White Paper

How Safe is X-ray Inspection of Food?

Contents

1 Introduction

X-ray inspection has become increasingly popular as food manufacturers worldwide strive to protect consumers' welfare, safeguard their brand reputations and comply with national and international regulations and legislation, as well as standards set by retailers.

However, some manufacturers still have reservations about adopting x-ray inspection as a method of product inspection. They are concerned their staff will object to bringing x-rays into the workplace and that consumers could switch to a brand that has not been subjected to x-ray inspection.

This white paper shows that although people are right to be wary of radiation, it does not mean they should be worried about using x-rays for food inspection. The paper begins by explaining why food manufacturers' use x-rays to inspect food, before exploring what radiation is and looking at the health and safety aspects of radiation.

To help readers understand radiation levels, the white paper compares dose rates from some natural and artificial sources of radiation that we are exposed to in day-to-day life. Finally, it discusses how modern x-ray systems are designed to protect users from the effects of radiation, and concludes that a factory containing correctly-maintained and well-managed x-ray equipment is just as safe as any other properly-controlled and monitored working environment.

2 Why Use X-rays to Inspect Food?

Food manufacturers use x-ray inspection technology to ensure product safety and quality. X-ray inspection gives them exceptional levels of metal detection for ferrous metal, non-ferrous metal, and stainless-steel. The technology is also extremely good at detecting other physical contaminants such as glass, mineral stone, calcified bone, and high-density plastics and rubber compounds.

In addition, x-ray systems can simultaneously perform a wide range of in-line quality checks such as measuring mass, counting components, identifying missing or broken products, monitoring fill levels, measuring head space, detecting product trapped within the seal, and checking for damaged product and packaging.

3 What is Radiation?

Radiation covers a lot of things and only a small part of that is from things that are radioactive. Emissions from a radioactive source are generally referred to as 'radiation', however, different forms of radiation have been harnessed by science for use in many different types of equipment that we often take for granted in everyday life.

Two main sources of radiation exist: natural and man-made. Examples of natural radiation include natural heat or light from the sun, radiation from the ground, and gamma rays from radioactive elements. Examples of man-made radiation include microwaves from an oven and x-rays from an x-ray tube light from a torch.

X-rays are a form of electromagnetic radiation, like light or radio waves. All types of electromagnetic radiation are part of a single continuum known as the electromagnetic spectrum (Figure 1). The spectrum runs from long-wave radio at one end to gamma rays at the other.

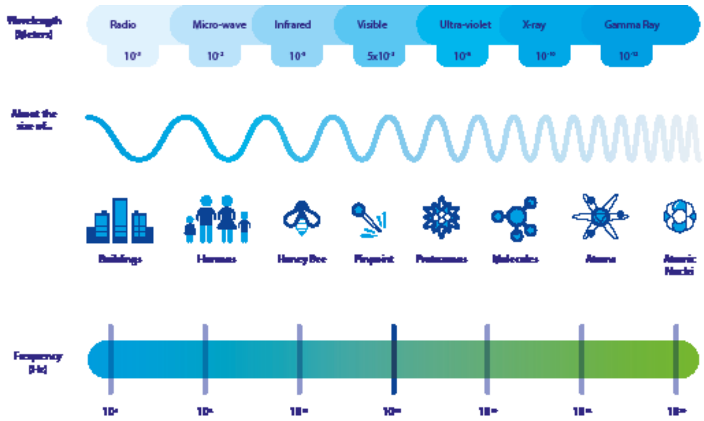

Figure 1: Electromagnetic Spectrum

Most parts of the electromagnetic spectrum are used in science for spectroscopic and other probing procedures, in which matter can be studied and characterized through the use of radiation.

X-rays are used for many purposes, from medical examinations to the identification of contaminants in foodstuffs and other materials.

The wavelength of x-rays enables them to pass through materials that block out visible light to a greater or lesser degree. The transparency of a material to x-rays is broadly related to its density, which is why x-ray inspection is so useful in the food industry: the denser the material, the fewer x-rays can pass through. Hidden contaminants, such as glass and metal, show up under x-ray inspection because they absorb more x-rays than the surrounding food.

X-rays used in the inspection of food (and pharmaceutical) products are not generated from naturally occurring radioactive materials. The x-rays are man-made, generated within the inspection equipment itself, and like an electric light bulb, they can be turned on and off at will. When the electricity supply to the system's x-ray generator is switched off, the flow of x-rays instantly ceases. Provided safety guidelines are followed, these x-rays are safe for those operating the equipment and at normal operating levels they are not expected to have negative effect on the products they inspect.

It is worth noting that the level of exposure to x-rays, or 'dose', is generally much lower in food inspection when compared to other sources of radiation, such as medical x-rays, security scanning, food irradiation or naturally occurring background radiation. This is because the energies of the x-rays are low, the quantity of x-rays used (the x-ray 'flux') is minimal and the exposure time is very short.

3.1 Ionizing Radiation

An ion is an atom or molecule in which the total number of electrons is not equal to the total number of protons (i.e. more protons than electrons). This gives the atom a net positive electrical charge (when there are more protons).

Ionizing radiation is radiation that has enough energy to force electrons out of atoms to create ions. X-rays are a form of ionizing radiation within the electromagnetic spectrum, and they have the ability to penetrate both synthetic and biological matter.

Other forms of ionizing radiation include alpha particles, beta particles and gamma rays, all of which are emitted by radioactive materials or sources. However, since radioactive materials are not used in x-ray inspection systems, their effects and applications are not covered in this white paper.

3.2 Background Radiation

Background radiation is all around us, and includes radiation from both natural and artificial sources. As humans, we have always been exposed to radiation from the environment in which we live; in fact natural sources account for approximately 82%* of the total radiation that we receive.

The chart (Figure 2) shows the four main sources of radiation that add up to the background radiation received by a typical person.

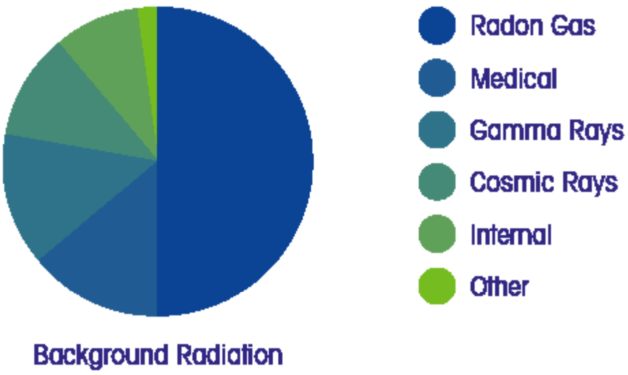

Figure 2: Major sources of background radiation

Radon Gas
Radium-226 is a chemical element, and all isotopes (variants) of radium are highly radioactive, with the most stable isotope being radium-226, which has a half-life (the amount of time required for it to halve in value) of 1600 years. This decays into radon gas. Many soils and rocks (particularly granite) naturally contain radium, which seeps out of these naturally-occurring materials in a gaseous form. Radon is often the single largest contributor to an individual's background radiation dose, and the proportion is typically around 50%, but it varies widely from location to location throughout the world.

Cosmic Radiation
Cosmic rays are immensely high-energy radiation, mainly originating outside the Solar System. They may produce showers of secondary particles that penetrate and impact the Earth's atmosphere and sometimes even reach the surface. They are composed primarily of high-energy protons and atomic nuclei.

Internal Radiation
This type of exposure arises when a person inhales or ingests radioactive material, normally in the form of a very fine dust. The various organs of the body then receive a radiation dose emitted by the radioactive material.

Medical Radiation
The main source of artificial radiation (contributing to 15% of all background radiation exposure) is from medical x-rays such as chest and dental x-rays.

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* The ionizing radiation exposure to the public is taken from the National Council on Radiation Protection and Measurements (NCRP Report No. 93), "Ionizing Radiation Exposure of the Population of the United States," 1987.

3.3 Radiation Dose, Quantities and Units

Where people are working in an environment which involves the use of radiation, the accrued radiation dose that individuals receive is the most important measure. These 'occupational exposure' limits are given in terms of the permitted maximum dose of radiation.

The unit of radiation dose is the Sievert (Sv), which is named after Professor Ralf Maximilian Sievert, a medical physicist who studied the biological effects of radiation. As occupational radiation levels are normally low, smaller units – millisievert (mSv: a thousandth of a Sievert) or microsievert (µSv: a millionth of a Sievert) – are more commonly used.

The radiation dose rate measures the rate at which radiation is absorbed over time. This is expressed in µSv/h. Dose Rate = Dose (µSv) ÷ Time (hours).

3.3.1 Putting Radiation Quantities into Context

To understand radiation levels, it is important to compare dose rates from some natural and artificial sources of radiation that we are exposed to in day-to-day life. Throughout this document the terms Sievert and Gray (Gy) are used, one gray is equivalent to one Sievert. Further information is available in Section 4.

Each person of the world population is exposed, on average, to 2,400 µSv a year of ionizing radiation from natural sources. Typically, this typically exceeds the radiation exposure received from a properly-installed and maintained x-ray inspection system (Figure 3).

For example, eating one average 150-gram banana (Figure 4) every day for a year exposes an individual to 36.5 µSv a year of ionizing radiation.

Frequent fliers (Figure 5) receive around 8% more radiation (200 µSv a year), compared to non-fliers, whilst airline pilots and cabin crew absorb around 2,000 µSv a year.

Figure 3: Maximum permitted leakage levels from an x-ray system = 1 µSv/hour (ROW regulations), 5 µSv/hour (US regulations)


Figure 4: Eat one average 150-gram banana each day for a year = 36.5 µSv/year


Figure 5: Frequent fliers = 200µSv/year Airline pilots and air crew = 2000µSv/year

4 X-ray Inspection versus Food Irradiation

Food processors use x-rays in two ways:
(1) to inspect food for contaminants or quality control, and
(2) to irradiate food (a process that destroys bacteria)

The technologies have one similarity – both processes involve radiation – but that is where the similarity ends.

Dose levels equivalent to several orders of magnitude* separate food irradiation from food inspection.

1 - Inspecting food for contaminants or quality control
X-ray inspection of food, pharmaceuticals or any other product does not cause it to become radioactive, just as a person does not become radioactive after having a chest x-ray.

Scientifically accepted based on evidence, x-rays do not harm food. A 1997 study by the World Health Organisation (WHO) confirmed that food radiation levels up to 10,000 Gy does not affect food safety or nutritional value. That means the food was subject to radiation doses around ten million times as great as those used in x-ray inspection. It proved that the food remains safe to eat and that it loses none of its nutritional value. This view is supported by the experience of leading brands across the world. Those that have already switched to x-ray inspection find that consumers experience no change in the quality other than the improvement by the removal of undesirable contamination.

The dose levels used in x-ray inspection are less than one ten millionth of those used in the WHO study. Food that passes through an x-ray inspection system spends about 250 milliseconds in the x-ray beam. During that short time it receives a radiation dose of around 200 sGy (0.2 mGy). The levels are so low that organic food can be subject to x-ray inspection with no diminution of its organic status.

2 - Irradiation of food
In comparison to x-ray inspection the dose levels for food irradiation are much higher and range from 500 Gy up to 10,000 Gy in approved protocols for food items. (Source: Radiation Threats and Your Safety, Armin Ansari, 2010, page 311).

The FDA does not regard a dose below 1kGy as an irradiation process. For example, to kill salmonella in fresh chicken requires a dose of up to 4.5 kGy, which is about 7 million times more radiation than a single chest x-ray. The radiation dose received by objects scanned by an x-ray system is typically 200 µGRAY (i.e. 200 micro-grays, each micro-gray measuring a millionth of a gray) or less – a level that is too low to affect the safety or nutritional value of food. Food producers who may be concerned about the implications of irradiation, should be reassured to know that this low-level dose is less than background radiation, and has no measureable effect on the food product.

In the UK, the Food Standards Agency (FSA) conducts independent nationwide reports on radioactivity in food. The survey measured radioactivity from different parts of the food chain, including radioactivity levels applicable to people who live close to nuclear sites and eat local food. The FSA combined this data with radiation levels from possible exposure to other authorized radioactive discharges. The report found that the total UK dose is under the EU annual dose limit for members of the public. That annual dose limit is 1 millisievert (a thousandth of a Sievert) for all exposures to radiation.

Whichever way you look at it, food that has passed through an x-ray inspection system is as good and tasty to eat as it was before it was scanned. There are no measurable changes to flavors, textures, or nutritional values: food that has been x-rayed is indistinguishable in every respect from food that hasn't.

5 Working with X-ray Inspection Systems

X-ray radiation has practical uses in medicine, research, and product inspection applications, where it can be used safely for many valuable purposes. However, if utilized improperly, it can present a health hazard to humans.

It is sometimes assumed that any dose of radiation, no matter how small, is a health risk. However, there is no scientific evidence of any health risk at doses below 20,000 μSv a year, which is the adult limit for occupational radiation exposure when working with radioactive material.

Modern x-ray systems for food (and pharmaceutical) applications do not contain sources of live radiation, such as uranium, and are designed to provide a perfectly safe working environment for operators. Provided safety guidelines are followed, there are no restrictions for anyone, including pregnant women and young adults, operating this type of equipment.

The x-rays within an x-ray inspection system are electrically generated, which means they can be turned on and off. This differs from radiation sources (such as uranium), which naturally emit radiation in the form of alpha, beta or gamma rays. These sources can only be made safe by proper containment.

5.1 Protection Principles

X-ray inspection systems have been specifically designed to protect users from the effects of radiation. Systems are designed with the x-ray generator installed in an enclosure; this is known as a 'cabinet system'. The cabinet system is fitted with access panels for cleaning and maintenance, these are electronically interlocked and immediately extinguish x-ray generation if the panel is opened.

The risk of being exposed to radiation can also be controlled through a series of protection principles: time, distance and shielding.

5.1.1 Time

For people who are exposed to radiation over and above natural background radiation, limiting or minimizing exposure time will reduce the dose. The dose rate is directly proportional to the amount of time spent in a given location.

Dose rate (μSv/Hour) = Dose ÷ Time

5.1.2 Distance

The intensity of radiation from an x-ray source decreases in proportion to the inverse of the square of the distance from it. This principle is commonly known as the Inverse Square Law. Dose rate is proportional to 1 ÷ $(\text{Distance})^2$.

For example, (Figure 6) if the radiation dose rate measured at A (a meter from the x-ray source/generator) is assigned a value of 1 (1 ÷ 12); at B (two meters from the source) it will be 0.25 (1 ÷ 22) i.e. a quarter of the dose rate at A.

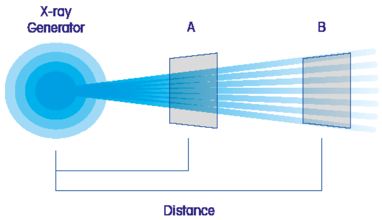

Figure 6 : Radiation intensity

5.1.3 Shielding

As mentioned previously, x-rays are absorbed when they pass through a material. The most efficient absorbers of x-rays are highly-dense materials, which is why x-ray systems are often made from stainless steel (Figure 7). The design of some x-ray generators also incorporates copper for additional containment of the x-rays.

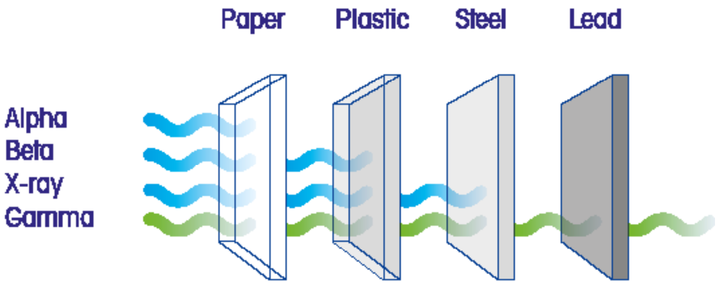

Figure 7 : Shielding material and effects

5.2 X-ray Inspection System Safety

When using x-rays for product inspection, the x-ray system must be built to comply with safety standards such as the Ionizing Radiation Regulations 2017 and the American Standard 1020.40 CFR. Meeting safety standards ensures that all personnel and production staff are safe when operating the x-ray system, providing they follow the safety procedures. For this reason, x-ray inspection systems should be built utilizing the following safety requirements:

- All systems should be fully CE certified.
- All systems must adhere to local rules and regulations, where supplying x-ray systems to – for example, in the UK, all systems should comply with the Ionizing Radiation Regulations 1999.
- Maximum allowable radiation leakage levels should not exceed 1 μSv/hour (ROW regulations), 5 μSv/hour (US regulations).
- Once installed and a certificate is issued, all x-ray systems are subject to a final critical radiation survey on installation to prevent accidental exposure.

6 Conclusion

The word 'radiation' can provoke different reactions and is often misunderstood. While people are right to be wary of radiation, it does not mean they should be worried about the use of x-rays in food inspection. Low level radiation is part of our everyday lives and humans have been exposed to it since the beginning of time.

As this white paper shows, the radiation dose levels used for x-ray inspection in the food industry are extremely low and have no effect on a food's safety, flavor, texture or nutritional value. Furthermore, the use of x-ray inspection equipment is both regulated and increasingly common. As long as operators follow safety guidelines, modern x-ray systems provide a safe working environment within the food industry.

The real risk to human health comes from physical contaminants, such as metal, glass, mineral stone, calcified bone, and high-density plastics and rubber compounds. Therefore, since x-ray inspection is good at detecting and rejecting contaminated food from the production line, it should be regarded as a force for improving food safety and quality, not reducing it.

7 Glossary

Orders of magnitude - http://en.wikipedia.org/wiki/Order_of_magnitude
Orders of magnitude are generally used to make very approximate comparisons. If two numbers differ by one order of magnitude, one is about ten times larger than the other. If they differ by two orders of magnitude, they differ by a factor of about 100.

Sv: Sievert (unit of radiation dose)
mSv: Millisievert (a thousandth of a Sievert)
µSv: Microsievert (a millionth of a Sievert)
SI: The International System of Units
(Abbreviated SI from the French Systeme Internatinal d'Unités)

For the purpose of this document only the measurement Sievert is used although it is common to use gray (Gy) as the standard unit of absorbed radiation dose (1 Gy = 1 Sv).

White Paper

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