Ionizing radiations

- Electron beam
- X-rays
- Gamma rays

What is irradiation?
- Exposure of a material to ionizing radiation so that a prescribed amount of energy is absorbed
  - Ionizing radiation is all particulate or electromagnetic radiation capable of producing electron pairs when interacts with matter
  - Particulate radiation: Subatomic particles possessing mass (electrons, alpha particles)
  - Electromagnetic radiation: Energy that does not possess mass or electrical charge (X-rays, gamma rays)

Electron beams, X-rays and gamma rays
Definitions

- **Radiation**
  - Transit of energy in the form of high speed particles or electromagnetic waves
  - Physical phenomenon where energy travels across space or matter

- **Radioactivity**
  - Spontaneous transformation of an unstable atom which often results in the emission of radiation

Definitions

- **Ionizing radiation**
  - Radiation with enough energy to, upon interaction with an atom, remove electrons from its orbits
    - This results in the atom becoming electrically charged (ionized)

- **Irradiation**
  - The application of energy or radiation to a specific material
**Compton deviation**

**Radiation units**

- **Rad**
  - Old unit
  - Still in use to some extent
- **Gray (Gy)**
  - Current unit
- 1 Gy = 1 Joule/kg of matter absorbing the energy
- 1 Gy = 100 Rad
- Food irradiation uses doses > 100 Gy
  - For preservation or food safety purposes, usual doses range between 1 – 10 kGy
    - Up to 10 kGy is approved by IAEA as safe
    - 30 kGy for sterilizing spices

**Water radiolysis**

- Most foods subjected to irradiation show a high water content
- H₂O + irradiation → \( \cdot \text{OH} + e^- + \cdot \text{H} + \text{H}_2 + \text{H}_2\text{O}_2 + \text{H}_3\text{O}^+ \)
  - Some of these radiolysis products are highly oxidizing
Effect of oxygen

- Presence of $O_2$ can affect the course of radiolysis:
  - $\cdot H + O_2 \rightarrow \cdot HO_2$ (hydroperoxyl radical)
  - $\cdot HO_2 \rightarrow H^+ + O_2$ (superoxide) $\rightarrow \cdot HO_2$
- Hydroperoxyl radical and superoxide anion are oxidizing agents
  - $\cdot H + O_2 + H^+ \rightarrow H_2O_2 + O_2$
  - $2\cdot HO_2 \rightarrow H_2O_2 + O_2$
- In the absence of $O_2$ these reactions are limited resulting in poor production of $H_2O_2$

Effects of irradiation on microorganisms

Two mechanisms for microbial inactivation

- Primary effect
  - Collision of energy (photons or electrons) with DNA
    - Other structures are damaged too; but DNA is the most important component affected
  - Results in a rupture in the DNA chains
    - One single chain, or the two chains if the position is adequate
- Secondary effect
  - Radiolysis
  - Radiolytic compounds react with DNA
  - Other structures may also be damaged
DNA damage
- DNA rupture can be so extensive that it is not reparable
  - Microorganism cannot reproduce
  - Technically it is destroyed
    - Inactivated
  - A two chain rupture is irreparable
  - If DNA damage is not extensive, a mutation can occur
- Some microorganisms can produce enzymes that restore (repair) the DNA

\[ D_{10} \text{ value} \]
- \( D_{10} \) or \( D \): Dose (kGy) needed to reduce the population of a microorganism by 1 log or 90%
  \[ D_{10} = \frac{d}{\log_{10} N_0 - \log_{10} N_1} \]
- \( d \) = absorbed dose
- \( N_0 \) = Bacterial population before irradiation
- \( N_1 \) = Bacterial population after irradiation

\[ D_{10} \text{-value for E. coli O157:H7 on spinach leaves using high precision dosing for e-beam} \]

\[ y = -4.4827x + 5.7526 \]
\[ R^2 = 0.90634 \]

Neal et al., 2008
Food irradiation

“Food Irradiation is a process that exposes food to a carefully controlled amount of ionizing energy to damage the DNA of parasites, fungi, and bacteria and eventually destroy these organisms.” (IFST, 1999)

Food irradiation in the U.S.

In the United States, ionizing irradiation of food is considered a food additive under current law and thus must be approved by FDA

21 CFR 179

TITLE 21—FOOD AND DRUGS
CHAPTER I—FOOD AND DRUG ADMINISTRATION
DEPARTMENT OF HEALTH AND HUMAN SERVICES
SUBCHAPTER B—FOOD FOR HUMAN CONSUMPTION
(CONTINUED)

PART 179. IRRADIATION IN THE PRODUCTION, PROCESSING AND HANDLING OF FOOD


### Food Commodities Approved for Irradiation under FDA Rule (21 CFR 179.26)

<table>
<thead>
<tr>
<th>Food</th>
<th>Purpose</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pork, non-heated</td>
<td>Control of Trichinella spiralis</td>
<td>0.3 kGy min. to 1 kGy max.</td>
</tr>
<tr>
<td>Fresh foods</td>
<td>Inhibition of ripening and growth</td>
<td>1 kGy max.</td>
</tr>
<tr>
<td>Foods</td>
<td>Anthropic disinfection</td>
<td>1 kGy max.</td>
</tr>
<tr>
<td>Dry or dehydrated</td>
<td>Enzymatic preparations</td>
<td>10 kGy max.</td>
</tr>
<tr>
<td>Spices/seasonings, dry or dehydrated</td>
<td>Microbial disinfection</td>
<td>30 kGy max.</td>
</tr>
<tr>
<td>Fresh and frozen poultry products</td>
<td>Pathogens control</td>
<td>3 kGy max.</td>
</tr>
<tr>
<td>Frozen packed meats (NASA only)</td>
<td>Sterilization</td>
<td>44 kGy min.</td>
</tr>
</tbody>
</table>

### Forms of Ionizing Radiation Used in Food Processing

- **Gamma rays**
  - Generated from isotopes such as $^{60}$Co $\gamma$ $^{137}$Cs
- **X rays**
  - Generated by accelerators operating at energy levels $\leq$ 5 mE
- **Electron beams**
  - Generated by accelerators operating at energy levels $\leq$ 10 mE

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*van Kooij, 1981*
Electromagnetic spectrum

Food irradiation technologies
Gamma rays
Food irradiation technologies

**Gamma rays**

Process area

Food irradiation technologies

**Electron beams**

Electron beam facility at Texas A&M

**LINAC**

**Canon or horn**
Electron beam facility at Texas A&M

Electron beam facility at Texas A&M

Food irradiation technologies

- Producing X-rays
  - Radioactive decomposition
  - Bremsstrahlung (breaking) radiation
- Bremsstrahlung radiation are X rays produced when electrons collide with a high-density material
  - Tungsten, tantalum, gold shield
- When electrons hit the shield:
  - Some are scattered by the nucleus of the metal atoms
  - Electrons lose energy
  - Are converted into X-rays
Food irradiation technologies

X Rays

Target Atom

M. Shaghiboloo
Bremsstrahlung Production 11/06/2015