

Characteristics of a computed radiography system for radiation therapy

Background

Computed radiography (CR) is a well-established process for capturing digital radiographic images. CR has been widely accepted in radiology departments because it replaces film and film processing, produces high-quality digital images, and does not require expensive changes to x-ray rooms.

CR also provides the benefits associated with digital imaging, including simple transmission and storage of images, easier access to images, unlimited image copies, and digital manipulation of the images. The KODAK 2000RT CR System can bring these same advantages to therapy imaging.

CR systems employ an imaging plate made of special phosphors that trap and “store” radiation. Like a piece of film, the storage phosphor imaging plate is placed in a cassette.



Figure 1. *The KODAK 2000RT CR System comes with a scanner, computer, and monitor.*

After exposure the plate is scanned by the CR reader, which produces a digital image. Because the storage phosphor plates and reader can acquire simulation or portal images, CR systems can be installed wherever film is currently used.

The properties of storage phosphors have been known for many years (1,2) but Fuji was the first company to commercialize a CR device for radiographic imaging (3). Kodak, Agfa, and Konica also market CR systems for diagnostic radiography. These systems are all about the size of a small refrigerator. Lumisys introduced the first desktop-sized CR system in 1998, which became the ACR-2000 in the Kodak product portfolio after Kodak purchased Lumisys in 2000.

The application of CR to megavoltage imaging was first investigated in the 1980s (4–8). This work showed that CR could acquire high-quality portal images. The KODAK 2000RT CR System leverages this research and adds a significant improvement: variable gain scans. By adapting the sensitivity of the scanner to the image type, the same phosphor plates and CR scanner can be used to acquire both digital simulation and digital portal images.

The KODAK 2000RT CR System (Figure 1) includes an ACR-2000i scanner, a computer, and KODAK Radiation Oncology Software that initiates an image scan, processes the digital signals, and formats a DICOM image. Image review and manipulation tools enable the therapist to check the

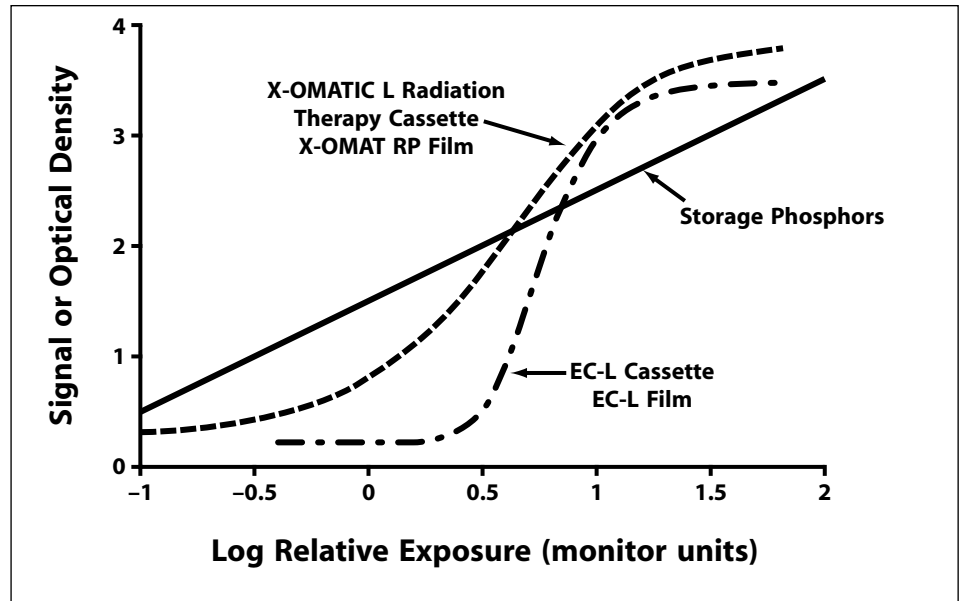


Figure 2. Storage phosphors (straight line) capture a wide range of exposures and produce a signal directly proportional to the energy they have stored. Portal film systems (S-shaped curves) are sensitive to only a narrow range of exposures. The wide-latitude response of the storage phosphors means that a high-quality image can be produced regardless of the relative amount of exposure to the plate.

digital images before sending them to a printer, a remote viewing workstation, or an image server. Images can be archived to the computer hard drive, a compact disk, a DVD, or any network or peripheral device. In addition, the 2000RT is small enough to be placed strategically in a facility so that therapists do not have to carry heavy cassettes to a central location for processing.

Storage Phosphor Imaging

In conventional imaging, film is exposed when it captures energy in its crystal structure as a latent image. The energy can either be light from intensifying screens (as in simulation

imaging and newer portal imaging systems) or electrons (generated by the copper and/or lead in older portal cassettes). The latent image on the film is developed into a visible image by the chemicals in a film processor.

In a similar manner, the CR imaging plate stores an image that is “developed” by the CR scanner. The imaging plate captures x-ray radiation or electrons in its phosphor crystal structure, creating a latent image. To readout an image the operator takes the exposed phosphor plate out of the cassette and places it in the input tray. Using the KODAK Radiation Oncology Software a portal or simulation scan is initiated. As the

laser beam in the CR reader scans across the imaging plate, the phosphors are excited and release the energy they have stored. This energy is emitted from the plate as a violet-blue glow. The strength of this glow is directly proportional to the amount of radiation absorbed. The phosphor glow is captured in the scanner and converted into a digital image. Because visible (“photo”) light excites (“stimulates”) the phosphors to glow (“luminesce”), this process is known as *photostimulated luminescence* and the phosphors are often called *photostimulable phosphors* or *storage phosphors*.

The laser scan does not extract all the energy stored in the crystals so the storage phosphor plate must be erased. After the plate is scanned it enters the eraser where it is flooded with bright fluorescent light. This intense light removes any residual energy remaining on the plate so that it can be used again. At the end of the erase cycle, the operator removes the storage phosphor plate from the eraser drawer and reloads it into a cassette. There is no evidence that the storage phosphors’ exposure or erasure response changes over time.

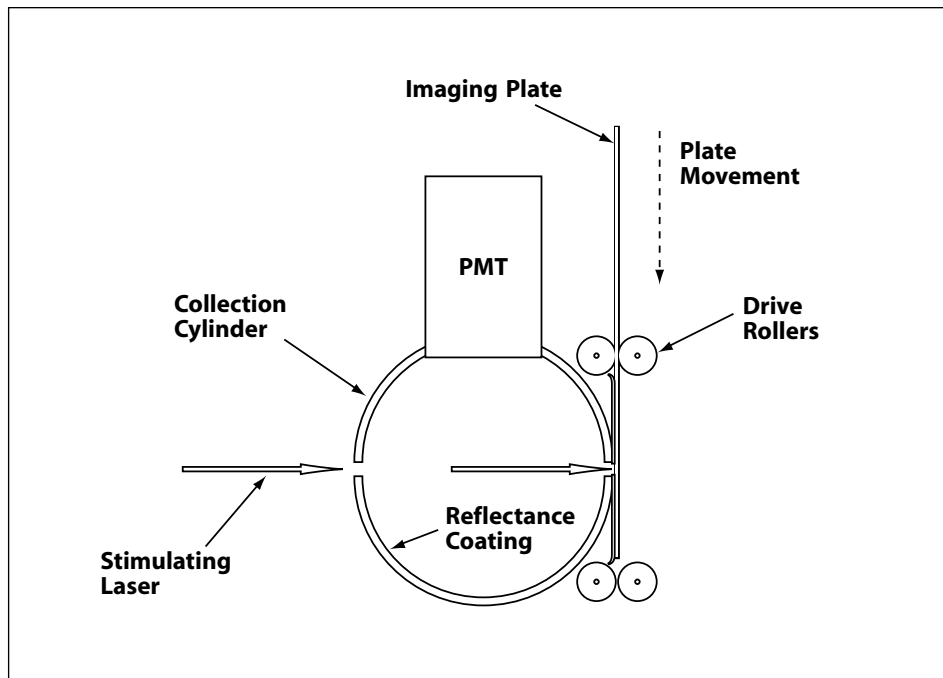


Figure 3. Cross-sectional diagram of the scanner showing the path of the laser and plate and the location of the photomultiplier tubes at the top of the collection cylinder. After scanning, the plate moves into an integrated eraser.

Storage Phosphor Plate Details

A useful property of storage phosphors is that they are sensitive to a wide range of radiation exposures. Regardless of the exposure, whether it is a low-level autoradiograph (9), a seconds-long nondestructive test image, or a portal verification image, the storage phosphors will capture the exposure.

In conventional film imaging the technique must match the sensitivity and contrast of the film system. Film has a limited dynamic range, and too little or too much exposure will make important anatomic details too light

or dark. If this happens the exam must be repeated. As shown in Figure 2, portal films have a very narrow dynamic range compared with the storage phosphor plates used in CR (a similar relationship holds true for the phosphor plates and simulation films). When the storage phosphor’s wide latitude is combined with digital image processing, simulation and portal images with good contrast can be produced regardless of the exposure.

Handling does not harm the storage phosphors or the latent image stored on the plate. All storage

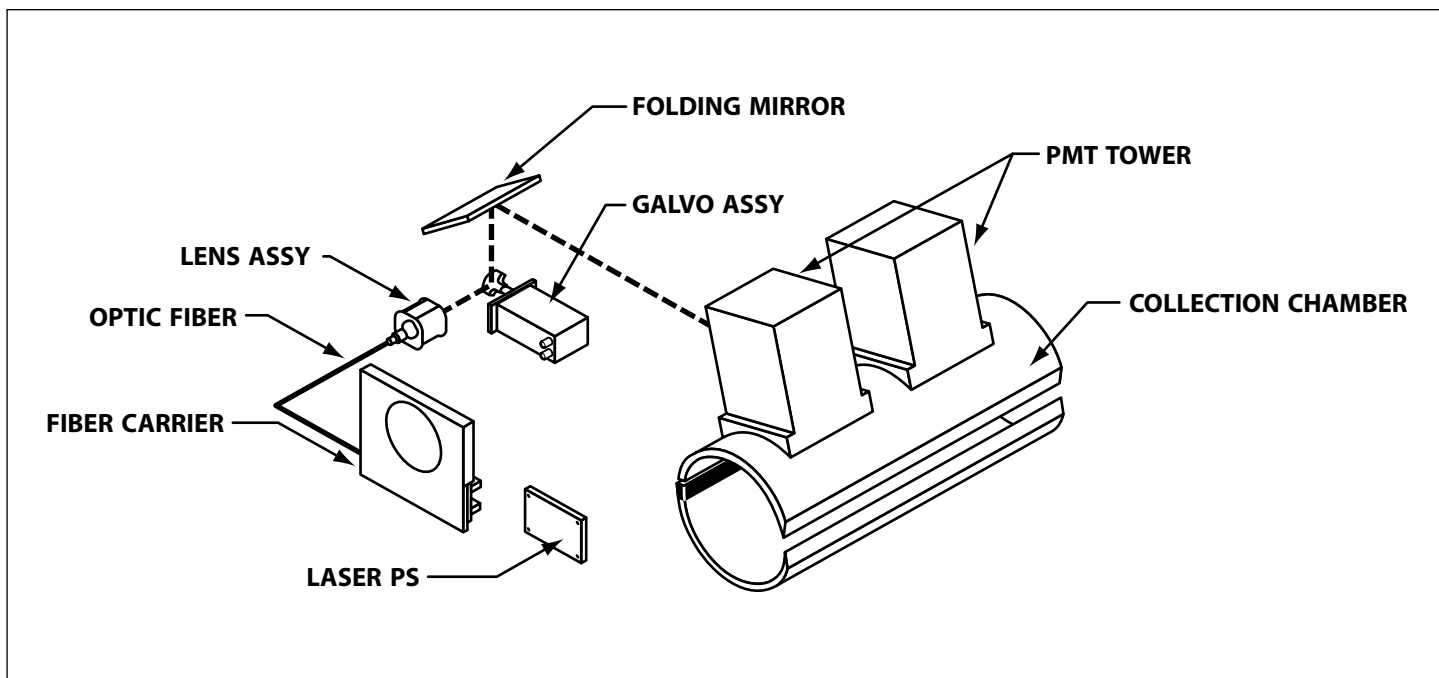


Figure 4. The laser beam is directed through an optical fiber and lens assembly onto a galvanometer-driven mirror. Another mirror directs the laser beam through the openings in the collection cylinder and onto the phosphor plate.

phosphors (europium-doped barium fluorohalides) are made in part with iodine. Over time if the iodine comes in contact with moisture the phosphors will yellow. Partly because of this, all storage phosphor plates have a protective overcoat and sealed

edges that prevent moisture from coming into contact with the phosphors. The protective overcoat reduces the probability that handling, scratches, or dust will damage the phosphors and be visible in the digital image. Regular cleaning of the

imaging plates with ethyl alcohol and a lint-free wipe is an essential quality-control practice for any CR system.

Brief exposure to roomlight does not affect the image stored in the phosphor plate. While fluorescent light is used to erase the residual image after scanning, this very high-intensity light is in close proximity to the plate surface for almost 30 seconds. In contrast, a few seconds under roomlighting will not be sufficient to erase or significantly alter the image on an exposed plate.

Table I. Operating characteristics of the 2000RT CR system. While the scanner can produce 2048 x 2510 pixel (10 MB) images, 1024 x 1255 pixel (2.6 MB) images are most commonly acquired in radiation therapy.	
Laser source	658 nm diode, 35 mW
Laser spot size at imaging plane (FWHM)	87 μ m
Image bit depth	12 bits, logarithmic input
Pixel size (35 x 43 cm plate)	0.34 mm
Image size	1024 x 1255
Scan time (35 x 43 cm plate)	25 seconds
Erase time	30 seconds
Scanner footprint	21 inches wide x 27 inches deep

Scanning Details

The only moving parts in the integrated plate reader and eraser are the three sets of rollers that move the plate and the mirror that deflects the scanning laser beam across the plate. The laser scans the exposed phosphor plate as it moves at constant speed through the reader (Figure 3).

Figure 4 shows the path of the laser beam in the reader. The red 658 nanometer (nm) 35 milliwatt (mW) laser diode is focused by an optical fiber and lenses, then directed onto a galvanometer-driven mirror, through the collection cylinder, and onto the phosphor plate. As the plate moves, the mirror scans the focused laser beam across the plate in a raster pattern, retracing between each scan line. As the laser moves across the plate, the integrating cylinder collects the stimulated luminescence. This integrating cylinder is similar to those used in laser film digitizers and has a special isotropic coating that captures the stimulated light over a wide collection angle. At the top of the collection cylinder are two photomultiplier tubes (PMTs). PMTs convert light into voltage signals, which are logarithmically amplified and digitized. The sampling process produces 1024 pixels for each scan

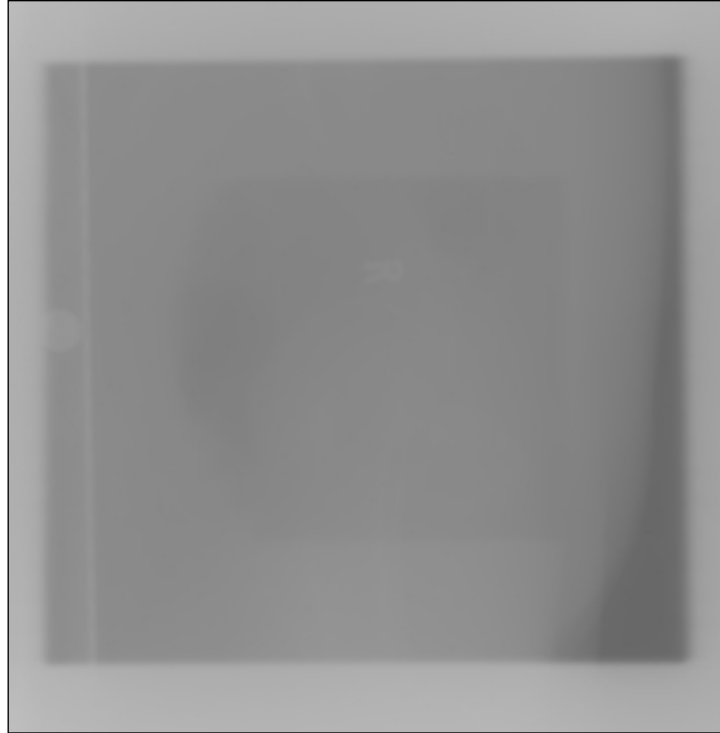


Figure 5. *A raw, unprocessed portal localization image.*

line. Each of these pixels is quantized to 4096 possible shades of gray. The 12-bit digital image is then transferred to the computer for image processing.

Table I summarizes the operating characteristics of the 2000RT CR system. Because imaging plates can be scanned and erased concurrently, the plate throughput is more than 70 plates an hour.

Characteristic Response

Unlike film, storage phosphors respond to a wide range of radiation exposures. The CR system must, therefore, be calibrated to respond to the exposures found in both portal and simulation

images. This requires tuning the PMT gain to the amount of light emitted by the plates.

Portal images are acquired at a much higher exposure level than simulation images. Consequently, the light released by the storage phosphors in a portal image is much brighter than the light released by a simulation image. When a portal scan is selected, the PMT sensitivity is about 1% of the simulation scan setting. Varying the PMT gain prevents the system from being overwhelmed by the photostimulated light in a portal image or being too insensitive to detect the luminescence emitted from a simulation exposure.

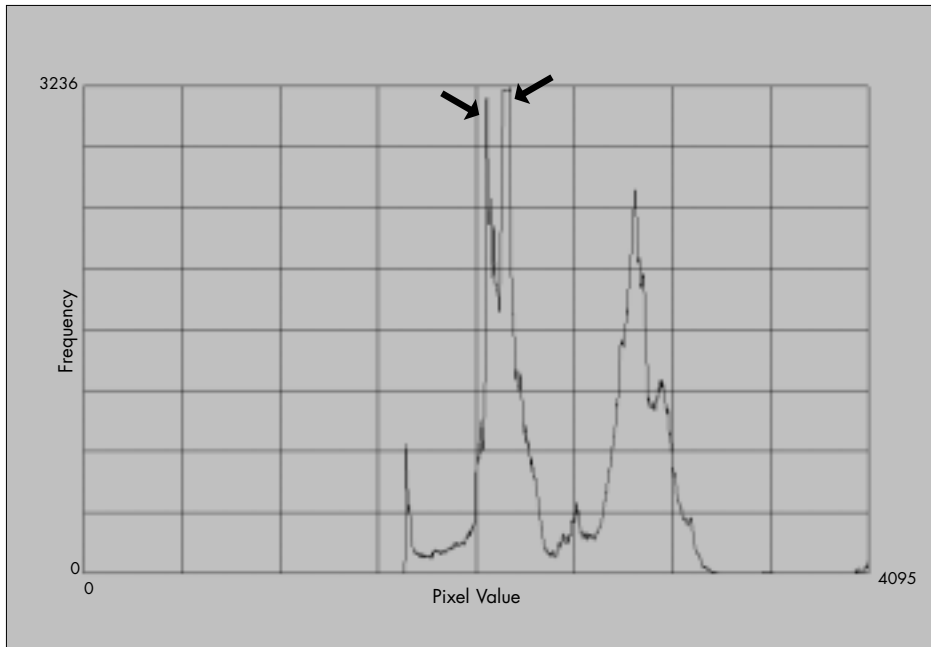


Figure 6. The signal distribution in Figure 5. The rightmost broad peak in the histogram represents scattered radiation outside the collimation. The two spikes (see arrows) reflect the treatment (left arrow) and open field (right arrow) exposures in the image. The narrow data range is indicative of a high-energy portal image and reflects how much the contrast must be enhanced in order to show the difference between bone and soft tissue in the image. In simulation images the histogram has a much broader distribution of image signals.

The system simulation scan calibration requires setting an 8 mR exposure (85 kVp with 1 mm added copper filtration and a 10-minute delay between exposure and readout) to a signal level of 600. The calibration can be influenced by a number of factors including variations in the sensitivity of the storage phosphor plate used for calibration, the delay time between storage phosphor plate exposure and scanning, or the x-ray beam energy spectrum. These factors should always be taken into consideration when setting or testing the system calibration.

With this calibration, the relationship between kilovoltage x-ray exposure and pixel code values (or signal level) is:

$$\text{Pixel code value} = 1000 \times \log(32/\text{exposure in mR})$$

This equation reflects:

- the logarithmic amplification of the signal
- the 12-bit image data is captured over four decades of exposure (from 0.0032 mR to 32 mR)
- that code values decrease with increasing exposure

For portal imaging, the gain of the PMTs is decreased to 1% of the sensitivity for simulation images. This means that for the same exposure the pixel code values are offset by about 2000 counts from simulation scans. However, the image data is still detected over four decades of exposure which is why it is possible to capture both portal localization and portal verification images with the same portal scan button.

Image Processing

The CR reader captures data over four decades of exposure; consequently there is no inherent contrast in the image data. The raw unprocessed image appears extremely flat and gray (Figure 5). The image must be manipulated to bring out an appropriate level of contrast for interpretation. This digital image enhancement involves remapping each pixel code value through a look-up table.

The first step in image processing is to analyze the raw image histogram (Figure 6). A histogram depicts the distribution of the 4096 grayscale values in the image. The histogram data is combined with edge detection to identify the exposed region on the plate. Everything outside the collimation is then masked out and only the exposed area of the plate is used for further analysis (Figure 7).



Figure 7. *The solid gray area outside the collimation shows that the image processing algorithms have correctly identified the unexposed areas of the image. The image analysis is only based on the localization exposure and not scattered or background signals.*

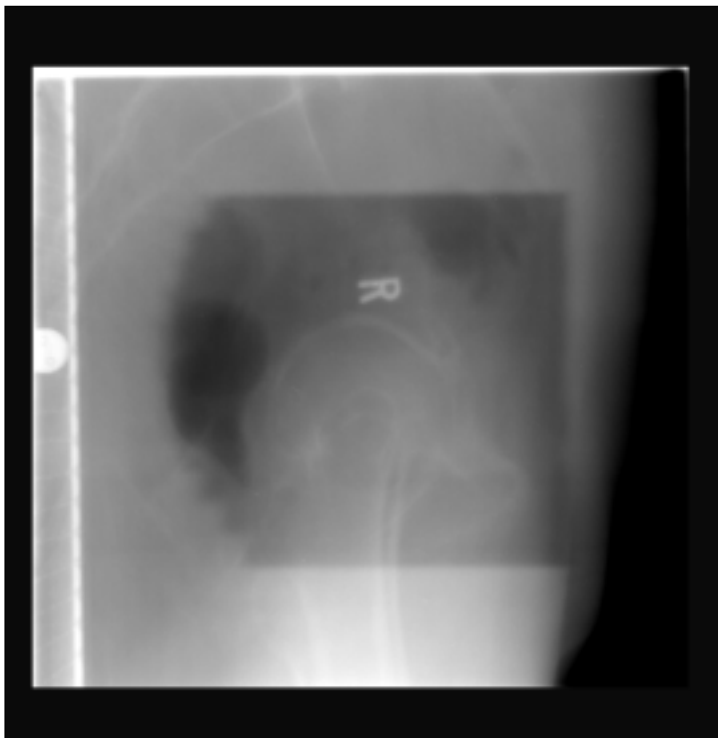


Figure 8. *The detail in the lateral pelvis image is easily visible in the processed image. Because the image data has been rescaled it is easy to further adjust the image contrast and brightness. Black masking applied to the area outside the exposure also improves the image contrast.*

The next step is to identify the start and end of the image data in the histogram. A tonescale algorithm then rescales the relevant image data so that the processed image appears with a window and level setting of 2048 and 2048. This produces an image with appropriate contrast, although further window and level adjustments can be made to the image (Figure 8).

Conclusion

The KODAK 2000RT CR System brings many advantages to radiation therapy departments besides digital therapy imaging. The CR system fits into current workflow and the KODAK Radiation Oncology Software is easy to use, so little training is necessary. Image processing provides consistent high-contrast images in both simulation and portal imaging applications while the wide latitude response of the storage phosphors enables a reduction in repeat exams. The 2000RT is small enough to place conveniently near the treatment rooms, reducing the time therapists spend away from patients. Finally, one CR system can support multiple treatment rooms and simulators, making digital imaging affordable.

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