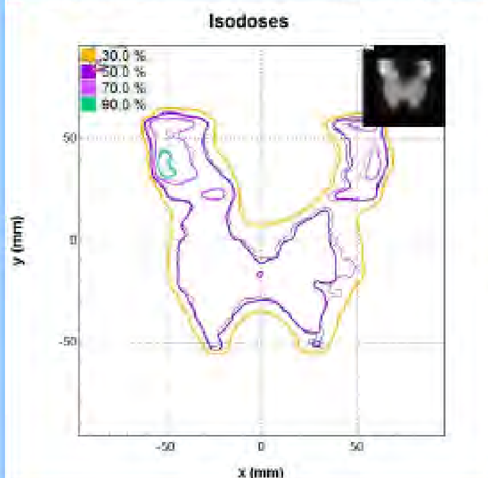
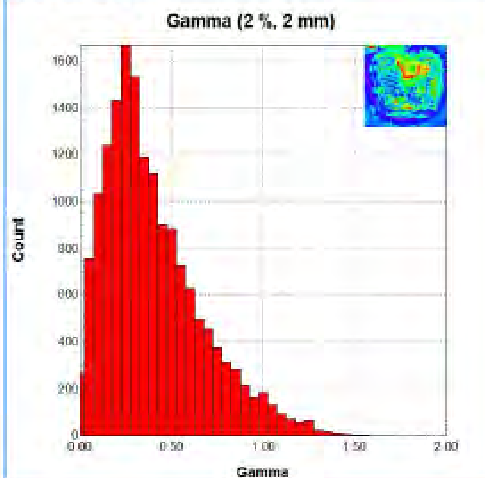
VIDAR RED - PORTRAIT 2% AND 2MM

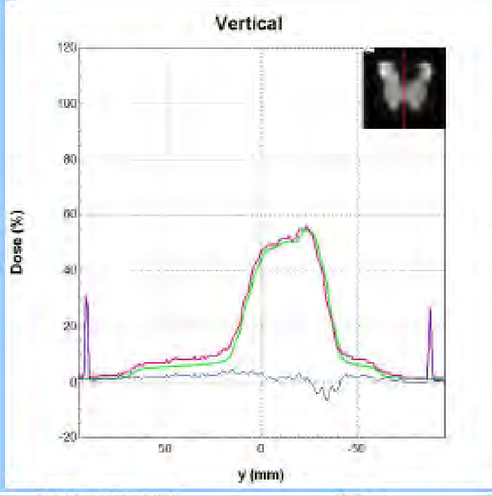
- Patient Name: EBT34351-05, Portrait
- Patient ID: Vidar red
- Site
- Plan
- Field ID: g0
- Database: ...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
- Case Folder: 20061201.001
- Report Folder: 20070816.006

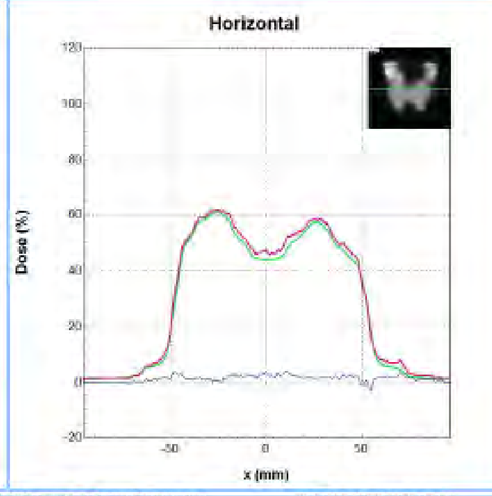


Pinnacle (thick lines)	100% = 43.770 cGy = 0.4377 cGy/MU for 100 MU
Dover (thin lines)	100% = 87.540 cGy = 0.4377 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	87.8%	Pixels passing	95.8%	Pixels passing	94.6%	Translation	<0.0, -1.5> = 1.5 mm
Pixels exceeding +3%	7.3%	Pixels failing	4.2%	Pixels failing	5.4%	Rotation	0.3°
Pixels exceeding -3%	4.9%	Mean	0.400	Mean	1.0 mm	Dose scaling	1.000
Mean	0.8%	StDev	0.286	StDev	1.2 mm		
StDev	3.2%						

Physicist: Elekta Watts   Date: 2007.08.16 13:08:59

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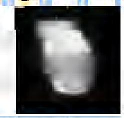
APPENDIX 3C

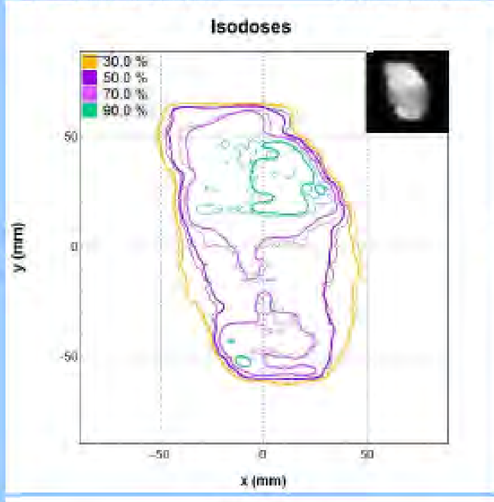
Evaluation of Measurement vs. Plan for EBT Films Digitized with the VXR-16 Scanner in Landscape Orientation

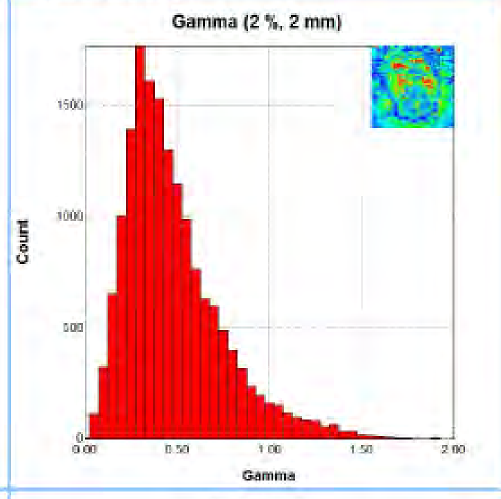
CAL-25 VIDAR VXR 16 2% AT 2MM

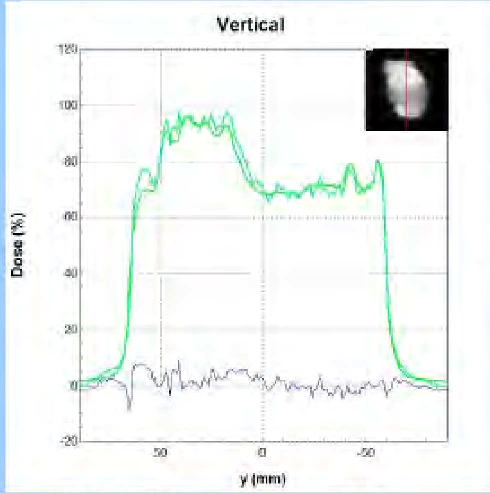
Patient Name	EBT34351,
Patient ID	VXR-16 Landscape cal-25
Site	
Plan	
Field ID	g257
Database	...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
Case Folder	20070721.002
Report Folder	20070818.007

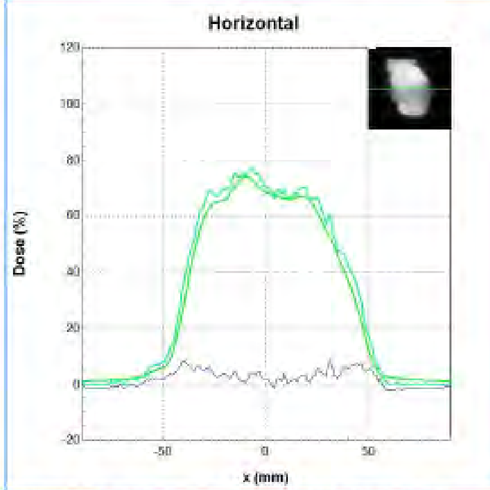


Pinnacle (thick lines)	100% = 60.030 cGy = 0.6003 cGy/MU for 100 MU
EBT - Landscape (thin lines)	100% = 120.060 cGy = 0.6003 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	81.2%	Pixels passing	94.4%	Pixels passing	94.5%	Translation	<-2.1, -0.6> = 2.2 mm
Pixels exceeding +3%	11.3%	Pixels failing	5.6%	Pixels failing	5.5%	Rotation	0.0°
Pixels exceeding -3%	7.5%	Mean	0.478	Mean	0.9 mm	Dose scaling	1.000
Mean	0.8%	StDev	0.264	StDev	1.4 mm		
StDev	3.0%						

Physicist: Elekta Watts Date: 2007.08.18 13:13:31

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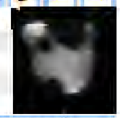
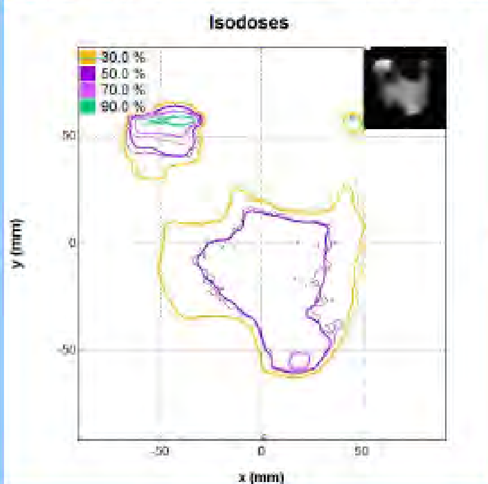
Hogg Cancer Center

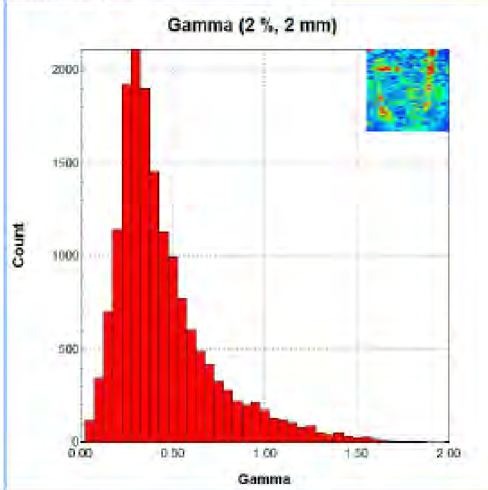
CAL-25 VIDAR VXR 16 2% AT 2MM

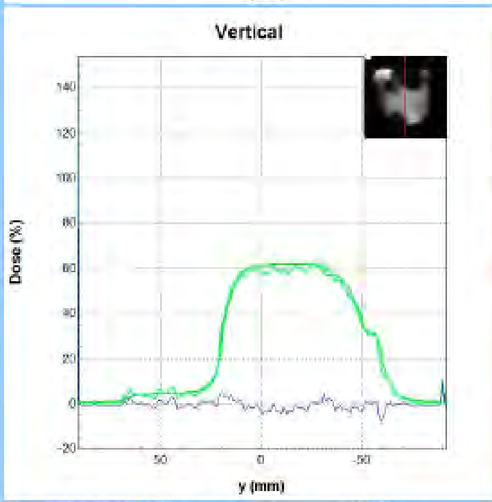
Patient Name	EBT34351,
Patient ID	VXR-16 Landscape cal-25
Site	
Plan	
Field ID	g206
Database	...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
Case Folder	20070721.002
Report Folder	20070818.007

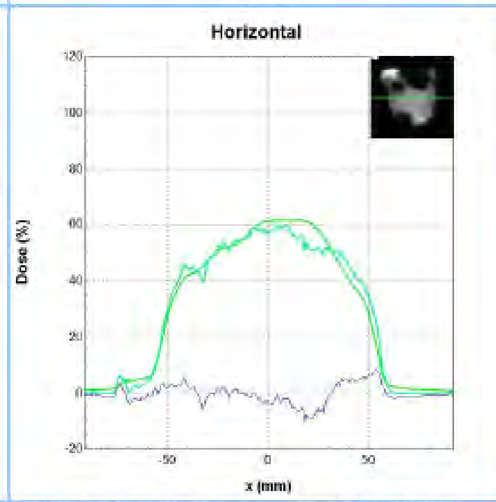


Pinnacle (thick lines)	100% = 48.630 cGy = 0.4863 cGy/MU for 100 MU
EBT - Landscape (thin lines)	100% = 97.260 cGy = 0.4863 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	82.6%	Pixels passing	93.8%	Pixels passing	94.7%	Translation	<-0.3, -1.7> = 1.7 mm
Pixels exceeding +3%	10.4%	Pixels failing	6.2%	Pixels failing	5.3%	Rotation	0.0°
Pixels exceeding -3%	7.0%	Mean	0.456	Mean	0.9 mm	Dose scaling	1.000
Mean	0.5%	StDev	0.319	StDev	1.4 mm		
StDev	3.2%						

Physicist: Elekta Watts Date: 2007.08.18 13:13:31

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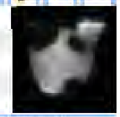
Hogz Cancer Center

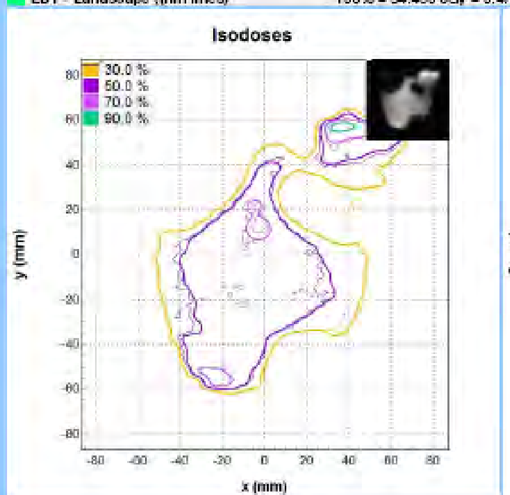
CAL-25 VIDAR VXR 16 2% AT 2MM

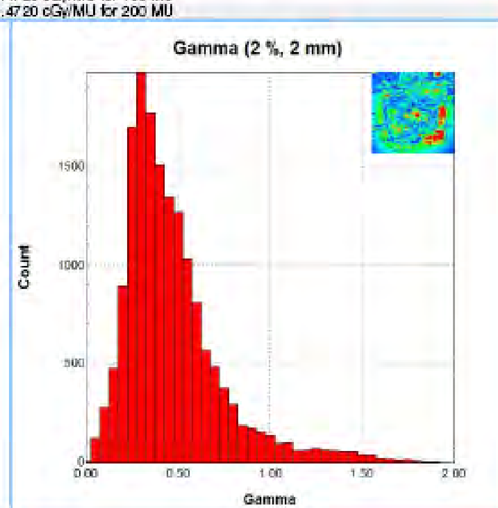
- Patient Name: EBT34351,
- Patient ID: VXR-16 Landscape cal-25
- Site
- Plan
- Field ID: g154

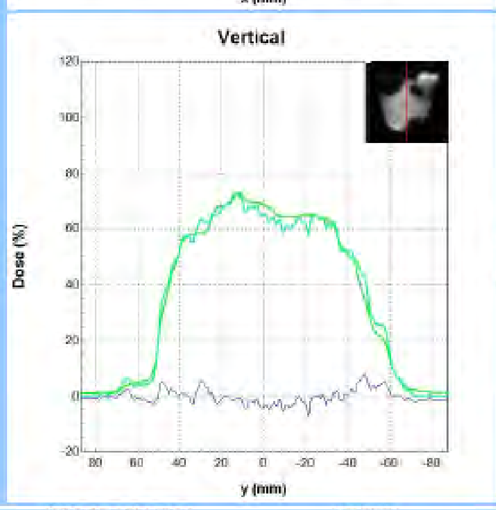


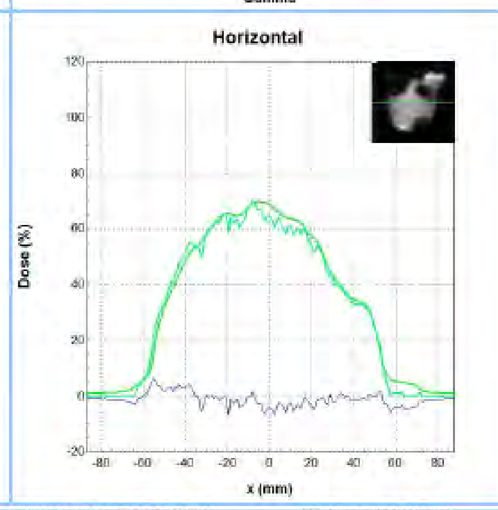
- Database: ...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
- Case Folder: 20070721.002
- Report Folder: 20070816.007

Pinnacle (thick lines)	100% = 47.200 cGy = 0.4720 cGy/MU for 100 MU
EBT - Landscape (thin lines)	100% = 94.400 cGy = 0.4720 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	82.8%	Pixels passing	94.3%	Pixels passing	92.3%	Translation	<-1.2, 2.7> = 3.0 mm
Pixels exceeding +3%	10.3%	Pixels failing	5.7%	Pixels failing	7.7%	Rotation	0.0°
Pixels exceeding -3%	6.9%	Mean	0.471	Mean	1.0 mm	Dose scaling	1.000
Mean	-0.3%	StDev	0.273	StDev	1.6 mm		
StDev	2.4%						

Physicist: Elekta Watts   Date: 2007.08.16 13:13:31

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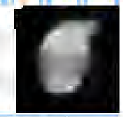
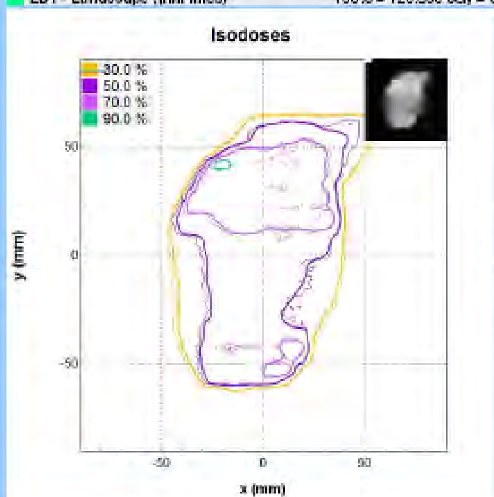
Hogg Cancer Center

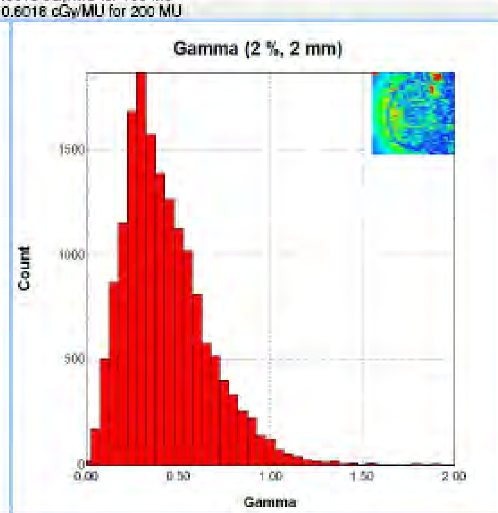
CAL-25 VIDAR VXR 16 2% AT 2MM

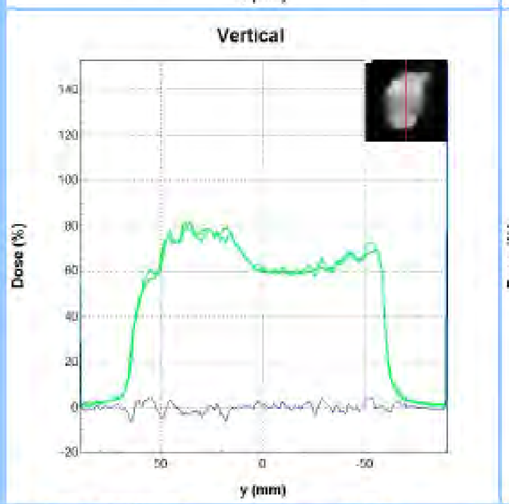
- **Patient Name** EBT34351,
- **Patient ID** VXR-16 Landscape cal-25
- **Site**
- **Plan**
- **Field ID** g103
- Database ...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
- Case Folder 20070721.002
- Report Folder 20070818.007

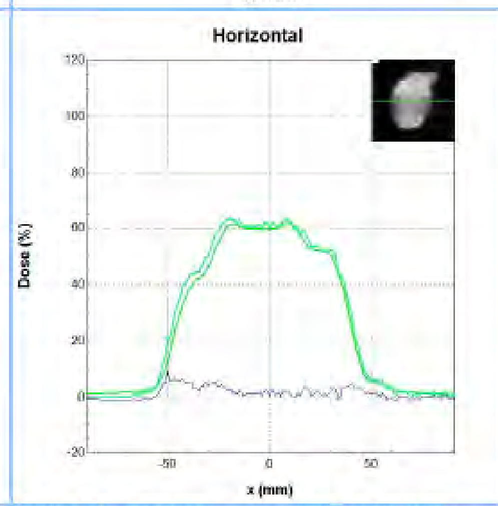


- **Pinnacle (thick lines)** 100% = 60.180 cGy = 0.6018 cGy/MU for 100 MU
- **EBT - Landscape (thin lines)** 100% = 120.360 cGy = 0.6018 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	86.4%	Pixels passing	97.1%	Pixels passing	88.9%	Translation	<-0.5, 0.0> = 0.5 mm
Pixels exceeding +3%	8.2%	Pixels failing	2.9%	Pixels failing	11.1%	Rotation	0.0°
Pixels exceeding -3%	5.5%	Mean	0.440	Mean	1.3 mm	Dose scaling	1.000
Mean	0.4%	StDev	0.287	StDev	2.4 mm		
StDev	2.7%						

Physicist: Elekta Watts **Date:** 2007.08.18 13:13:31

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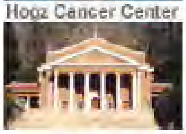
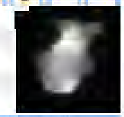
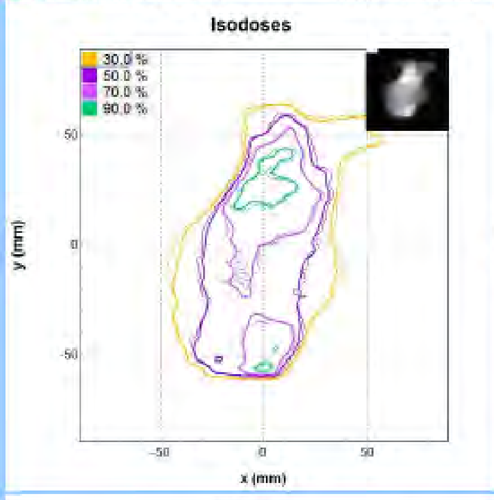
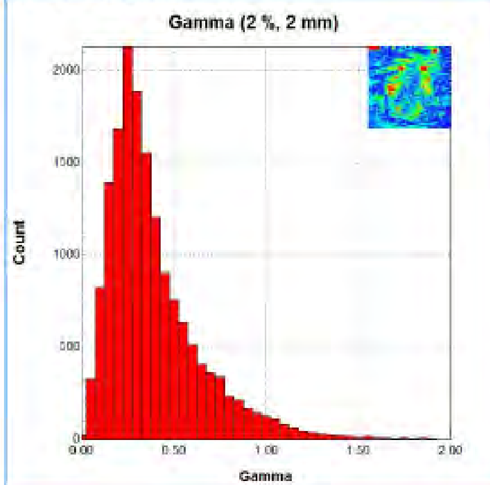


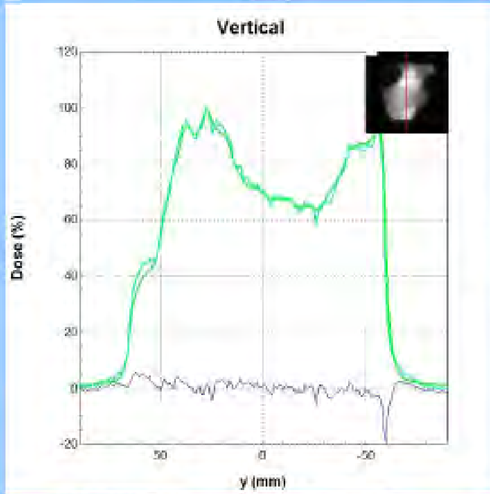
CAL-25 VIDAR VXR 16 2% AT 2MM

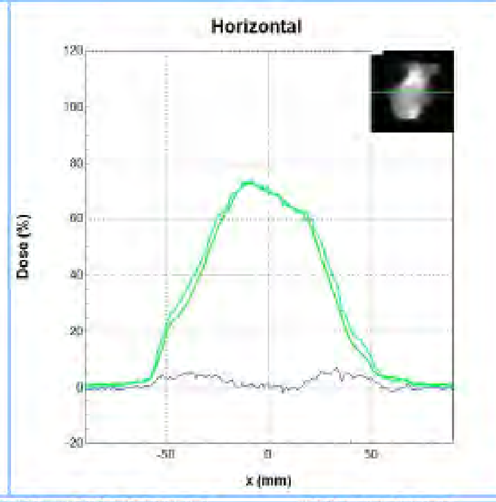
Patient Name	EBT34351,	
Patient ID	VXR-16 Landscape cal-25	
Site		
Plan		
Field ID	g52	
Database	...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb	
Case Folder	20070721.002	
Report Folder	20070818.007	

Pinnacle (thick lines)	100% = 75.690 cGy = 0.7569 cGy/MU for 100 MU
EBT - Landscape (thin lines)	100% = 151.380 cGy = 0.7569 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	85.8%	Pixels passing	95.7%	Pixels passing	97.7%	Translation	<-2.2, 0.0> = 2.2 mm
Pixels exceeding +3%	8.5%	Pixels failing	4.3%	Pixels failing	2.3%	Rotation	-1.0°
Pixels exceeding -3%	5.7%	Mean	0.412	Mean	0.7 mm	Dose scaling	1.000
Mean	0.9%	StDev	0.396	StDev	1.0 mm		
StDev	3.3%						

Physicist: Elekta Watts Date: 2007.08.18 13:13:31

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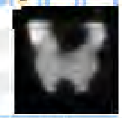
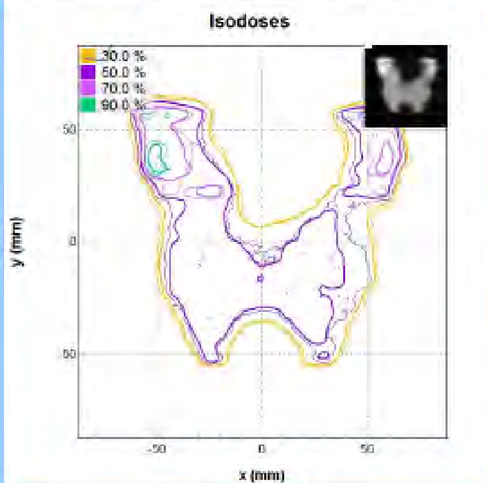
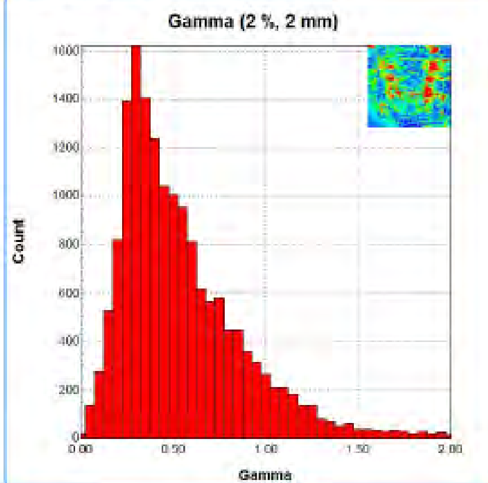
CAL-25 VIDAR VXR 16 2% AT 2MM

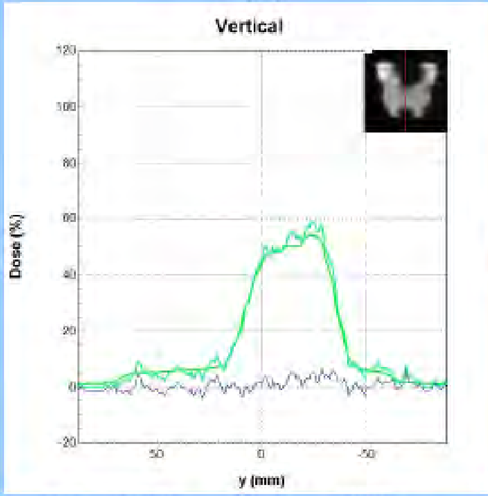


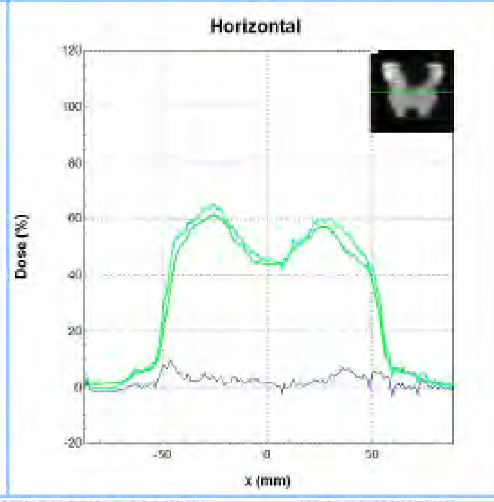
Patient Name	EBT34351,
Patient ID	VXR-16 Landscape cal-25
Site	
Plan	
Field ID	g0
Database	...ognition\FilmQA\FilmQA 1.1.0615_demo.mdb
Case Folder	20070721.002
Report Folder	20070818.007

Pinnacle (thick lines)	100% = 43.770 cGy = 0.4377 cGy/MU for 100 MU
EBT - Landscape (thin lines)	100% = 87.540 cGy = 0.4377 cGy/MU for 200 MU









DOSE-DIFFERENCE (tolerance = ±3%)		GAMMA (dose = ±2%, dist. = 2 mm)		DISTANCE-TO-AGREEMENT (dist. = 3 mm)		USER ADJUSTMENTS	
Pixels within ±3%	69.3%	Pixels passing	89.0%	Pixels passing	96.1%	Translation	<-0.7, -2.9> = 3.0 mm
Pixels exceeding +3%	18.4%	Pixels failing	11.0%	Pixels failing	3.9%	Rotation	-0.3°
Pixels exceeding -3%	12.3%	Mean	0.556	Mean	0.8 mm	Dose scaling	1.000
Mean	1.9%	StDev	0.386	StDev	1.2 mm		
StDev	3.9%						

Physicist: Elekta Watts Date: 2007.08.18 13:13:31

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