

# How do X-ray Systems Find Foreign Bodies?



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# How do X-ray Systems Find Foreign Bodies?

**Modern x-ray systems are very specialised, efficient and advanced, and are commonly used in a range of industries for inspection purposes, including medical diagnostics; food and pharmaceutical product inspection; construction (structural, mining and engineering); and security.**

X-rays are used in the medical world to 'see' what is happening inside the body and in security applications to 'look' inside baggage or parcels; and food and pharmaceutical manufacturers are increasingly relying on x-ray systems to detect and reject contaminated products from the production line, in order to protect consumers, reduce the risk of product recalls and safeguard their brands.

But how do x-ray systems actually find foreign bodies? This white paper begins by explaining what x-rays are and the main components and operating principles of an x-ray inspection system, before identifying typical foreign bodies and looking at how x-ray systems detect these in products and packaging, as well as considering some of the issues manufacturers face when using x-ray systems to detect foreign bodies.

## 1. What are X-rays?

X-rays are one of several naturally-occurring sources of radiation and are an invisible form of electromagnetic radiation, such as radio waves.

All types of electromagnetic radiation (Figure 1) are part of a single continuum known as the Electromagnetic Spectrum, which is arranged according to frequency and wavelength, and runs from radio waves at one end (which have a long wavelength) to gamma rays at the other (which have a short wavelength).

The short wavelength of x-rays enables them to pass through materials that are opaque to visible light, but they don't pass through all materials with the same ease. The transparency of a material to x-rays is broadly related to its density - the denser the material, the fewer x-rays that pass through. Hidden contaminants, including foreign bodies like glass, bone and metal, show up because they absorb more x-rays than the surrounding product.

## 2. Principles of X-ray Inspection

In simple terms, an x-ray system uses an x-ray generator to project a beam of low-energy x-rays onto a sensor or detector.

X-ray inspection involves passing a product or pack through the x-ray beam before it reaches the detector. The amount of x-ray energy absorbed during the beam's passage through a product is affected by the product's thickness, density and atomic number.

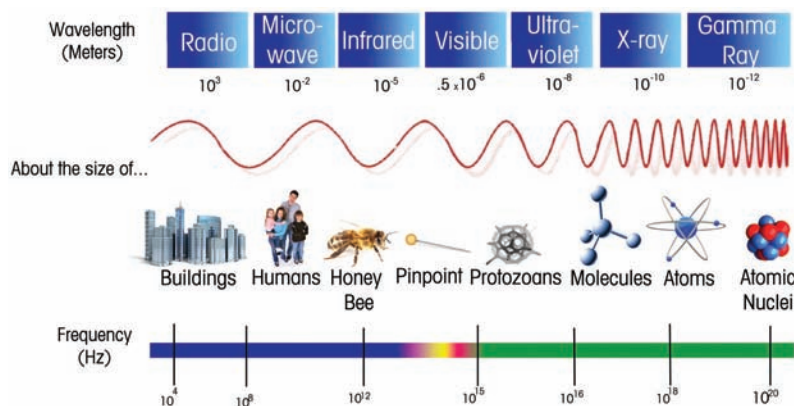


Figure 1: Electromagnetic Spectrum

When the product passes through the x-ray beam only the residual energy reaches the detector and measurement of the differences in absorption between the product and a contaminant is the basis of foreign body detection in x-ray inspection.

## 2.1 What Makes up an X-ray System?

There are three key components of an x-ray inspection system: (Figure 2)

- an x-ray generator (A)
- a detector (B)
- a computer (C)

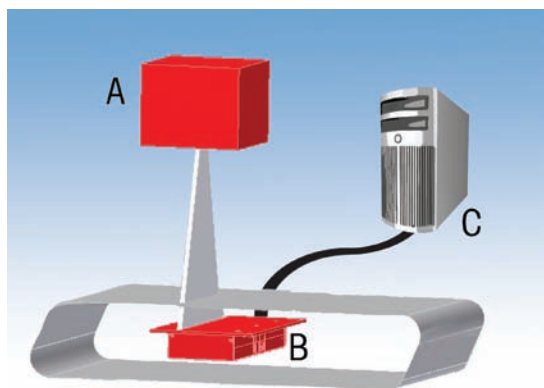


Figure 2: Components of an X-ray system

The x-ray beam is generated by an x-ray tube encased in the x-ray generator. It leaves via an exit window and travels in a straight line through a collimator (a device for narrowing the stream of x-rays to a smaller fan beam). The x-ray beam then passes through the product or pack being inspected, before finally reaching the detector.

## 2.2 X-ray Generator

The x-ray generator contains an x-ray tube which generates an x-ray beam.

Modern x-ray tubes consist of a glass envelope, a filament cathode, a copper anode and a tungsten target. The cathode (A) which is the source of the electrons is a tungsten filament heated to incandescence by an electrical current. The electrons are accelerated to the target (B) by applying a high voltage between the anode (C) and the cathode. When the electrons hit the tungsten target mounted inside the copper anode, they decelerate rapidly and this deceleration creates the x-ray emissions.

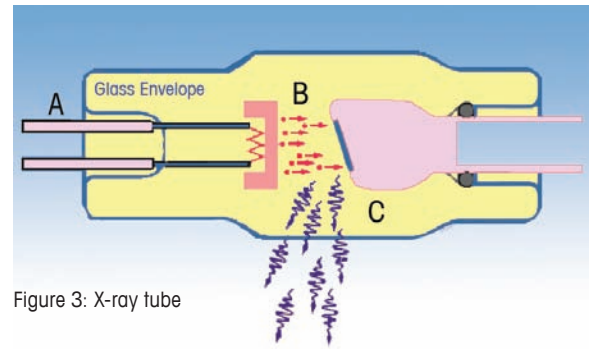


Figure 3: X-ray tube

There are two types of x-ray tube used for food and pharmaceutical inspection. The difference is in the filtration material used for the x-ray beam. This may either be a glass/aluminium filter (most common) or alternatively a beryllium filter. Beryllium filtration allows the softer x-rays to exit the tube giving enhanced image contrast and improved sensitivity to lower-density foreign bodies such as glass, stone and bone, however, the benefits are limited to thinner packs and bulk-flow products.

## 2.3 X-ray Beams

Choosing the right system is fundamental to the success of x-ray inspection as systems cannot optimally detect foreign bodies unless each element from beam angle to reject mechanism has been chosen to best fit the application. X-ray systems fall into three categories: vertical beam, horizontal beam and systems that are a combination of the two.

Most x-ray systems use a vertical x-ray beam from the generator to scan the product as it passes through the x-ray system. Most fast-moving consumer goods are usually smaller in depth than they are in width and length so inspecting them through the vertical cross-section where the least product depth is provides the best sensitivity. Machines for sealed packs, including products in flow wraps, pouches, cartons, trays or cases, tend to have vertical beam systems.

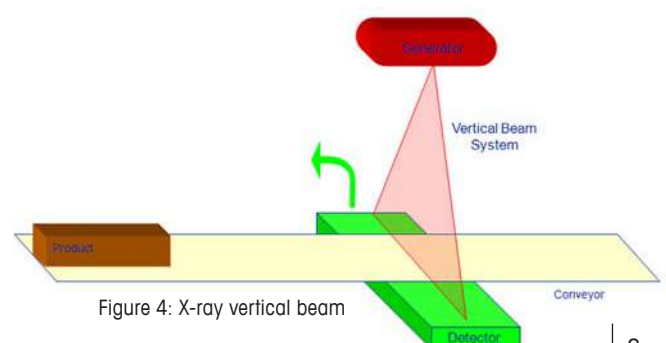


Figure 4: X-ray vertical beam

Horizontal systems use a side-mounted x-ray generator to scan products passing on the conveyor belt and are primarily used for packaged products that are taller than they are wide. Since a key factor in detection sensitivity is the depth of product that the x-rays have to pass through, horizontal systems usually offer better detection for these products as they can scan through the side of containers

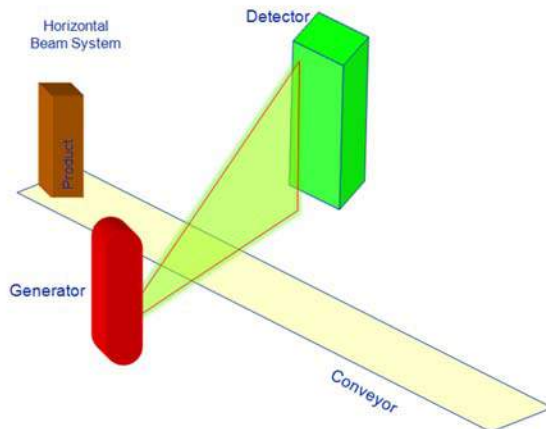


Figure 5: X-ray horizontal beam

## 2.4 Building an Image

An x-ray inspection system is essentially a scanning device. When a product passes through the system at a constant speed, internal sensors capture a 'greyscale' image of the product, which is generated by measuring the amount of x-ray energy reaching the detector.

Software within the x-ray system analyses the image and compares it to a pre-determined acceptable standard. On the basis of this comparison, the system either accepts or rejects the image and in the case of rejection, software sends a signal to an automatic reject system, which then removes the product from the production line.

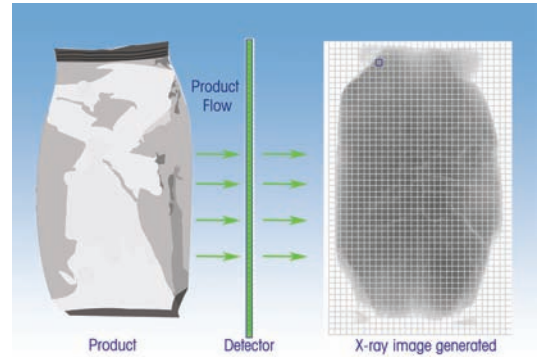


Figure 7: X-ray image generation

The diodes (individual elements of the detector) are available in different sizes to give a different image resolution. Smaller diodes require higher x-ray energies to maintain image quality so there is often a trade off in this area.

One of the key reasons x-ray inspection is fast becoming a common feature in food and pharmaceutical industries throughout the world is because a wide range of typical foreign bodies (both metallic and non-metallic) absorb more x-rays than the surrounding product and are therefore able to be detected. Additionally x-ray inspection is less affected by metallic packaging material and therefore lends itself better to this application area.

## 3. Typical Foreign Bodies

Contamination detection is directly related to the density of the product and the foreign body, and most food products have a similar density to water, which has a Specific Gravity (SG) of 1.0. As a general rule, if a potential contaminant floats in water it is likely to be difficult to detect using x-ray inspection.

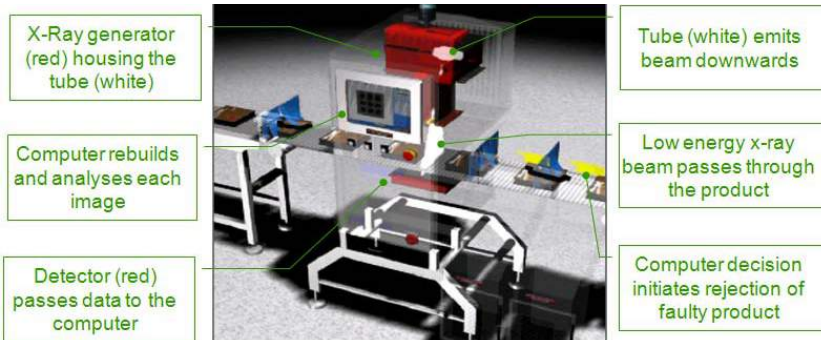


Figure 6: Building the X-ray image

Each image is made up of 'pixels' and each pixel has a value to denote a value on a greyscale (from black 0 to white 255). As the product or pack passes over the detector each line of grey level data is rebuilt to provide a complete product image.

The table below shows the SG of typical foreign bodies.

Typical Contaminant	Specific Gravity
Wood	0.7
String	0.7
Insects	0.7
Fruit stones and stalks	0.7
Low-density plastics	0.9 - 1.2
Water	1.0
Food	1.0
Bone	2.5
Dense rubber	2.5
Agglomerates	2.5
Dense plastics	3.0
Mineral stone	3.0
Glass	3.5
Ceramics	3.5
Non-ferrous metal	7.5
Ferrous metal and stainless steel	7.5 - 8.0
Lead	13
Gold	22

X-ray inspection has the capacity to detect many foreign bodies, including glass, stone, bone, and high-density plastics and rubber compounds, regardless of their shape, location within a product or the size of the packaging, and also offers exceptional levels of detection for stainless steel and ferrous and non-ferrous metals, even in products packaged in cans, metallised film or foil.

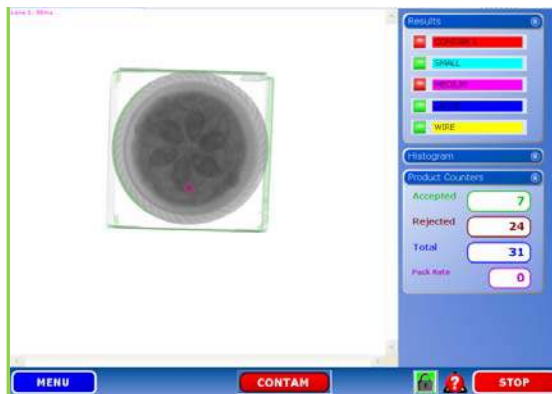


Figure 8: Apple pie in aluminium foil tray – 0.6mm SS detected

#### 4. Finding Foreign Bodies in Products and Packaging

X-ray systems can be used to detect foreign bodies at various stages of the production process, in a range of applications from raw products in bulk flow to packaged ready meals, and products pumped through a pipeline to products in glass jars, bottles or metal cans.

Even products in blister packs or sachets can be inspected. In a single pass, and at high line speeds, x-ray systems can detect foreign bodies of the minimum possible size, although the effectiveness of x-ray inspection is limited by several factors, including the thickness, homogeneity, density and size of products. For example, x-ray inspection systems work better with homogenous products, like cheese, as they create clearer images, compared to non-homogenous products, such as a box of cereal with various components of differing density i.e. flakes, nuts and vine fruit.

#### Bulk-flow machines – wet or dry, free-flowing products

These systems inspect bulk-flow, loose products before they are packaged or added as ingredients to a finished product, and typical applications include grains, peanuts, extruded snacks, dried fruits, tea and coffee, powders, vegetables and pulses. Sensitivity of detection in bulk-flow products is usually better than in final closed packs as the depth of product is typically much less. A single layer of product, or a constant depth of product flow, can be achieved and improves the sensitivity of detection.

Consideration should be given to the location of these machines in the production line. For example, when placed early in the process, they can inspect incoming goods or raw materials, allowing foreign bodies to be removed at source and immediately traced back to the supplier. Foreign bodies in incoming goods are at their largest and most easily detectable, however, further downstream, there is a chance they may get broken into smaller, less detectable fragments, as part of the manufacturing process, not to mention posing a potential threat of damage to machinery. Eliminating foreign bodies early in the production process has numerous advantages, including preventing further value being added to products through processing and packaging, thereby minimising waste and overall production costs.

#### Pipeline machines – pumped products

These systems are designed for inspection of pumped products, typically slurries, semi-solids and fluids before final packaging and further value is added. Applications include sauces, jams, minced meat, whole muscle, chocolate, fruit puree, dairy spreads and pharmaceutical slurries.

A beam scans the product as it passes through a pipe and detects product containing foreign bodies, which is then diverted away from the good product via a reject diverter valve. Like bulk-flow machines, the x-ray pipeline system is usually located upstream to inspect product at an early stage, and offers good detection levels as the product is homogeneous. Finding a foreign body in a pipeline system is much easier than finding it in a glass jar, although as glass packaging carries its own risks, there may be a need for more than one critical control point on a production line.

While the technology remains the same, x-ray systems can be adapted to suit particular applications. For example, multiple x-ray beams may be used rather than a single beam to optimise the probability of detection in a glass jar.

Two x-ray beams from a single generator (known as a split beam) increase the probability of detection of foreign bodies, as two images are created from different angles simultaneously

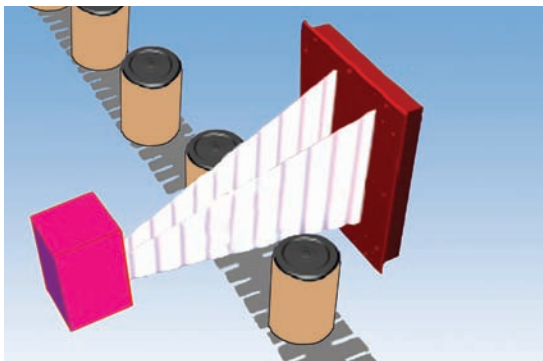


Figure 9: A split dual-beam arrangement

This is particularly useful for packaging such as metal cans where it is difficult to detect foreign bodies on the base or side walls of the can.



Figure 10: Product inspected twice to catch contaminant

By striking two separate detectors, the split dual-beam system overcomes this challenge as every can is imaged twice, and each image represents a different viewing angle, thereby increasing the coverage inside the container and the probability of detection.

Dual x-ray beams from two separate generators similarly increase detection by providing images from two opposing angles.

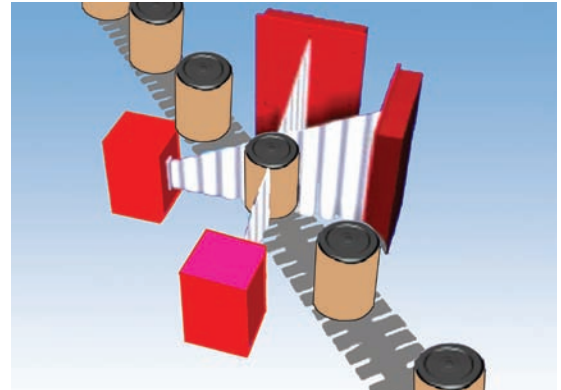


Figure 11: Probability of detection is improved by using two separate generators

Products packaged in glass bottles and jars are among the most challenging to inspect as the base, sidewalls and neck can cause 'blind spots' when inspected using a single x-ray beam and even dual beams cannot offer 100% inspection. The probability of detection can, however, be improved by using multiple x-ray beams – a combination of vertical and horizontal beams. For example, one vertical and three horizontal x-ray beams will scan the product simultaneously to produce a series of images from a range of angles, reducing blind spots and optimising detection. The orientation of the beam may also be optimised at different angles to suit the type of container and product type.



Figure 12: Combination and arrangement of beams provide complete coverage

## 5. Protecting Product Integrity

Manufacturers don't just use x-ray inspection to detect contaminants; x-ray systems can simultaneously perform a wide range of in-line quality checks.

The additional tasks an x-ray system can perform include:\*

- Measuring product length, width, area and volume;
- Measuring the mass of a product;
- Counting components;
- Identifying missing or broken products;
- Monitoring fill levels;
- Inspecting the integrity of a product seal or closure; and
- Checking for damaged product and packaging.

\* For more information please visit: [www.mt.com/safeline-xray](http://www.mt.com/safeline-xray)

## 6. Conclusion

With food and drug safety regulations intensifying, compliance and traceability through every stage of a product's life cycle is growing in importance and x-ray inspection is increasingly being used by manufacturers of well-known brands to detect and reject contaminated products.

X-ray inspection systems can find foreign bodies at every stage of production for raw, bulk, pumped, and packaged products, but the effectiveness of the technology depends on the density, thickness and homogeneity of the product.

X-rays don't pass through all materials with the same ease and measuring the differences in absorption between the product and a contaminant is the basis of foreign body detection in x-ray inspection. The transparency of a material to x-rays is broadly related to its density – the denser a product, the more x-rays it absorbs - and hidden contaminants, including foreign bodies like glass, bone and metal, show up because they absorb more x-rays than the surrounding product, meaning they appear darker on a greyscale image.

Although the basic principles of x-ray inspection are the same, it's a versatile technology and different applications require different x-ray systems. Choosing the right system is crucial to the success of x-ray inspection as foreign bodies can't be detected unless each element, from beam angle to reject mechanism, has been selected to fit the line and the product. An understanding of the various formats and their suitability for different types of foreign body detection challenges therefore underpins system specification and choice.

However, one thing's for certain, the product that successfully passes x-ray inspection contains no shocks, surprises, or disappointments. By detecting foreign bodies, x-ray inspection enhances food and pharmaceutical manufacturers' confidence in the quality and safety of their products and helps them comply with industry standards, including Hazard Analysis and Critical Control Points (HACCP), the Global Food Safety Initiative (GFSI) and Good Manufacturing Practice (GMP).

## 7. Glossary

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