GE Lunar Technology Advantages

DXA stands for **D**ual-Energy **X**-ray **A**bsorptiometry. It is a measurement method that uses the differences in the absorption of high energy and low energy X-ray photons by different elements in a body to quantify the amount of bone and soft tissue in the body. For example, certain elements in bone minerals (e.g. calcium) will absorb more low-energy X-rays than the elements in soft tissue, enabling a precise and accurate estimate of bone mineral density (BMD). By using relevant algorithms, we can also use the same measured data to determine body composition due to the different density and composition of fat and lean tissue. Based on DXA technology, the GE Healthcare Lunar bone densitometry product portfolio (iDXA,™ Prodigy,™ and Aria™*) empowers physicians and clinicians to diagnose osteoporosis and fracture risk.** iDXA and Prodigy may also perform body composition analysis (fat and lean tissue mass). After a DXA scan, the measured values are compared to a reference population at the sole discretion of the physician to achieve desired clinical results.

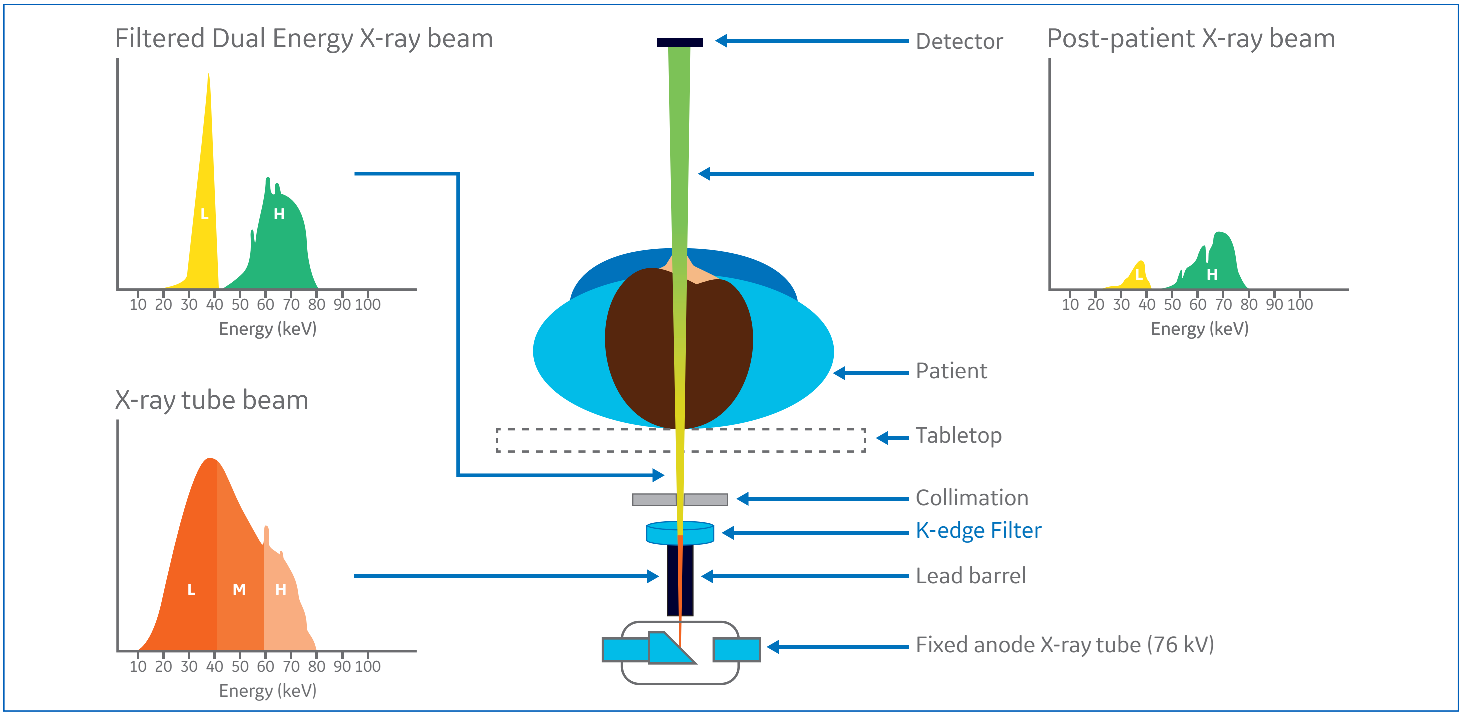
DXA X-ray Beam Generation Methods

There are two fundamental approaches to create the X-ray beams needed for a DXA scan: K-edge Filter technique and Energy Switching technique.

K-edge Filter Technique

GE Lunar uses a "K-edge filter" that absorbs the X-rays in the middle energy range, but allows most high energy and low energy X-rays to pass through to the patient (Figure 1).

Figure 1: DXA X-ray system using K-edge filter.

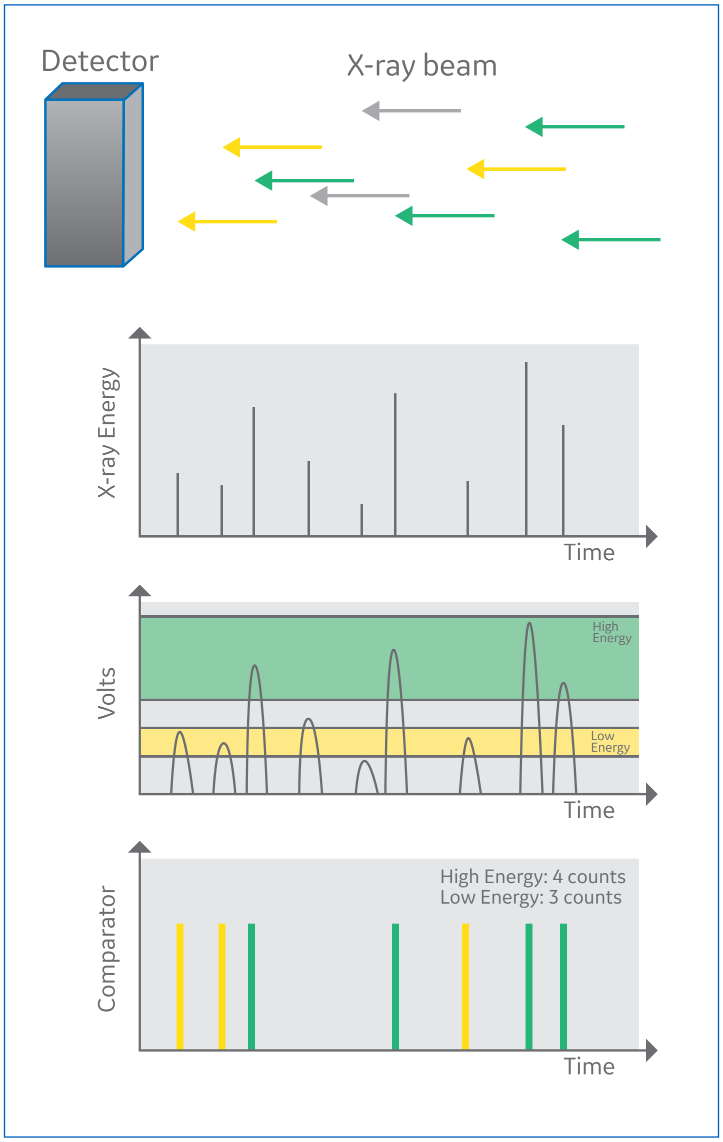


*Available in select markets

** For full description of intended use, refer to the appropriate product user manual.

The initial beam (red/orange) is created using an ultra-stable X-ray generator with a fixed anode X-ray tube. The K-edge filter creates distinct low energy and high energy portions of the X-ray beam (yellow-green) before transmission through the patient. The patient absorbs more of the low-energy X-rays (yellow) than the high-energy X-rays (green). An energy-sensitive detector absorbs the transmitted X-rays and counts each X-ray photon as either low or high energy as highlighted in Figure 2.

Figure 2: GE Lunar Photon Counting Method. X-rays with various energies are incident on a photon-counting detector. Amplifiers create voltage pulses proportional to X-ray energy and comparators sort them into low and high energy bins.



GE Lunar's "photon counting" method is a very dose-efficient DXA technique since low and high energy X-rays are simultaneously and individually counted. Furthermore, by blocking X-rays in the middle of the energy range before the patient, the K-edge filter lowers patient dose while improving performance, since it removes X-rays which would not efficiently distinguish between bone and soft tissue. For Prodigy and Aria, the X-ray generator runs at 76 kV and the effective energy of the low- and high-energy portions of the beam are ~35 keV and ~61 keV. iDXA uses a 100 kV generator and K-edge filtering results in ~39 keV and ~71 keV X-ray effective energies. These energies are optimized for bone and tissue separation. Figure 3 shows the difference in attenuation of cortical bone and soft tissue as a function of incident X-ray energy for Prodigy and Aria. The arrows highlight how the bone and soft tissue attenuation differ between low- and high-energy X-rays.

Figure 3: Linear attenuation coefficient of cortical bone and soft tissue (left axis) and the Prodigy™ and Aria™ X-ray beam intensity (right axis) vs. X-ray energy.

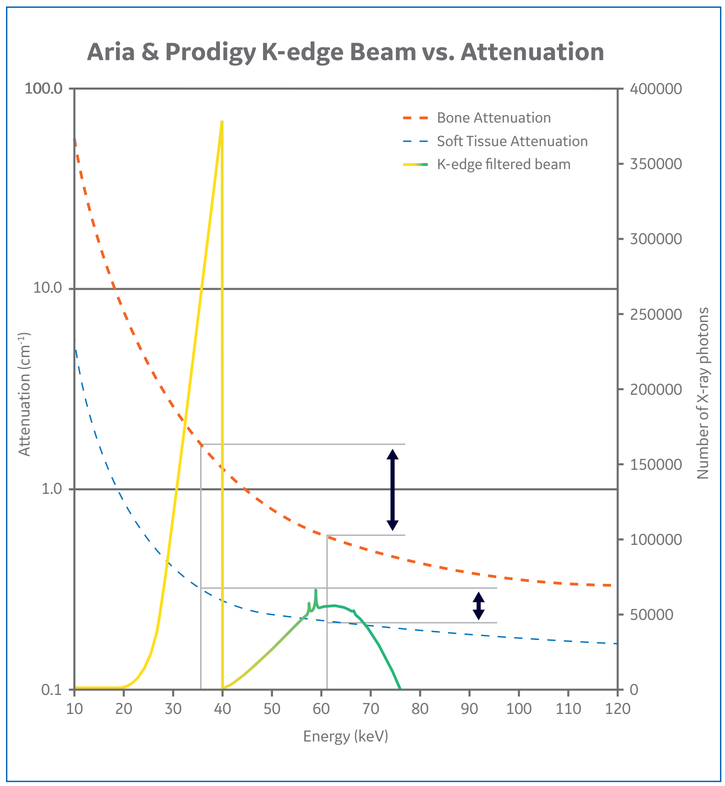
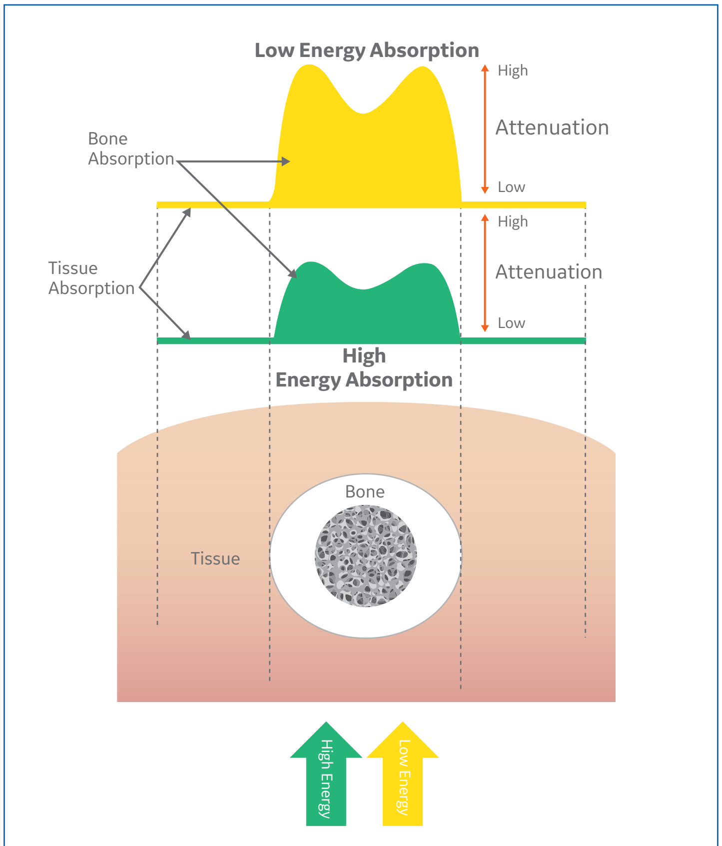


Figure 4 is a simplified illustration of how bone mass is calculated. Low and high energy X-rays attenuate differently through a region of tissue containing bone. Attenuation through the material is largely determined by its thickness and density. In regions without bone, the tissue provides a baseline attenuation. Bone mass is calculated by subtracting this baseline from the combined attenuation of tissue and bone.

Figure 4: Attenuation differences between low and high energy X-rays through tissue and bone enable bone mineral mass measurements.



Energy Switching Technique

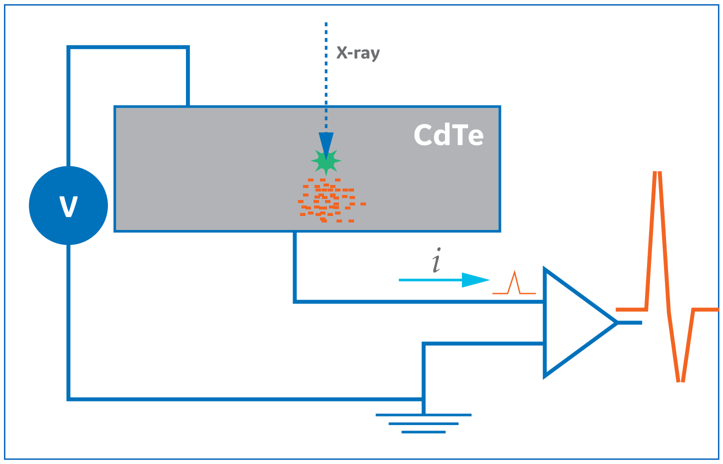
Another approach for X-ray generation uses an "energy-switching" X-ray generator to rapidly cycle between low and high voltage. A GE Lunar competitor uses a generator switching between 100 kV and 140 kV, synchronized to the 50-60 Hz power line frequency. Because the X-ray energy is unstable during data acquisition, it is necessary to correct each pixel measurement using a complex "spinning drum" composed of air, soft tissue, and bone equivalents. Each pixel needs six sequential measurements (2 energies through 3 chambers) leading to greater dose to the patient.

X-ray Detector Technology

The detectors in GE Lunar products perform a crucial task – count each individual X-ray photon and classify it as either "low-energy" or "high-energy."

iDXA detectors use solid-state crystals (Cadmium Telluride or CdTe) to generate a signal. The X-ray energy is absorbed by the crystal and results in the immediate release of electrons from their atoms (i.e. *direct conversion*). An applied voltage pushes the electrons out of the crystal, effectively creating a current pulse whose magnitude is proportional to the X-ray energy. Sensitive, low-noise amplifiers boost the signal so that counting electronics can perform the final identification as low or high energy. See Figure 5.

Figure 5: iDXA X-ray detector signal generation



Recently GE Lunar embraced a state-of-the-art technology from the field of Nuclear Medicine known as solid-state photomultipliers* (SSPM) to maintain high performance and provide value. Both Aria and recent Prodigy detectors are now composed of ultra-fast and bright LYSO scintillators (Lutetium-Yttrium Oxyorthosilicate, $Lu_{2(1-x)}Y_{2x}SiO_5$) coupled to solid-state photomultipliers. LYSO crystal has the advantages of high light output and density, fast decay time and excellent energy resolution. In comparison, a GE Lunar competitor uses conventional CT-style Gadox scintillators which are slow, energy-integrating detectors that CT researchers and manufacturers now recognize are intrinsically less dose efficient than photon counting detectors.[1,2]

*Also known as silicon photomultiplier (SiPM)

X-rays are absorbed in the scintillator which rapidly and efficiently converts X-ray energy into light (i.e., *indirect conversion*). Light is channeled to a solid-state photomultiplier which produces a highly amplified signal that is ready for the counting electronics (Figure 6). SSPM's combine the function of the conventional photomultiplier with the compactness, simple operation and low voltage of photodiodes.

Figure 6: Prodigy10 X-ray detector signal generation

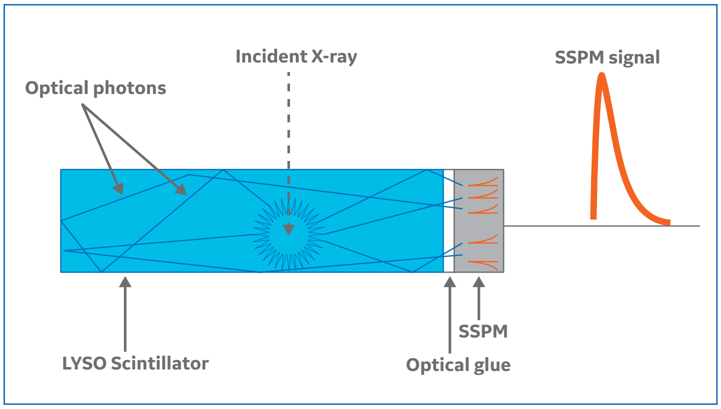
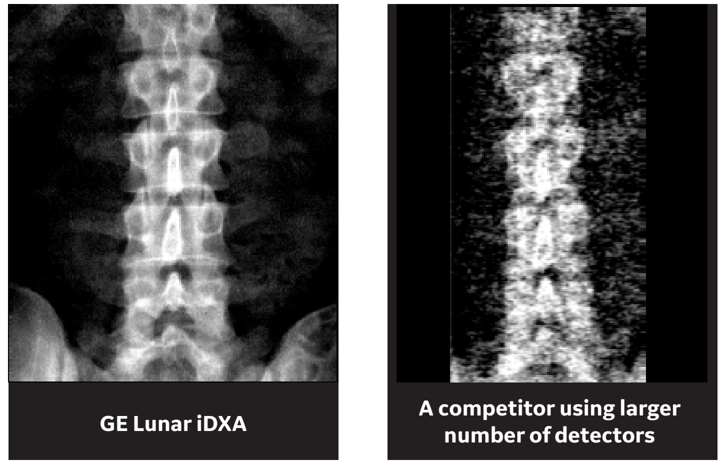


Image Quality

Image quality and BMD precision fundamentally depend on the number of low- and high-energy X-rays detected per image pixel. An image pixel is the geometric projection of the detector area to the image plane. As may be expected, image quality improves with higher density of image pixels and higher X-ray flux per pixel. The difference in image quality within GE Lunar's DXA portfolio reflects this. For example, the *pixel density* of iDXA images is higher than Prodigy images and iDXA's 100 kV source emits more X-rays than Prodigy and Aria's 76 kV source. By balancing smaller image pixels with higher X-ray flux, iDXA maintains good BMD precision (1%) and produces GE Lunar's highest quality images.

It is important to note that increasing the number of detectors does not necessarily improve image quality unless it is accompanied by a *higher density* of image pixels.* Furthermore, scanning too quickly or with insufficient X-ray source current for a patient's thickness will degrade image quality by starving each image pixel of X-rays. Figure 7 compares a lumbar spine image of a heavy patient (BMI = 46.5) captured from GE Lunar's iDXA scan vs. that captured by our competitor's DXA equipment that uses a higher number of detectors. The sharper image of the iDXA scan is a result of higher X-ray flux per image pixel.

Figure 7: Higher Image Resolution of GE Lunar's Narrow Fan Beam Technology on heavier patients



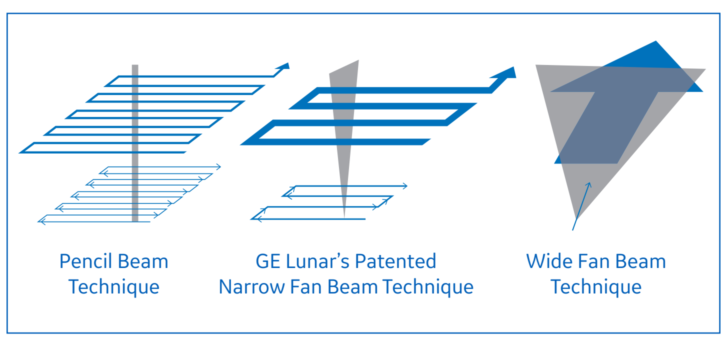
Lumbar Spine Scan, Male Subject – Weight: 229 lb/103.9 kg – Height: 5.1 ft/ 154.4 cm – Bone Mineral Density: 1.28 g/cm^2

Pencil vs. Narrow Fan vs. Wide Fan Beam Technology

The earliest DXA scanners used a pencil beam that performed "raster scans" back-and-forth across the patient. Pencil beams have the advantages of low patient dose and no magnification effects. They perform well and today are a reasonable choice for value product lines or for low-volume customer sites. However, their beam size necessarily requires many sweeps and long scan times.

Fan beam systems shorten scan times significantly and two approaches have been commercialized. One of our competitors uses a wide fan beam which makes a single sweep along the patient axis. Whereas, GE Lunar developed and patented the use of a narrow fan beam technology which combines the best features of pencil beams (no magnification, low dose) with the short scan time of fan beams. Figure 8 shows the three common beam shapes.

Figure 8: Pencil, Narrow Fan, and Wide Fan beam scanning techniques



*By analogy, recent improvements in picture quality on smartphones only occurred when the number of pixels increased while the screen size remained the same.