SAFELINE

Metal Detection & X-ray Inspection

Contaminant Detection: Making the right choice

Choosing between Metal Detection and X-ray Inspection

METTLER TOLEDO

Choosing Between Metal Detection and X-ray Inspection: making an informed choice

The choice of an inspection system for your production line may seem confusing, perhaps daunting. Often there are many factors to take into consideration. On the one hand, you may need to assess the feasibility of different approaches based on detailed knowledge of the physical space available at different locations in the process. Alternatively, you may need to prepare a careful economic justification based on up-front and lifetime costs.

There may be corporate guidelines on the contaminant size that must be detected - can you meet them? You may need to review the types of contaminant and defects that occur in your production process and assess how best to combat them. To be sure, any contaminant or defect detection and rejection machine should only be part of an overall plan to prevent the contamination and the cause of defects.

Metal detectors are well established in the food industry. There are several hundreds of thousands installed throughout the world. Their reliability can be depended on and the cost of installation, set-up and running is well understood. But what do you do if you need to find non-metallic contamination?

You know that x-ray systems are capable of much more than just detecting metal, but how do you assess the risks in applying new methods for your application? X-ray can detect non-metallic contamination, for example stones, glass and PVC.

Contaminants	Metal Detection	X-ray
Ferrous Metal	✓	✓
Brass, Phosphor Bronze, etc.	✓	✓
Stainless Steel	✓	✓
Aluminium	✓	
Glass		✓
Stone		✓
PVC		✓
Calcified Bone		✓

X-ray is capable of defect detection, finding missing or misshapen parts, and checking the weight of food in individual compartments of a multi-compartment package. Is the increase in cost of x-ray justified by these capabilities?

Understanding the Technologies: the core principles

Understanding the important differences between metal detector and x-ray technology is a key step to making the right choice. In the next section you will find a description of each of the technologies. This is followed by a comparison of their relative merits.

Total Cost of Ownership

In addition to purchase costs, understanding lifetime costs are often an important factor in purchase decisions:

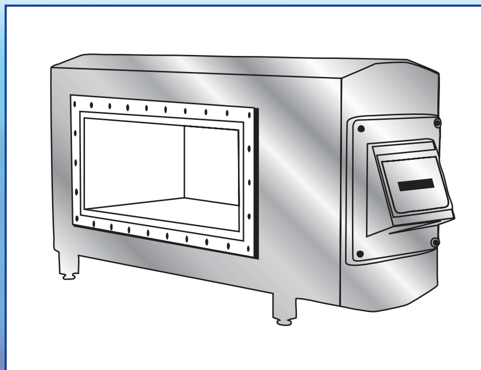
Direct Costs
- Installation
- Commissioning
- Operator training
- Performance verification
- Product changeover
- Sanitation
- Downtime
- Annual maintenance

Indirect Costs
- Brand Image
- Supply Chain Confidence
- Product Recall Costs
- Scrapped Product

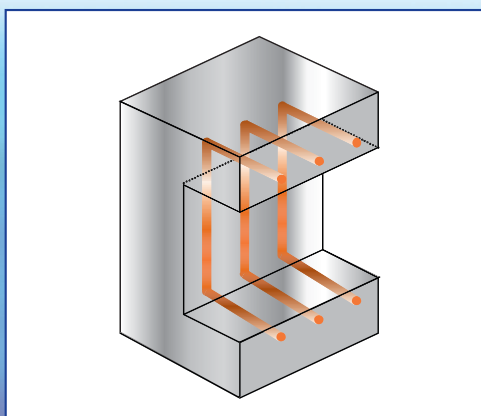
The Conventional Metal Detector

In a conventional metal detector, the product passes through a tunnel, or aperture, in the unit. It might be taken through on a conveyor belt, or it may be dropped through. Inside the metal detector, surrounding the aperture are three encircling coils, usually made of copper.

Rectangular Aperture Metal Detector



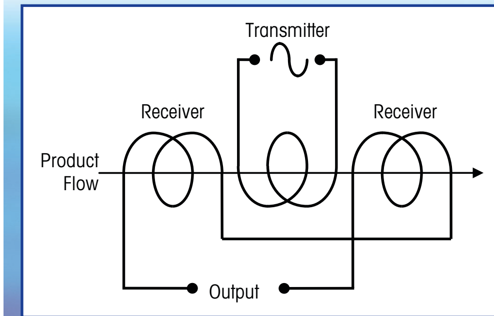
Section through metal detector, showing coils



One coil, the transmitter, has an alternating electric current applied, which produces an alternating magnetic field. The other two coils, which form the receiver, are spaced equally on either side of the transmitter. A voltage is induced in each of these coils, and, if symmetrical to each other, the voltages in both receiver coils will be equal.

By connecting the coils back to back, the voltage will cancel. However, when anything disturbs the magnetic field, the voltages no longer cancel. If amplified, this differential voltage can be used to detect whatever disturbs

Balanced Three Coil System



the magnetic field. This could be magnetic material, but can also be conductive material, since, in an alternating field, electrical conductors will have an eddy current induced in them, making them look like small alternating magnets.

The electrical conductivity of your product may produce a disturbance of the magnetic field, and this effect - the 'product effect' - must be suppressed before any metallic contamination can be reliably found. Similarly, if the food is to be inspected within its packaging, and if that packaging contains metal (for example, aluminum foil trays, metalized film wrap), the effect of this must also be avoided.

Robust Design: essential for reliable operation

A metal detector designed for the food industry is capable of finding a pinhead in a loaf of bread. To be this sensitive, and to operate reliably in a production environment without false rejects, the detector must be very mechanically stable.

If the casework of the metal detector moves only a few microns relative to the coil system, the magnetic field will be disturbed causing a false rejection of product. Metal detector manufacturers use extreme measures to achieve

As the pack size increases, the aperture and coil inside must also increase. At larger coil sizes, metal detector sensitivity reduces.

Aperture size		Ferrous ball size that can be detected (diameter mm)
(mm)	(inches)	
76x22	3 x 7/8	0.15
100 circular	4 circular	0.4
350x175	14 x 7	0.8
1000x400	40x16	2.0
1000x1000	40x40	5.0

the necessary mechanical stability.

In addition, since the metal detector must operate at radio frequencies, it is also a very sensitive radio receiver, and a false rejection can be caused by electrical or radio interference. Again, great care is taken by manufacturers to minimize this problem by designing electronic circuits that are not disturbed by external fields.

Product Effect: handling conductive products

The signal from a conventional metal detector is a continuous voltage corresponding to disruption of the alternating magnetic field in the metal detector's coil system. Two signals can be detected.

One originates from reactive effects and is shown in red in the chart below: this can be caused by case movement, large pieces of metal moving in the vicinity of the metal detector and by magnetic material passing though the aperture.

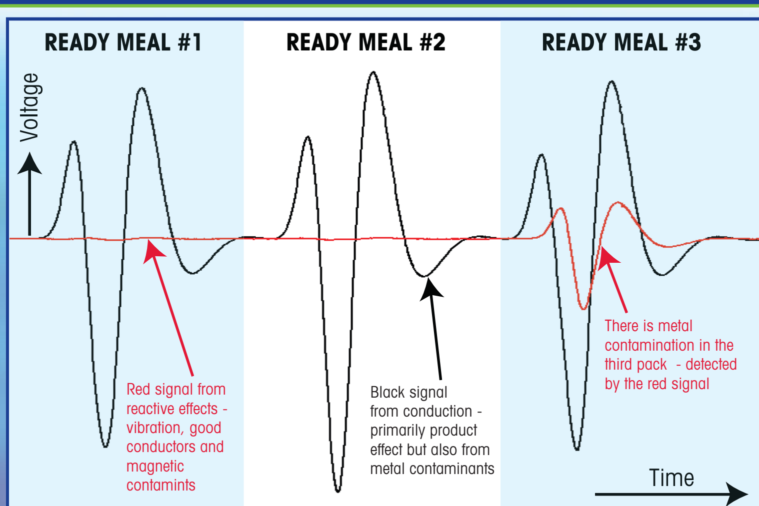
The second signal occurs as a result of resistive effects and is shown in black in the chart below: this is caused by absorption of energy when an object with electrical conductivity passes through the aperture.

Some food products have electrical conductivity as a result of their salt or acid content. Small metal contaminants produce both reactive and conductive effects in varying proportions that depend on the type of metal and on the size and shape of the particle.

There are two important potential causes of false triggering in a metal detector: (a) vibration causing very small movements of the metal detector case with respect to the coil system and appearing predominantly on the reactive signal; and (b) electrical conductivity of food products which appears mostly on the resistive signal, particularly at high frequencies.

The signal processing in the metal detector must be arranged so as to reject these two effects, but maintain the best possible sensitivity to a real metal contaminant. When there is no product signal, the resistive signal can be used at very high sensitivity to detect the very smallest metal particles and the reactive signal is largely ignored, since it contains only vibration signals. When the product effect is large, the reactive signal must be used, but at reduced sensitivity, in order to avoid the effects of vibration.

Metal detector signals from three ready meal products passing through the aperture



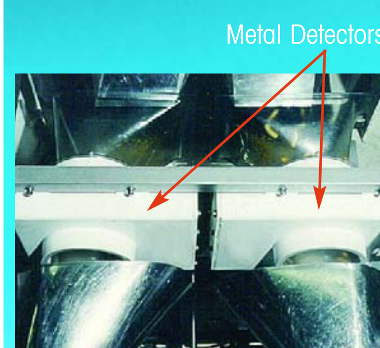
Case Study: Snack Food

A major snack food producer was building new plant as part of an expansion program to meet increased demand. They had for years used 'Throat' metal detectors, which require as little as 200mm of vertical installation space.

These are inserted between the multi-head weigher and the forming tube or 'throat' of the vertical form, fill and seal (VFFS) machine. The performance deficit usually associated with metalized film packaging is avoided by performing the metal detection just before the product enters the packaging.

The new development consisted of eight multi-head weighers each feeding a VFFS machine. These feed into a single case packing line and the feasibility of utilizing a single x-ray machine at this point was investigated. One x-ray machine could potentially replace eight metal detectors.

Choice of technology came down to contaminant detection performance. The metal detectors will detect down to 1.0mm Fe and 1.5mm SS test ball. In practice, the x-ray system could not match the 1.0mm ferrous metal ball test and the decision was made to stay with the metal detection technology.



Packaging Effect: managing conductive packaging

While a metal detector is extremely sensitive to detecting metal, its ability to ignore metal or conductive packaging, or parts that are meant to be there, is limited.

There is an increasing use of metalized film in packaging which acts as a good gas barrier and extends product shelf life. Metalized film employs a thin layer of aluminum which can have a considerable effect on metal detector performance. In order to combat the effect, the metal detector may have to operate at a low frequency where it will be less sensitive to stainless steel.

The toughest challenge for metal detector performance comes from aluminum foil trays for goods that are to be baked at home. In this case the volume of metal passing through the metal detector with each product is considerable.

Over the years, metal detector manufacturers have developed various alternatives to the three-coil radio frequency technology to help detect metal contamination in foil trays. So-called ferrous-in-foil metal detectors use constant magnetic fields so that the eddy current effect is minimized. As a result, these systems can only really detect magnetic materials. Austenitic stainless steel grades such as 304 or 316 cannot be found very efficiently because they are mostly non-magnetic. However, these materials are used extensively in the food industry and they frequently turn up as contaminants.

Performance Verification: maintaining detection standards

Metal detectors are traditionally tested using ball bearings, usually ferrous, non-ferrous and stainless steel. In practice these are made from, respectively, a low alloy chromium steel (case hardened for bearing applications), brass, and non-magnetic stainless steel; either grade 304 or 316. These are readily available in a variety of sizes. Using a sphere means that it does not matter what the orientation of the test piece is, it will always perform equally well. It is then possible to check the performance of a metal detector in a test that takes just a few minutes.

Test pieces are inserted into samples of the product, usually in three positions: front. middle and back. The test ball is always positioned at the least sensitive part of the aperture, which is in the middle. A routine test can be performed on a regular basis, e.g. every 4 hours. The spiked product must go into the reject bin every time in order to pass the test.

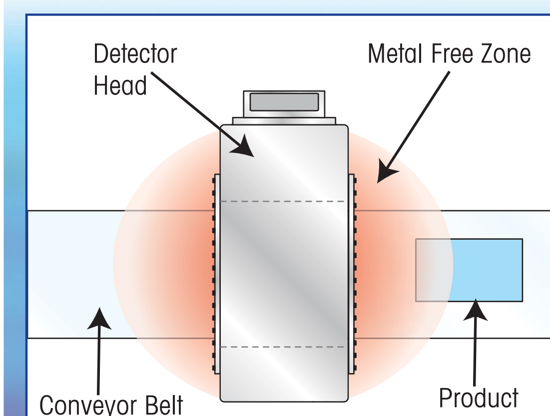
These tests have become standard practice in the food industry because they are relatively easy to perform and produce very consistent results.

The Metal Free Zone: achieving and maintaining performance in the plant environment

With a metal detector, because it is so sensitive to metal, a metal free zone must be created around the detector. Conveyor components, including belt materials, must be metal free and reject mechanisms must be positioned at a sufficient distance to prevent their movement falsely re-triggering the metal detector.

Where space on the production floor is particularly limited, metal detectors with reduced metal free zones are available, but can compromise the sensitivity of the detector.

Metal Free Zone: Plan view of detector



X-ray Inspection

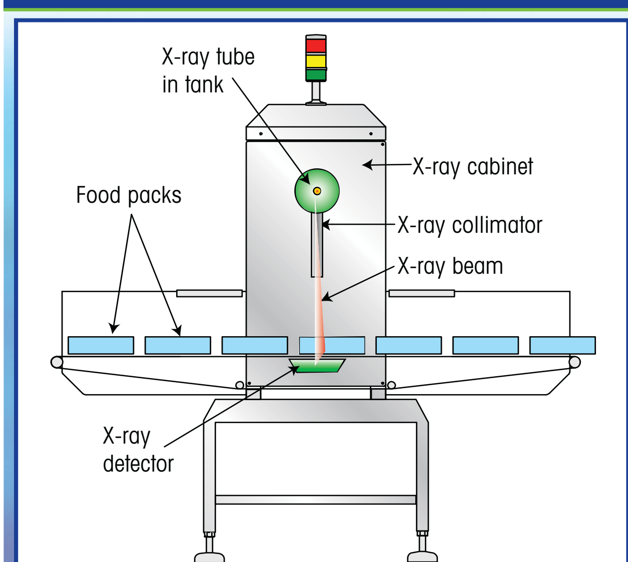
X-ray inspection machines operate using technology essentially the same as that used for medical x-ray and baggage security x-ray imaging, but with one significant difference: For high-speed production lines in the food and pharmaceutical processing industries, we require these systems to operate fully automatically. This necessitates a computer controlled system to apply the pass or reject criteria.

The x-ray image is formed by scanning the product in two directions: one direction is the movement of the pack on a conveyor belt or pumped through a pipe. The second direction is perpendicular to the motion of the product, generated by the x-ray tube on one side of the product, and detected by a linear detector array on the other side. Data from the detector is passed to a computer where it is assembled into a complete image of the product. Image processing algorithms are then used to determine if contaminant or defects are present. The images are complex, and require well proven algorithms to achieve sensitive and reliable results.

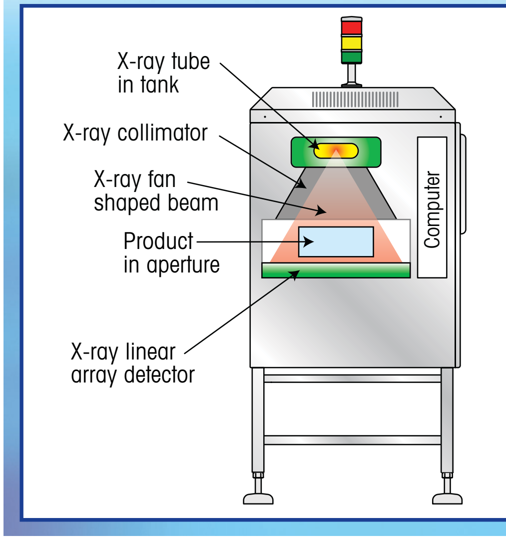
Data Collection: A wealth of information

Compared with metal detection, the data collected by x-ray inspection on a product is much more diverse, and potentially far more

Front View of X-ray Inspection Machine



End View of X-ray Inspection Machine



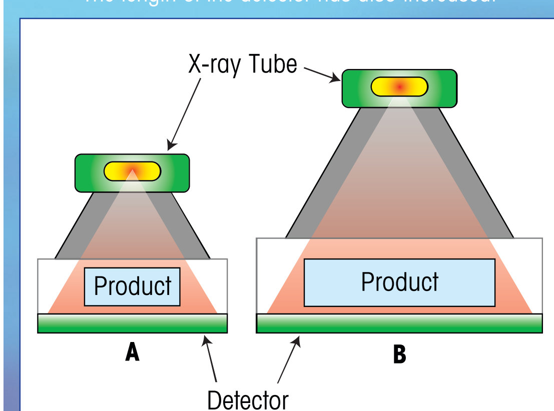
useful to the line management team.
A 2-dimensional image - essentially a cross section of the product - is captured. Software algorithms can then exclude packaging and known features, isolate individual components within the pack, check the number, shape and size of these individual components and even calculate the mass of material in individual compartments. In some cases, x-ray offers the only method of check-weighing certain types of product, i.e. individual compartments in a web of connected products such as milk powder pouches.

Larger Pack Sizes: maintaining sensitivity

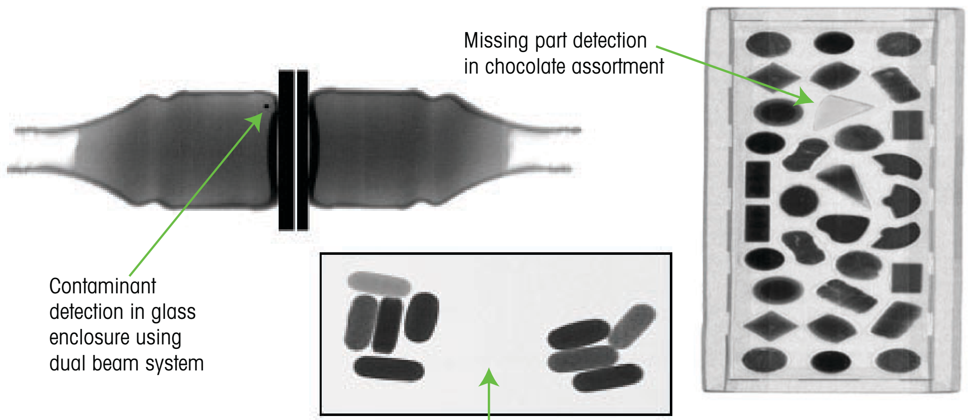
With large product sizes, an x-ray system will

Increasing Pack Size

The small increase in pack size from A to B has resulted in twice the operating distance for the x-ray tube requiring four times the power. The length of the detector has also increased.



X-ray Image Examples



often out-perform metal detection. The signal from a given piece of metal contaminant gets smaller when its distance from the coil of a metal detector increases. So for larger size coils needed for larger apertures, the sensitivity at the centre of the aperture degrades, lowering the overall metal detector performance.

As pack size increases on the x-ray system, so the voltage of the tube is increased to 'see' through the increasing thickness of the product, and sensitivity is maintained. The power of the x-ray tube must increase as the square of the distance from tube to detector. The higher power x-ray system does increase the cost of the x-ray components.

X-ray's sensitivity to detect small contaminant depends on the resolution, or pixel size, of the product image generated. This can be improved by decreasing the size of diodes used in the detector, giving an increased number of diodes in the detector array, and an increased image resolution. Again, this can increase the component cost of the system.

However, with these improvements, the sensitivity does not degrade with size increase as it does with metal detection.

Higher Line Speeds: maintaining sensitivity

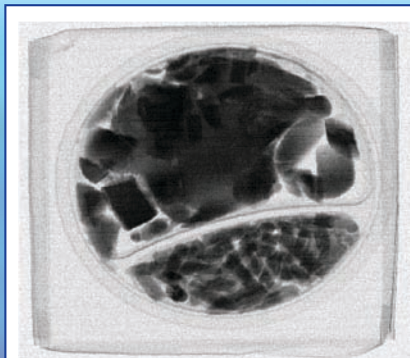
Metal detectors can operate at up to 5000 ft/min (1500 m/min) for blown pipeline applications and can handle high speed flow wrap lines, running at up 2000 packs per minute or more. Modern X-ray systems operate at up to 600 ft/min (180 m/min)and for conveyorized applications, they can tackle all but the fastest flow wrap lines. At the highest speeds, they may require increased power to maintain good image quality.

Water Depth and Texture

X-ray imaging performance is limited by two main factors: the x-ray density of the material through which the x-rays must pass, and the texture of the object.

X-ray density is often referred to as 'water depth', that is, the equivalent depth of water to attenuate, or absorb, x-rays to the same degree.

The texture of the product is the ultimate limit to contaminant detection - if the contaminant is not distinguishable from the natural variation in the product, then it cannot be detected i.e. ready meals chicken and rice



Since water is a major constituent of denser foods, then the water depth is often similar to the physical depth of the product. If a very high proportion of the x-rays are being absorbed by a given water depth, then the x-ray energy level must be increased to improve penetration. If the energy levels have to be increased, the detection of fine detail in the image reduces and lower density contaminants are more difficult to find.

Product texture, or variations in the x-ray density, caused by the granularity of a non-homogeneous product, can limit performance. The power setting of the x-ray tube may be correct for the average density of the product, but will be too low for more dense elements, but also too high for less dense elements, reducing the sensitivity to detect contaminants and product features. Modern x-ray systems have electronic controls for the voltage and power of the x-ray tube, so that these can be optimized for each product type to be inspected.

Mass estimation

X-ray density is not the same as atomic mass, so estimating mass from x-ray absorption is not exact. For applications where the proportion of different elements remains reasonably constant, then very accurate mass estimation is possible. Some compensation for ingredient changes can be achieved using dual energy technology, but this does not ensure total accuracy.

Mass attenuation coefficients for common elements at 20 keV and 50 keV compared with the atomic mass

	20 keV	50 keV	Atomic Mass
H	0.369	0.336	1
C	0.442	0.187	12
N	0.618	0.198	14
O	0.865	0.213	16
Na	2.06	0.280	23
Al	3.44	0.368	27
Cl	7.74	0.648	35
K	10.9	0.868	39
Ca	13.1	1.02	40
Fe	25.7	1.96	56
Cu	33.8	2.61	64
Zn	37.2	2.89	65

Performance Testing

The test procedure using metal spheres employed routinely with metal detectors will not yield consistent results with x-ray. This is because there is considerably more variation in signal from small test spheres in x-ray than there is in metal detection. in the graph below, the probability of detection of metal spheres is plotted against their size. It is easy to specify a ball size that will always be detected in a metal detector. For x-ray, even though the average size of test sphere that can be detected is smaller, the test sphere size that will always be detected is much larger.

If an x-ray machine is testing for missing or deformed components, glass and plastic contamination, (in addition to metal), then each of these capabilities must also be tested with appropriate test pieces and quantified. Validating the performance of an x-ray system on a regular basis, and to the same standards as is routinely done in metal detection, requires significant resource. However, performance testing of the inspection equipment is a vital part of achieving product integrity. Your equipment vendor will be able to advise you on how this can be achieved at minimal cost for your application.

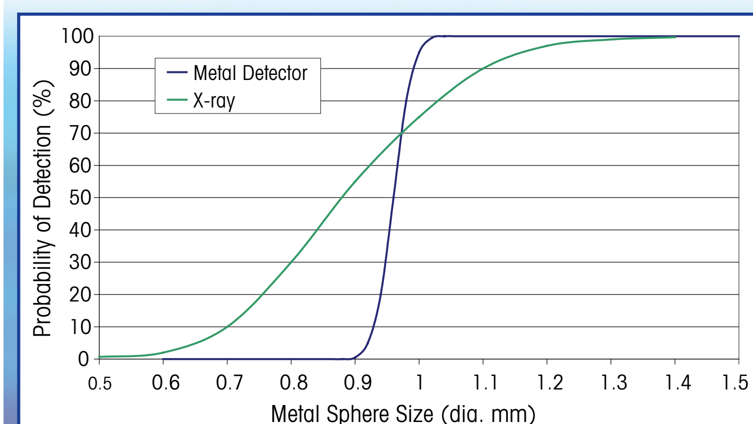
Case Study: Flow Wrapping in metalized Film

A baked goods manufacturer supplying flow wrapped product for a premium brand needed to implement contamination detection.

Two main alternatives became apparent: a metal detector offering down to 6mm stainless steel detection capability because of the metalized film wrap or an x-ray system that could achieve 1.5mm stainless steel.

Although the x-ray system was significantly more expensive, the company chose x-ray. "We will be able to exploit the x-ray machine's capability to check correct placement of chocolate toppings to the cakes; this, and the vastly improved detection of stainless steel contaminant meant that investment in x-ray was the correct decision for us."

Probability of Detection for Metallic Spheres
Comparing Metal Detector and X-ray Technology



Comparison of the Technologies

Choosing between x-ray and metal detection technologies may require a careful analysis of all the factors although in some cases the choice is simple (see flow chart on next page). If you need to detect shredded aluminum drinks cans, then metal detection is probably your only alternative, as it is if your product is gravity fed. If it is vital that you detect non-metallic contaminants or that you check part counts, detect misshapen product or estimate weight of product, then x-ray is your choice. In other cases, however, the whole production operation needs to be considered; there may be a case for metal detection at one stage of the process and x-ray at other locations.

You will always seek to match or excel the quality requirements of your customer while minimizing the total cost of ownership of the equipment. This section highlights some of the application issues that may influence your decision.

Metallic Contamination Detection in non-metallic packaging

If your requirement is the detection of metallic only contamination in product packaged in non-metallic materials, and if your budget is limited, then in many cases metal detection technology will offer the best alternative.

However, if your product is large, then x-ray inspection will out perform metal detection on a basic contaminant sensitivity specification in the majority of cases, but the costs will be higher.

The Effects of Aluminum: as a contaminant and as a packaging material

Aluminum is a good electrical conductor but has lower x-ray density than other commonly occurring metal contaminants. Therefore, if aluminum is a contaminant threat, than metal detection will do the best job of identifying and rejecting aluminum contaminant. However, if aluminum is included in the packaging, either in the form of metalized film or as a foil tray, then its low x-ray density can be exploited - the x-ray system will largely ignore it and will do a superior job of inspecting the contained product for the metal contaminants.

Available Space

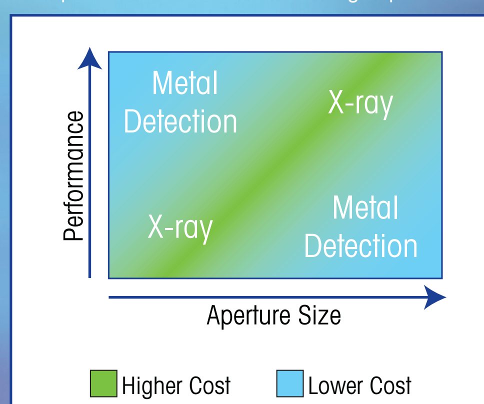
The space available for installation of your inspection machine may be an important consideration. A significant number of metal detectors are used where performance has to be balanced against the space available.

Although very small in footprint, remember that with a metal detector you must also take account of the metal free zone, so even though the detection unit is small, it may not be possible to position it as close to other machinery as hoped.

Where x-ray machines must be fitted into small spaces, the focus is often on reducing the in feed and out feed tunnel. However, under the regulations in force in many countries, the tunnel must be sufficiently long to prevent a person reaching into the unit. This problem can be overcome in some cases by incorporating adjacent machinery into the guarding provision. However, the operators safety must always take precedent.

Metallic Contamination Detection Without Metallic Packaging

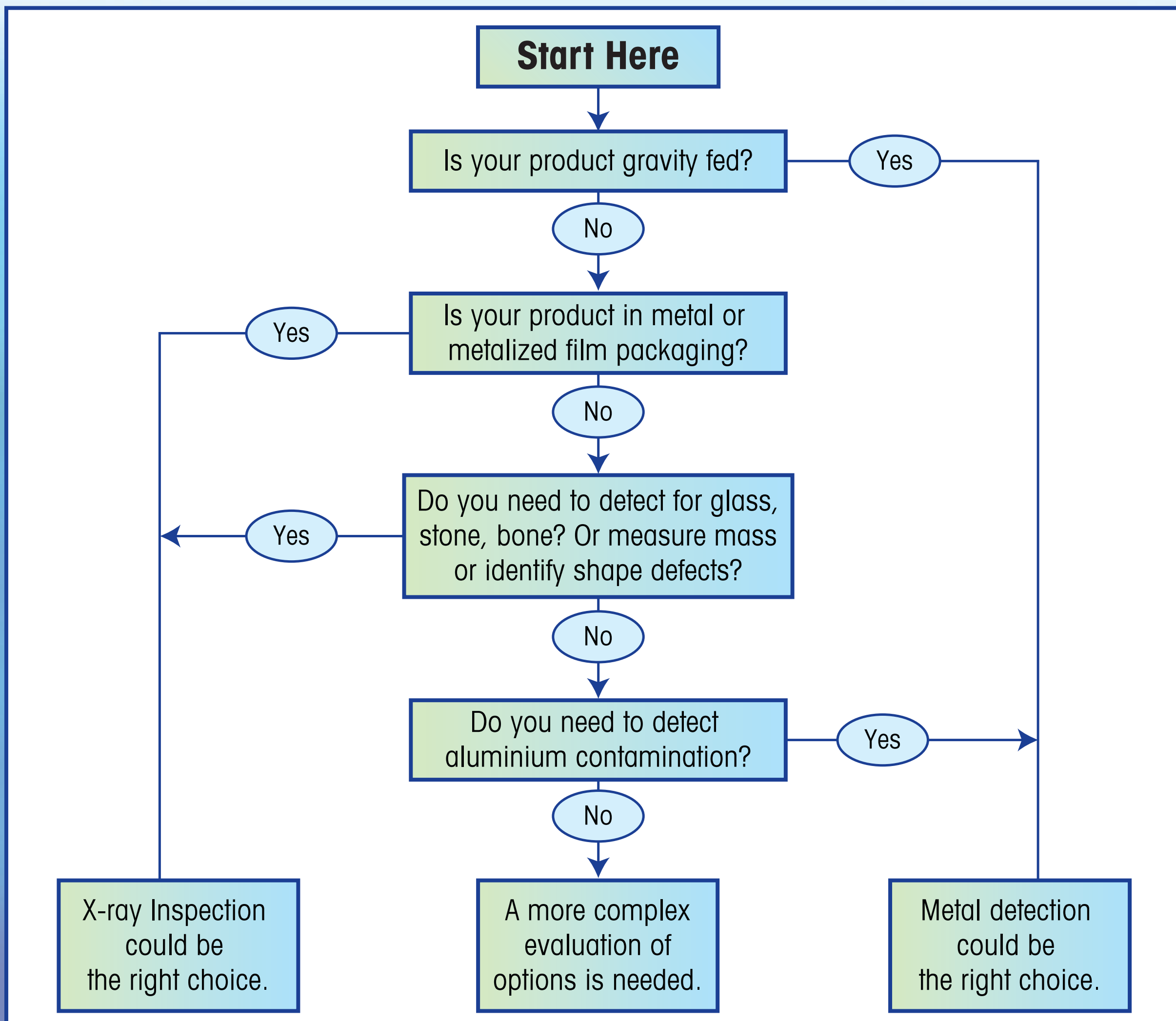
For metallic contaminant detection, metal detectors offer greater performance at small apertures than x-ray systems, and the cost is lower. However x-ray may be the correct choice if other inspection capabilities are needed. X-ray outperforms metal detection at large apertures.



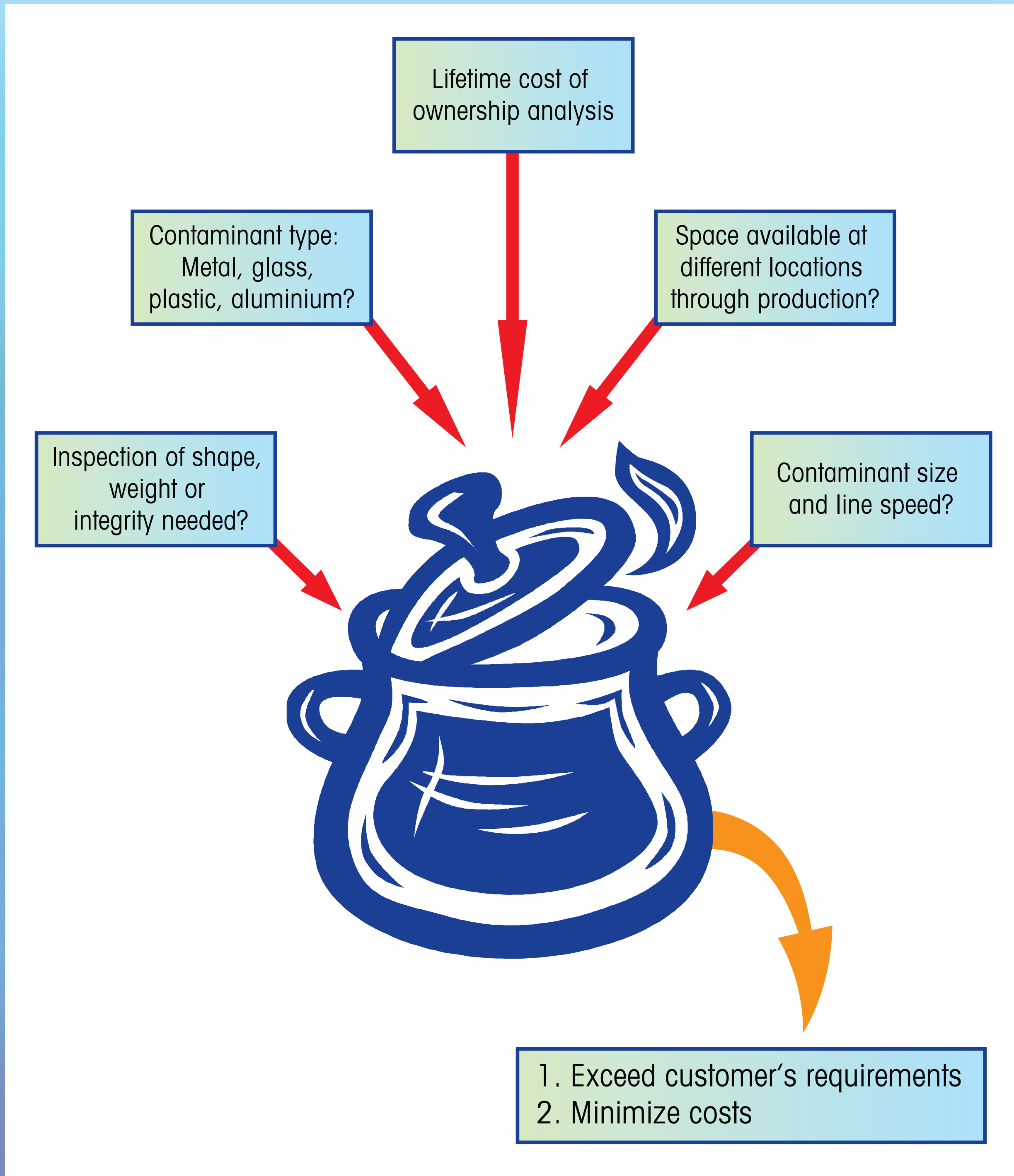
Key Differences

Metal Detection	X-ray Inspection
Product can be on conveyor, in pipe or drop fed	Product must be at constant speed - cannot be drop fed
Costs increase only slightly with increased aperture size	Costs increase with increased aperture size
Significant sensitivity reduction with increase in aperture size	Only slight reduction in sensitivity with increase in aperture size
Reduced performance with a short conveyor length or insertion distance with incorporation of metal free zone (MFZ)	May need special guarding with short conveyor length
Detectable contaminants must be magnetic or electrically conductive	Detectable contaminants must have a different X-ray density from product
Product texture not important	Product texture may limit performance
Product electrical conductivity may limit performance	Product electrical conductivity not important
Aluminium packaging limits performance - you may only be able to detect magnetic material	Aluminium packaging generally does not reduce performance
Can detect aluminium contaminant	Aluminium can't easily be detected
Can operate at very fast speeds	May be limited in speed

Some Initial Questions on Choice of X-ray or Metal detection



Many factors go into the melting pot before achieving the solution that exceeds your customer's expectations and minimizes your total lifetime costs.



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