RADIATION IMAGING TECHNIQUES

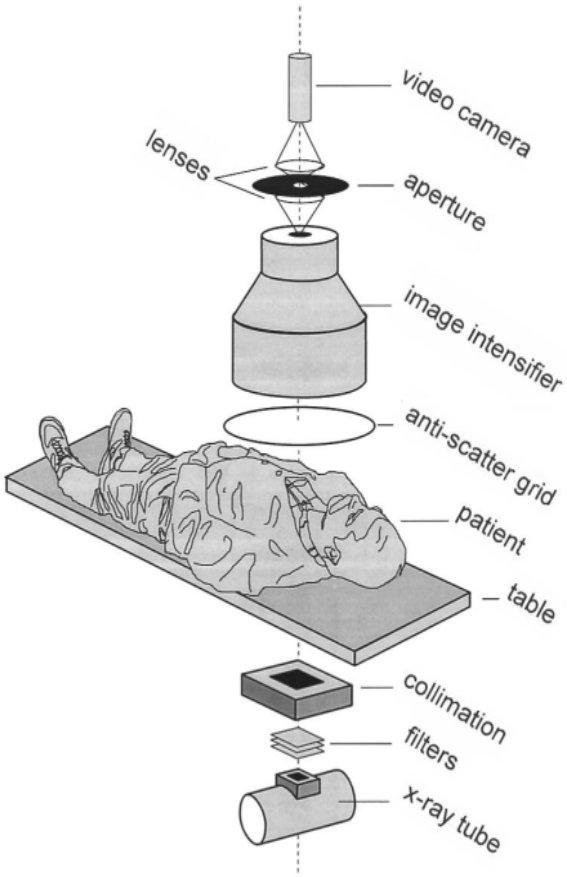
Fluoroscopy, Angiography, Image Intensifier, PET, SPECT, Collimators, Grids, Bucky Grids

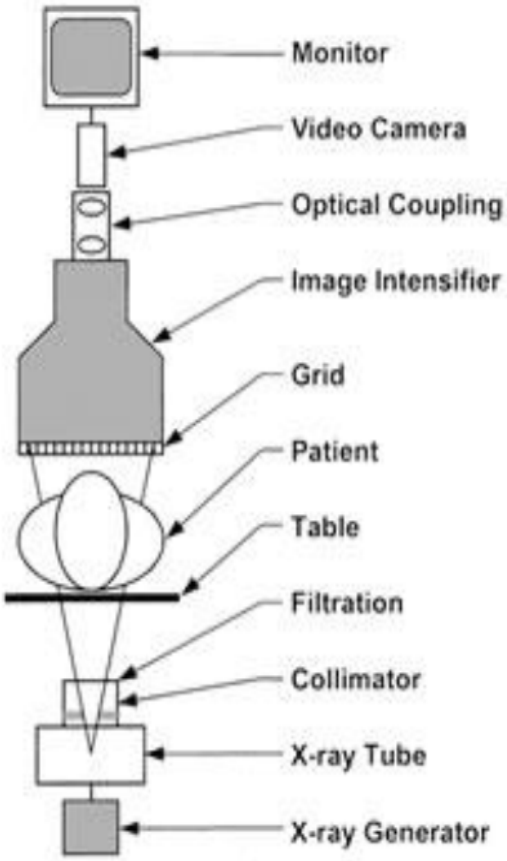
Fluoroscopy:

Fluoroscopy is a study of moving body structures--similar to an X-ray "movie." A continuous X-ray beam is passed through the body part being examined. The beam is transmitted to a TV-like monitor so that the body part and its motion can be seen in detail.

The components included in a modern fluoroscopic imaging system. Some components are similar to those included in systems used exclusively for radiography, whereas others are unique to fluoroscopy. Typically, additional apparatus are attached to allow for image recording, such as a spot-film device, film changer, photospot camera, cine camera, or analog-to-digital converter. The following section contains a description of the function of each component.

Fluoroscopic Imaging Chain





X-ray Generator

An **X-ray generator** is a device used to generate X-rays. It is commonly used by radiographers to acquire an x-ray image of the inside of an object (as in medicine or non-destructive testing) but they are also used in sterilization or fluorescence. The x-ray generator allows selection of kilovolt peak (kVp) and tube current (mA) that is delivered to the x-ray tube. Two methods are used to energize the x-ray tube for fluoroscopy: continuous and pulsed exposure.

For continuous fluoroscopy, the generator provides a steady tube current while the fluoroscope is activated. Images are acquired at a rate of 30 frames per second, resulting in an acquisition time of 33 msec per image. For pulsed fluoroscopy, the exposure is delivered in short pulses, 3–10 msec in length. Typically, a pulse rate of 30 pulses per second is used, with some units allowing the selection of lower pulse rates (15 or 7.5 pulses per second). One advantage of pulsed fluoroscopy is improvement in temporal resolution. Motion blur occurring within each image is reduced because of the shorter acquisition time, making pulsed fluoroscopy useful for examining rapidly moving structures such as those seen in cardiovascular applications. In addition, pulsed fluoroscopy can be used as a method of reducing radiation dose, particularly when the pulse rate is reduced.

Another important feature of a fluoroscopic x-ray generator is ABC, which acts to keep the overall image brightness seen on the monitor at a constant level as the image intensifier is panned over body parts of differing thickness and attenuation. Constant brightness is achieved by automatically adjusting the kVp and mA settings as needed to maintain the x-ray exposure level at the entrance to the image intensifier.

X-ray Tube

The x-ray tube converts electrical energy provided by the generator into an x-ray beam. Within the x-ray tube, electrons are produced by a heated filament and accelerated toward a positively charged tungsten anode. The interaction of the electrons with the anode results in the emission of x rays. The entire assembly is placed within an evacuated envelope and shielded housing. The area of the anode that is struck by electrons is referred to as the focal spot. A small focal spot size is desirable so that geometric unsharpness is minimized.

Collimator

The collimator contains multiple sets of radiopaque shutter blades that define the shape of the x-ray beam. Two sets of blades are generally present within the collimator: round and rectangular. A round iris conforms the x-ray beam to the circular FOV. Rectangular blades can be brought in manually to further reduce the beam size. Collimation reduces the exposed volume of tissue, resulting in reduced scatter production and improved image contrast.

Most fluoroscopy systems used for angiography and interventional applications also contain equalization filters. These filters, also called contour or wedge filters, are partially radiolucent blades used to provide further beam shaping in addition to collimation. Equalization filters reduce glare from unattenuated radiation near the edge of the patient and equalize light exposure to the video camera.

As a result, they improve operation of the ABC system. The filters are made from tapered lead-rubber or lead-acrylic sheets.

Filters

Filtration material is added to attenuate low-energy x rays from the beam. Low-energy x rays are absorbed in patient tissue without being transmitted to the image receptor, contributing to patient dose with little improvement in image quality. Aluminum is the most common added filtration material. Copper can also be used for improved low-energy x-ray filtering. The use of copper filtration material has become more prevalent in fluoroscopy systems used for high-dose procedures such as angiography and interventional applications.

Patient Table and Pad

Patient tables for fluoroscopic systems must provide adequate strength to support large patients and, at the same time, result in minimal x-ray attenuation. Carbon fiber composite material satisfies both these requirements. Patient support pads should also be made of a material that provides minimal x-ray attenuation. Thin foam pads are generally acceptable, but thick gel pads have been found to result in excessive attenuation.

Grid

Anti-scatter grids are used to improve image contrast by reducing the scattered x rays that reach the image receptor. However, use of grids requires an increase in radiation exposure. The grid ratios for fluoroscopy range from 6:1 to 10:1, which is generally lower than common radiographic grid ratios (8:1 to 16:1). For fluoroscopy, removal of the grid may be desirable to reduce patient dose when the amount of scatter produced is low.

Image Intensifier

The image intensifier converts incident x rays into a minified visible light image and, in the process, amplifies the image brightness by about 10,000 times for better visibility to the viewer. The major components of an image intensifier include an input layer to convert x rays to electrons, electron lenses to focus the electrons, an anode to accelerate them, and an output layer to convert them into a visible image. All the components are contained within an evacuated bottle.

Optical Coupling

The optical coupling system distributes light from the image intensifier output window to a video camera and other image recording devices. The optical distributor may include a partially silvered, beam-splitting mirror, which directs a portion of the light from the image intensifier output window to an accessory device for image recording and passes the remainder to the video camera. A circular aperture is also included to set the proper light level required by the video camera. As a result, the ABC system increases the radiation exposure to maintain the light level at the camera,

producing a fluoroscopic image with low noise. Alternatively, when the aperture is set wide open, the radiation exposure level is low and more image noise is apparent.

Television System

A closed-circuit television system is used to view the image intensifier output image. The television system consists of a video camera that converts the image to a voltage signal and a monitor that receives the signal and forms the image display. In addition, fluoroscopic units can be equipped with an analog-to-digital converter to digitize the video camera voltage signal for additional processing and electronic image recording.

The basic video camera consists of a vacuum tube cylinder (approximately 2.5 cm in diameter) with a photoconductive target and a scanning electron beam. In recent years, Charge coupled device (CCD) cameras consist of a solid-state array of light sensors, which store the image as pixels until they are read out as voltage pulses representing the two-dimensional image. Compared with traditional video cameras, CCD cameras are smaller, are more rugged, require less power, and have a longer lifetime.

Image Recording

A fluoroscopic imaging system may include additional devices to record images during an examination. Recording methods include spot film devices, film changers, photospot cameras, cine cameras, and digital photospots.

Fluoroscopy

A fluoroscope produces a video x-ray. During a fluoroscopic exam, a continuous X-ray beam is used to view an organ or part of the body in real time. The live images are displayed on a computer screen or television monitor. Fluoroscopes are used for interventional procedures such as guiding the placement of a catheter during an arteriography, for assessing stomach and bowel movement and function, and for detecting obstructions in the airway or blood vessels. A contrast agent may also be used to enhance the images.

Fluoroscopy is most often used to view the upper GI tract, which includes the stomach, esophagus, duodenum, and the upper small intestine. It is also used to view the lower GI tract.

How fluoroscopy works

The fluoroscope is a type of x-ray machine that can use either a continuous or a pulsing x-ray beam. The x-ray machine has an x-ray tube that is constructed of glass or metal and has a vacuum seal inside. It generates x-rays by converting electricity from its power line (AC current of 120-480 volts) into electricity that falls into the 25-150 kilo volt range. This creates a stream of electrons that are shot against a tungsten target. When the electrons hit this target (called an anode) the atomic structure of the tungsten stops the electrons, causing a release of x-ray energy. This energy is focused by the x-ray tube onto the area of the body to be imaged.

These very energetic electromagnetic waves can pass through the body and create images of internal structures. Because the different tissues within the body are of different densities, those waves are attenuated (weakened) at differing rates as they pass through. Bone, for example, is very dense and absorbs a lot of the x-rays, while the tissues surrounding the bone are less dense and absorb less of the x-ray.

It is this difference in the absorption of the waves that creates variations in the exposures and allows the detail of the image to be formed.

With a fluoroscope, when the beam passes through the body it hits an image intensifier that increases the brightness of the image many times (e.g. x1000 to x5000) so that it can be viewed on a display screen. The image intensifier itself is coupled to a video camera that captures and encodes the two-dimensional patterns of light as a video signal from the x-ray machine. The signal is converted back into a pattern of light seen as the image on the monitor. The camera output can be digitized for computer image enhancements.

The fluoroscope produces a low dose of radiation, slightly higher than a regular x-ray so it is very important that you let the doctor know if you are pregnant or think you might be.

What to expect when you have fluoroscopic imaging:

Fluoroscopic imaging is painless. Before the imaging you will need to remove any jewelry or clothing that are in the area being scanned. For GI studies, you will usually need to drink barium, or have a barium enema. The barium provides the contrast needed to produce a clear image that can detect polyps and other abnormalities or obstructions.

You will then lie on a table or stand depending on the purpose and area being imaged. The camera will be moved to a position above or in front of you in order to get the proper angle for the images. The procedure will take anywhere from a few minutes to an hour depending on the purpose of the imaging. For example, fluoroscopy is often used in interventional radiology to aid the positioning of a needle for a biopsy or other procedure.

IMPORTANT: *If you are pregnant, or if you think you MIGHT be pregnant, tell the technician or radiologist. While x-rays are safe for you, they are not safe for the developing embryo.*

X-ray image intensifiers for fluoroscopy

The x-ray image intensifier converts the transmitted x rays into a brightened, visible light image. Within an image intensifier, the input phosphor converts the x-ray photons to light photons, which are then converted to photoelectrons within the photocathode. The electrons are accelerated and focused by a series of electrodes striking the output phosphor, which converts the accelerated electrons into light photons that may be captured by various imaging devices. Through this process, several thousand light photons are produced for each x-ray photon reaching the input phosphor. Most modern image intensifiers use cesium iodide for the input phosphor because it has a high absorption

efficiency and thus decreases patient dose. Image intensifiers come in various sizes, most having more than one input image size or magnification mode. Modern image intensifiers are specified by conversion factors, which is the measure of how efficiently an image intensifier converts x rays to light. Because of design restrictions, image intensifiers are subject to inherent and induced artifacts that contribute to image degradation. Both spatial and contrast resolution gradually decrease during the lifetime of the image intensifier because the brightness gain of an image intensifier decreases with time as the phosphor ages. A well-run quality control program for the image intensifier is needed to detect the inevitable changes in settings before they appear on clinical images.

Early fluoroscopic procedures produced visual images of low intensity, which required the radiologist's eyes to be dark adapted and restricted image recording. In the late 1940s, with the rapid developments in electronics and borrowing the ideas from vacuum tube technology, scientists invented the x-ray image intensifier, which considerably brightened fluoroscopic images. Commercial x-ray systems with image intensifiers were introduced in the mid 1950s. The x-ray image intensifier enabled the radiologist to visualize the output image without dark adaptation. The intensified visual image could be easily captured by film and television camera tubes. When the image intensifier was first introduced, it had a small input size and a glass vacuum case. Modern image intensifiers have input field sizes up to 57 cm in diameter with little image distortion, and the vacuum cases are usually made of metal.

An x-ray image intensifier has two major functions: (*a*) to intercept the x-ray photons and convert them into visible light photons and (*b*) to amplify or intensify this light signal. The image intensifier creates a large gain (or intensification) in luminance at the output screen compared with that at the input screen. The output screen image can be viewed with closed-circuit television or recorded with film.

Construction and Principles of Operation

In a modern fluoroscopy system, the image intensifier is located opposite the x-ray tube. The image intensifier is contained in a cylindrical protective case because it is a very delicate device under high vacuum and needs to be handled with care. At the entrance end of this protective case, there is usually a mechanical sensory device to prevent the image intensifier from pushing too hard on the patient or other objects, which may cause damage to the image intensifier. Image intensifiers come in various sizes depending on the specific application. Usually, the larger the image intensifier the higher the cost.

The operational principles of an image intensifier can be briefly described as follows. X-ray photons penetrate the input window of the vacuum case. The input phosphor absorbs the x-ray photons and

converts them into optical photons (a phenomenon called luminescence). These optical photons are converted to photoelectrons at the photocathode. The photoelectrons are accelerated by the electric field produced by the strong electric potential difference of the image intensifier and are collected at the output phosphor. Each accelerated electron produces many optical photons at the output phosphor.

Image Intensifier Components

An image intensifier consists of the following major components: an input window, an input phosphor and photocathode, several electrostatic focusing lenses, an accelerating anode, an output phosphor screen, and a protective vacuum case.

Input Window

The shape and choice of material for the input window results from a compromise among many factors, such as minimizing patient distance, x-ray absorption, x-ray scatter, manufacturing cost, and mechanical strength of materials. The input side of the image intensifier usually has a convex shape and is generally made of aluminum ($Z = 13$). The convex shape not only minimizes the patient distance thus maximizing the useful entrance field size, but it also gives the image intensifier better mechanical strength under atmospheric pressure. This aluminum input window is approximately 1 mm in thickness.

Input Phosphor and Photocathode

X rays transmitted through the input window are converted into fluorescent light photons by the input phosphor. The input screen is a substrate made of aluminum coated with a phosphor layer, an intermediate coupling layer, and finally the photocathode layer. The thickness of the input phosphor layer is a compromise between spatial resolution and x-ray absorption efficiency. A thicker phosphor layer has higher x-ray absorption efficiency, which means more x-ray photons can be absorbed and converted to light photons in the phosphor layer. A thicker phosphor layer requires fewer x-ray photons to generate the same amount of light photons at the image intensifier output window, thus reducing patient dose. However, with a thicker input phosphor layer, more light photons are scattered laterally within the phosphor layer, thus reducing the spatial resolution. Currently, the thickness of an input phosphor layer typically measures between 300 and 450 μm, depending on the image intensifier type and technology used.

To maximize the conversion efficiency from x-ray photons to photoelectrons, the mass attenuation coefficient of the input phosphor material should be matched with the spectrum of the x rays emerging from the patient. Ideally, the light spectrum of the input phosphor should also match the sensitivity profile of the photocathode. The initial phosphor used in early image intensifiers was zinc-cadmium sulfide (ZnCdS), whereas the current phosphor of choice is cesium iodide (CsI:Na). There are several reasons for replacing ZnCdS with CsI:Na as the input phosphor material. First, the mass attenuation coefficient of CsI:Na better matches the x-ray spectrum of the radiation transmitted from the patient. The mass attenuation coefficients of the two phosphors in relation to the relative spectral distribution of the transmitted radiation from the patient. The mass attenuation peaks in CsI:Na,

compared with those of ZnCdS, are more closely matched to the transmitted x-ray spectrum, thus increasing the absorption of the transmitted x-ray photons. As mentioned, increasing the absorption efficiency decreases the patient's dose. A second advantage for using CsI:Na as the phosphor is that it has a high atomic number from Cs ($Z = 55$) and I ($Z = 53$), which also results in higher x-ray absorption. Consequently, most modern image intensifiers use CsI:Na for the input phosphor material.

The photocathode layer is made of antimony-cesium ($SbCs_3$). To maximize the conversion efficiency from light photon to photoelectron, light emitted from the input phosphor should match the sensitivity spectrum of the photocathode. CsI:Na has a better spectral match to the antimony-cesium compound ($SbCs_3$). This is another reason why CsI:Na is a better input phosphor material than ZnCdS. The photocathode has a thickness of about 20 nm and a photoelectron production efficiency of 10%–15%. Approximately 200 photoelectrons will be created for a single 60-keV x-ray photon absorbed in the input phosphor.

In addition to its high absorption efficiency, CsI:Na can be evaporated onto the substrate in crystal needle form. These needles act like light pipes, in a manner similar to the light propagation in a fiber-optic faceplate, thus reducing cross scatter inside the phosphor screen and yielding better spatial resolution. A cross-sectional diagram of the input screen. The CsI:Na needles are approximately 5 μm in diameter. Input phosphor screens in modern image intensifiers are approximately 300–500 μm in thickness and absorb 60%–70% at 60 keV. Because of the crystalline structure of the needles, the surfaces of the crystals, and the reflectivity of the substrate, approximately 2,600 luminescence photons are generated from each 60-keV x-ray quantum. Of these 2,600 luminescence photons, approximately 1,600 reach the photocathode.

Electron Optics

Photoelectrons are accelerated from the photocathode to the output phosphor by the anode. The accelerated photoelectrons are focused down to the size of the output phosphor by a series of electrostatic focusing electrodes. The number of photoelectrons within the image intensifier will not increase: Only the speed of the photoelectrons will increase. The total current produced by these photoelectrons is approximately 600 nA (600×10^{-9} A).

The focusing electrodes are very sensitive to external electrical and magnetic fields. Extraneous electrical and magnetic fields (even the earth's magnetic field) may cause image distortions in the image intensifier. This effect must be monitored and controlled for fluoroscopes operated near magnetic resonance imaging units. Furthermore, the high voltages on the electrodes must be kept very stable to guarantee the image quality, since ripple in the voltage will be noticed as periodic variation in image diameter.

On the vacuum side of the output phosphor surface, the anode of the electron optics system has a thin aluminum film coating. This aluminum film allows electrons to pass through, but it is opaque to light photons generated on the fluorescent screen. It stops these photons from being scattered back into the image intensifier and exposing the photocathode. The film also serves as a reflector to increase the output luminance.

Output Phosphor and Window

The output phosphor of the x-ray image intensifier, which typically is called P20, is a fluorescent compound made of silver-activated zinc-cadmium sulfide (ZnCdS:Ag). The emission spectrum of P20 is at a maximum around 530 nm (green light). The P20 layer is very thin, having a thickness of 4–8 μm, and is deposited on the glass output window. Approximately 2,000 luminescence photons are generated for every accelerated 25-keV photoelectron. Because every electron was produced by one light photon, this represents a luminescence gain of 2,000. The output window is carefully designed so that the fluorescent photons reflected back to the input screen are minimized. The luminescence decay time of the output phosphor determines the temporal resolution of the image intensifier.

Image Intensifier Housing

The x-ray image intensifier is enclosed in a metal housing consisting of lead to absorb scattered radiation, mu-metal to shield the electron optics from extraneous magnetic fields, and an outer aluminum shell. On the input side of the housing, the aluminum shell protects the input window of the image intensifier. Although the housing will provide some shielding from external electromagnetic fields, the presence of strong magnetic or electrical fields too close to the image intensifier will degrade image quality.

Physical Characteristics

The input size, brightness gain, conversion factor, contrast ratio, magnification mode, and spatial resolution characterize an image intensifier. The size of an image intensifier is obviously the most visible property, and the larger the image intensifier, the larger the field of view. A large field of view allows one to visualize a larger area, which can be very helpful in some clinical procedures. However, a larger image intensifier is more difficult to make and thus more expensive.

Brightness Gain and Conversion Factor

The brightness gain comes from two sources that are completely unrelated: the minification gain and the flux gain. The minification gain is defined as the ratio of input area to the output area of the image intensifier. Because the number of photoelectrons leaving the photocathode is equal to the number striking the output phosphor, the number of photoelectrons per unit area at the output phosphor increases. The minification gain does not improve the statistical quality of the fluoroscopic image. It will not change the contrast of the image, but it will make the image appear brighter. A smaller output window size will just compress more photons into a smaller area, producing a smaller but brighter image.

Flux gain is defined as the number of photons generated at the output phosphor for every photon generated at the input phosphor. The flux gain results from the acceleration of photoelectrons to a higher energy so that they generate more fluorescent photons at the output phosphor. Each light

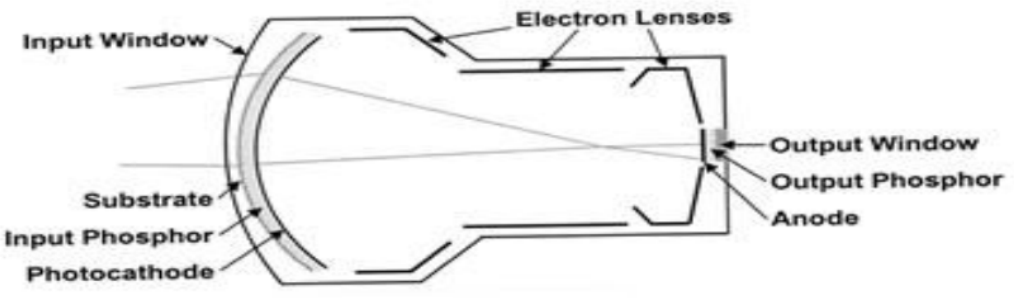
photon generated at the input phosphor will generate approximately 100 photons at the output phosphor, resulting in a flux or luminance gain of 100. The total brightness gain of the image intensifier is the product of minification gain and flux gain (total brightness gain = flux gain × minification gain).

The size of the output window of an image intensifier is usually between 1.5 and 6.0 cm in diameter. The minification gain for a 23-cm image intensifier with an input entrance field size of 22 cm (380 cm^2) and a 2-cm output window (3.14 cm^2) is approximately 120. With a flux gain of approximately 100, the total brightness gain for this image intensifier would be approximately 12,000.

The original definition of brightness gain is the output luminance level (or brightness) of an image intensifier divided by the output luminance level of a Patterson B-2 fluoroscopic screen when both are exposed to the same quantity of radiation. The Patterson B-2 fluoroscopic screen was typically used for fluoroscopy before image intensifiers were introduced. If the image intensifier gives 5,000 times brighter output than the Patterson B-2 fluoroscopic screen, the brightness gain is 5,000. The drawback of using this definition is the lack of reproducibility of the Patterson B-2 screen.

The International Commission on Radiological Units and Measurements (ICRU) has recommended another method of evaluation called the conversion factor. Today, most x-ray image intensifiers are specified by the conversion factor. The conversion factor is defined as the output luminance level of an image intensifier divided by its entrance exposure rate. It is a measure of how efficiently an image intensifier converts the x rays to light. Conversion factors have units of candela per square meter per milliroentgen per second ([cd/m^2]/[mR/sec]). A typical 23-cm image intensifier has a conversion factor of approximately 200 cd/m^2/mR/sec. The conversion factor usually equals to 1% of the brightness gain in value. Conversion factors tend to deteriorate (decrease) as image intensifiers age, resulting in higher patient dose for older image intensifiers. The higher the conversion factor, the more efficient the image intensifier.

Cross sectional schematic of an image intensifier shows its major components



Medex Gamma camera has crystal upto 500 mm in diameter, 6.4mm or 9.6 mm thick with an array of 61, 75 or 93 PMTs.

The no of gamma rays received by an region on the crystal is directly and to amount of nudide located directly below the region.

Only 0.01% of rays emitted are detected and used for image formation.

A Polaroid camera mounted on top of escilloscope photograph 50,000 dots on the screen.

Benefits/Risks

Fluoroscopy is used in a wide variety of examinations and procedures to diagnose or treat patients. Some examples are:

- Barium X-rays and enemas (to view the gastrointestinal tract)
- Catheter insertion and manipulation (to direct the movement of a catheter through blood vessels, bile ducts or the urinary system)
- Placement of devices within the body, such as stents (to open narrowed or blocked blood vessels)
- Angiograms (to visualize blood vessels and organs)
- Orthopedic surgery (to guide joint replacements and treatment of fractures)

Fluoroscopy carries some risks, as do other X-ray procedures. The radiation dose the patient receives varies depending on the individual procedure. Fluoroscopy can result in relatively high radiation doses, especially for complex interventional procedures (such as placing stents or other devices inside the body) which require fluoroscopy be administered for a long period of time. Radiation-related risks associated with fluoroscopy include:

- radiation-induced injuries to the skin and underlying tissues ("burns"), which occur shortly after the exposure, and
- radiation-induced cancers, which may occur some time later in life.

The probability that a person will experience these effects from a fluoroscopic procedure is statistically very small. Therefore, if the procedure is medically needed, the radiation risks are outweighed by the benefit to the patient. In fact, the radiation risk is usually far less than other risks not associated with radiation, such as anesthesia or sedation, or risks from the treatment itself. To minimize the radiation risk, fluoroscopy should always be performed with the lowest acceptable exposure for the shortest time necessary.

Information for Patients

Fluoroscopy procedures are performed to help diagnose disease, or to guide physicians during certain treatment procedures. Some fluoroscopy procedures may be performed as outpatient procedures while

the patient is awake – for example, upper gastrointestinal series to examine the esophagus, stomach and small intestine, or a barium enema to examine the colon.

Other procedures are performed as same-day hospital procedures or sometimes as inpatient procedures, typically while the patient is sedated – for example, cardiac catheterization to examine the heart and the coronary arteries that supply blood to the heart muscle. Still other fluoroscopy procedures may be performed under general anesthesia during surgery – for example to help align and fix fractured bones.

The clinical benefit of a medically appropriate X-ray imaging exam outweighs the small radiation risk. The FDA encourages patients and parents of pediatric patients to engage in a discussion with their health care provider about the benefits and risks of fluoroscopy procedures (see the Medical X-ray Imaging webpage for advice on questions to ask your health care provider).

Extensive information is available on fluoroscopy, diseases and conditions where fluoroscopy is used for diagnosis or treatment, and on the risks and benefits of fluoroscopy. In addition to the patient information links on the Medical X-ray Imaging webpage, more specific information on procedures conducted using fluoroscopy is provided below:

- Patient Information on interventional radiology procedures from the Society of Interventional Radiology
- Information on heart disease and cardiology procedures, including cardiac catheterization and coronary artery stenting can be found at the Society for Cardiovascular Angiography and Interventions
- The Heart Rhythm Society's Patient Information addresses heart disease, abnormal heart rhythms and treatment of abnormal heart rhythms
- The Society of Vascular Surgery's Vascular Conditions, Tests, Treatments contain information on diagnosis and treatment of abnormalities of blood vessels

Resources for patients on concerns about radiation from fluoroscopy include:

- The Alliance for Radiation Safety in Pediatric Imaging: The Step Lightly campaign for interventional radiologyand the Pause and Pulse campaign for fluoroscopy
- International Atomic Energy Agency (IAEA) Radiation Protection of Patients (RPOP):
  - Information for Patients: Interventional Procedures
- National Cancer Institute of the National Institutes of Health on Interventional Fluoroscopy: Reducing Radiation Risks for Patients and Staff