The Nanox Source in Pulsed Fluoroscopy

ALARA

One of the essential principles in the X-ray technologist's work is the ALARA principle. ALARA is an acronym for "As Low As Reasonably Achievable". This is a general principle guiding radiation exposure. ALARA's goal is to keep exposure to radiation dose as low as is possible for each procedure while obtaining needed clinical information. Correctly applying this principle is even more critical in children, who are more sensitive to radiation than adults.

The X-ray Tube

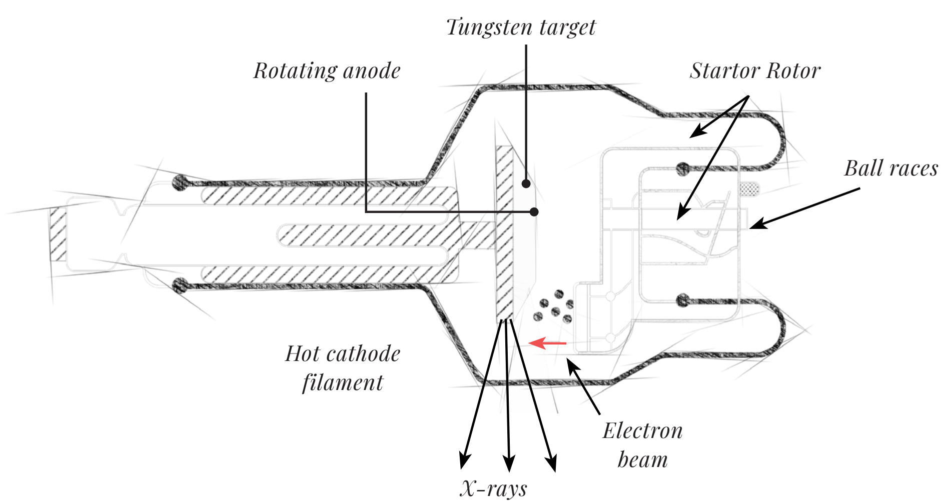


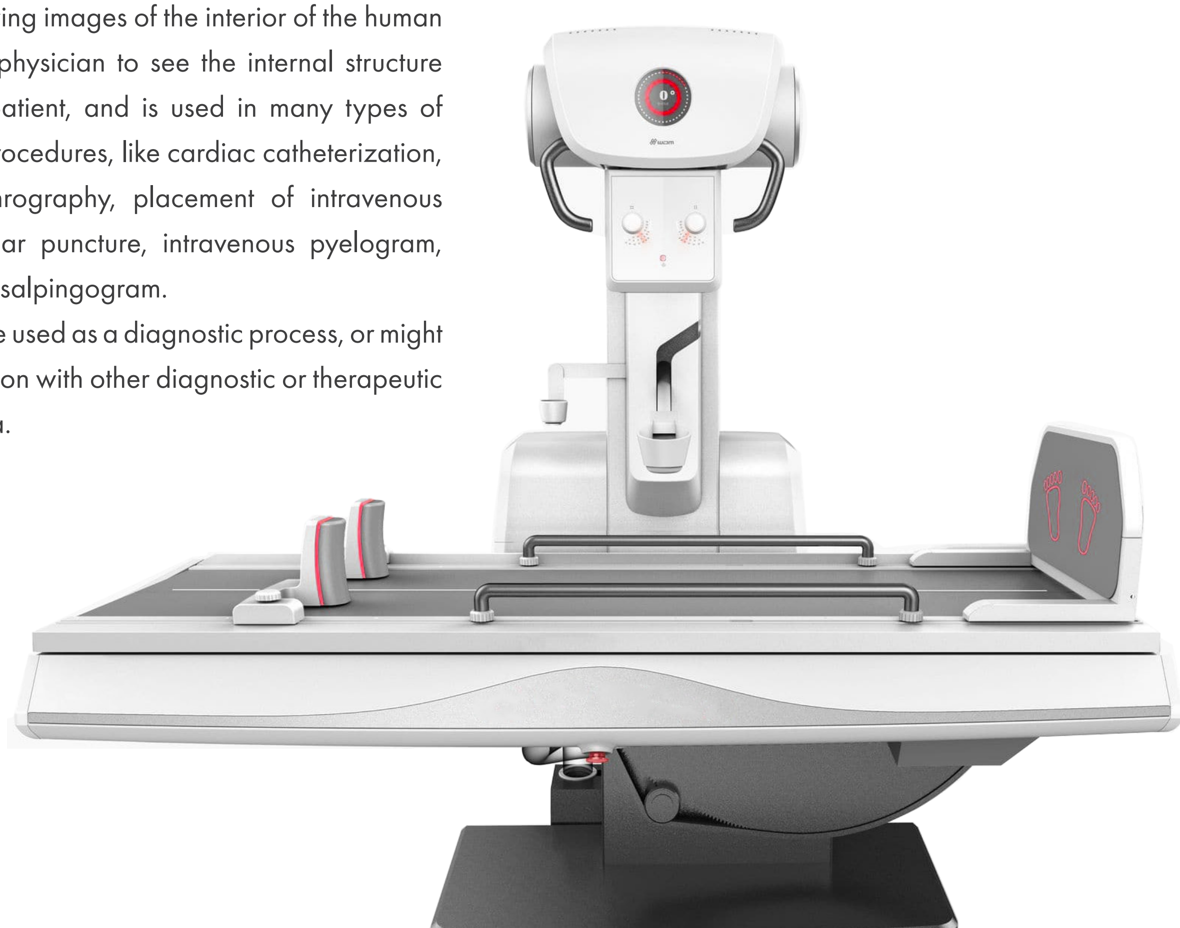
Figure 1 -Basic X-Ray tube

The process by which a standard Cathode emits the free electrons when it is heated is called thermionic emission. In X-ray tubes using thermionic Cathodes, the Cathode filament is electrically heated to incandescence, so it emits free electrons from the metal surface. The number of free electrons emitted by the Cathode depends on two factors: the amount of heat applied and the work function.

The higher level of heat is applied, the more electrons are emitted. Similarly, if a lower temperature is applied, fewer free electrons are emitted. The minimum amount of energy required to remove the free electrons from the metal is called the work function. Metals with low work function will require less heat energy to emit free electrons. On the other hand, metals with high work function will require more heat energy to emit the free electrons. Most thermionic emitters used in X-ray production include oxide-coated Cathode, tungsten, and thoriated tungsten.

Fluoroscopy

Fluoroscopy is an imaging technique that uses X-rays to obtain real-time moving images of the interior of the human body. It allows the physician to see the internal structure and function of a patient, and is used in many types of investigations and procedures, like cardiac catheterization, barium X-rays, arthrography, placement of intravenous (IV) catheters, lumbar puncture, intravenous pyelogram, biopsies and hysterosalpingogram.
Fluoroscopy might be used as a diagnostic process, or might be used in combination with other diagnostic or therapeutic procedures or media.



Pulsed fluoroscopy

Based on the ALARA principle, one of the main techniques used to lower radiation in fluoroscopy is to use an operational mode called pulsed fluoroscopy. Older-generation systems used continuous fluoroscopy. This was a constant-on radiation mode, where the X-rays are generated continuously for the clinician to see real-time X-ray Imaging.

Continuous fluoroscopy technology was eventually replaced with pulsed fluoroscopy, which was an improvement in terms of dose reduction. In this mode, X-ray beams are time-separated: the generator switches the beam on and off in pulses, with varying amounts of pulses per second. This method can drastically lower the patient and staff dose while still providing sufficient time-sensitive information to the clinician. Figure 2 depicts the patient dose saving for standard pulsed fluoroscopy modes.

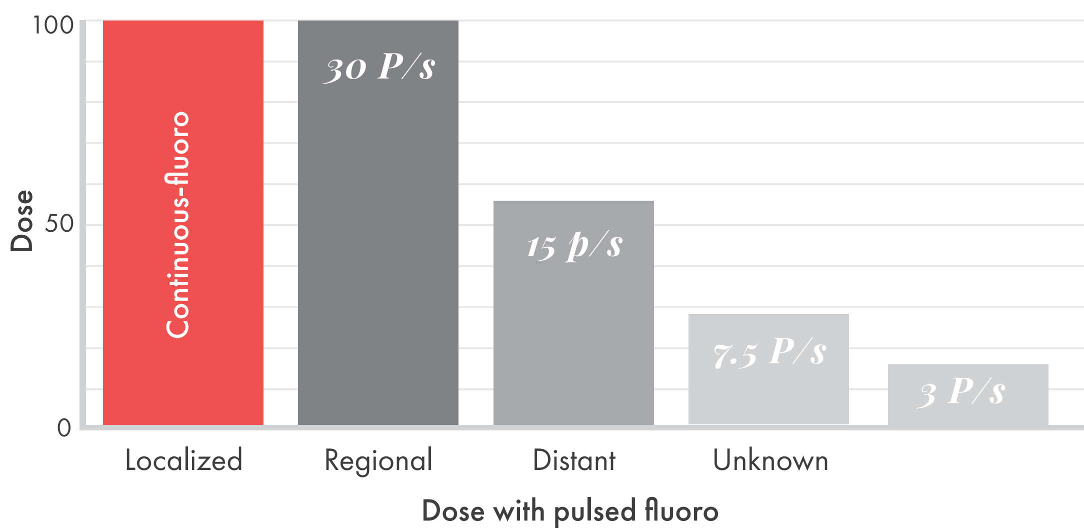


Figure 2 – Dose with Pulsed fluoroscopy. reference: IAEA Training course on radiation protection for non-radiologists

Most fluoroscopy procedures can be accurately performed using pulsed fluoroscopy as low as 7.5 p/s (pulses per second). For example, for applications like DSA (Digital Subtraction Angiography), where exams tend to be lengthy, or when imaging young children, pulses in the range of 3-7.5p/s may be used. For applications where high-speed motions are required for capture, 15p/s or more may be used. One exception to this is the Videofluoroscopic Swallowing Study (VFSS)[12], which requires a pulse rate of at least 30 pulses per second to adequately visualize the patient's swallowing mechanism. It is worth noting that when using pulsed fluoroscopy, the beam is off between pulses, but the image is displayed continuously and updated with each pulse to prevent image flickering on the operator screen.

[1] American Speech-Language Hearing Association guideline for speech-language pathologists performing videofluoroscopic swallowing studies.
[2] https://www.imagewisely.org/Imaging-Modalities/Fluoroscopy/Diagnostic-Procedures

X-ray Pulse Creation Mechanisms

kV-switching

To produce the pulsed X-ray bursts, manufacturers may opt to use high-speed kV switching. In this operation mode, the high voltage applied between the Anode and the Cathode is rapidly pulsated on and off, resulting in pulsed X-ray bursts.

However, due to the inherent capacitance of the high-voltage cables that feed the tube, a phenomenon called "ramp-and-trail effect" causes the X-ray pulsed to have leading and trailing edges, which effectively increase the pulse width. This results in an associated decrease in motion sharpness and an increase in patient dose. These are depicted in red in Figure 3 – Pulsed fluoroscopy using generator-controlled pulses.

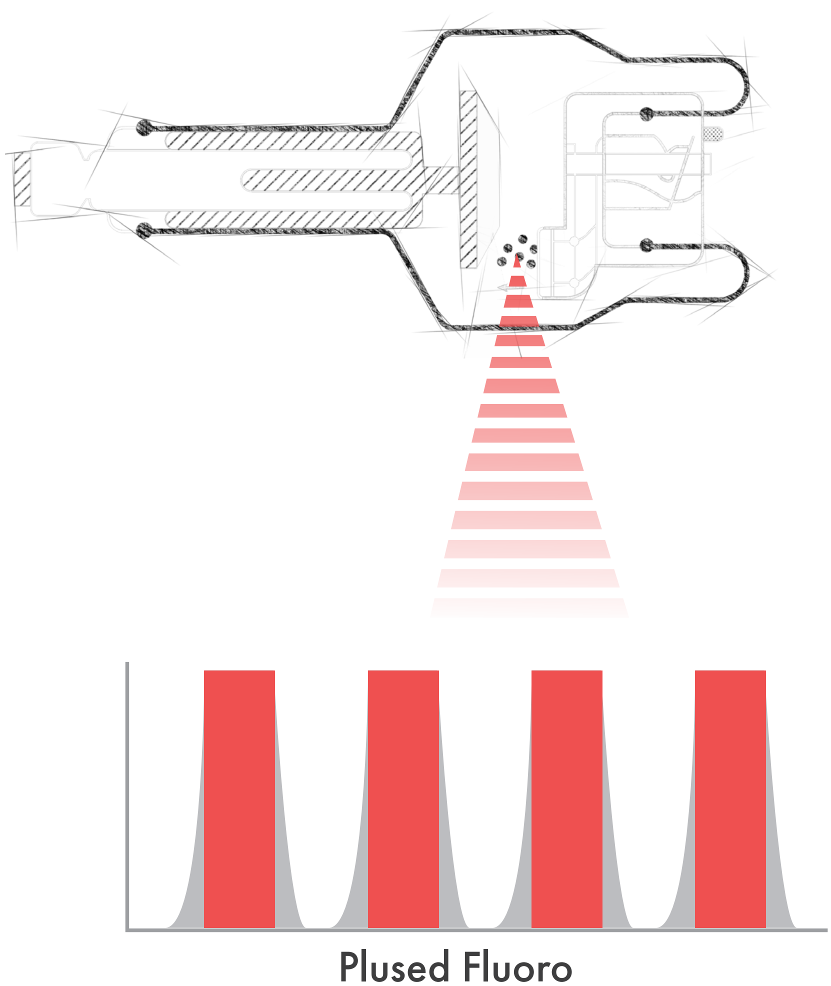


Figure 3 – Pulsed fluoroscopy using generator-controlled pulses

Grid controlling of X-ray Pulses

Generally speaking, Grid Control is a method for controlling an electron current in a vacuum. In the context of X-ray production in an X-ray tube, a metal lattice is placed in the path of electrons coming out of the Cathode and traveling down the electrical potential to the Anode.
The lattice (or "grid") can be placed under electrical potential and thus block the electron stream - or let it pass through.

This grid typically has a neutral electrical potential so that the X-ray production can take place. The holes of the grid are relatively large, so the free electrons move easily from Cathode to Anode through the openings of the control grid. However, one can decide to cut the exposure by introducing a negative charge on the grid. This will then stop (repel)

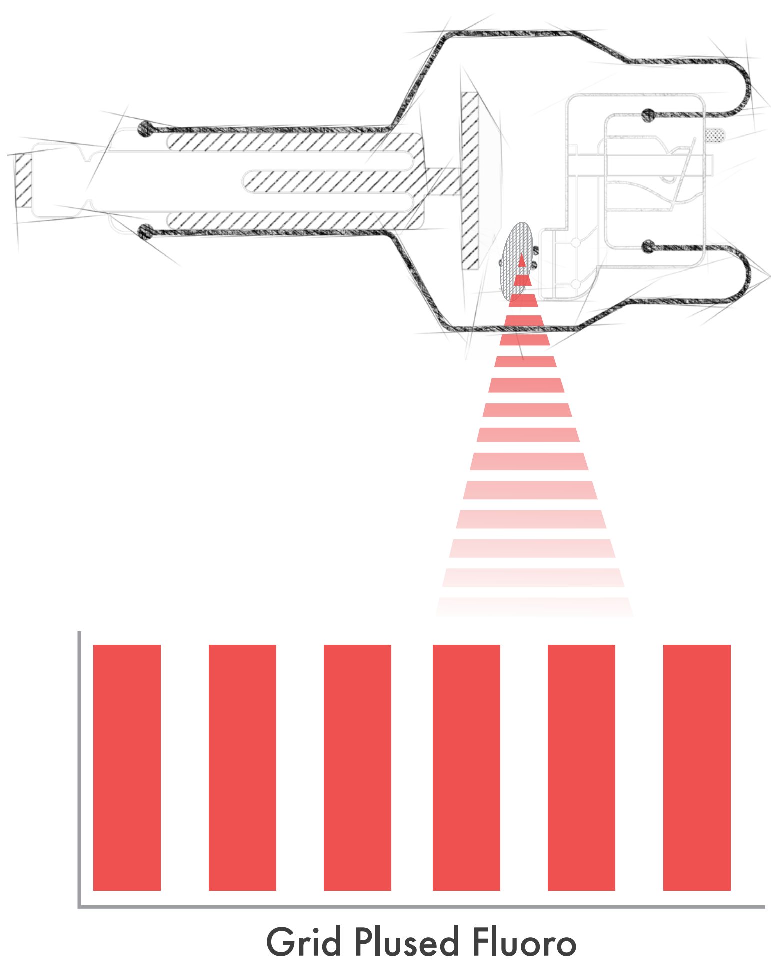


Figure 4 - Grid controlled X-ray tube

the electrons from reaching the Anode, and thus, X-ray production shall be stopped.

Since applying the control voltage to the grid is done using a relatively low voltage and practically zero current, the X-ray tube can be switched/controlled at a much higher rate and precision than with the kV-switching method. The ramp-and-tail effect is eliminated, and a true squared wave is formed, minimizing soft radiation to the patient skin and unnecessary scatter radiation to the imaging staff.

Grid control complexity

Since the control grid is installed at the electron orbit in the tube, it poses challenges to imaging systems manufacturers, both mechanically and electronically.

In terms of mechanical challenges, the placement of the grid in the tube, the size of the holes in it, the material from which it is made – all must be precisely determined and manufactured. In terms of electronic challenges, operating a grid-controlled tube requires specially-designed generators and circuits, making the imaging systems complicated and expensive to manufacture and maintain.

Nanox Chip Advantages in Fluoroscopy

Cold Cathode technology

Nanox has developed a silicon chip which operates as a field-emission-type Cathode, or "Cold Cathode". A Cold Cathode extracts electrons from metal by applying an external electric field.

Using proprietary Micro-Electrical-Mechanical-Systems (MEMS) techniques, the Nanox chip contains millions of nanoscale gates in a single chip, about one square centimeter in size. A very high electric field is induced at the nanoscale gap between the cone emitters and the hole right above them (called the "gate hole"). The high electric field is highly effective at extracting electrons from the cone emitters.

These electrons make up the electron beam between the Cathode and the Anode.

Simpler Design

Nanox's Cold Cathode chip can eliminate the need for complex grid-enabled X-ray tubes and the expensive HV-generators capable of operating such grid-controlled X-ray tubes. The Nanox gate electrodes practically "eject" electrons from the Cathode and can digitally control the amount of X-ray radiation, enabling precise control over the X-ray, and by that - can fulfill the requirement for efficient and cheap pulsed fluoroscopy.

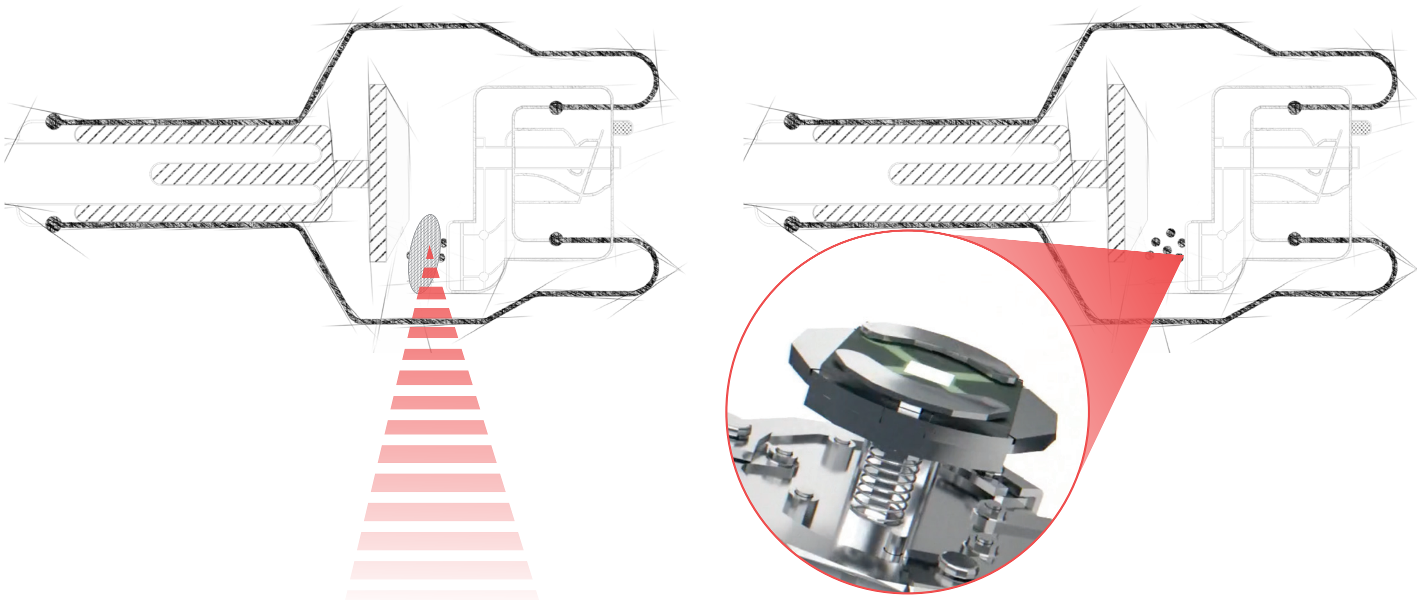


Figure 5 - Pulsed electron beam generation using Nanox Cold Cathode Chip

Dose savings using pulsed electron beam generation

As noted before, in a Hot Cathode X-ray tube that does not use Grid Control, pulsation of the electrons beam towards the Anode (thereby creating X-rays) is done by switching a high voltage supply. This process takes time (on the order of milliseconds).

The Nanox cold Cathode chip is driven by pulses and does not need constant filament current, like in hot Cathodes. One can set the high-kV Anode-to-Cathode voltage at a specific, constant level – and switch only the chip gate voltage – a process that can take microseconds. This is an improvement in the range of three orders of magnitude. In this operation mode the X-ray pulses again are perfectly square with no leading or trailing radiation edges.

Dose savings using Precise timings

Digital fluoroscopic detectors generally operate in a fast acquire-refresh mode, where the detector acquires radiation dose for a few milliseconds (typically 50-100ms), read the data to its internal registers and refresh the circuits, again for a few milliseconds, and then acquire dose for the next image. Having a n X-ray tube with rapid time switching on the scale of microseconds, means that the tube can synchronize its pulses only to those times where the detector is in acquire mode, thus saving additional dose to the patient.

Compact and safe mobile systems

The Nanox tube size is a fraction of the size and weight of a conventional X-ray tube. Using Nanox's unique technology in mobile C-arm fluoroscopy systems has the potential to:

- Minimize the mobile C-arm system footprint and size: Since the tube's weight is significantly reduced, the physical mechanisms that support it (e.g., elevating motors, counter-weights, springs, slip-rings, etc.) can be minimized – or even completely removed. This benefit can be heightened even more when using a DR-based image receptor rather than an Image-intensifier.

- Minimize collision risks: Most tubes in mobile C-arm fluoroscopy systems are positioned beneath the patient to lower the scatter radiation to the radio-technicians and doctors. This arrangement leads either to the risk of a destructive collision of the tube with the operating table base or to the limitation of its axial rotation. A smaller fluoroscopy tube will have the benefit of smaller tube housing, less susceptible to these risks

- Maximize the system approach to the operating table: A smaller tube shall provide larger vertical stroke, better positioning of the C-arm along the patient's body, and expanded C-arm SID – an essential feature for larger patients. A light and agile C-arm gantry has an added benefit in studies involving contrast medium chase (such as in Hemodialysis clinics) or ERCP studies.

Focal Spot Flexibility

Nanox's chip and tube design can change the size, position, and shape of the tube focal spot. This can be done digitally and dynamically during both radiological and fluoroscopic studies.

The focal size and shape can be adjusted on the fly, by either operating certain gate groups on the Nanox chip, or dynamically using the tube focus ring – an component placed between the Cathode and the Anode, and used to focus the electrons on a smaller spot of the anode – thereby improving the image detail.

Changing the focal size can be highly beneficial in managing the Anode heat for X-ray tubes using a stationary (non-rotating) Anodes – focal size can be dynamically increased or decreased for each type of study or the current heat load of the Anode – thereby extending its operational lifetime. Digitally adjustable focus size can also be used in certain study scenarios, such as quickly switching to view thin metal wires during angiography or imaging small body structures. Figure 6 shows the process of changing the focal size in a Nanox tube.

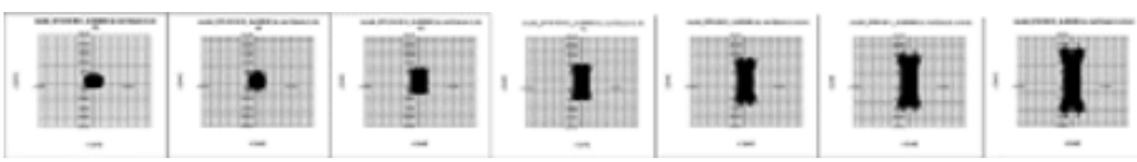


Figure 6 – Digitally flexible focal spot