Risk Assessment Studies
Report No. 37

Safety of Irradiated Food

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Centre for Food Safety
Food and Environmental Hygiene Department
The Government of the Hong Kong Special Administrative Region

Correspondence:

Risk Assessment Section

Centre for Food Safety,

Food and Environmental Hygiene Department,

43/F, Queensway Government Offices,

66 Queensway, Hong Kong.

Email: enquiries@fehd.gov.hk

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Abstract

Food irradiation is the processing of food products by ionising radiation in order to control foodborne pathogens, reduce microbial load and insect infestation, inhibit the germination of root crops, and extend the durable life of perishable produce. The use of irradiation has been approved for about 50 different types of food and at least 33 countries are using the technology commercially. Despite the fact that irradiation has been used for decades for food disinfection that satisfies quarantine requirements in trade, health concerns over the consumption of irradiated food continue to attract attention. This study reviewed the basic principles, applications and the associated potential health risk, if any, posed to consumers as a result of consumption of irradiated food. Review of the available evidence showed that although irradiation processing leads to chemical changes and nutrient losses, the safety and nutrient quality of irradiated foods are comparable to foods that have been treated with other conventional food processing methods such as heating, pasteurisation and canning when the technology is used as recommended and good manufacturing practices are followed.

Risk Assessment Studies –

Irradiation Treatment of Foods

OBJECTIVES

This study aimed to provide an overview of the basic principles of food irradiation technology and its application; and to have a review in the safety of irradiated food.

INTRODUCTION

2. Food irradiation is the processing of food products by ionising radiation in order to control foodborne pathogens, reduce microbial load and insect infestation, inhibit the germination of root crops, and extend the durable life of perishable produce.[1]

3. According to the International Atomic Energy Agency (IAEA), more than 50 countries have approved the use of irradiation for about 50 different types of food, and 33 are using the technology commercially **[Annex I]**.[2] The positive list of irradiated products varies between countries but is often limited to spices, herbs, seasonings, some fresh or dried fruits and vegetables, seafood, meat and meat products, poultry and egg products. Despite the fact that irradiation has been used for decades for food disinfection and satisfying quarantine requirements in trade, there is considerable debate on the issue of health concerns over the

consumption of irradiated food. These include concerns over the toxicity of the chemicals generated and the change in nutritional quality of food products after irradiation.

PRINCIPLES OF FOOD IRRADIATION

Ionising radiation and their sources

4. According to the Codex General Standard for Irradiated Foods, ionising radiations recommended for use in food processing are: (I) gamma rays produced from the radioisotopes cobalt-60 (^{60}Co) and cesium-137 (^{137}Cs), and (II) machine sources generated electron beams (maximum level of 10 MeV) and X-ray (maximum level of 5 MeV).[3]

(I) Gamma rays produced from radioisotopes cobalt-60 and cesium-137

5. Cobalt-60 is produced in a nuclear reactor via neutron bombardment of highly refined cobalt-59 (^{59}Co) pellets, while cesium-137 is produced as a result of uranium fission. Both cobalt-60 and cesium-137 emit highly penetrating gamma rays that can be used to treat food in bulk or in its final packaging. Cobalt-60 is, at present, the radioisotope most extensively employed for gamma irradiation of food.[4]

(II) Electron beams and X-ray generated from machine sources

6. A major advantage of machine-sourced ionising radiation is that no radioactive substance is involved in the whole processing system. Powered by electricity, electron-beam machines use linear accelerators to produce

accelerating electron beams to near the speed of light. The high-energy electron beams have limited penetration power and are suitable only for foods of relatively shallow depth.[4]

7. Electron beams can be converted into various energies of X-rays by the bombardment with a metallic target. Although X-rays have been shown to be more penetrating than gamma rays from cobalt-60 and cesium-137,[4] the efficiency of conversion from electrons to X-rays is generally less than 10% and this has hindered the use of machine sourced radiation so far.[5]

Effects of ionising radiation

8. When ionising radiation passes through matter such as food, the energy is absorbed and leads to the ionisation or excitations of the atoms and molecules of the food constituents, which in turn, results in the chemical and biological changes known to occur when food is irradiated.

Chemical effects of food irradiation

9. The chemical effects of irradiation results from breakdown of the excited molecules and ions and their reaction with neighbouring molecules, giving a cascade of reactions. The primary reactions include isomerisation and dissociation within molecules and reactions with neighbouring species to produce series of new products including the highly reactive free radicals. Usually the free radicals generated in food on irradiation have a short lifetime. However, in dried or frozen foods containing hard component such as bone, the free radicals will have limited mobility and therefore, persist for a longer period of time.[4,6]

10. Another important chemical reaction resulted from ionizing irradiation is water radiolysis. Hydroxyl radicals and hydrogen peroxide generated upon the irradiation of water molecules are highly reactive and readily react with most aromatic compounds, carboxylic acids, ketones, aldehydes, and thiols.[4] These chemical changes are important in terms of their effects on the elimination of living food contaminants in foods. However, undesirable side effects, such as off-flavour, will be inevitable for certain food commodities if condition of irradiation is not well controlled.[6]

Biological effect of food irradiation

11. The major purpose of irradiating food is to cause changes in living cells. These can either be the contaminating organisms to reduce pathogenic microorganisms or cells of the living foods to achieve better quality. The biological effect of ionising radiation is inversely related to the size and complexity of the organism. The exact mechanism of action on cells is not fully understood. However, the chemical changes described in the previous paragraphs are known to alter cell membrane structure, reduce enzyme activity, reduce nucleic acid synthesis, affect energy metabolism through phosphorylation and reduce compositional changes in cellular DNA.[6]

12. The DNA damage may be due to direct but random strikes of the ionising radiation that causes the formation of lesions on either both or one of the DNA strands. Double strand lesions are almost invariably lethal.[7] This direct effect on DNA predominates under dry conditions, such as when dry spores are irradiated. Alternatively, the radiations may produce free radicals from other molecules, especially water, which diffuse towards and cause damage to the

DNA.[6]

Factors affecting the efficacy of food irradiation

13. The efficacy of ionising radiation for microorganism inactivation depends mainly on the dose of use and the level of resistance of the contaminating organisms. Radiation resistance varies widely among different species of bacteria, yeasts and moulds. Bacterial spores are generally more resistant than vegetative cells, which is at least partly due to their lower moisture content. Yeast is as resistant as the radiation-tolerant bacterial strains. Viruses are highly radiation resistant.[8] Other factors such as temperature, pH, presence of oxygen and solute concentration have also been shown to correlate with the amount of radiolytic products formed during irradiation which in turn affect the ultimate effectiveness of ionising radiation.[4]

Food Irradiation Equipment

14. To have a better view on the actual practice of food irradiation with regards to both the general requirements for irradiation and requirements for facilities and process control, a site visit was arranged to an irradiation plant in Guangzhou.

15. Gamma irradiation produced by cobalt-60 was used as the energy sources to provide ionising radiation for the process. The common features of all commercially irradiation facilities are the irradiation room and a system to transport the food into and out of the room. The major structural difference between irradiation plant to any other industrial building is the concrete shielding (usually 1.5-1.8 metres thick) surrounding the irradiation room, which ensures that

ionising radiation does not escape to the outside of the room.[5]

16. As in any gamma irradiator, the radionuclide source continuously emits radiation and when not being used to treat food, the radiation source is stored in a water pool (around six metres in depth). Known as one of the best shields against radiation energy, water absorbs the radiation energy and protects workers from exposure if they must enter the room.[5]

17. The transport system employed in the food irradiation facility is a rail system which conveys the food products through the irradiation chamber for irradiation treatment. By controlling the time and the energy of the irradiation source, specific dose of ionising radiation is delivered to the food products to achieve specific purpose.

18. In China, industrial food irradiation facilities must be licensed, regulated and inspected by national radiological safety and health authorities. Reference was made to irradiation standards[9] and codes of practice[10,11,12] established by other authorities. The IAEA and FAO have jointly developed the Food Irradiation Facilities Database which provides a list of authorised food irradiation facilities by country for public reference.[13]

APPLICATION OF FOOD IRRADIATION

Reduction of pathogenic microorganisms

19. Since irradiation does not substantially raise the temperature of food under irradiation, it is of particular importance for the control of food-borne illnesses in seafood, fresh produces, and frozen meat products. Ionising radiation has been shown to reduce the number of disease-causing bacteria such as *Listeria monocytogenes*,[14,15] *Escherichia coli* O157:H7,[15,16] *Salmonella*,[17,18] *Clostridium botulinum*,[19] *Vibrio parahaemolyticus*,[18] *etc*. in various food commodities and allow food to be irradiated in its final packaging. However, irradiation alone may not be sufficient to reduce the number of food poisoning outbreaks, it is essential to adhere to good manufacturing practice to prevent subsequent contamination during processing.

Decontamination

20. Spices, herbs and vegetable seasonings are valued for their distinctive flavours, colours and aromas. However, they are often contaminated with microorganisms because of the environment and processing conditions under which they are produced.[5] Until the early 1980s, most spices and herbs were fumigated, usually with sterilising gases such as ethylene oxide to destroy contaminating microorganisms. However, the use of ethylene oxide has been banned in a number of countries due to its proven carcinogenicity. Irradiation has since emerged as an alternative and widely used in the food industry for the decontamination of dried food ingredients.[20] In addition to the improvement of hygienic quality of various foods, irradiation has also been used as a method for

decontaminating medicinal herbs.[21]

Extension of shelf-life

21. The shelf-life of many fruits and vegetables, meat, poultry, fish and seafood can be considerably prolonged by treatment with irradiation.[5] Depending on the dose of ionising energy applied, irradiation produces virtually no or minor organoleptic changes to food under irradiation that make it particularly important for the control of postharvest quality of fresh produces[22] by modifying the normal biological changes associated with ripening, maturation, sprouting, and aging.[23] Exposure to a low dose of radiation has been demonstrated to slow down the ripening of bananas, mangoes and papaya, control fungal rot in strawberries and inhibit sprouting in potato tubers, onion bulbs, yams and other sprouting plant foods.[24,25]

Disinfestation

22. The major problem encountered in preservation of grains and grain products is insect infestation. Irradiation has been shown to be an effective pest control method for these commodities and a good alternative to methyl bromide, the most widely used fumigant for insect control, which is being phased out due to its ozone depleting properties. Disinfestation is aimed at preventing losses caused by insects in store grains, pulses, flour, cereals, coffee beans, fresh and dried fruits, dried nuts, and other dried food products including dried fish. It is worth mentioning that proper packaging of irradiated products is required for preventing reinfestation of insects.[5,26]

Other potential applications

23. Besides the sanitary purposes, irradiation has been studied to reduce or eliminate undesirable or toxic materials including, food allergens,[27,28] carcinogenic volatile N-nitrosamines[29,30] and biogenic amines[31] On the other hand, irradiation has been shown to enhance colour of low-nitrite meat products[32] and low-salt fermented foods.[33] In addition, ionising radiation can be used to destroy chlorophyll b in vegetable oil resulting in protection of oil from photooxidation and elimination of undesirable colour change in oil processing industry.[34]

SAFETY OF IRRADIATED FOOD

Radiological safety

24. Irradiation process involves passing the food through a radiation field at a set speed to control the amount of energy or dose absorbed by the food. Under controlled conditions, the food itself should never come into direct contact with the radiation source.[35]

25. At high energy levels, ionising radiation can make certain constituents of food become radioactive.[23] Studies showed that induced radioactivity was detected in ground beef or beef ashes irradiated with X-rays produced by 7.5 MeV electrons. However, the induced activity was found to be significantly lower than the natural radioactivity in food. Corresponding annual dose is several orders of magnitude lower than the environmental background. The risk to individuals from intake of food irradiated with X-rays generated by electrons with nominal energy as high as 7.5 MeV is trivial.[36]

26. Studies carried out by IAEA showed that increase in radiation

background dose from consumption of food irradiated to an average dose below 60kGy with gamma-rays from cobalt-60 or cesium-137, with 10 MeV electrons, or with X-rays produced by electron beams with energy below 5 MeV are insignificant, and best characterized as zero.[37]

27. Based on the experimental findings of WHO, FAO and IAEA, Codex has set out the maximum absorbed dose delivered to a food should not exceed 10kGy and the energy level of X-rays and electrons generated from machine sources operated at or below 5 MeV and 10 MeV respectively, in part, to prevent induced radioactivity in the irradiated food.[3]

Microbiological safety

28. Two concerns that have been raised regarding the irradiation of microorganisms present in food are the effect of the reduction in the natural microflora on surviving pathogens and the potential for the development of radiation resistant mutants.

29. Ionising radiation significantly reduces the populations of indigenous microflora in foods. There is concern that these "clean" foods would allow a more rapid outgrowth of bacteria of public health concern, since the lower populations of indigenous microflora would have less of an antagonistic effect on the pathogenic bacteria.[38] It has also been hypothesised that irradiated foods would be more amenable to the growth of foodborne pathogens if the food was contaminated after irradiation.[39] However, studies in irradiated chicken and ground beef has illustrated that the growth rates of either salmonellae (chicken and beef) or *Escherichia coli* O157:H7 (beef) were the same in both nonirradiated and irradiated meats suggesting that the indigenous microflora in these products does

not normally influence the growth parameters of these bacteria.[40,41]

30. The concern with radiation mutations is significant because ionising radiation has been known for years to induce mutations.[42] Induction of radiation-resistant microbial populations occurs when cultures are experimentally exposed to repeated cycles of radiation.[43] Mutations developed in bacteria and other organisms can result in greater, less, or similar levels of virulence or pathogenicity from parent organisms. Although it remains a theoretical risk, there was no report of the induction of novel pathogens attributable to food irradiation.[44,45] Bacteria that undergo radiation-induced mutations are more susceptible to environmental stresses, so that a radiation-resistant mutant would be more sensitive to heating than would its nonradiation-resistant parent strain.[8,45]

Toxicological safety

Toxicity studies in animals

31. The possible toxicological effects of consuming irradiated foods have been extensively studied since the 1950s.[46] Feeding trials involved a variety of laboratory diets and food components given to human and different species of animals including rats, mice, dogs, quails, hamsters, chickens, pigs and monkeys have been conducted to assess the toxicological safety of irradiated foods.[8]

32. Animal feeding trials conducted included lifetime and multi-generation studies to determine if any changes in growth, blood chemistry, histopathology, or reproduction occurred that might be attributable to consumption of different types of irradiated foods. Data from many of these studies were

evaluated by the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food (JECFI). In 1980, JEFCI concluded that "Irradiation of any food commodity up to an overall average dose of 10 kGy introduces no toxicological hazard; hence, toxicological testing of food so treated is no longer required".[45] The safety of irradiated food was also supported by recent study with laboratory diets that had been sterilised by irradiation. Several generations of animals fed diets irradiated with doses ranging from 25 to 50 kGy, which is considerably higher than dose used for human foods, suffered no mutagenic, teratogenic and oncogenic ill effect attributed to the consumption of irradiated diets.[47]

Human clinical studies

33. There have been relatively few trials performed on humans, the majority being carried out by the US Army. The subjects were assessed by clinical examination and for cardiac performance, haematological, hepatic and renal function. All studies have been short term. No clinical abnormalities were discovered up to one year following the trials.[48]

34. One of the best known human feeding trials is that performed in 1975 where 15 malnourished children in India were fed a diet containing irradiated wheat at dose of 0.75 kGy. Increase in the frequency of polyploidy and number of abnormal cells were observed during the course of the trial. When the irradiated diet was discontinued, the abnormal cells reverted to a basal level. The author attributed these observations to the consumption of the irradiated food. [49] However, when the report was examined more closely, it was found that only 100 cells from each of the five children in each group were

counted. The sample number was too small upon which to base any conclusion.[5]

35. A number of concerns regarding the impact of irradiated food on health have been raised. Among these was the criticism of the design and execution of a number of *in vitro* studies into toxicological safety. These studies used food juices, extracts and digests in mutagenic studies using cells of mammalian, bacterial and vegetable origin and largely produced negative effects. Some possible chromosome changes and cytotoxic effects were reported but, as food contains many compounds that may interfere with the tests, the result were not deem significant.[50] There was also concern that when the WHO published its report on the wholesomeness of foods irradiated at doses of above 10 kGy, five peer reviewed publications, all of which were feeding trials reporting toxicological effects of irradiated food, were disregarded.[45] It also has been pointed out that all the animal studies were of much too short duration to demonstrate carcinogenicity of irradiated food, which usually takes several decades.[51]

Chemical toxicological studies

36. The presence of several compounds, most notably 2-alkylcyclobutanones(2-烷基环丁酮) and furan has generated some concerns about the safety of irradiated foods.

2-Alkylcyclobutanones

37. Irradiation of fat-containing food generates a family of molecules, namely 2-alkycyclobutanones (2-ACBs), that result from the radiation induced breakage of triglycerides.[52] The 2-ACBs have been found exclusively in irradiated fat-containing food, and have until now never been detected in

non-irradiated foods treated by other food processes.[53,54] Thus, these compounds were considered to be unique markers for food irradiation. In irradiated foods, level of 2-ACBs generated is proportional to the fat content and absorbed dose.[55] Depending on the dose absorbed, the concentration of 2-ACBs in irradiated food ranged from 0.2 to 2 μg/g of fat.[56]

38. Previous study feeding rats daily with a solution of highly pure solution of 2-ACBs and injected with a known carcinogen azoxymethane (AOM) showed that the total number of tumours in the colon was threefold higher in the 2-ACB-treated rats than in the AOM controls six months after injection. Medium and larger tumours were detected only in animals treated with 2-ACB and AOM. This demonstrated that 2-ACBs found exclusively in irradiated dietary fats may promote colon carcinogenesis in animals treated with a chemical carcinogen. It does also suggest that the 2-ACBs alone does not initiate colon carcinogenesis. However, it is worth noting that the amount of 2-ACBs consumed was much higher in this study than that a human would consume in a diet containing irradiated food.

Furan

39. Furan is regarded as a possible carcinogen by the International Agency for Research on Cancer.[57] A number of studies have been performed on the effect of gamma irradiation on furan levels in foods. There was evidence that level of furan increased linearly with increasing irradiation dose and that both pH and substrate concentration affected the amount of furan produced.[58] Recent studies have also demonstrated low levels of furan were induced by irradiation in fruits that had a high amount of simple sugars and low pH, such as grapes and

pineapples.[59] However, the level of furan detected in irradiated foods purchased from supermarket in the US were in general much lower than those in some thermal processed foods.[60,61]

Nutritional adequacy

40. Food processing and preparation methods in general tend to result in some loss of nutrients, and food irradiation is no exception. Nutritional changes in food attributable to irradiation are similar to those results from cooking, canning, pasteurising, blanching and other forms of heat processing [62] Irradiation-induced changes in nutritional value depend on a number of factors: radiation dose, the type of food, the temperature and atmosphere in which irradiation is performed, packaging and storage time. In general, macronutrients (protein, lipid and carbohydrate) quality does not suffer due to irradiation[8] and minerals have also been shown to remain stable.[62] However, loss of vitamins during irradiation is an obvious concern and has been studied in detail in a variety of foods.

41. Different types of vitamin have varied sensitivity to irradiation. Some vitamins such as riboflavin, niacin, and vitamin D, are fairly resistant to irradiation but vitamins A, B1 (thiamine), E and K are relatively sensitive. Their sensitivities depend on the complexity of the food, whether the vitamins are soluble in water or fat, and the atmosphere in which irradiation occurs. In general, the effects of irradiation on nutritional value of foods are insignificant for low dose (up to 1 kGy) but may be greater at medium doses (1-10kGy) if food is irradiated in the presence of air. At high doses (above 10 kGy), losses of sensitive vitamins such as thiamine may be significant. Vitamin losses can be

mitigated by protective actions, for example, using low temperatures and air exclusion during processing and storage. As irradiated foods are normally consumed as part of a mixed diet and the process will have little impact on the total intake of specific nutrients.[45]

CONTROL OF FOOD IRRADIATION

International perspectives

42. The Joint Expert Committee on Food Irradiation (JECFI) convened by the Food and Agricultural Organization (FAO), the International Atomic Energy Agency (IAEA), and the World Health Organization (WHO) are of particular importance in the development of food irradiation in the international arena. JECFI is a group of scientists working on the wholesomeness of irradiated foods and gives decisive interventions on the safety of food irradiation. These declarations resulted in the development and eventual adoption of the Codex General Standard for Irradiated Foods[3] stipulating both the general and technological requirements for the process, and its associated Recommended Code of Practice for the Operation of Radiation Facilities Used for the Treatment of Foods[12,63] to provide guidelines to ensure radiation processing of food products is implemented safely and correctly.

43. Codex has also developed a set of guidelines for irradiated food labelling. The Codex General Standard for the Labelling of Pre-Packaged Foods[64] contains provisions for labelling of irradiated foods that a food which has been treated with ionising radiation shall carry a written statement indicating such treatment in close proximity to the name of the food. An international food

irradiation symbol shown below may also be used but which is optional.[64]

44. Declaration in the list of ingredients should also be made if an ingredient used in the food product has been irradiated. Furthermore, if a single ingredient is prepared from a raw material which has been irradiated, the label of the product shall contain a statement indicating the treatment.[64] Based on these standards, many different countries have developed their own national regulation for labelling of irradiated foods **[Annex II]**.

Situation in Hong Kong

45. While there is currently no irradiation facility for food treatment in Hong Kong, the labelling requirement for irradiated food has been stipulated in the Food and Drugs (Composition and Labelling) Regulation of the Public Health and Municipal Services Ordinance (Cap. 132) that every container containing irradiated food shall be clearly and legibly marked with the words "IRRADIATED" or "TREATED WITH IONIZING RADIATION" in English capital lettering and "輻照食品" in Chinese characters.

46. Regular surveillance to monitor compliance to the labelling requirements on food irradiation is being conducted. Food commodities are collected at both import and retail levels to determine if proper labelling has been made for those food products that have been treated with ionising radiation.

47. In 2000, 69 food samples were taken for detection of ionising treatment. Six of these samples showed positive results. As these products did not bear proper irradiation labelling, warning letters were issued to their sellers requesting the products either be withdrawn from the market or properly labelled. In all cases, the products were withdrawn. No further non-compliance was detected in subsequent surveillances (from 2001-2008).

48. A method routinely employed by the Government Laboratory for testing of irradiated food is the electron spin resonance (ESR) spectroscopy which is a technique that can be used to detect radiation-induced free radicals and used to determine whether certain foods have been irradiated.[65]

CONCLUSION

49. The use of ionising radiation in food industry provides a means to control pathogenic bacteria and parasites in foods, prevent postharvest food losses and extending the shelf life of perishable produces. Many studies have been conducted to evaluate the safety as well as the nutritional adequacy of irradiated foods. Although evidence showed that irradiation processing leads to chemical changes and nutrient losses, the safety and nutrient quality of irradiated foods are comparable to foods that have been treated with other conventional food processing methods such as heating, pasteurisation and canning when the technology is used as recommended and follow good manufacturing practices.

ADVICE TO TRADE

- Follow closely international guidelines on the code of practice for radiation

processing of food to ensure the absorbed dose fall in a safe range for consumer, and not destroy nutrition value, structural integrity, and sensory attributes of food.

- Every container containing irradiated food shall be properly labelled.

- Food after irradiation should be handled under quality controlled and hygienic conditions to prevent subsequent contamination.

ADVICE TO PUBLIC

- The safety and nutrient quality of irradiated foods are comparable to foods that have been treated with other conventional food processing methods when the technology is used as recommended and good manufacturing practices are followed. Consumption of irradiated foods has little impact on the total intake of specific nutrients and poses no additional risk to human health.

- Maintain a balanced diet and avoid overindulgence of food items.

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Annex I

Foods Approved for Irradiation in Major Countries

Countries	Dose#	Objective	Product
Australia	Low	Control sprouting, Disinfestation	Herbal infusions, Spices and herbs
		Quarantine treatment	Breadfruit, Carambola, Custard apple, litchi, Longan, Mango, Mangosteen, Papaya (paw paw), Rambutan
	Medium	Microbial control	Herbal infusions, Spices and herbs
Canada	Low	Disinfestation	Wheat and wheat products
		Sprout inhibition	Onions, Potatoes
	Medium	Microbial control	Dry vegetables seasonings spices
China	Low	Control of parasites	Pork
		Disinfestation	Beans, Cereal grains (rice, wheat), Dried nuts and fruits
		Shelf-life extension	Any (fresh fruits)
		Sprout inhibition	Any (fresh vegetables)
	Medium	Microbial control	Beef and poultry meat (frozen), Cooked meat food for livestock and poultry, Pollen, Spices, Sweet potato wine
Japan	Low	Sprout inhibition	Potatoes
Republic of Korea	Low	Disinfestation	Chestnuts, Mushrooms
		Sprout inhibition	Garlic, Onion, Potatoes
	Medium	Disinfestation	Cereals or legumes and their powder as ingredients of food products
		Microbial control	Algae food, Aloe, Cereals or legumes and their powder as ingredients of food products, Dried food of animal origin (meat, fish), Dried vegetables, Egg powder, Enzime preparations, Ginseng, Other powdered products (Doenjang, Kochujang, Kanjang), Sauces, Soy bean and red pepper paste, Soy sauce, Spices (dried), Starch as ingredient of food products, Sterile meals (for 2nd pasturisation), Tea (included later), Vegetable seasonings (dried), Yeast powder
New Zealand	Low	Quarantine treatment	Breadfruit, Carambola, Custard apple, litchi, Longan, Mango, mangosteen, papaya (paw paw), Rambutan
	Medium	Control sprouting	Herbal infusions, Herbs, Spices
		Disinfestation	Herbal infusions, Herbs, Spices
		Microbial control	Herbal infusions
	Medium to high	Microbial control	Herbs, Spices

United States of America	Low	Control of parasites	Pork meat
	Medium	Delay ripening/physiological growth	Any fresh fruits and vegetables
		Disinfestation	Any fresh fruits and vegetables, Wheat and wheat powder
		Quarantine control	Any fresh fruits and vegetables
		Sprout inhibition	Potatoes (white)
		Microbial control	Enzime preparations (dried or dehydrated), Seeds for sprouting
	High	Reduction of pathogenic microorganisms	Fresh shell eggs, Poultry meat and their products, Red meat and meat by products, Shellfish (fresh or frozen)
		Shelf-life extension	Poultry meat and their products, Red meat and meat by products
		Microbial control	Animal feed and pet food, Herbs, Spices, Vegetable seasonings

[#] Low-dose irradiation – up to 1kGy; Medium-dose irradiation – 1 to 10kGy, High-dose irradiation – above 10kGy[5]

Annex II

Labelling Practices of Irradiated Foods in Major Countries

Country	Irradiated foods shall carry a written statement indicating the treatment	International food irradiation symbol should be used	If an irradiated product is used as an ingredient, it should be declared in the ingredient list
Australia	√		√
Canada	√	√	√ **(>10%)**
China	√	√	√
EU	√		√
New Zealand	√		√
USA	√	√	