Chapter 15 Radiation Protection of Foods and Nature of Microbial Radiation Resistance

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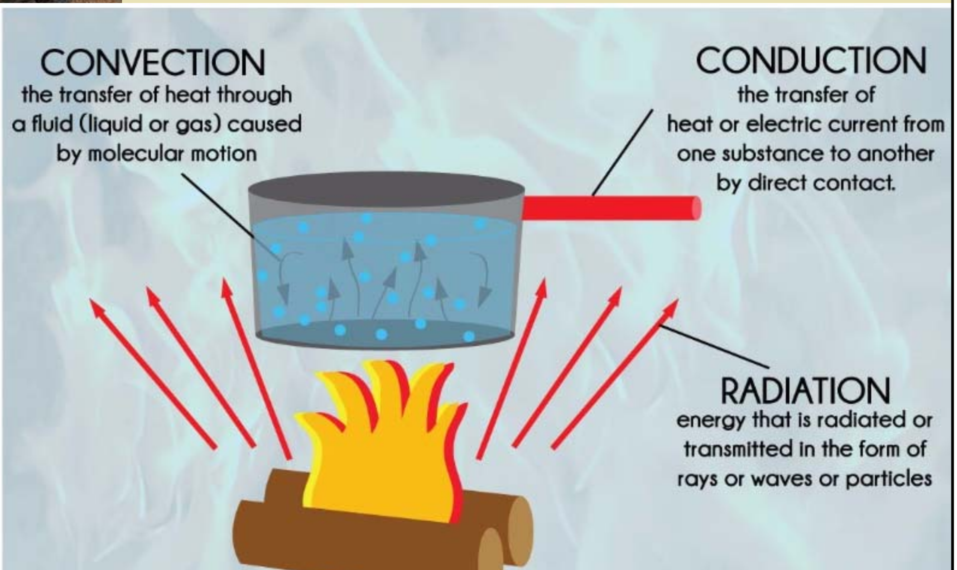
節錄自Modern Food Microbiology, Jay, J. M., 7th ed.

Introduction



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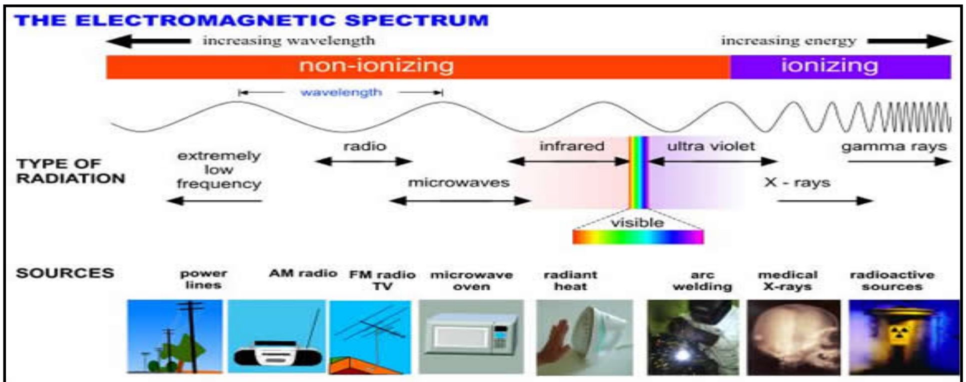


- Radiations are **separated on the basis of their wavelengths**, with the **shorter wavelengths** being the most damaging to microorganisms.
- The radiations of interest in food preservation: **ultraviolet light, beta rays, gamma rays, X-rays, and microwaves**.

Introduction

- The radiations of primary interest in food preservation are **ionizing radiations**, ➔wavelengths of 2000 Å or less➔**beta rays, gamma rays, X rays**➔ ionize molecules in their paths➔ **destroy microorganisms without raising temperature➔cold sterilization (冷殺菌)**
- A **rad** is a unit equivalent to the absorption of **100 ergs/g** of matter. A **kilorad** (krad) is equal to1000 rads, and a **megarad** (Mrad) is equal to 1 million rads.
- The newer unit of absorbed dose is the **gray** (1 Gy = 100 rads = 11 joule/kg; 1 kGy = 10^5 rads).

Characteristics of Radiations of Interest in Food Preservation

1. Ultraviolet light

- **Ultraviolet (UV) light** ➔ **bactericidal agent** ➔ most effective wavelength being about 2600 Å.
- It is **nonionizing** and **is absorbed by proteins and nucleic acids**➔ may **lead to cell death**
- The mechanism of UV death in the bacterial cell ➔ production of **lethal mutations** ← action on cell nucleic acids.
- **Poor penetrative capacities** ➔ limit to **surface applications**

Characteristics of Radiations of Interest in Food Preservation

2. **Beta "rays"**

- **Streams of electrons** emitted from radioactive substances.
- **Cathode "rays"** are the same except that they are emitted from the cathode of an evacuated tube.
- **Poor penetration power.**

Characteristics of Radiations of Interest in Food Preservation

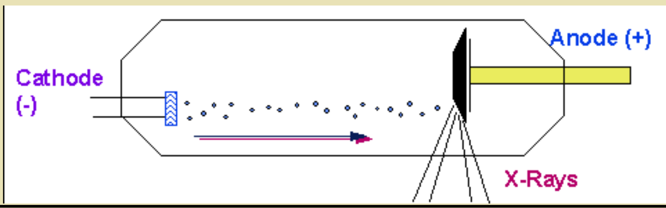
3. Gamma rays

- **Electromagnetic radiations** emitted from the excited nucleus of elements, such as ^{60}Co and ^{137}Cs $\rightarrow$ importance in food preservation
- **excellent penetration power**

Characteristics of Radiations of Interest in Food Preservation

4. X-rays

- produced by the bombardment of heavy-metal targets with **high-velocity electrons** (cathode rays) within an evacuated tube.
- essentially **the same as gamma rays** in other respects.



Characteristics of Radiations of Interest in Food Preservation

5. Microwaves

- When electrically neutral foods are placed in an electromagnetic field, the oscillation of the charged asymmetric molecules will result in **intermolecular frictions** that are created as a heating effect.

PRINCIPLES UNDERLYING THE DESTRUCTION OF MICROORGANISMS BY IRRADIATION

Factors to be considered in the use of radiation on microorganisms

- **1. Types of Organisms**
  - Resistance to irradiation: **Gram-positive bacteria > Gram-negatives; Sporeformers > nonsporeformers**
  - **Radioresistance** generally parallels **heat resistance** among bacteria.
  - **Radioresistance: yeasts > molds> Gram-positive bacteria>Gram-negative bacteria**

PRINCIPLES UNDERLYING THE DESTRUCTION OF MICROORGANISMS BY IRRADIATION

- **2. Numbers of Organisms**
  - The larger the number of cells, the less effective is a given dose.
- **3. Composition of Suspending Menstruum (溶媒) (Food)**
  - Microorganisms in general are more sensitive to radiation when suspended in buffer solutions than in protein-containing media. ➔**Proteins exert a protective effect against radiations**, as well as against certain antimicrobial chemicals and heat.

PRINCIPLES UNDERLYING THE DESTRUCTION OF MICROORGANISMS BY IRRADIATION

4. Presence or Absence of Oxygen

- The **radiation resistance** of microorganisms is **greater in the absence of oxygen** than in its presence. Complete removal of oxygen from the cell suspension of *Escherichia coli*➔ increase its radiation resistance up to threefold.
- The **addition of reducing substances** ➔**increasing radiation resistance** as an anaerobic environment.

PRINCIPLES UNDERLYING THE DESTRUCTION OF MICROORGANISMS BY IRRADIATION

5. Physical State of Food

- The **radiation resistance of dried cells is higher** than that for moist cells. ← **radiolysis of water by ionizing radiations.**
- **Radiation resistance of frozen cells is greater** than that of nonfrozen cells.

6. Age of Organisms

- Bacteria are most resistant to radiation in **the lag phase just prior to active cell division**.
- The cells become more radiation sensitive as they enter and progress through the log phase and reach their minimum at the end of this phase.

PROCESSING OF FOODS FOR IRRADIATION

Prior to being exposed to ionizing radiations, several processing steps must be carried out in much the same manner as for the freezing or canning of foods.

- **1. Selection of Foods**
  - **freshness** and **desirable quality**.
  - spoilage would be avoided.
- **2. Cleaning of Foods**
  - All visible debris and dirt should be removed→ **reduce the numbers of microorganisms**

PROCESSING OF FOODS FOR IRRADIATION

3. Packing

- **Afford protection against postirradiation contamination**.
- **Clear glass containers undergo color changes** when exposed to doses of radiation of around 10 kGy

PROCESSING OF FOODS FOR IRRADIATION

4. Blanching or Heat Treatment

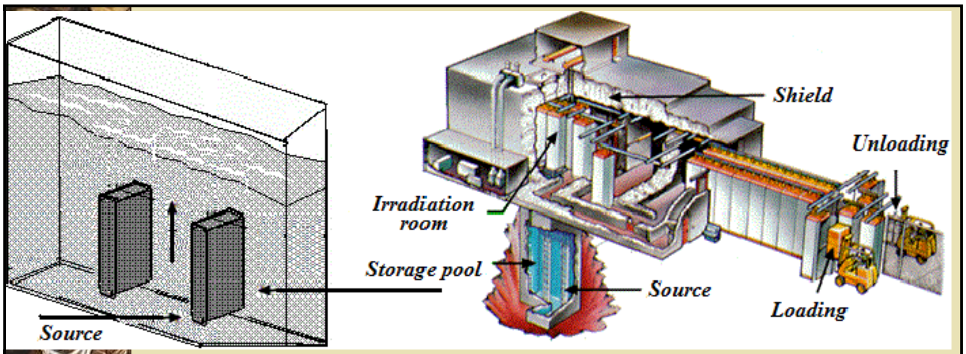
- Sterilizing doses of radiation are **insufficient to destroy the natural enzymes** of foods (Fig. 15-2).
- In order to avoid undesirable postirradiation changes, it is necessary to destroy these enzymes. The best method is a **heat treatment**—that is, **the blanching of vegetables** and **mild heat treatment of meats** prior to irradiation.

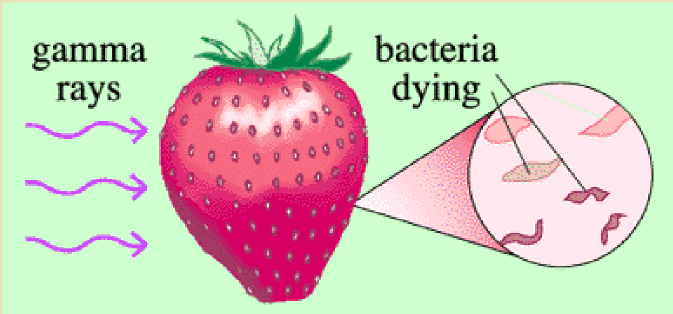
APPLICATION OF RADIATION

- The two most widely used techniques of irradiating foods are
  - **gamma radiation** from either ^{60}Co and ^{137}Cs
  - **electron beams** from linear accelerators

Gamma Radiation

- ^{60}Co and ^{137}Cs are relatively **inexpensive byproducts of atomic fission** **(核分裂)**
- 1. In an experimental **radiation chamber**, the radioactive material is placed on the top of an elevator that can be moved up for use and down under water when not in use.
- 2. Materials to be irradiated are placed around the radioactive material (the source) **at a suitable distance for the desired dosage**.
- 3. Once all personnel have vacated the chamber, the source is raised into position, and the gamma rays irradiate the food.





Disadvantages of Gamma Radiation

- The isotope source **emits rays in all directions** and **cannot be turned "on" or "off" as desired** (Fig. 15-3).
- The **half-life of ^{60}*Co* (5.27 years) requires that the source be changed periodically** in order to maintain a given level of radioactive potential. This is overcome by the use of ^{137}**Cs**, which has a half-life of around **30 years**.

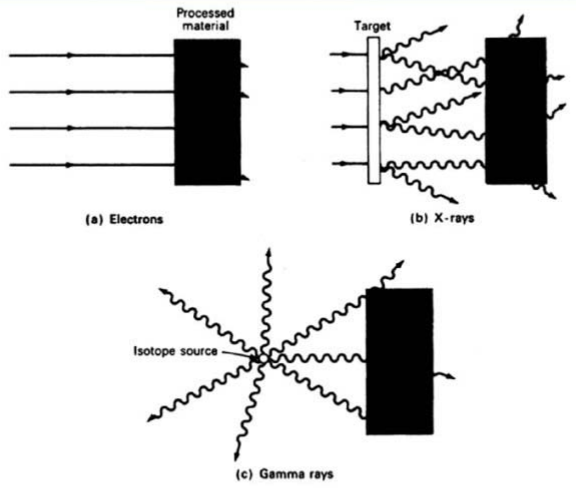
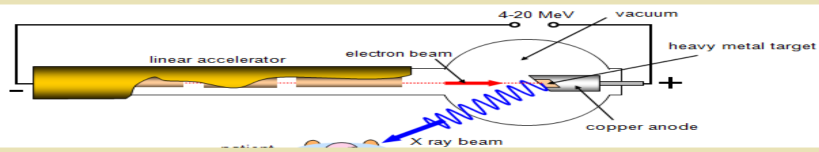


Figure 15–3 The three basic techniques for radiation processing—interactions of electrons, X-rays, and gamma rays in the medium. *Source*: From Koch and Eisenhower,[39] 1965, *Radiation Preservation of Foods*, Publication 1273, Advisory Board on Military Personnel Supplies, National Academy of Sciences, National Research Council.

Electron Beams/Accelerated Electrons

- **Advantages of electron accelerators** over radioactive elements:
  1. **High efficiency for the direct deposition of energy** of the primary electron beams ➔**high plant-product capacity.**
  2. The **efficient convertibility of electron power to X-ray power** ➔**can handle very thick products**
  3. The **easy variability of electron-beam current and energy** ➔**flexibility in the choice of surface and depth treatments**



Electron Beams/Accelerated Electrons

4. The **monodirectional** characteristic at the higher energies ➔ **a great flexibility in the food package design**.
5. **The ability to program and to regulate automatically ➔ efficiently processing various shapes** (small, intricate, or not uniform).
6. electron accelerator can **be turned off or on easily ➔ shut down during off-shifts or off-seasons** without a maintenance problem and transport the radiation source without a massive radiation shield.

Electron Beams/Accelerated Electrons

- Two differences between gamma rays and accelerated electrons are:
  - **Gamma has higher penetration capacity** than accelerated electron but the penetration capacity of accelerated electron increases with their energy.
  - **Dose rate**. The gamma rate from ^{60}Co is **1-100 Gy/min**, whereas electron beams from an electron accelerator are **10^3-10^6 Gy/sec**

RADAPPERTIZATION, RADICIDATION, AND RADURIZATION OF FOODS

- **Radappertization** (食品的高劑量射線滅菌處理): Equivalent to **radiation sterilization** or "**commercial sterility**," as it is understood in the canning industry. ➔ **30-40 kGy**.
- **Radicidation** (食品的低劑量射線滅菌處理): Equivalent to **pasteurization—of milk**, for example. ➔ **reduction of the number of viable specific nonsporeforming** ***pathogens***, other than viruses➔ **none is detectable** by any standard method➔ **2.5-10 kGy**.
- **Radurization** (食品的低劑量射線延長貯期處理): May be considered equivalent to pasteurization. ➔ **enhancement of the keeping quality** of a food by causing **substantial reduction in the numbers of viable specific** ***spoilage*** **microbes** ➔**0.75-2.5 kGy**

Radappertization (30-40 kGy) 食品的高劑量射線滅菌處理

- The effect of this treatment on **endospores and exotoxins of** ***C. botulinum*** is of obvious interest.
- **Resistance increases at the colder temperatures** and decreases at warmer temperatures (Table 15.1).
- **Irradiation treatments do not make the foods radioactive.**
- **Viruses are considerably more resistant** to radiation than bacteria.

Radappertization (30-40 kGy) 食品的高劑量射線滅菌處理

- **Enzymes are also highly resistant** to radiation.
- **The main drawbacks➔ color changes** and/or the production of **off-odors**.
- Radappertization of bacon is one way to **reduce nitrosamines.** When bacon containing 20 ppm $NaNO_2$ + 550 ppm sodium ascorbate was irradiated with 30 kGy, the resulting nitrosamine levels were similar to those in nitrite-free bacon.

Radicidation (2.5-10 kGy) 食品的低劑量射線滅菌處理

- Irradiation at levels of **2-5 kGy is effective in destroying nonsporeforming and nonviral pathogens and no health hazard**.
- **Raw poultry meats** should be given the highest priority because they are often contaminated with **salmonellae** and because radicidation is effective on prepackaged products, thus eliminating the possibilities of cross-contamination.

Radicidation (2.5-10 kGy)
食品的低劑量射線滅菌處理

- A radiation dosage up to **7 kGy** **(0.7 Mrad)** has been approved by the World Health Organization as being "**unconditionally safe for human consumption**".

- Fresh poultry, cod and red fish, and spices and condiments have been approved for radicidation in some countries (Table 15-5).

Radurization (0.75-2.5 kGy)
食品的低劑量射線延長貯期處理

- Irradiation treatments can extend the shelf life of seafoods, vegetables, and fruits.
- The **gram-negative nonsporeforming rods are among the most radiosensitive** of all bacteria, and they are the principal spoilage organisms for these foods.
- The **gram-negative** coccobacillary rods belonging to the genera ***Moraxella*** **(莫拉菌屬)** and ***Acinetobacter*** **(不動桿菌屬)** have been found to possess degrees of **radiation resistance** higher than for all other gram negatives.

Radurization (0.75-2.5 kGy) 食品的低劑量射線延長貯期處理

- The ultimate spoilage of radurized, low-temperature-stored foods is usually caused by ***Acinetobacter*** **(不動桿菌屬),** ***Moraxella*** **(莫拉菌屬)** or **lactic acid bacteria**.
- In general, **shelf-life extension is not as great for radurized fruits** as for meats and seafood because **molds are generally more resistant to irradiation** than the gram-negative bacteria.

LEGAL STATUS OF FOOD IRRADIATION

- At least 36 countries had approved the irradiation of some foods.
- At least 20 different food packaging materials have been approved by the U.S. Food and Drug Administration (FDA) at levels of 10 or 60 kGy.
- **Sprout inhibition** and **insect disinfestation** continue to be the most widely used direct applications of food irradiation.

LEGAL STATUS OF FOOD IRRADIATION

- WHO has given approval for radiation dosages up to **7 kGy (0.7 Mrad)** as being unconditionally safe.
- One of the obstacles to getting food irradiation approved on a wider scale in the United States is **the way irradiation is defined.** It is considered an **additive** rather than a process, which it is. This means that **irradiated foods must be labeled**.

EFFECT OF IRRADIATION ON FOOD QUALITY

- The **undesirable changes** may be caused **directly by irradiation** or **indirectly by postirradiation reactions.**
- **Water undergoes radiolysis when irradiated** .
- **Radiolysis**: $3H_2O \rightarrow H + OH + H_2O_2 + H_2$
- **free radicals are formed** and react with each other as diffusion occurs. Some of the products can then react with solute molecules.

EFFECT OF IRRADIATION ON FOOD QUALITY

- By **irradiating under anaerobic conditions, off-flavors and off-odors are somewhat minimized** due to the lack of oxygen to form peroxides.

- One of the best ways to minimize off-flavors is to **irradiate at subfreezing temperatures**. The effect of subfreezing temperatures is to **reduce or halt radiolysis** and its consequent reactants. Other ways to reduce side effects in foodstuffs are presented in Table 15-6.

Methods for reducing side effects in foodstuffs exposed to ionizing radiation (Table 15-6)

1. **Reducing temperature**
2. **Reducing oxygen tension**
3. **Addition of free-radical scavengers (清除劑)**
4. **Concurrent radiation distillation**
5. **Reduction of dose**

EFFECT OF IRRADIATION ON FOOD QUALITY

- **Sensitivity to irradiation of food components:** **water > proteins and other nitrogenous compounds > lipids and fats**
- The irradiation of lipids and fats ➔ **oxidation products** such as peroxides, especially if irradiation and/or subsequent storage takes place in the presence of oxygen.

EFFECT OF IRRADIATION ON FOOD QUALITY

- High levels of irradiation lead to the production of "**irradiation odors**" in certain foods, especially meats.
- In addition to **flavor and odor changes** produced in certain foods by irradiation, certain detrimental effects have been reported for irradiated fruits and vegetables.
  - One of the most serious is the **softening** of these products caused by the **irradiation-degradation of pectin and cellulose**, the structural polysaccharides of plants.

STORAGE STABILITY OF IRRADIATED FOODS

- Foods subjected to radappertization doses of ionizing radiation may be expected to be as shelf stable as commercially heat-sterilized foods.
  - However, there are two differences between foods processed by these two methods that affect storage stability:
    - **Radappertization does not destroy inherent enzymes**, which may continue to act, and
    - some **postirradiation changes** may be expected to occur.

STORAGE STABILITY OF IRRADIATED FOODS

- Employing **45 kGy** and **enzyme-inactivated** chicken, bacon, and fresh and barbecued pork, products were acceptable after storage for up to **24 months**.

- The effect of irradiation on beefsteak, ground beef, and pork sausage held at refrigerator temperatures for **12 years** were reported. These foods were packed with flavor preservatives and treated with **10.8 kGy**. The appearance of the meats as excellent after 12 years of storage. **A slight irradiation odor** was perceptible but was not considered objectionable.

NATURE OF RADIATION RESISTANCE OF MICROORGANISMS

Biology of Extremely Resistant Species

- The most resistant of all known nonsporeforming bacteria consist of four species of the genus ***Deinococcus*** (異常球菌屬) and one each of ***Deinobacter*** (異常桿菌屬), ***Rubrobacter*** (放線菌屬), and ***Acinetobacter*** (不動桿菌屬).

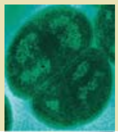



- Some characteristics of these species are presented in Table 15-8.

NATURE OF RADIATION RESISTANCE OF MICROORGANISMS

Biology of Extremely Resistant Species

- One of the most **unusual features of deinococci** is the **possession of an outer membrane**; unlike other gram-positive bacteria.
- Radiation D values of the nondeinococcal species are 1.0-2.2 kGy, whereas many strains of the deinococci can survive 15 kGy. ***Deinococcus radiophilus*** **(耐輻射奇異球菌) is the most radioresistant species**.




NATURE OF RADIATION RESISTANCE OF MICROORGANISMS

Apparent Mechanisms of Resistance

- Why these organisms are so resistant to radiation is unclear. **The extreme resistance of deinococci to desiccation has been observed** and presumed to be related in some way to radioresistance.

- All radiation resistance species are **highly pigmented** and contain various carotenoids, a fact that suggests some relationship to radiation resistance. However, these pigments have been found to play no role in the resistance of *D. radiophilus*.

NATURE OF RADIATION RESISTANCE OF MICROORGANISMS

Apparent Mechanisms of Resistance

- The **radiolysis of water** leads to the **formation of free radicals and peroxides**, and radiation-sensitive organisms appear to be unable to overcome their deleterious effects.

- **Effective nucleic acid repair mechanisms** appear to be one reason for extreme radioresistance**.** ***D. radiophilus*** has been shown to possess an **efficient excision repair system**.