White Paper

SAFELINE
Metal Detection & X-ray Inspection

Metal Detection, X-ray or Both?

Making the Right Choice

Contents

METTLER TOLEDO

Metal Detection, X-ray Inspection or Both?
Making the Right Choice for Product Safety and Quality Control

The final quality of food and pharmaceutical products is dependent on the level of diligence exercised during the production process and the rigour with which manufacturers keep contaminants out of the finished product.

Food and Pharmaceutical product manufacturers have an obligation to comply with industry legislation and regulation. Standards within the Global Food Safety Initiative (GFSI) which include the British Retail Consortium (BRC), Food Safety System Certification 22000 (FSSC22000) and International Feature Standard for Food (IFS) make the need for effective inspection processes in the food industry very clear where a risk of contamination is identified. Manufacturers in the heavily regulated pharmaceutical industry also have a need to meet compliance requirements.

The choice of protection and inspection equipment to identify potential contaminants can have a huge effect on product quality and safety and on consumer confidence.

Of the inspection choices manufacturers' face, a key one is whether to install a metal detection system, an x-ray inspection system, or both. This white paper helps you decide. It begins with a brief description of how the two technologies work. Knowing their strengths and weaknesses helps you understand why one technology may perform better than the other at different points on a production line.

The paper goes on to review the performances of the two technologies across a range of applications. In some circumstances metal detection is a clear winner; in others x-ray inspection comes out on top. But not everything is quite so clear-cut. Often there is not much to choose between them. And sometimes the most reliable solution may well be to install both technologies in different locations on the production line.

1. Metal Detection

1.1 Why Metal Detection?

Industrial metal detectors have been in existence since the 1960s and are used by food manufacturers at Critical Control Points (CCPs) in many production processes where a Hazard Analysis and Critical Control Points (HACCP) audit has identified the risk of metal contamination.

Modern metal detectors can identify all metals including ferrous (chrome, steel, etc.), non-ferrous (brass, aluminium, etc.) and both magnetic and non-magnetic stainless steels. Systems can be installed to inspect incoming raw materials prior to processing, at numerous other points in the manufacturing process, or at the end of the production or packing line.

1.2 How Does a Metal Detector Work?

In very basic terms, a metal detector consists of three coils wound around a rectangular or circular supporting frame (sometimes known as a former) to create three loops through which the product is passed. The middle coil is charged with an electrical current and acts as a transmitter.

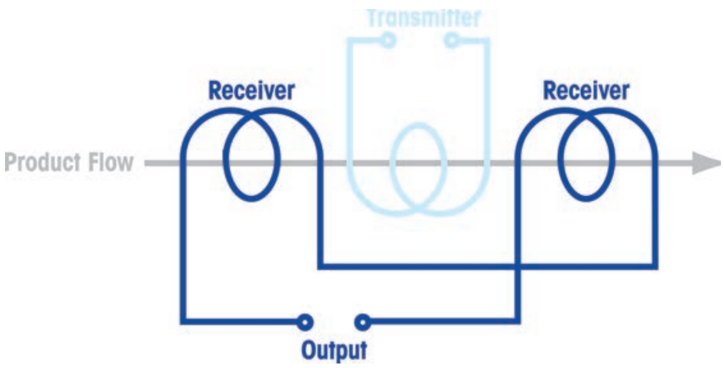

Figure 1: Balanced three coil system

The transmitter coil induces a current in the other two coils, which are positioned in close proximity before and after the middle coil (Figure 1). These coils effectively act as receivers. As the first and last coils are connected back to back, the induced currents cancel each other out. When this happens, the coil system is said to be "balanced." The coil arrangement creates an electro-magnetic field within the former through which the product passes (Figure 2).

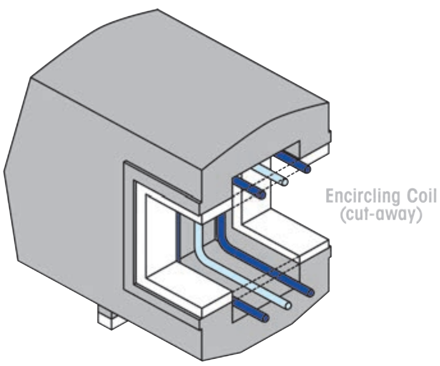

Figure 2: Shows encircling coil cut away

The electro-magnetic field remains undisturbed and the induced voltages in the coil system remain in balance until something metallic disturbs the magnetic field. When this happens, the voltage in each coil changes by just a few nanoVolts. Although the voltage change is very small, it is enough to be detected and interpreted by sophisticated electronic circuitry and advanced software algorithms. The software is able to generate an electronic signal, which can be used to raise an alarm and activate an automated product rejection mechanism to take the foreign bodies product out of the production process. Alternatively, the signal can be used to stop the production process by de-activating the conveyor or other packaging or processing machine.

(To find out more or request a free copy of the publication Reduction of Metal Contamination - Building an Effective Programme visit www.mt.com/mdguide.)

1.3 Stable Online Performance is Critical

A well-designed metal detector for use in the food industry can detect a pinhead in a loaf of bread and a metal detector designed for pharmaceutical applications can detect metal contaminants less than 0.3mm in diameter. However robust construction and stable, consistent performance is critical.

If the coil system is allowed to move or vibrate by just a few microns, the disturbance could be enough to cause rejection of a perfectly acceptable loaf or uncontaminated tablets or capsules.

Equipment construction must be rigid enough to eliminate any movement of the coil system. This is a pre-requisite for a high-quality metal detector.

In a low-quality detector, the coils system may also be sensitive to electrical and radio interference. High-quality design and construction shield the coils system, eliminating the possibility of external interference. Consideration should also be given to maintaining a metal-free zone immediately adjacent to the detector to avoid interference. Modern design and construction techniques and the use of "Zero Metal Free Zone" (ZMFZ) technology can minimise this requirement.

1.4 Dry Products

It is relatively easy to detect metal contaminants in dry products. The lack of moisture in the product generally makes them non-conductive so the product does not generate a "product effect" or "product signal". This means that metal detectors can inspect at high frequency settings where they can achieve very high levels of sensitivity detecting very small contaminants.

1.5 Conductive Products

Many products, especially salty or acidic products, or those with a high moisture content, are conductive. When they pass through a metal detector, they can create a disturbance of the detection field. These signals (referred to as a "product effect") can be largely eliminated through the use of software algorithms and selection of the correct operating frequency. A quality metal detector is able to operate at any one of many hundreds of frequencies to overcome this issue and still have sufficient sensitivity to pick up signals from very small metal foreign bodies. On 'dry' or non-conductive products where the product effect is negligible, sensitivity is significantly increased.

1.6 Metallised Film Packaging

Products packed in metallised film packaging can usually be effectively inspected by metal detectors using low-frequency operation, (depending on the film thickness) this can lead to reductions in the level of achievable on-line sensitivity. In some cases, if the metallised film is particularly thick, it is preferable to inspect these products prior to packing.

1.7 Aluminium Foil Packaging

Aluminium packaging such as foil wraps and product trays are a bigger problem for metal detectors. Detectors using balanced coil technology (described in section 1.2) are unable to inspect products in aluminium packaging. That's when a different technology, known as "ferrous-in-foil" detection, comes into play. These detectors use strong, permanent magnets to create a constant magnetic field, which is disturbed by the introduction of magnetic metals. Although this equipment only detects magnetisable ferrous metals and magnetic stainless steels, it remains a cost-effective solution in many food inspection applications.

1.8 Product Size Limitations

Metal detectors can be designed to accommodate any product size. Walk-through detectors at airports are a good indication of just how large the aperture can be if required. Extremely good sensitivity can be achieved when the height of the aperture of the metal detector is moderate in size (Figure 3). For larger packs and products, the aperture height has to be increased and, as a rule of thumb, the larger the aperture height, the less sensitive the metal detector will be. The reductions in sensitivity can be largely overcome by adjusting the pitch of the coil system within the detector. The use of variable frequency technology can also be used to overcome sensitivity problems.

Aperture size		**Ferrous ball size that can be detected (diameter mm)**
(mm)	(inches)	
76 x 22	3 x 7/8	0.15
100 circular	4 circular	0.4
350 x 175	14 x 7	0.8
1000 x 400	40 x 16	2.0

Figure 3: As the pack size increases, the aperture and coil inside must also increase.

1.9 Inspection Capabilitites

Metal detection can be used to inspect a variety of different product types, including loose, unpackaged products, pumped products such as liquids, pastes and slurries, bulk powders or free-flowing solids under gravity-fall conditions, as well as packed

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products. Metal detectors can also be used to inspect tall, rigid containers such as bottles, jars and composite containers but inspection needs to take place before metal caps or closures are applied.

2. X-ray Inspection

2.1 Why X-ray Inspection?

X-ray inspection systems made their first appearance on production lines in the late 1980s and are used by food and pharmaceutical manufacturers to ensure product safety and quality.

X-ray inspection technology has the capability to detect a wider range of contaminants than metal detectors, including metal, glass, stone, calcified bone, high-density plastics and rubber compounds. They can also simultaneously perform a range of in-line quality checks such as measuring mass, counting components, identifying missing or broken products, monitoring fill levels, inspecting seal integrity, and checking for damaged product and packaging.

2.2. How Does X-ray Inspection Work?

X-rays are invisible. Like light or radio waves, they are a form of electromagnetic radiation. Because their wavelength is short, x-rays can pass through materials that are opaque to visible light. (Figure 4) But they don't pass through all materials with the same ease. In general, the transparency of a material to x-rays is related to its density; the denser the material, the fewer x-rays that pass through.

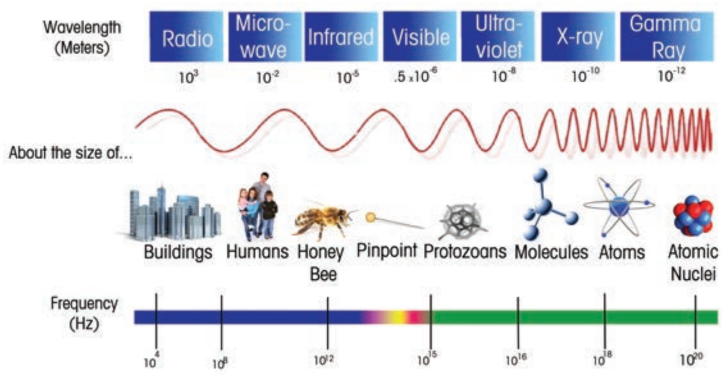


Figure 4: The electromagnetic spectrum

Hidden contaminants, like glass and metal, show up under x-ray inspection because they absorb more x-rays than the surrounding product.

An x-ray system is essentially a scanning device. When a product passes through the unit, it captures a greyscale image of the product. The software within the x-ray system analyses the greyscale image and compares it to a pre-determined acceptance standard. On the basis of this comparison, it either accepts or rejects the image. In the case of a rejection, the software sends a signal to an automatic reject system, which removes the product from the production line.

2.3 X-ray Inspection Equipment Design

There are three key components of an x-ray inspection system (Figure 5).

- An x-ray generator (A)
- A detector (B)
- A computer (C)

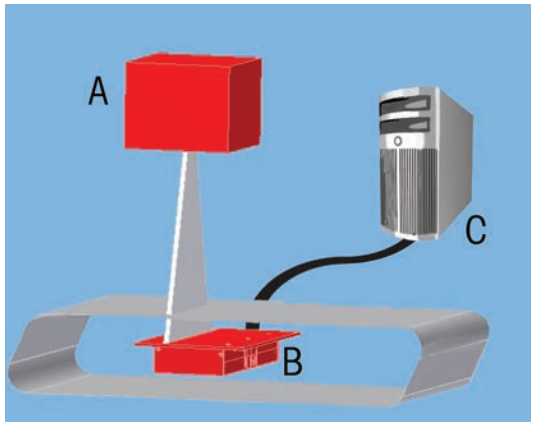


Figure 5: Components of an x-ray system

After leaving the exit window of the x-ray generator, the x-ray beam travels in a straight line through a collimator (a device for narrowing the stream of x-rays, typically to a 2mm wide fan beam), through the product, and onto the detector. A greyscale x-ray image is created and can be analysed (Figure 6).

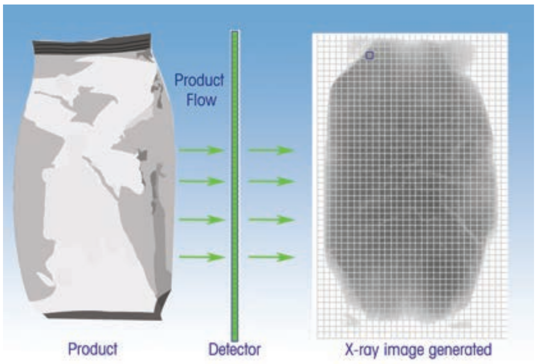


Figure 6: X-ray image generated

To accommodate larger products, the x-ray generator has to be moved further away to create an x-ray beam wide enough to inspect the whole product. Increasing the distance between generator and detector reduces the sensitivity of the system.

The whole assembly is encased in a stainless steel x-ray cabinet with a highly-visible lamp stack that signals the system status (Figure 7). The lamp stack is wired to a safety circuit; if the lamps fail, the x-ray source automatically switches off.

(To find out more or request a copy of The X-ray Inspection Guide – Building an Effective Programme visit www.mt.com/xray-guide)

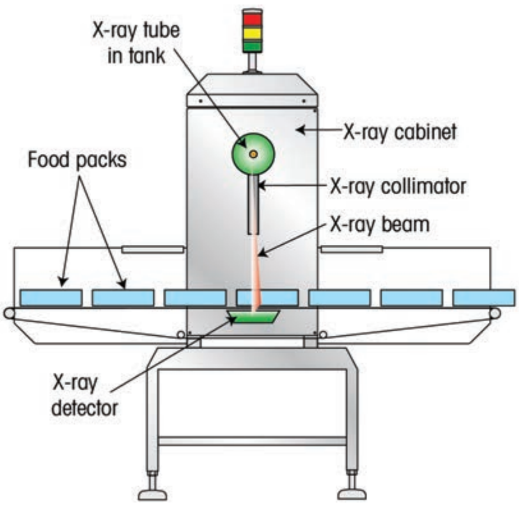


Figure 7: Side view of an x-ray inspection machine

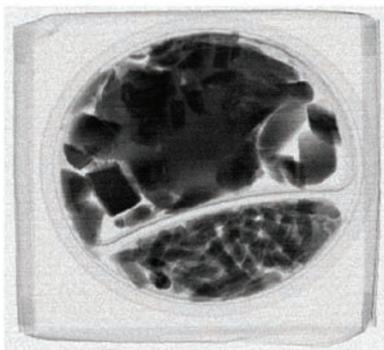
2.4 Product Density and Texture

X-ray Inspection is all about differences in absorption. 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 mass number. The absorption is known as the linear attenuation coefficient. When a pack or product passes through the x-ray beam, only the residual energy reaches the detector. Measurement of the differences in absorption between a product and a contaminant is the basis of foreign body detection in x-ray inspection.

For the most part, food and pharmaceutical products contain compounds made from elements with an atomic mass of 16 and under – mainly hydrogen, carbon and oxygen. The absorption of x-rays by products containing low-mass elements is proportional to their density and thickness. In other words, the thicker or denser the product, the more x-rays are absorbed.

A potential contaminant becomes detectable by x-ray systems if it has a high atomic mass, a feature that is generally related to the contaminant's density. Since products contain low atomic mass elements and have low density, while contaminants contain high atomic mass number elements and generally have higher density, it is convenient to use density as the benchmark for foreign body detection.

In general, contamination detection is only possible on contaminants that are denser (i.e. have a higher specific gravity) than the product in which they are embedded (Figure 8). This means that low-density contaminants such as insects, wood and polyethythene film cannot normally be detected effectively by x-ray technology.



2.5

Figure 8: Contamination detection is only possible if the contaminant is denser than the food product

Packaging Capabilities

X-ray systems can inspect a wide range of different product types, from pumped products like slurries, fluids and semi-solids to bulk, loose products.

They are ideal for the inspection of packaged products in all sizes and shapes, as well as products packaged in foil or metallised film packaging. They also work well with tall, rigid containers such as glass jars, bottles and metal cans.

3. Which Technology - Metal Detection and/or X-ray Inspection?

The easiest way to choose between metal detection and x-ray inspection is to start with your application. The first step is to carry out a Hazard Analysis and Critical Control Points (HACCP) audit and understand the requirements of any customer or compliance related issues driven by the GFSI and/or major retail groups.

This will identify the risks of contamination being introduced in your manufacturing process, and the types of contamination likely to be encountered. Critical Control Points (CCPs) should be established to mitigate the risks, and product inspection equipment needs to be installed at these points. If the HACCP audit determines that metal is the only likely contaminant to be found, then a metal detector is probably the best solution. Likewise, if other contaminants like glass, stone or dense plastics are identified as likely to be encountered, then x-ray is a more suitable solution. In many cases, there is only one suitable solution. And in just as many others, either technology will do. But there are also occasions where it could be necessary to install both systems at different points on the production line.

3.1 Installation and Verification Requirements

Metal Detection and X-ray Inspection systems can be supplied with a variety of product handling devices including an array of fully automatic reject devices. Inspection systems should be installed by competent engineers with the installation and commissioning process being thoroughly documented in order to meet compliance needs. Both metal detection and x-ray inspection systems also require regular performance verification checks to be carried out at prescribed intervals.

3.2 Aluminium Contaminants in Non-Metal Packaging

Aluminium is a lightweight metal and a good electrical conductor. Since its density is not much greater than that of water, x-ray inspection systems do less well at finding aluminium as a contaminant. Metal detection is generally the better solution.

3.3 Metal Contaminants in Aluminium Foil Packaging

When you pack your products in aluminium foil, the choice swings the other way. Metal detectors struggle to spot the contaminants amidst the packaging. But x-ray inspection can see straight through the low-density foil to get a better view of the metal contaminants within. X-ray inspection is the better solution.

3.4 Metal Contaminants in Non-Metal Packaging

For cost-effectiveness, metal detectors are usually the best solution when you are looking for metal contaminants only.

However, if the product is very large, you'll need a bigger detector aperture which can slightly reduce the sensitivity of the detector.

Using variable frequency technology, changing the detection coil arrangements and other design innovations can address the challenge, enabling good levels of sensitivity to be obtained, although the overall size of the machine required will be larger.

Product size is also an issue for x-ray, but the issue can be improved by increasing the x-ray power, which can improve the sensitivity of detection in large products. As the size increases, so does the cost of installing x-ray. Therefore choice is driven by the type of contamination risks (metallic or non-metallic). Metal only would typically favour metal detection, but an additional need to protect against non-metallic contamination will direct the choice to x-ray inspection.

3.5 Metal Contaminants in Gravity-Fed Products

Gravity-fed, powdered or granular products do not travel at the same speed; they accelerate as they fall, plus the direction of travel is not uniform as they bounce off each other. X-ray inspection systems do not offer a solution when handling this type of product; metal detection is the only solution in this case. The same situation applies when inspecting vertically-packed products immediately prior to packing.

3.6 Non-Metal Contaminants in Any Packaging

X-ray inspection is the only solution and has the ability to detect non-metallic contaminants such as glass, stone, bone and high-density rubber and plastic.

3.7 Quality Control Issues

X-ray inspection systems can perform a wide range of other quality control checks simultaneously with contamination detection.

They include:
- Measuring mass
- Counting components
- Identifying missing or broken products
- Monitoring fill levels
- Inspecting seal integrity (products or contaminants trapped in the seal)
- Checking for damaged packaging

Additional features such as these can help food and pharmaceutical manufacturers justify the additional cost of x-ray inspection technology.

3.8 Fast / Variable Line Speeds

Metal-detection and x-ray inspection systems are both suitable for variable and fast production lines.

Metal detectors will detect contaminants in products moving at low and high speeds, including conveyors running at speeds above 400m/min (although very few conveyorised processes run at such high speeds). Even higher inspection speeds can be achieved in pumped, liquid applications.

X-ray inspection systems can monitor conveyor lines running at up to 120m/min. The choice of system – x-ray or metal detection – is dependent on multiple factors such as types of contaminant, product type and packaging material.

3.9 Limited Space

A metal detection search head takes up much less space than an x-ray inspection unit so in situations where installation space is limited and metal is the likely contaminant, a metal detector maybe be the best solution.
If packed products are being inspected, both systems will normally need a conveyor system and an automated reject system. In some situations, the differences in overall system length can be very small.

3.10 Industry Standards & Codes of Practice

Recent changes in food and pharmaceutical industry safety standards are forces driving the adoption of metal detection and x-ray inspection systems. A growing number of major retailers are setting their own codes of practice which contain specific advice regarding product inspection equipment.

4. Simplifying the Choice

The points made in section 3 are easily organised into a simple yes-and-no flow chart (Figure 9).

The chart is a good starting point for choosing an appropriate system, but it cannot provide all the answers. There's an area of indecision in the middle that represents applications in which the product is not packaged in foil, and metals other than aluminium are the potential contaminants.

If cost was your sole criterion for deciding, metal detection may seem a more suitable solution. However product safety decisions are rarely that simple. The performance of each solution is affected by the size of the product to be inspected, plus it is important to compare lifetime costs, not just the upfront capital costs.

The type of product and the likely contaminants will also affect your choice and consideration must be given to the HACCP audit and CCPs on your production line.

Sometimes the answer is to install more than one detection system at different CCPs on the same production line. For example a metal detector placed at a point early in the processing line can remove large metal contaminants before they reach delicate machinery downstream where they could damage the machine or become fragmented into multiple, smaller, more difficult to detect contaminants.

As well as protecting the machinery, the metal detector removes contaminants before further processing increases the cost of product waste.

An additional more sensitive metal detection system installed at the end of the line can then make checks to ensure the final product is free of metal contaminants. Additionally, an x-ray inspection system can be installed at this point to detect a wider range of contaminants and carry out other quality checks such as confirming pack integrity and checking the contents of the pack before the product leaves the factory.

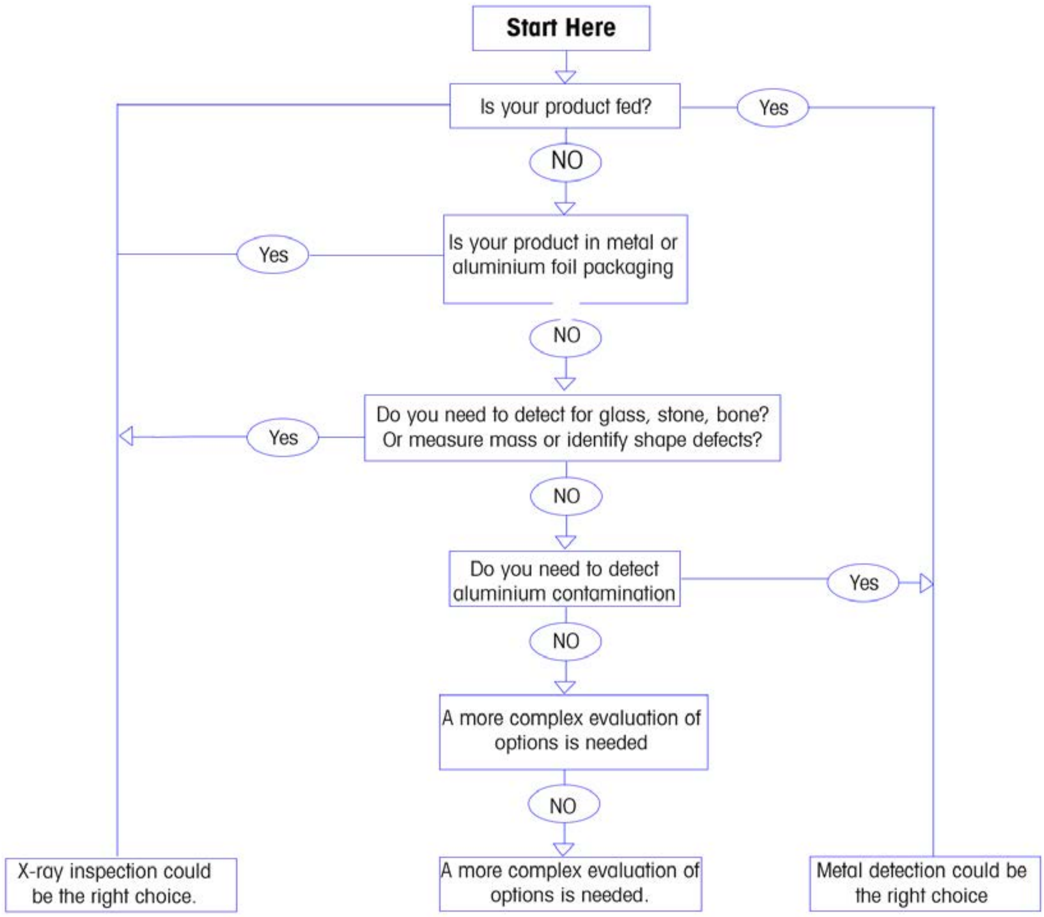


Figure 9: Flow chart - Metal Detection or X-ray Inspection

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5. Conclusion

Metal detection and x-ray inspection offer differing capabilities. In some ways it makes choosing between them simple. You can lay out a grid of features and see which ones match your application or you can reduce the problem to a series of questions. The answers to the questions should lead you straight to one technology or the other.
But neither approach is infallible.
There is an area of overlap between the two technologies where you could choose either one. Then it's not so much a question of which technology is better, but which technology is most appropriate for your particular application and budget.

As with any investment, cost is an important factor. The overall cost of an inspection system includes not only purchase price but also ongoing expenditure incurred in the lifetime of the machine. A full evaluation should be undertaken when selecting any inspection solution to fully understand the total cost of ownership.

6. Summary Table

The following table summarises the key differences between the two technologies:

	Metal Detection	X-ray Inspection
Product formats	Packaged, conveyorised products, loose, bulk products, free-falling and vertically-packed products (including powders and granular products), pumped liquids, pastes and slurries, continuous web products	Packaged, conveyorised products, loose, bulk products, pumped liquids, pastes and slurries, continuous web products
Contamination detection	Detection of all metal contaminants, including ferrous, non-ferrous (including aluminium) and magnetic and non-magnetic stainless steels	Detection of dense contaminants like ferrous, non-ferrous and stainless-steel, as well as other contaminants like glass, stone, bone, high-density plastics and rubber compounds
Detectable contaminants	Contaminants must be austenitic (magnetisable) or electrically conductive	Contaminants must be high-density or have a high atomic mass number
Aluminium contaminants	Easily detected	Detectable, but not as easily detected as other metals
Quality checks	Detection of metal contaminants	Detection of dense contaminants and simultaneous quality checks for mass measurement, seal inspection, fill-level control, component count, detection of missing and broken products, as well as packaging
Product texture	No effects	May limit performance
Conductive product	Can be inspected	Can be inspected
Metallised film-packed products	Can be inspected	Can be inspected
Aluminium foil-packed products	Cannot be inspected	Can be inspected
Pack size effects	The larger the pack, the less sensitive	The larger the pack, the less sensitive
Increased aperture size	Sensitivity can decline, and costs increase moderately	Sensitivity can decline, and costs increase significantly
Short conveyor length	Short conveyor lengths or space required for insertion	Short conveyor length may need special guarding for radiation safety
High line speeds	Operates at high line speeds	Operates at high line speeds
Variable line speeds	Operates at variable line speeds	Operates at variable line speeds

Further Information about Product Inspection

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METTLER TOLEDO has published a range of authoritative product inspection guides that cover GARVENS Checkweighing, CI Vision Inspection and SAFELINE Metal Detection and X-ray Inspection.

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