Food Irradiation

Food Toxicology
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Food Toxicology

Learning Objectives

- Define food irradiation.
- Explore the background of ionizing radiation and its application to food.
- Describe the various food irradiation processes.
- List the benefits of food irradiation.
- List the food safety, food quality, and non-food concerns of food irradiation.
- Explore the consumer opinions of food irradiation.
- Explore the current food uses and future of food irradiation.

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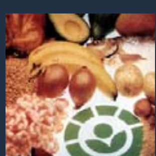
Food Irradiation

- Food irradiation is the exposure of food products to ionizing radiation to destroy microorganisms, insects, and parasites that cause disease and spoilage
- Compare to non-ionizing radiation
  - Cooking - IR
  - Microwave ovens



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Ionizing Radiation

- Ionizing radiation is from X-rays or radioactive decay
  - Alpha particles, beta particles, gamma rays
- Can cause chemicals reactions and alterations of chemicals in tissues
  - Can be toxic or fatal to humans in high dose
- Much of the reactivity in organisms is with water.
- Produces:
  - Superoxide radical ($O_2 \bullet^-$)
    Hydroxyl radical (HO•)
    Hydroperoxyl radical (HOO•)
    and hydrogen peroxide.

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Ionizing Radiation

Manahan

- Recall "oxidative stress" from free radicals
  - Endpoints: lipid peroxidation, DNA strand breaks, enzyme inactivation, covalent binding to nucleic acids, covalent binding to proteins.
- Direct ionization of organic molecules can yield carbonium ions CH_3^+
  - Can alkylate DNA.
- Example: Radon, a noble gas that emits alpha particles
  - Results from the decay of U and Ra in naturally occurring minerals.
  - Accumulates in basements of some homes
    - Presents the most risk of any element to humans.

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Radioactive Decay

- The decrease in the amount of any radioactive material with the passage of time, due to the spontaneous emission from the atomic nuclei of either alpha or beta particles, often accompanied by gamma radiation.

$$^{60}Co \rightarrow {}^{60}Ni + e^- + \nu_e$$

NC-DRP

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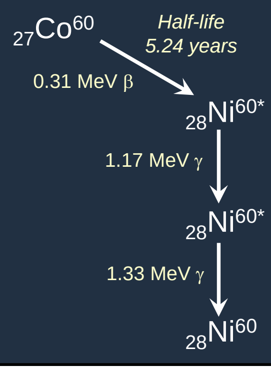
Cobalt-60 Radioactive Decay



Alpha Particle

- A positively charged particle ejected spontaneously from the nuclei of some radioactive elements.
  - Low penetrating power and a short range.
- The most energetic alpha particle will generally fail to penetrate the dead layers of cells covering the skin.
- Alphas are hazardous when an alpha-emitting isotope is inside the body.

Beta Particle

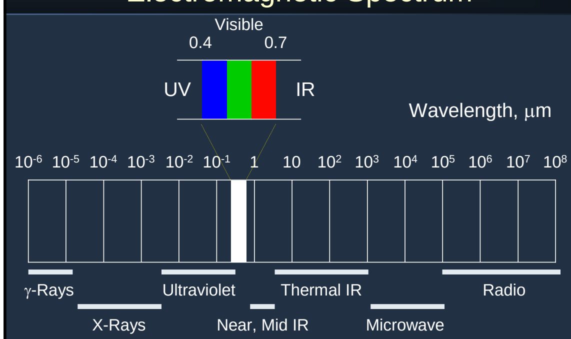
NC-DRP

- A charged particle emitted from a nucleus during radioactive decay.
  - Mass equal to 1/1837 that of a proton.
  - A negatively charged beta particle is identical to an electron; a positively charged beta particle is called a positron.
- Large amounts of beta radiation may cause skin burns, and beta emitters are harmful if they enter the body.
- Beta particles may be stopped by thin sheets of metal or plastic.

Gamma Ray

- High-energy, short wavelength, electromagnetic radiation (photon; a packet of energy) emitted from the nucleus.
  - Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission.
  - Ionizing radiation.
- Gamma rays are very penetrating and are best stopped or shielded by dense materials, such as lead or uranium.
- Gamma rays are similar to X-rays: no mass or charge.

Electromagnetic Spectrum



Measurements of Radiation

- One *gray* (Gy) is the *absorption* of one joule of radiation energy by one kilogram of matter
- 1 Gy = 1 J/kg
  - Gray (Gy) = 100 rads
  - rad is older unit
    - "radiation **a**bsorbed **d**ose".
- Kilogray (kGy) = 1000 Gy

Lethal Doses

- Vegetative bacteria - 0.5-10 kGy
- Bacterial spores - 10-50 kGy
- People and animals - 0.005 - 0.01 kGy
- Insects - 0.1-1.0 kGy

Food Irradiation

- Radiation energy applied to food; does not induce radioactivity
- Uses γ radiation (ionizing radiation from Co^{60} or Cs^{137} decay), X-rays (high energy photon from accelerated e^- colliding with W metal), or accelerated e^- (e^- beams from accelerators)
- Passes through food w/o generating intense heat
- Will disrupt some cellular processes (i.e. DNA)
  - Sprouting, microorganisms, etc.

Historical

- 1895 - X-rays discovered
- 1896 - suggested use in food preservation
- 1903 - process patented by US and France
  - Destruction of *Trichinella* in pork

Rontgen Radiograph

Historical

- Cost and scarcity of radiation sources reduced industry interest
- Adverse sensory attribute were a problem
- Military research continued
  - Stable field rations

Historical

- 1962 - Army research facility in Massachusetts
- Demonstrated meat shelf-life in years w/o refrigeration
- Performed many safety studies
  - Basis for much toxicology data

Historical

- 1958 - FDA ruled irradiation sources as food additives
- Part of Food Additives Amendment
- Delayed commercialization
- Industry lost interest
- Late 1960s - FDA approved irradiation of potatoes (sprout inhibition) and grains (reduce insect infestation)

Historical

- 1965 - Surgeon General announced irradiated foods were safe and wholesome
- NASA adopted for space program
- 1991 - First US commercial irradiation plant
  - Vindicator of Florida, Inc.

Food Irradiation Processes: Categories

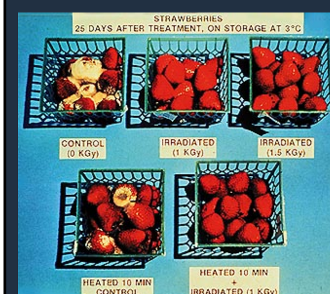
- Rad-urization
- Rad-icidation
- Rad-apperization

- Based on radiation dose

Radiation Processes

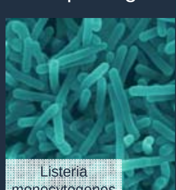
- Radurization: (0.75-2.5 kGy)
- Inhibit sprouting, delay ripening, insect disinfestations and shelf-life extension
- Mimics *pasteurization*

Strawberries, 1 KGy, 25 Days @ 3 ºC



Radiation Processes

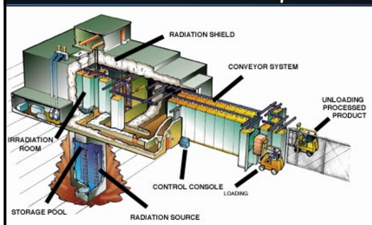
- Radicidation: (2.5-10 kGy)
- Eliminate spoilage microorganisms and non-spore-forming pathogens
- Problem - food will not spoil but still may contain some pathogens



Radiation Processes

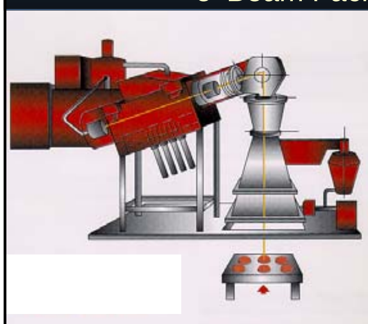
- Radapperization: (10-50 kGy)
- Reduction of microorganisms to the point of sterility
  - 12D process for *C. botulinum* (30-45 kGy)
    - 12 log cycle spore reduction: 99.9999999999%
- Not approved for general use on food
- Diets for immuno-deficient
- Military and NASA operations

$^{60}\mathrm{Co}\ \gamma$ Facility



X-Ray Facility

e^- Beam Facility



Food Irradiation: Benefits

- Reduce foodborne disease
- Reduce food spoilage/increase food supply
- Reduce insect infestations
- Prevent spouting/delay ripening
- Reduce use of fumigants
- Cheaper than freezing and refrigeration

Food Safety Concerns: FDA

- Radiological safety
- Toxicological safety
  - Free radicals, URPs
- Microbiological safety
- Nutritional adequacy

FDA Food Safety Concerns: Radiological Safety

- No concern
- Approved radiation sources too low energy to produce radioactive products

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FDA Food Safety Concerns: Toxicological

- Bureau of Foods, Irradiated Foods Committee
- Reviewed all toxicology data
- No toxicity studies required
  - 1 kGy or below doses
  - Low consumption foods in diet
- Higher doses on case-by-case basis

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FDA Food Safety Concerns: Toxicological

- Irradiation above 1 kGy
- Chemi-generic clearance concept
- Foods of the same class produce similar products when irradiated
  - e.g. carbohydrate solutions (apple juice) and increased malondialdehyde (MDA)
- Toxicity studies from one muscle food could serve as source of data for others
  - e.g. chicken for red meat or fish

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FDA Food Safety Concerns: Free Radicals

- Free radicals also formed by
  - Exposure to sunlight
  - Frying, baking, grinding, drying
- Disappear in most foods within msec
- Fewer changes than cooking
- Toxicity studies show no adverse effects

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FDA Food Safety Concerns

Unique Radiolytic Products - URPs

- Similar compounds occur in all cooked foods at various levels
- Occur at very low levels (ppb)
- All toxicity studies are negative
- Alkyl-cyclobutones may be marker

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FDA Food Safety Concerns: URPs

- FDA makes two assumptions
  - URPs are formed in irradiated food
  - 1-kGy dose = 3 mg URPs/kg food (much higher that actual)
  - Maximum concentration of URPs is then 3 PPM
- Basis for acceptance of irradiated food up to 1-kGy without animal testing

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FDA Food Safety Concerns: Microbiological

- Can irradiation mutate microbes and produce more virulent pathogens?
- Will irradiation reduce spoilage microbes and reduce competition for pathogens?

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FDA Food Safety Concerns: Microbiological

- No evidence of radiation-induced increased virulence
- More evidence for decreased virulence
- FDA requires proof the process reduces target microbes w/o allowing *Clostridium botulinum* growth

FDA Food Safety Concerns: Microbiological

- Major food spoilage bacteria in meat are Gram-negative psychrotrophs that are virtually eliminated by 1 kGy radiation
- Gram-positive spoilage bacteria are quite resistant up to 5 kGy

FDA Food Safety Concerns: Nutritional

- Does irradiation reduce nutritional quality of food?
- Is the food irradiated a significant source of an affected nutrient?

FDA Food Safety Concerns: Nutritional

- No effect on trace elements/minerals
- Proteins, carbohydrates and fats not affected up to 10 kGy
- Macronutrient losses small up to 50 kGy

FDA Food Safety Concerns: Nutritional

- Vitamins are most sensitive
- Very dependent on dose, temperature atmosphere and food type
- Low temperature and no oxygen are best
- Enhanced nutrition in case of water soluble vitamins
- Conclusion = Not likely to have vitamin deficiency from eating irradiated foods

Irradiated Food Safety: WHO

- No adverse toxicological effects on human health
- No increased microbiological risk
- No adverse effects on nutritional status
- Irradiated foods are safe and wholesome at any radiation dose

Food Quality Concerns: Sensory

- Early trials produced undesirable sensory qualities, especially in meat
  - Burnt, metallic, bitter, cheesy, goaty, wet dog-like
- Problems with doses as low as 1.5 kGy
- Higher doses produce more sensory effects

Food Quality Concerns: Sensory

- Radiolytic products cause oxidation of myoglobin and fat in meat
  - Off-odor and off-flavor compounds
- Mostly controlled by irradiating in low temperature, oxygen-free atmosphere

Food Quality Concerns: Sensory

- Some products not suitable for irradiation
- Causes softening in some fruits and changes in aroma and texture
  - Grapefruit, oranges, pears, avocado, cantaloupe, plum
- Dairy products - off-odors

Food Quality Concerns: Packaging

- Irradiation of packaging films can release gases, low MW hydrocarbons and halogenated polymers
- FDA must approve all packaging material
- 21 CFR 179.45

Food Irradiation: Regulation

- 1970 - International Joint Experts Committee on Food Irradiation
  - Irradiation at 10 kGy was safe
- 1970 - FDA approved 1 kGy dose
  - Food treated at 1 kGy had negligible URPs
  - Protected some food spoilage organisms - spoil before toxins developed

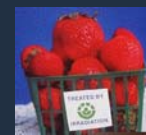
Food Irradiation Regulation: Labeling

- Wholesale – *"Treated by irradiation, do not irradiate again"*
- Retail - *"Treated with irradiation"* or *"Treated by irradiation"* along with international radura symbol
- Other statements permitted about purpose of irradiation and type
- Currently under FDA review
  - "Cold pasteurization" rename?

Food Irradiation Regulation

- 1983 - 30 kGy level approved for spices
  - Because of problems with infestation
  - Comprise < 0.1% of diet
  - Chemical fumigants were banned
  - No other practical way of treatment

Food Irradiation Regulation: Specific Foods



- 1963 - 0.5 kGy - wheat/wheat flour
  - Insects
- 1964 - 0.15 kGy - white potatoes
  - Sprouting
- 1985 - 1 kGy - pork -
  - *Trichinella*
- 1986 - 1 kGy - fresh fruit
  - Ripening delay, infestation

Food Irradiation Regulation: Specific Foods

- 1990 - 3 kGy - poultry
  - Microbial control
- 1995 - 44 kGy - packaged, frozen meat
  - Microbial control, only NASA
- 1997 - 4.5 kGy – frozen, chilled meats
  - Microbial control
- World-wide 50 routinely irradiated foods
  - 36 countries

Food Irradiation:

Consumer Acceptance - 1995

- 72% aware of process
- 82.5% did not know much about it
- 45% would buy
- 19% would not buy
- 36% did not know

Food Irradiation

Consumer Acceptance - 1995

- Most were more worried about food additives, pesticides, animal drugs, hormones, and bacteria
- Willing to pay 0.81 cents/meal more to avoid food borne illness
  - 10X the cost of irradiation
- 92% favor labeling

Food Irradiation Regulation: Problems

- Hard to tell if product is irradiated
- Many of the same changes occur by other methods of preservation
- Cannot assess dose of irradiation

Food Irradiation: Detection

- Chemical
- Physical
- Histological
- Morphological

Food Irradiation: Detection-Chemical

- Lipids and DNA most sensitive
- 2-alkly-cyclobutone from irradiated fatty acids
- 99% detection in 134 samples
- DNA changes show promise
  - Single/dbl strand breaks and crosslinking
  - Harder to tell from other processing effects

Food Irradiation: Detection-Physical

- Detection of membrane damage
- Electrical impedance
  - Potatoes
- Electron spin resonance (ESR)
  - Bone-containing food, shellfish
- Thermal and near-IR analysis spices

Food Irradiation: Detection-Histological

- Viability of seeds in fruit
- Cell structural damage
  - Time consuming; may not be practical
- Ratio of G-positive/G-negative bacteria

Food Irradiation: Detection-Best Candidates

- Lipid foods - hydrocarbons, alkylcylobutones
- Bone-containing - ESR
- Spices - thermoluminescence

- No one technique for all foods

Food Irradiation Concerns: Non-Food Related

- Radiation hazards to workers or public
- Increased risk of nuclear accidents
- Add to nuclear wastes
- Only a use for radioactive wastes
- Radiation resistant microbes
- Effect on environment and ground water

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Food Irradiation Concerns: Non-Food Related

- Radiation hazards to workers
  - Processes are very controlled
  - Only incidents involve violation of safety procedures
  - Safety equated to being electrocuted in plant that uses electricity
- Increased nuclear accidents
  - No effluents
  - Cobalt pencils can be stored on site - 5.3 yr half life
  - No possibility of meltdown - energies too low

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Food Irradiation Concerns: Non-Food Related

- Add to nuclear waste
  - Cobalt pencils are negligible to total nuclear waste (2.68 million cubic ft/yr)
  - Actually would help utilize low level waste not good for medical use
- Radiation resistant microbes
  - Exist in some nuclear plants
  - Not competitive
  - Not very viable
- Groundwater
  - Co^{60} not water soluble

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Food Irradiation: The Future

- Implementing irradiation in meat and poultry processing industries
- Develop suitable packaging
- Develop methods to detect irradiated foods
- Education of public
- Additional research

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