



Setting New Standards - Food Irradiation



PURIDEC
Proven Solutions for
Food Irradiation

Setting New Standards

Pasteurization, an interesting parallel

100 years ago the developed world resisted the introduction of pasteurized milk. Various arguments were raised in opposition;

“... it is an excuse to sell contaminated milk. It will result in a lowering of production standards.”

“... it may produce harmful by-products.”

“... it diminishes the nutritional value of milk.”

No one accepts these arguments today. Pasteurization puts a seal of quality and safety on milk. Instead, we now hear these old arguments being raised against a new technology of ‘cold pasteurization’; food irradiation.

Food Irradiation

What is the need?

There are three main issues addressed by irradiating food; foodborne illness, spoilage and quarantine.

Foodborne illness: Latest assessments estimate that 76 million cases of foodborne illness (FBI) occur every year in the USA alone. As many as 5,000 of these result in death. Children and the elderly are at greatest risk. The USA is not a special case, there is a world-wide problem with micro-organisms contaminating food and causing illness.

Pathogen	Primary Global Sources	Incidences in USA per 100,000 Population 1998
Campylobacter	Poultry	21.7
Salmonella	Meat, Poultry, Shell fish, Frogs legs, Herbs/Spices	12.4
E-coli: O-157:H7	Ground Beef, Alfalfa Sprouts	2.8
Yersinia enterocolitica	Pork, Raw Sausage	1.0
Listeria monocytogenes	Soft Cheeses, Ready-to-eat meats	0.5
Vibrio	Oyster, Shellfish	0.3

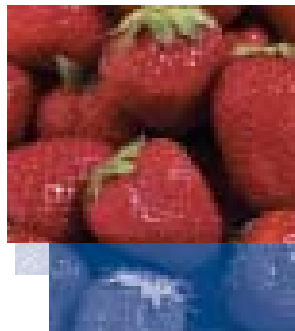
Most common sources of foodborne illness

Food	Pathogen	Importing Country
Alfalfa Sprouts	Salmonella spp.	Finland, Sweden, USA
Raspberries	Cyclospora spp.	USA
Crabs, Clams	Vibrio cholerae	USA, Japan
Spices, paprika flavoured snacks	Salmonella spp.	Germany
Infant dried milk	Salmonella spp.	UK, Ireland

Examples of outbreaks of FBI in the 1990's associated with international trade in food.

'Healthy eating' and international trade contribute to the problem. We eat more fresh fruit and vegetables from a wider market than ever before. Developing countries often have less advanced food hygiene and basic sanitation. The use of polluted irrigation water and untreated organic fertilizers is common. It is not surprising that food becomes contaminated. The costs of such contamination can be huge in terms of human suffering, healthcare expenditure, product recall, loss of consumer confidence, legal pursuits and damage to international trade and tourism.

Spoilage: At least 25% of world food production is lost after harvesting. In developing countries, where climatic conditions hasten deterioration of stored produce, losses of vegetables and fruits can be up to 50%. Current treatments designed to prevent spoilage include the use of fumigants, chemical washes and pesticides. These are surface treatments that can leave chemical residues on the skins. Some of these are potentially harmful and importing countries, including the USA, Japan and many in Europe, have banned the use of several common fumigants such as ethylene dibromide, ethylene dichloride and ethylene oxide. The remaining fumigant most widely used, methyl bromide (MeBr), is highly ozone depleting. Under the Montreal Protocol for environmental protection MeBr is to be phased-out in advanced countries by 2005 and in developing countries by 2015.



Q. Is there any risk to health in irradiating food that contains pesticide residues? - No. The US FDA has calculated that for typical pesticide concentrations of 1 ppm the concentration of radiolytic products produced by irradiation at relatively high dose levels is effectively zero.

Quarantine: To avoid introduction of harmful agricultural pests, such as fruit fly, into non-infested areas, bulk crops are chemically fumigated, often while in transit. MeBr is used most commonly. Quarantine applications of MeBr are currently exempt from phasing out by 2005/15. A major producer of MeBr is the USA, where there will be reduced production after 2005. Costs will almost certainly rise and there might be trade barriers to the import of MeBr treated produce.

Food Irradiation

What are the benefits?

The safety, quality and stability of many foods can be preserved through irradiation, reducing losses to producers, improving stability for suppliers and reducing health risks to consumers. Specific benefits arising from irradiation include:

High risk, staple produce such as chicken, will be free from harmful bacteria reducing the probability of cross contamination in the home

A premium quality brand identity can be created for the safe consumption of rare beef and raw shellfish

Reduced risk of illness means reduced risk of litigation for food processors

A global food market with a common insurance against infection from foodborne disease

A bigger market available to developing countries leading to improved production standards

Less spoilage will bring about lower costs and greater food supplies

Longer shelf-life for fruit and vegetables using fewer pesticides and insecticides in production

The end of fumigation and resulting residual chemicals left on the skins of fresh produce

Limiting use of MeBr will help preserve the ozone layer



Food Irradiation

How does it work?

Food irradiation describes the process of using ionizing radiation to kill harmful, spoilage micro-organisms, and to prevent germination and sprouting. Many people misinterpret terms like 'radiation' leading to a suspicion that food irradiation makes food radioactive. It does not.

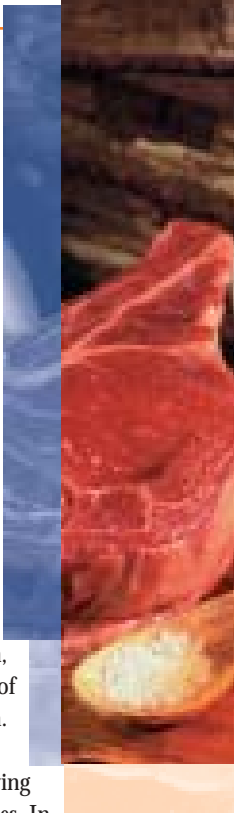
Radiation is all around us. TV and radio signals, visible light and heat are all forms of radiation. Along with gamma and X-rays they are part of the electromagnetic spectrum. From the perspective of physics, the principal difference between them is the energy they contain.

Gamma radiation, used in food irradiation, has enough energy to knock electrons out of the atoms within molecules, ionizing them. This denatures the molecules that are necessary for the survival and growth of living cells i.e. DNA, cell membranes and enzymes. In this way irradiation kills "food poisoning" pathogenic micro-organisms, spoilage organisms and prevents plant cells from sprouting.

How does irradiation compare with pasteurization?

The effects of irradiation and pasteurization are similar. Both can kill micro-organisms, although some heat resistant micro-organisms can survive the pasteurization process and some simple micro-organisms are resistant to low doses of radiation.

Both processes affect food molecules as well as the molecules of living cells. However, ionizing radiation is much more damaging to the rapidly multiplying cells of living pathogens and the cells involved in ripening and sprouting processes. Consequently, irradiation allows food products to be 'cold pasteurized' and have their shelf-life increased without suffering significant change to the chemical composition, nutritional value, taste or appearance of the fresh product.



The appeal of using ionizing radiation is that it can pasteurize fresh or frozen food, wrapped and packaged ready for shipment. It ensures there is no chance of further contamination before the food is unwrapped. Irradiation of the product in its final packaging is the ultimate terminal critical control process.

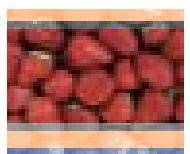
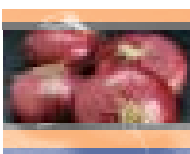
Q. Is there any risk to health in irradiating foods in contact with plastic or other packaging materials? - No. Research shows that most commonly used food packaging materials tested are suitable for use at doses up to 10 kGy, which is the internationally approved limit for irradiating foods.

What dose of radiation is required?

The amount of radiation necessary to make food safe depends on the application, and the type of organism being treated. The D_{10} -value is the amount of radiation necessary to achieve a 10-fold (90%) reduction in microbial population. E-coli has a D_{10} -value of 0.3 kGy. A dose of only 1.8 kGy reduces the population by six factors of 10 (by 99.9999%) effectively eliminating it completely. Advanced organisms such as insects, pests and parasites are more susceptible to radiation and require even lower doses.

The absorbed dose is measured in Gray (Gy). 1Gy is 1 Joule of energy absorbed per kilogram of food irradiated. A dose of four thousand Gray (4 kGy) will raise the temperature by approximately 1°C.

Application	Food Product	Typical Dose / kGy
Reduction or elimination of microbial population in dry food ingredients	Spices, Starch, Enzyme preparations, Animal feed	3 - 10
Pasteurization	Meat, Poultry, Shell Fish Frogs Legs, Herbs/Spices	1 - 7
Increase Shelf Life	Fruits, Vegetables, Meat Poultry, Fish	0.5 - 5
Parasite disinfection	Meat, Pork, Fish	0.1 - 3
Insect Dis-infestation	Grain, Flour, Fruits etc.	0.2 - 0.8
Inhibition of Sprouting	Onions, Garlic, Potatoes	0.03 - 0.14



Food Irradiation

Is it really safe? A long history

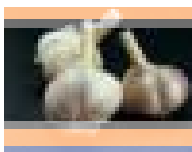
Gamma irradiation technology is probably the most exhaustively researched food processing method ever proposed. The immense body of evidence is unanimous in its support of irradiation as a safe and effective method for treating food.


1905-30's	First Patents Issued for Food Irradiation	Britain, USA & France
1940's	Shelf stable food first available	US Forces supplied
1950-60's	Extensive Research and Animal Trials	International collaboration
1980's	Regulatory Endorsement Human Trials	World Health Organisation China 400 volunteers
1990's	Review of dose limits	No upper limit necessary

- Astronauts have eaten irradiated food since Apollo 17 in 1972.
- Hospitals and hospices provide irradiated food for patients with immune deficiency diseases.
- Each year about half a million tonnes of food products and ingredients ranging from spices through deboned chicken to fruits and vegetables are irradiated in 37 countries worldwide. This is still a small fraction of total world production.

Global Regulatory Acceptance

- Food irradiation is endorsed by the United Nations World Health Organisation (WHO), the Food and Agriculture Organisation (FAO), the International Atomic Energy Association (IAEA), the International Consultative Group on Food Irradiation (ICGFI), the American Medical Association, and the American Public Health Association.
- 1961-80 - WHO/FAO/IAEA - Reviewed all research data generated to-date and announced:
“Irradiation of any commodity up to an average dose of 10 kGy presents no toxicological hazard and hence toxicological testing of foods so treated is no longer required. In addition treatment of food with irradiation introduces no special nutritional or microbiological problems.”
- 1992/4 - WHO - Update report on food irradiation:
“Safety studies have so far shown no deleterious effects.”



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- For ten years between 1987-97, sixty generations of mice with immune deficiency were fed irradiated food with no ill effects.
 - 1997 - WHO study on the wholesomeness of food treated with high dose (>10 kGy), finding: No upper dose limit is needed. The organoleptic properties of food naturally limit the dose. GMP, GHP & HACCP are still obligatory.
 - 1999 - The Codex Committee on Food Additives and Contaminants (CCFAC) will review the statement proposed by FAO/WHO/IAEA: “Food irradiated to any dose to achieve the technological objective is both safe and nutritionally adequate.”

Food Irradiation

Concerns and Worries

Despite the above findings, there will inevitably be some consumers and lobbyists, and indeed producers and manufacturers, with reservations about this ‘new’ technology. It is possible to address some of these directly.

Nutrition

“Irradiation does not induce special nutritional problems in food.” - WHO, FAO, IAEA - 1980

It is true that certain vitamins such as Vitamins A, E, K and Vitamin B-1 (thiamine) are susceptible to radiation degradation. Vitamin C (ascorbic acid) is converted into dehydro-ascorbic acid, but this is an equally usable form. In fact, the loss of vitamin content due to irradiation is less than that in canning, and other heat treatments. Even the highest Food and Drug Administration (FDA) approved sterilization dose causes less than 10% vitamin loss. No protein, fats, carbohydrates or minerals are lost.

Costs

Low doses might incur costs ranging from US\$10 to \$15 per tonne (e.g. to inhibit sprouting). High doses may incur costs ranging from US\$100 to \$250 per tonne (e.g. sterilization of spices). Dis-infestation treatment of bulk crops with irradiation could cost 10-20% of the cost of vapor-heat treatment. Irradiated meat may cost an extra 2-10 US cents per pound compared with non-irradiated product.

Consumer Acceptance

The food industry itself may fear that consumers will reject irradiated food but the evidence seems to counter this fear.

- In Indiana in 1993, after a program of education and food tasting, 99% of participants wanted to buy irradiated foods
- In a USA national survey of consumers in 1996:
 - 60% would buy irradiated foods with a longer shelf life
 - 70% would buy food irradiated to destroy harmful bacteria
 - 60% would pay up to 10 cents per pound more for irradiated ground beef
- Key acceptance issues are:
 - Organoleptic properties of the food i.e. taste, appearance and smell, remain unchanged
 - Clear, informative labelling

Identifying Irradiated Food

In the USA the International Radura symbol is required by law to appear on all irradiated food alongside a statement indicating treatment by irradiation. It could become the recognised seal of quality for products “irradiated to remove harmful bacteria.”

Food Production and Processing Standards

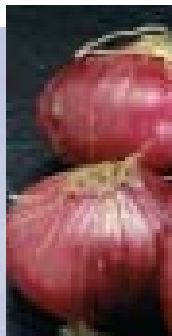
Food irradiation is a self limiting process; high dose treatment increases cost and diminishes the sensory qualities of the food. Foods with viruses or preformed microbial toxins are not suitable for irradiation pasteurization. It cannot make bad food look or taste good, and is no substitute for good manufacturing and hygiene practice (GMP and GHP). It does not remove the obligation on manufacturers to implement Hazard Analysis Critical Control Point (HACCP) procedures.

Induced Radioactivity

Treatment of food by irradiation does not cause it to become radioactive. There is a low level of radioactivity in everything around us; this is how carbon dating works. The source of radiation works like a light bulb so the food never comes into contact with the radioactive material sealed inside and there is no chance of contamination.

Radiolytic Products

Radiolytic products are new molecules resulting from the ionization of other molecules following the absorption of high energy radiation. In the same way, thermolytic products are formed by the fragmentation of molecules following absorption of low energy radiation e.g. heat,



during cooking. Many radiolytic products are naturally present in foods. For example, eggs naturally contain 100 times more benzene than the highest levels ever detected in food irradiated with a maximum dose. No unknown radiolytic compounds have been identified in more than 40 years of research.

Free Radicals

Free radicals are produced in food in the irradiation process but also during natural oxidation and in various processes including frying, freeze drying and toasting. They are the source of radiolytic molecules and are not a cause for concern. During extensive animal studies over ten years and human tests in China there has been no evidence that consumption of irradiated foods presents a health risk.

Technology

What form of radiation is used?

Food can be irradiated using gamma, electron-beam (E-beam) or X-ray sources:

Gamma Sources

- Gamma radiation is produced by the natural radioactive decay of Cobalt-60 (Co-60) into non-radioactive Nickel. This process releases two well-defined gamma rays with energies of 1.17 and 1.33 million electron volts (MeV).
- Co-60 can not be switched off. It is always emitting gamma radiation. It needs no external power supply. Co-60 sources have a well-defined power output which is proportional to the source strength, measured in Curies (Ci) or Becquerels (Bq). Over 5.27 years the power falls by half. This is predictable and can be calculated and adjustments made to the irradiation process on a daily basis.
- Co-60 sources are sealed stainless steel tubes, “pencils”, filled with Co-60. Stainless steel is transparent to gamma radiation which shines through the tube like a light bulb. When new, they have a typical strength of 10 thousand Curies (kCi) equivalent to approximately 150 W of power output.
- Co-60 sources have a typical working life of 20 years after which they may be returned to the supplier for re-processing or use in low dose applications.

- In an industrial irradiation facility the gamma source is comprised of up to 1500 pencils of Co-60 held in a rack, with a total strength of between 500 kCi (7.5 kW) and 7 MCi (105 kW). The power output employed is matched to the volume of product to be processed.

Electron Beam and X-ray Sources

- Electron-beams (E-beams) are generated by technology similar to that found on a small scale in a television set. Electrons are released from a plasma and accelerated to ultra high velocity, 99.7% of the speed of light. At these speeds they have energies measured in millions of electron volts, ranging up to typically 5 or 10 MeV in this application.
- X-rays are produced when an E-beam is fired into a metal film. They typically have a spread of energies up to 5 MeV.
- E-beam and X-ray machines are high technology devices employing the latest advances in radio frequency and linear accelerator design. The reliability and power efficiency of modern accelerators is much improved in recent years.
- The power output of E-beam and X-ray machines is proportional to the number of electrons emitted per unit time, measured in Watts (W). 20 to 150 kW machines are typical in this application. The energy and the power output of E-beams and X-rays depend upon the stability and reliability of the local electricity supply.

Gamma Sources - Benefits

- Low technology - never obsolete, simple, reliable, predictable.
- Highly controlled energy source - leads to very predictable chemistry in irradiated food.
- Predictable power output - accurate calculation of absorbed dose.
- Radiation is emitted symmetrically - product can be processed on both sides of the source simultaneously.
- Low service requirements - little down-time, predictable running costs.
- Suitable for processing diverse product range.
- High penetration depth - good for bulk packaged product.
- Good dose homogeneity.
- 7 polymer films approved for use with pre-packaged foods intended for gamma irradiation.

Constraints

- Radioactive material needs a shielded processing area - subject to site control and licensing laws.
- Requires source disposal and replenishment.
- Can not be switched off - needs a shielded storage area.
- 24 hour operation often essential for cost effectiveness.
- Low dose rate increases oxidation effects.

E-Beam and X-ray Sources - Benefits

- On/Off technology - perceived safety.
- Good on-line processing potential.
- Best suited to processing low density products at high speed.
- High dose rate reduces oxidation effects.
- Size - can be relatively compact.

Constraints

- Complex electronic technology - maintenance costs, skilled technicians, risk of down time, also needs shielded processing area.
- High technology devices have a typical working life of 10-15 years before they become obsolete.
- Low product penetration - not suitable for bulk packaged product.
- Only ethylene vinyl acetate (EVA) has been approved as suitable for use with pre-packaged foods intended for irradiation with E-beam.
- Radiation emission is uni-directional - product can only be processed sequentially.
- Poor power efficiency - 20 to 45% for E-beam, depending on the power output capacity dropping to 2% for X-ray.
- Power output dependent upon reliable electricity, and water-cooling supply - variable dose delivered.
- 10 MeV E-beams can generate X-rays in the product with energies greater than the permitted 5 MeV.

Do any restrictions apply to Irradiation Facilities ?

Irradiation plants look like any other warehousing facility on an industrial park. However, gamma facilities need a special site licence from the appropriate national licensing

authority. E-beam plants are regulated by radiation safety authorities. There are three key components to all facilities:

The Irradiation Cell

- A concrete room, which may be refrigerated, shielding the irradiation source within the warehouse.
- Multiple safety interlocks prevent human access during the treatment of product by gamma, E-beam or X-radiation.
- Product entry on a conveyor is via a labyrinth to avoid radiation leaking into the normal warehouse environment.
- When not in use, Co-60 sources are lowered into a pool of water 6 to 9m deep to shield the environment from gamma radiation. In this state it is safe to enter the irradiation cell wearing normal clothing.
- PURIDEC gamma irradiation cells are fitted with fail safe interlocks with four-fold redundancy to ensure operator access is only possible when the source is shielded.

Conveyor Systems

- Conveyors are designed to withstand the harsh environment within the irradiation cell.
- They carry product on pallets, in totes, and in individual packages depending upon the application.
- PURIDEC plants have moveable tracks to provide the greatest processing flexibility.

The Control System

At the heart of every irradiation facility is a procedure-based control system:

- Product scheduling, tracking, treatment protocol and documentation must all be integrated to ensure a reliable service.
- The dose delivered and absorbed must be validated and recorded to prove adequate processing and satisfy regulatory requirements.
- History archives must log processing and system amendments to provide a traceable record.
- All plant safety systems must be monitored to enable the source to be made safe in the event of critical component failure.
- I-CON is PURIDEC's modular integrated control system - designed to grow with your business needs.

Choosing the Right Technology Option

What products do you wish to irradiate?

	Gamma	E-Beam (10MeV, 35 kW)
Dose rate	Low	High
Processing Speed/Hr	3.5 tonnes/MCi @ 4 kGy	2.7 tonnes/MCi @ 4 kGy**
Dose Homogeneity	High	Low
Working Product Thickness*	80 - 100 cm	8 - 10 cm

* Assuming product density = 0.5 gcm⁻³ and doubled-sided irradiation.

** Assuming 30% power conversion efficiency.

Product	Product Type	Appropriate Technology
Meat	Patties - Boxed - In-line Whole Cuts Carcasses	Gamma E-beam E-beam/Gamma Gamma
Poultry	Whole Whole Cuts De-boned (MSM)	Gamma E-beam Gamma/E-beam
Shell Fish/Fish	Frozen - Boxed	Gamma
Frogs Legs	Frozen	Gamma
Eggs	Whole/Liquid/Frozen Dried	Gamma E-beam
Herbs/Spices	Bulk/Consumer packages	Gamma
Grain	Bulk Flowing	Gamma E-beam
Fresh Produce eg. Onions/Potatoes	Bulk	Gamma
Soft Fruits/ Tropical Fruits	Tertiary Packaging	Gamma
Dried Fruits/ Dried Vegetables	Bulk	Gamma/E-beam

Glossary of Terms

Becquerel *n.* The S.I. unit of radioactivity, Bq.
(1 Curie = 37×10^9 Bq)

Codex Alimentarius Commission: A joint body of the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) representing more than 130 countries

D₁₀-Value *n.* Deseccation value is the radiation dose required to reduce the specified microbial population by a factor of ten i.e. 90%. $1D = 1 \log_{10} = 90\%$ certainty

Electromagnetic spectrum *n.* The whole range of wavelengths from long radio waves to short gamma waves, over which electromagnetic radiation occurs

Foodborne illness (FBI): Commonly referred to as “food poisoning” is the result of consuming food contaminated with pathogenic micro-organisms such as Salmonella, Campylobacter Jejuni, E.coli and Listeria monocytogenes or parasites such as Toxoplasma gondii and Yersinia enterocolitica

Free Radicals *n.* Free radicals are molecules with an unpaired electron. They are created in the ionization process and are highly reactive and short lived

Half-life *n.* The time taken for the radiation from a radioactive substance to decay to half its initial value.
(Co-60 $t_{1/2} = 5.27$ years)

Ion *n.* An electrically charged atom or molecule formed by the loss or gain of electrons

Ionize *vt.* The process of creating ions

Irradiate *vt.* To expose to radiation from the electromagnetic spectrum

Organoleptic *n.* Sensory properties of (food); taste, texture, smell, color etc.

Radiation *n.* Energy transmitted as waves or particles

US FDA: United States Food and Drug Administration

Bibliography

A complete list of the references and websites used in this publication is available from the PURIDEC website. Copies of the references and other PURIDEC publications and literature are available on request by FAX or e-mail from the UK office address given on the back of this booklet.

For information on all PURIDEC products and services please contact:

North America

PURIDEC Irradiation Technologies

O'Hare Corporate Run

2128 South Wolf Road

Des Plaines, Illinois 60018, USA

Tel: (847) 795 8822

Fax: (847) 795 8833

E-mail: puridecNA@reviss.com

Asia/Pacific

PURIDEC Irradiation Technologies

Room 322, He Qiao Mansion

8A Guanghua Road, Beijing 100026

People's Republic of China

Tel: +86 (0)10 6503 5323

Fax: +86 (0)10 6503 5324

E-mail: puridecAP@reviss.com

Europe and Rest of World

PURIDEC Irradiation Technologies

6 Chiltern Court, Asheridge Road,

Chesham, Buckinghamshire, HP5 2PX, UK

Tel: +44 (0)1494 777444

Fax: +44 (0)1494 777457

E-mail: puridec@reviss.co.uk

Website <http://www.puridec.co.uk>



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