# Food preservation by irradiation

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# Radiations

- Radiation is an energy form travelling through space (radiant energy) in a wave pattern and can be either naturally occurring (e.g. from the sun or rocks) or produced by man made objects (e.g. microwaves and television sets).
- The frequency or wavelength of the energy waves produced by different sources distinguishes the different types and functionality of radiation, with high frequency radiation of UV, X-rays and gamma-rays posing the most significant risk to human health.

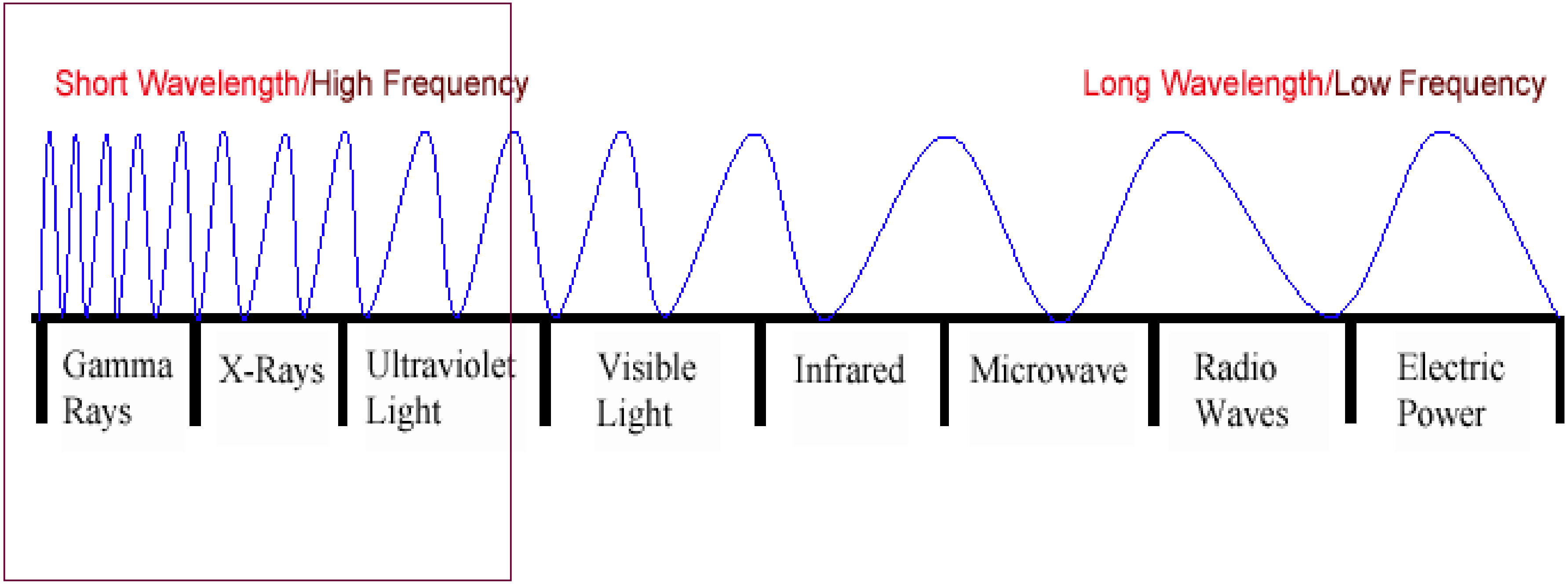
# Ionising and non-ionising radiations

- Radiation is called ionising radiation when it is at a sufficiently high frequency (gamma rays and X-rays) that it results in the production of charged particles (ions) in the material that it comes in contact with.
  - Ionising radiation has higher energy - high enough to change atoms by knocking an electron from them to form an ion, but not high enough to split atoms and cause exposed objects to become radioactive. Therefore, the sources of radiation allowed for food processing cannot make food radioactive.

# Ionising and non-ionising radiation

- Non-ionising radiation, such as that from microwaves, does not produce ions but can create heat under moist conditions and is routinely used for purposes such as cooking and re-heating of foods.
  - Electric power, radio and television, microwaves, and light have lower energies. They cause molecules to move, but they cannot structurally change the atoms in those molecules.

# Ionising radiations



# Human exposure to ionising radiation

- We are all exposed to low levels of ionising radiation on a daily basis from a variety of natural and man made sources.
- Under normal circumstances, almost 90% of the ionising radiation we are exposed to is due to natural radiation emitted from rocks, radon gas and even cosmic rays from space.
- The remaining exposure is due to man made sources such as nuclear reactors, medical x-rays and various electrical household appliances such as televisions.

# Irradiation

- Food irradiation facilities that are built and maintained to accepted standards are no more hazardous than hospitals that carry out numerous X-rays each day and as such do not pose a significant exposure risk.
- Under the standard covering the irradiation of food in Australia and New Zealand, this energy can be in the form of Cobalt 60 sourced gamma rays, machine generated X-rays, or an electrically generated electron beam

# Irradiation

- Irradiation can kill harmful bacteria and other organisms in meat, poultry, and seafood, disinfest spices, extend shelf-life of fresh fruits and vegetables, and control sprouting of tubers and bulbs such as potatoes and onions.
- It is a safe process that has been approved by the U.S. Food and Drug Administration (FDA) and over 50 other national food control authorities for many types of foods.

# Radiation sources

- Only certain radiation sources can be used in food irradiation. Energies from these radiation sources are too low to induce radioactivity in any material, including food
- These are
  - Accelerated electron machines having a maximum energy of 10 MeV.
  - Gamma rays using the radionuclides cobalt-60 (used commonly) or cesium-137 (used very rarely);
  - X-ray machines having a maximum energy of 5 million electron volts (MeV); or

# Accelerated electron beams (E-beams)

- The Electron Beam Linear Accelerator, (E-beam) Accelerators work on the same principle as a television tube. Instead of being widely dispersed and hitting a phosphorescent screen at low energy levels, the electrons are concentrated and accelerated to 99% of the speed of light. This produces rapid reactions on the molecules within the product. The Electron Beam Linear Accelerator machine generates and accelerates electrons to energies of 5,7.5 or 10 MeV (Million electron volts) with beam power of up to 10 kW.

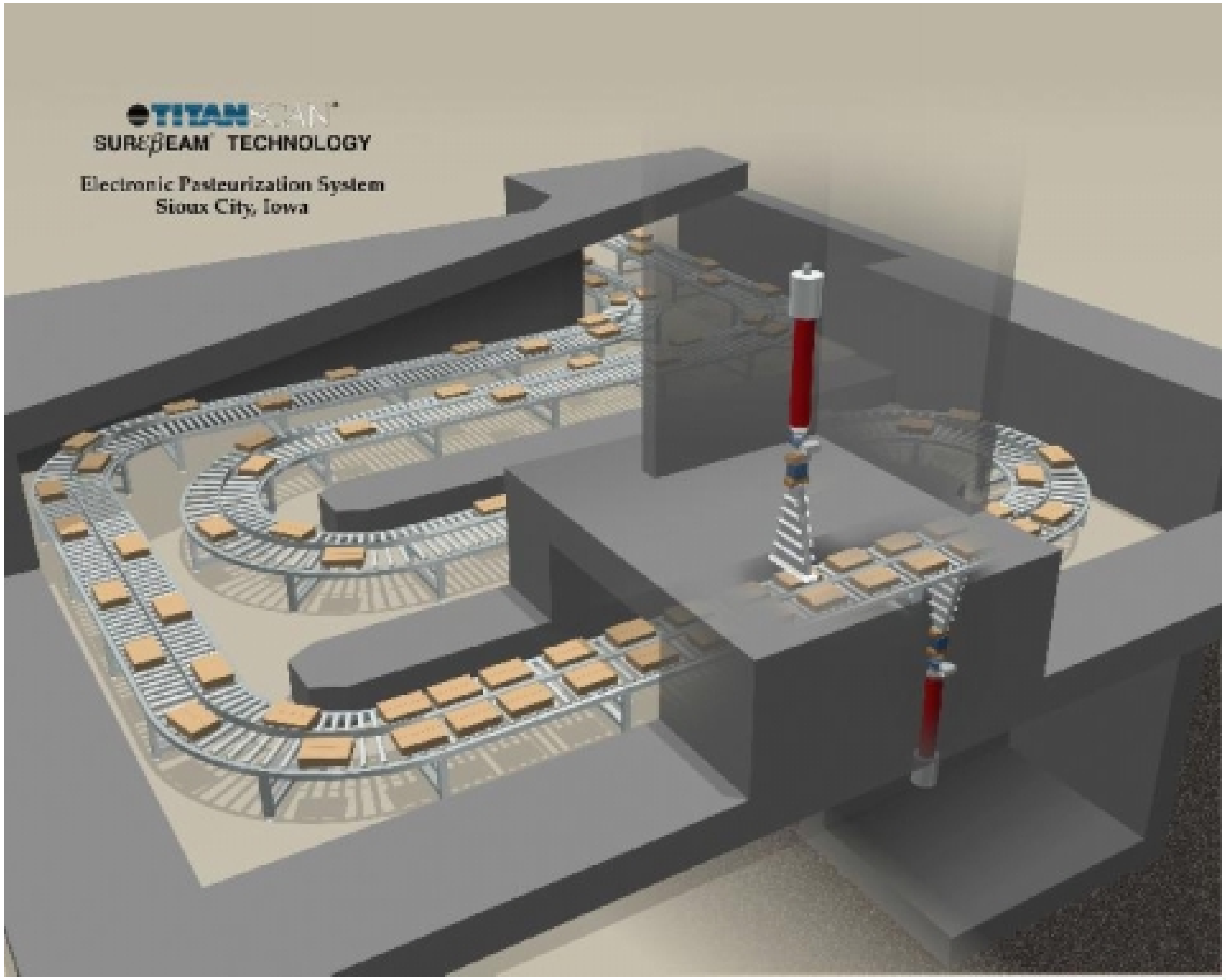
# Accelerated electron beams (E-Beams)

- The electron beam is a stream of high energy electrons, propelled out of an electron gun.
- The electron gun apparatus is a larger version of a standard television tube.
- The electron beam generator can be simply switched on or off. There are no radioactive materials in the process.
- The electrons can penetrate food only to a depth of 3-5 cm, so the food to be treated must be no thicker than that to be treated all the way through. Two opposing beams can treat food that is twice as thick.
- E-beam medical sterilizers have been in use for at least 15 years

# Electron beam treatment

- A Conveyer or cart system moves the product to be irradiated under the electron beam at a predetermined speed to obtain the desired dosage. Products move in and out of the irradiation area continuously. Product thickness depends on density and electron energy. For example, e-beam energy can penetrate meat a total of 8-9 cm with treatment on the top and bottom of a package

# Electron beam treatment

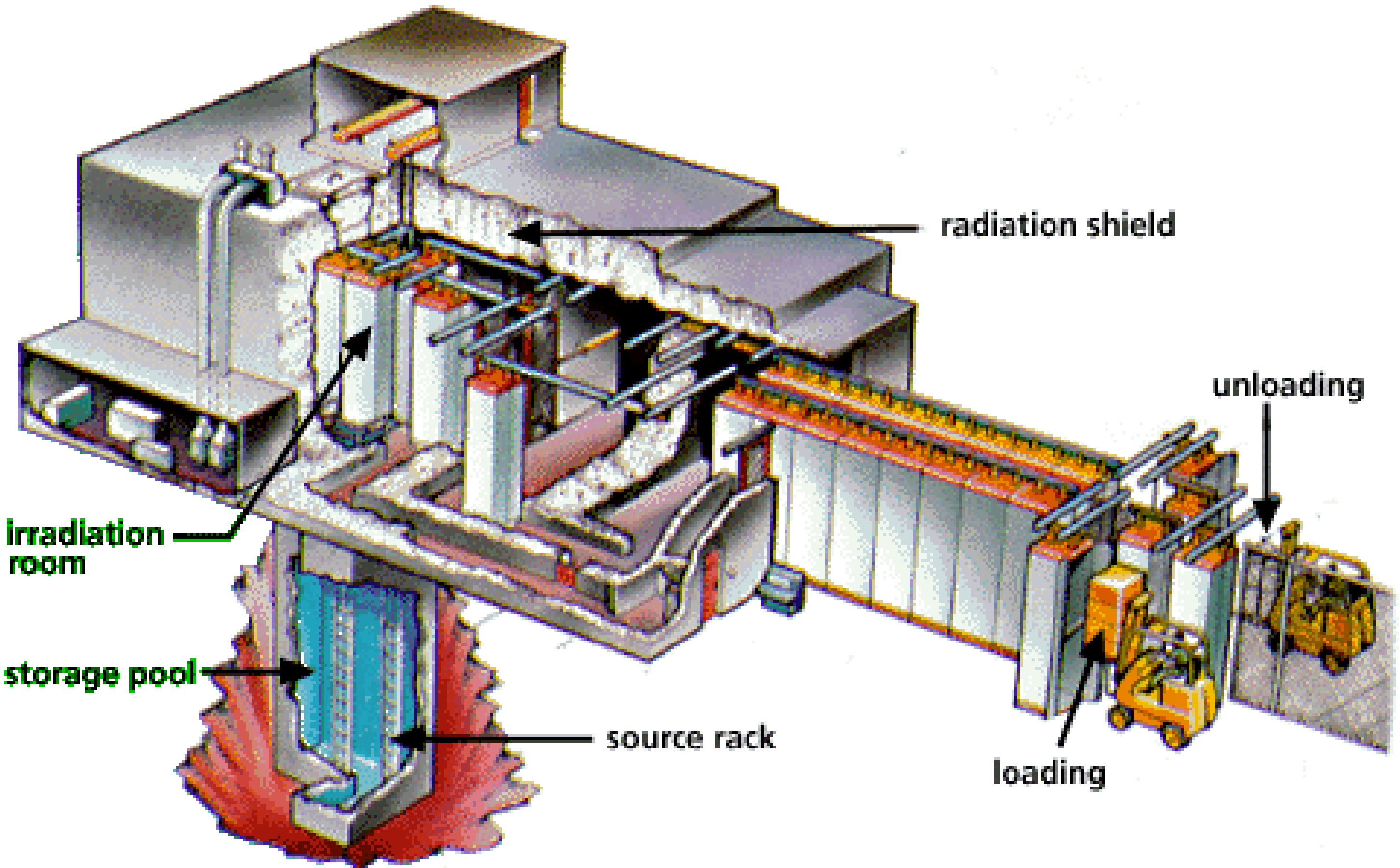



http://ccr.ucdavis.edu/irr/

# Co-60 gamma radiation

- The most common source of ionizing energy.
- The radioactive material is contained in two sealed stainless steel tubes (one inside the other - double encapsulated) called "source pencils."
- These are placed in a rack and the entire rack is immersed in a water chamber underground when not in use. When irradiation takes place, the rack is raised. Packaged food products move along the conveyer belt and enter an inner room where they are exposed to the rack containing source pencils. Energy in the form of gamma rays (or photons) pass through the encapsulation and treat the food.

# Co-60 Gamma radiation




http://www.sercoassurance.com/answers/resource/areas/shield/food_irradiation.htm

# X-Rays

- X-rays are caused by atomic transitions and they are usually less energetic than gamma rays.
- X-rays with varying energies are generated by machines.
- The X-ray machine for food irradiation is a more powerful version of the machines used in many hospitals and dental offices to take X-ray pictures.
- To produce the X-rays, a beam of electrons is directed at a thin plate of gold or other metal, producing a stream of X-rays.
- Like E-beams, the machine can be switched on and off, and no radioactive substances are involved.

# X-ray irradiation

- In this system an electron beam accelerator targets electrons on a metal plate. Some energy is absorbed and the rest is converted to X-rays. Like gamma rays, X-rays can penetrate food boxes up to 15 inches thick or more, thus permitting food to be processed in a shipping container.

# X-ray radiation unit

http://www.faxitron.com/cp160.htm

# Radiation unit

- Radiation dose is the quantity of radiation energy absorbed by the food as it passes through the radiation field during processing.
  - It is measured in Gray (Gy) [1 Gy equals one Joule of energy absorbed per kilogram of food being irradiated] or in rad (1 Gy = 100 rads).
  - Practical range for food use: 50-10,000 Gy
  - International health and safety authorities have endorsed the safety of irradiation for all foods up to 10,000 Gy (10 kGy).

# Radiation approvals in the US

| Approval | Food | Purpose |
|---|---|---|
| 1963 | Wheat flour | Control of mould |
| 1964 | White potatoes | Inhibit sprouting |
| 1986 | Pork | Kill Trichina parasites |
| 1986 | Fruit and vegetables | Insect control<br>Increase shelf life |
| 1986 | Herbs and spices | Sterilization |
| 1990 - FDA<br>1992 - USDA | Poultry | Bacterial pathogen reduction |
| 1997 - FDA<br>1999 - USDA | Meat | Bacterial pathogen reduction |

http://uw-food-irradiation.engr.wisc.edu/Facts.html

# Examples of food uses

| Type of food | Effect of Irradiation |
|---|---|
| Meat, poultry | Destroys pathogenic fish organisms, such as Salmonella, Clostridium botulinum, and Trichinae |
| Perishable foods | Delays spoilage; retards mold growth; reduces number of microorganisms |
| Grain, fruit | Controls insect vegetables, infestation dehydrated fruit, spices and seasonings |
| Onions, carrots, potatoes, garlic, ginger | Inhibits sprouting |
| Bananas, mangos,papayas, guavas, other non-citrus fruits | Delays ripening avocados, natural juices |
| Grain, fruit | Reduces rehydration time |

# Applications of irradiation

- Radiation pasteurisation (sanitary treatment)
- Radiation sterilisation
- Replacing chemical fumigation of food
- Sprout inhibition
- Enhancing food quality
- Eliminating certain parasitic hazards in food

Irradiation is a versatile process

# Sterilisation or pasteurisation

- Irradiation is sometimes referred to as "cold pasteurisation" since the result achieved is similar to heat-based pasteurisation but without the heat.
- Low to medium doses of irradiation successfully reduce bacterial contamination but are not sufficient to affect viruses or toxins.
- Higher radiation doses can be used to kill all living contaminants creating sterile foods. Such foods are necessary for people with reduced immunity such as AIDS or cancer patients, but are also used to feed astronauts and some armed forces.

# Radiation pasteurisation (sanitary treatment)

- Food-borne illnesses take a heavy toll on the economy and productivity of populations in most countries. In the US
  - 76 million illnesses;
  - 325,000 hospitaliza-tions
  - 5,000 deaths each year or approximately 100 deaths per week.
- Micro-organisms such as *E. coli* O157:H7, *Campylobacter, Salmonella, Listeria, Vibrio* and *Toxoplasma* are responsible for 1,500 deaths annually in the US.

# Radiation pasteurisation (sanitary treatment)

- The most important public health benefit of food irradiation is its ability to destroy pathogenic (disease causing) organisms through pasteurisation.
- It is the only process that can do so effectively in raw and frozen foods.

# Radiation sterilisation

- Sterilisation by irradiation can be applied to foods
  - a relatively high dose of irradiation (above 10 kGy), together with a mild heat treatment and proper packaging, can kill all microorganisms and allow foods to be kept for long periods at room temperature.
  - This process is analogous to canning, which uses heat treatment to achieve the same preservation status.
  - Meat, poultry, some types of fish and shellfish, some vegetables and entire meals are suitable for radiation sterilization

# Radiation sterilisation

- Radiation sterilization has been used in the U.S. to sterilize food for NASA's astronauts and for some patients with impaired immune systems.
- Radiation sterilization of food/meals could help outdoor enthusiasts (campers, mountain climbers, sailors, etc.) carry safe, nutritious and ready to eat food that requires no refrigerated storage.

# Replacing chemical fumigation of food

- Irradiation can kill insects and micro-organisms in cereals, legumes, spices and dried vegetable seasonings, as well as other stored foods.
- Irradiation could be used in place of chemical fumigation with ethylene dibromide (EDB, now banned in the U.S. and most other countries), ethylene oxide (banned in the European Union and Japan) and methyl bromide (MB).

# Sprout inhibition

- Very-low-dose irradiation treatment inhibits the sprouting of vegetables such as potatoes, onions and garlic.
- Irradiation can replace the chemicals currently used for this purpose.
- The US and many other nations have approved this use of irradiation for several types of roots, tubers, and bulbs.
- Currently, irradiation is used extensively to control sprouting of garlic and potatoes in China and Japan, respectively

# Enhancing food quality

- Low-dose irradiation also delays ripening and therefore extends the shelf-life of some fruits, including bananas, mangoes, papayas, guavas and tomatoes.
- Medium doses can be used to control mould growth on strawberries, raspberries and blueberries, thereby extending their shelf-life.
- Cap opening of mushrooms can also be delayed by relatively low dose irradiation and cool storage.

# Enhancing food quality

- Irradiation can produce desirable physical changes in some foods.
  - Bread made from irradiated wheat has greater loaf volume when certain dough formulations are used,
  - Irradiated dehydrated vegetables reconstitute more quickly than non-irradiated vegetables, and
  - when fruits such as grapes are irradiated they yield more juice than non-irradiated ones.

# Eliminating parasite hazards in foods

- A low dose of radiation can eliminate the hazards of humans contracting trichinosis and toxoplasmosis from consumption of fresh foods such as pork without significantly affecting the flavour or texture of the meat.
  - Irradiation treatment works by impairing the development of these parasites (*Trichinella spiralis*, *Toxoplasma gondii*) so that they cannot mature, complete their life cycles or cause human diseases.

# Effects of irradiation on foods

- Is Irradiation the Same Thing as cooking in a Microwave Oven?
- Does Irradiation Make Food Radioactive?
- Does Irradiation Generate Radioactive Wastes?
- Effects on Microorganisms in Foods
- Effects on Nutrients in Foods
- Effects on Sensory Quality of Foods

# Uses of various doses for food safety and preservation

| Purpose | Effective Dose Range (kGy*) | Products |
|---|---|---|
| **Low Dose** (up to 1 kGy) | | |
| (a) Inhibition of sprouting | 0.06-0.20 | Potatoes, onions, garlic, ginger root, chestnut, etc. |
| (b) Insect disinfestation (including quarantine treatment) | 0.15-1.0 | Cereals and legumes, fresh and dried fruits, dried fish and meat, etc. |
| (c) Parasite disinfection | 0.3-1.0 | Fresh pork, freshwater fish, fresh fruits. |
| (d) Delay of ripening | 0.5-1.0 | Fresh fruits. |

OzScientific

# Uses of various doses for food safety and preservation

| Purpose | Effective Dose Range (kGy*) | Products |
|---|---|---|
| **Medium Dose** (1-10 kGy) | | |
| (a) Extension of shelf-life | 1.0-3.0 | Raw fish and seafood, fruits and vegetables. |
| (b) Inactivation of spoilage and pathogenic bacteria | 1.0-7.0 | Raw and frozen seafood, meat and poultry, spices and dried vegetable seasonings. |
| (c) Improving technical properties of foods | 3.0-7.0 | Increasing juice yield (grapes), reducing cooking time (dehydrated vegeta-bles) |

OzScientific

# Uses of various doses for food safety and preservation

| Purpose | Effective Dose Range (kGy*) | Products |
|---|---|---|
| **High Dose** (above 10 kGy) | | |
| (a) Industrial sterilization (in combination with mild heat) | 30-50 | Meat, poultry, seafood, sausages, prepared meals, hospital diets, etc. |
| (b) Decontamination of certain food additives and ingredients | 10-50 | Spices, enzyme preparations, natural gum, gel, etc. |

# Effects on egg shell

| | Dosage (kGy) | | | | |
|---|---|---|---|---|---|
| | 0 | 0.97 | 2.37 | 2.98 | S.E.M. |
| Hauge unit | 79.7 | 28.4 | 12.1 | 14.2 | 10.3 |
| Apparent viscosity (egg white) (cp) | 12.4 | 6.5 | 5.0 | 4.0 | 0.45 |
| Apparent viscosity (egg yolk) (cp) | 1770 | 1470 | 2160 | 2180 | 93.5 |
| % overrun | 1146 | 981 | 1354 | 1446 | 91.3 |
| E.A.I. ($m^2/g$) | 6.74 | 7.07 | 10.94 | 11.05 | 0.485 |
| Gel hardness (N) | 7.02 | 7.59 | 8.60 | 7.27 | 0.202 |
| Angel cake volume (mL) | 854 | 936 | 1005 | 1009 | 14.4 |

[a]Averages of 2–4 determinations; S.E.M.—standard error of the mean; E.A.I.—emulsification activity index.

Ma, C.Y.(1996). Radiat. Phys. Chem, 48, 375

# Effect of irradiation on D-values of food pathogens

| Pathogen | D values (kGy) | Suspending medium | Irradiation temperature (°C) | References |
|---|---|---|---|---|
| *A. hydrophila* | 0.14 - 0.19 | Beef | 2 | Palumbo et al., 1986 |
| *C. jejuni* | 0.18 | Beef | 2 - 4 | Clavero et al., 1994 |
| *E. coli* O157:H7 | 0.24 | Beef | 2 - 4 | Clavero et al., 1994 |
| *L. monocytogenes* | 0.45 | Chicken | 2 - 4 | Huhtanen et al.,1989 |
| *Salmonella* spp. | 0.38 - 0.77 | Chicken | 2 | Thayer et al., 1990 |
| *S. aureus* | 0.36 | Chicken | 0 | Thayer et al., 1992 |
| *Y. enterocolitica* | 0.11 | Beef | 25 | El-Zawahry and Rowley, 1979 |
| *C. botulinum* (spores) | 3.56 | Chicken | -30 | Anellis et al., 1977 |

D-value: Decimal reduction or dose required to destroy 90% of micro-organisms

Food Technology, Jan 1998

# Effect of irradiation on vitamins in cooked chicken

| Vitamin (per 1 kg) | No irradiation | With irradiation |
|---|---|---|
| Vit A, IU | 2200 | 2450 |
| Vit E, mg | 3.3 | 2.15 |
| Thiamin, mg | 0.58 | 0.42 |
| Riboflavin, mg | 2.10 | 2.25 |
| Niacin, mg | 58.0 | 55.5 |
| Vit B6, mg | 1.22 | 1.35 |
| Vit B12, mg | 21 | 28 |
| Pantothenic acid, mg | 13 | 17 |
| Folacin,mg | 0.23 | 0.18 |

J.Food Processing and Preservation, 2, 229, 1978

# Thiamin retention comparison

| | | |
|---|---|---|
| **Meat** | **Percent in irradiated sample** | **Percent in canned sample** |
| Beef | 21 | 44 |
| Chicken | 22 | 66 |
| Pork | 12 | 57 |

Journal of Food Science 46:8, 1981

# Detection of irradiation

- The appearance of a food is not an indicator of whether or not it has been irradiated but laboratory tests have been developed. These methods employ techniques to identify certain molecular and spectroscopic characteristics of particular foods that are altered as a result of irradiation.
  - Gas chromatography, mass spectrometry, spectroscopy, luminescence and DNA analysis.

# Safety of irradiated foods

- Are Irradiated Foods Safe to Eat?
  - Yes. Safety has been thoroughly studied for over 50 years
- Determining the Safety of Irradiated Foods
  - Radiation Chemistry
  - General Toxicology/Animal Testing
  - Nutrition
  - Microbiology
  - Packaging

**Loaharanu, 2003, Irradiated Foods, American Council on Science & Health**

# Labelling irradiated foods in Australia

- Food can only be irradiated if there is no other safe method available. Any irradiated food must go through a strict safety assessment by Food Standards Australia New Zealand and, if approved, must be labelled as having been treated by irradiation.
- To date, in Australia and New Zealand, only herbs and spices and some tropical fruits have been approved to be irradiated.

# Labelling irradiated foods

- Any irradiated food, or food containing an irradiated ingredient must carry the word "Irradiated" in a prominent position either as part of the main label or next to the ingredient that has been irradiated. It may also (optional) show the international icon for irradiated food called the "Radura" symbol:

# Further reading

- Food Irradiation – A Guidebook (by M. Satin), 1996, Technomic Publishing Company, Lancaster, PA
- Irradiated Foods (by Loaharanu, P), 2003, American Council on Science & Health, NY

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