Irradiation Processing of Foods

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Outline

1. Food Irradiation Technology
2. Current state of food irradiation in US and worldwide
3. Irradiation Basics
   a. Microbial inactivation
   b. Gamma/Electron Beam/X-ray technology
4. Public misconceptions and scare tactics
History of Irradiation Technology

- German physicist W.C. Roentgen discovered X-rays 1895
- French physicist A.H. Becqueral discovered radiation being emitted from uranium
- British Patent issued in 1905 to J. Appleby and A.J. Banks for their invention, “to bring about an improvement in the condition of foodstuffs and their general keeping quality”
- US patent issued to D.C. Gillett in 1918 “for an apparatus to preserving organic materials by use of X-rays.
- 1921 – USDA scientist recommended the use of X-rays to control trichinae in pork
- 1947: pulsed electron accelerator was developed (Capacitron) by A. Brasch and W. Huber, “foodstuff and meat can be sterilized by high-energy electron pulses”
- 1951 B.E. Proctor and S.A. Goldblith reviewed these early studies to lay the foundation for food irradiation
Food Irradiation Technology

• Most extensively studied technology with over 100 years of data
• Approved in over 60 countries
• Used extensively in the US, European Union and Asia
• NOT ONE irradiated food item has been removed from shelves due to consumer complaints
# Foods Currently Permitted to be Irradiated in the US

<table>
<thead>
<tr>
<th>Food</th>
<th>Purpose</th>
<th>Maximum Allowable Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh, non-heated processed pork</td>
<td>Control of <em>Trichinella spiralis</em></td>
<td>0.3 kGy min. to 1 kGy max.</td>
</tr>
<tr>
<td>Fresh foods</td>
<td>Growth and maturation inhibition</td>
<td>1 kGy max.</td>
</tr>
<tr>
<td>Foods</td>
<td>Arthropod disinfection</td>
<td>1 kGy max.</td>
</tr>
<tr>
<td>Dry or dehydrated Enzyme preparations</td>
<td>Microbial disinfection</td>
<td>10 kGy max.</td>
</tr>
<tr>
<td>Dry or dehydrated spices/seasonings</td>
<td>Microbial disinfection</td>
<td>30 kGy max.</td>
</tr>
<tr>
<td>Fresh or frozen, uncooked poultry products</td>
<td>Pathogen control</td>
<td>3 kGy max.</td>
</tr>
<tr>
<td>Refrigerated, uncooked meat products</td>
<td>Pathogen control</td>
<td>4.5 kGy max.</td>
</tr>
<tr>
<td><strong>Frozen uncooked meat products</strong></td>
<td><strong>Pathogen control</strong></td>
<td><strong>7 kGy max.</strong></td>
</tr>
<tr>
<td>Fresh shell eggs</td>
<td>Control of <em>Salmonella</em></td>
<td>3.0 kGy max.</td>
</tr>
<tr>
<td>Seeds for sprouting</td>
<td>Control of microbial pathogens</td>
<td>8.0 kGy max.</td>
</tr>
<tr>
<td>Fresh or frozen molluscan shellfish</td>
<td>Control of <em>Vibrio</em> species and other foodborne pathogens</td>
<td>5.5 kGy max.</td>
</tr>
<tr>
<td>Fresh iceberg lettuce and fresh spinach</td>
<td>Control of food-borne pathogens, and extension of shelf-life</td>
<td>4.0 kGy max.</td>
</tr>
</tbody>
</table>
Commercial Food Irradiation in the US Today

- Approximately **15 million -18 million pounds (8,000 MT)** of frozen and fresh ground beef irradiated annually
  - Primarily to control foodborne pathogens

- Approximately **8 million pounds (4,000 MT)** of produce irradiated annually
  - Primarily for insect disinfestation

- Approximately **175 million pounds (70-80,000 MT)** of spices irradiated annually
  - Primarily to control foodborne pathogens

- Shellfish (oysters) currently being commercially irradiated
  - Primarily to control *Vibrio* spp.

  - Irradiated foods are actually increasing in the US stores (eg groundbeef, spices, mangoes, guavas and shellfish)
## Volume of Foods Irradiated in EU (2011)

### 2.15. Summary for the EU

The following table summarises the quantities of foodstuffs (in tonnes) treated by ionising radiation in approved irradiation facilities within the European Union in 2011:

<table>
<thead>
<tr>
<th>Category of products</th>
<th>BE</th>
<th>CZ</th>
<th>DE</th>
<th>EE</th>
<th>ES</th>
<th>FR</th>
<th>HU</th>
<th>NL</th>
<th>PL</th>
<th>RO</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dehydrated blood</td>
<td>84,1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>84,1</td>
<td>1,04</td>
</tr>
<tr>
<td>Egg white</td>
<td>32,8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>422</td>
<td>0</td>
<td>0</td>
<td>454,8</td>
<td>5,64</td>
</tr>
<tr>
<td>Fish, Shellfish, Shrimps</td>
<td>153,1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>38,5</td>
<td>0</td>
<td>0</td>
<td>191,6</td>
<td>2,37</td>
</tr>
<tr>
<td>Frog legs</td>
<td>3050,9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>510,6</td>
<td>0</td>
<td>352,6</td>
<td>0</td>
<td>0</td>
<td>3914,1</td>
<td>48,52</td>
</tr>
<tr>
<td>Gum arabic</td>
<td>2,1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>69,2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>71,3</td>
<td>0,88</td>
</tr>
<tr>
<td>Herbs and spices</td>
<td>238,1</td>
<td>24,2</td>
<td>152</td>
<td>19,2</td>
<td>307,5</td>
<td>0,6</td>
<td>142</td>
<td>199,6</td>
<td>105,8</td>
<td>20</td>
<td>1208,9</td>
<td>14,98</td>
</tr>
<tr>
<td>Poultry</td>
<td>1378,7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>114,4</td>
<td>0</td>
<td>111,9</td>
<td>0</td>
<td>0</td>
<td>1605,0</td>
<td>19,89</td>
</tr>
<tr>
<td>Rice meal</td>
<td>44,2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>44,2</td>
<td>0,55</td>
</tr>
<tr>
<td>Vegetables</td>
<td>4,8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4,8</td>
<td>0,06</td>
</tr>
<tr>
<td>Dehydrated products</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>446,8</td>
<td>0</td>
<td>0</td>
<td>446,8</td>
<td>5,54</td>
</tr>
<tr>
<td>Other</td>
<td>41,9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>41,9</td>
<td>0,52</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5030,7</td>
<td>24,2</td>
<td>152</td>
<td>19,2</td>
<td>307,5</td>
<td>694,8</td>
<td>142</td>
<td>1571,4</td>
<td>105,8</td>
<td>20</td>
<td>8067,5</td>
<td>100</td>
</tr>
<tr>
<td>% of total</td>
<td>62,36</td>
<td>0,30</td>
<td>1,88</td>
<td>0,24</td>
<td>3,81</td>
<td>8,61</td>
<td>1,76</td>
<td>19,48</td>
<td>1,31</td>
<td>0,25</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>
Harnessing E-Beam and X-Ray Technologies to Clean, Heal, and Feed the World, and beyond...
Non-Ionizing Radiation

• This type of radiation is not energetic enough (does not have enough energy) to ionize atoms and interact with materials

• Examples
  – Radiowaves (Shortwave, FM, UHF, VHF)
  – Microwaves
  – Ultraviolet
Ionizing radiations

- This type of radiation has sufficient energy to remove electrons from atoms or molecules leading to the formation of ions.
Core Technology Options

Ionizing Irradiation

- E-Beam
- X-ray
- Cobalt-60
<table>
<thead>
<tr>
<th>Differences between Gamma &amp; E-Beam Irradiation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gamma Irradiation</strong></td>
</tr>
<tr>
<td>Radioactive isotope is the source</td>
</tr>
<tr>
<td>Gamma rays/photons</td>
</tr>
<tr>
<td>Environmental issues associated with transport, storage and disposal</td>
</tr>
<tr>
<td>Source cannot be switched off</td>
</tr>
<tr>
<td>Slow process (days)</td>
</tr>
<tr>
<td>Highly penetrating</td>
</tr>
<tr>
<td>Dose rate is very slow (1-100 Gy/min)</td>
</tr>
<tr>
<td>Multidirectional irradiation</td>
</tr>
<tr>
<td>Relatively Inexpensive</td>
</tr>
</tbody>
</table>
Gamma Ray radiation

- Cobalt -60, cesium -137 are gamma ray emitters
- photons of electromagnetic radiation
- They have no charge or mass
- Can penetrate deeper into material
Core Technology

- **Isotope based radiation**
  - Gamma radiation eg., cobalt-60 and cesium-137

- **Machine generated (linear accelerators)**
  - Electron Beam (E-Beam) : electrons
  - X-ray: photons
How does Electron Beam Irradiation Work?
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Basic effects of ionizing radiation

• Primary effects
  – Non-specific
  – Can strike any molecule that is in the track of the ionizing radiation
  – No preference to a particular atom or group of atoms
  – Eg. Direct DNA damage

• Secondary effects
  – Are the various reactions of the primary species that result in the ultimate molecular products
  – Indirect DNA damage due to highly reactive entities
Mechanism of Action

• **Indirect Effect**
  - radiolysis of water
  - formation of free radicals
  - toxic oxygen derivatives
  - cell damage from free radicals & toxic oxygen derivatives
Mechanism of Microbial Inactivation

- **Direct Damage (DNA damage)**
  - Single-stranded breaks (SSB)
  - Double-stranded breaks (DSB)

- **Indirect Damage (Indirect Effects)**
  - Free radicals due to ionization of water molecules
  - Protein damage, cell membrane
Types of DNA damage

- Normal ds DNA
- Single strand break (easily repaired)
- Double strand break (can be repaired)
- Directly opposed double strand break (irreparable)
• D-10 is the dose required to achieve 90% reduction of the target numbers.

• Very useful when comparing irradiation resistance between organisms

• $1 \, D_{10} = 90\%$
• $2 \, D_{10} = 99\%$
• $3 \, D_{10} = 99.9\%$
• $4 \, D_{10} = 99.99\%$
• $5 \, D_{10} = 99.999\%$
• $6 \, D_{10} = 99.9999\%$
• $7 \, D_{10} = 99.99999\% \ldots$ and so on
Generic *E. coli* inactivation by E-Beam
<table>
<thead>
<tr>
<th>Product</th>
<th>Temp (°C)</th>
<th>Organism</th>
<th>D10 value (kGy)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey breast meat</td>
<td>5</td>
<td><em>Staphylococcus aureus</em></td>
<td>0.45</td>
<td>Thayer et al., 1995</td>
</tr>
<tr>
<td>Ground turkey</td>
<td>5</td>
<td><em>Campylobacter jejuni</em></td>
<td>0.19</td>
<td>Lambert and Maxcy, 1984</td>
</tr>
<tr>
<td>Ground turkey</td>
<td>30</td>
<td><em>Campylobacter jejuni</em></td>
<td>0.16</td>
<td>Lambert and Maxcy, 1984</td>
</tr>
<tr>
<td>Ground turkey</td>
<td>-30</td>
<td><em>Campylobacter jejuni</em></td>
<td>0.29</td>
<td>Lambert and Maxcy, 1984</td>
</tr>
<tr>
<td>Turkey breast meat</td>
<td>5</td>
<td><em>Salmonella spp.</em></td>
<td>0.71</td>
<td>Thayer et al., 1995</td>
</tr>
<tr>
<td>Poultry (air packed)</td>
<td>0</td>
<td><em>Salmonella heidelberg</em></td>
<td>0.24</td>
<td>Licciardello et al., 1970</td>
</tr>
<tr>
<td>Poultry (vacuum packed)</td>
<td>0</td>
<td><em>Salmonella heidelberg</em></td>
<td>0.39</td>
<td>Licciardello et al., 1970</td>
</tr>
<tr>
<td>Egg powder</td>
<td>5</td>
<td><em>Salmonella enteriditis</em></td>
<td>0.6</td>
<td>Matic et al., 1990</td>
</tr>
</tbody>
</table>
Electron Beam Pasteurization
Harnessing E-Beam and X-Ray Technologies to Clean, Heal, and Feed the World, and beyond...
Irradiated Fruits and Vegetables in US
(8 m lbs total / 6 m by Electronic pasteurization)
Harnessing E-Beam and X-Ray Technologies to Clean, Heal, and Feed the World, and beyond…
Arguments Used Against Food Irradiation

• Formation of radiolytic products
  
  Reality: radiolytic volatile compounds found in irradiated foods such as alkanes, alkenes, ketones and aldehydes are also found in non-irradiated products and are considered safe for human consumption

• Benzene and its derivatives acylcyclobutanones (ACBs)
  
  Reality: normally present at similar or higher levels in a number of non-irradiated foods such as beef, fish and eggs

• Genotoxicity associated with irradiated foods
  
  Reality: No mutagenicity has been observed in studies

Harnessing E-Beam and X-Ray Technologies to Clean, Heal, and Feed the World, and beyond...
Arguments Used Against Food Irradiation (cont’d)

• Nutrient and vitamin losses
  – no loss in macronutrients such as protein, lipid and carbohydrates even in food irradiated above 10 kGy.

• Sensory changes
  – huge body of scientific literature confirming that food irradiation does not cause any significant difference in the flavor, texture or color of beef, poultry or produce when irradiated at optimal levels.

• Consumer Acceptance
  – recent studies are reporting that consumer awareness has increased significantly over the past 10 years
  – if the products are available, consumers purchase the product
  – Studies have shown that if consumers are made aware of the benefits of food irradiation they are willing to pay a premium for the irradiated product
Corporate Responsibilities

- Food irradiation **SHOULD NEVER** be used as a clean-up technology

- Food irradiation **SHOULD ONLY** be used as an integral step of comprehensive GAP, GMP, HACCP plans
  - Not a replacement for current practices

- **Consider food irradiation as the “finishing touch” of a portrait!**
  - Value-adding technology
Applications of eBeam Technology

• Food and food ingredient pasteurization
• Phytosanitary treatment of produce to prevent importation of insects
• Feed sterilization
• Crosslinking polymers
• Decontaminating municipal wastewater and sludges
• Sterilization of medical devices and pharmaceuticals
• Development of vaccines
• Pasteurization of space foods