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# Safety Aspects of Irradiated Food
# Chemical, Radiological Effects

CMC
COOPERATIVE MONITORING CENTER

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# Overview

- Radiation Effects on Food
  - Chemical
- Example: Effects of Irradiation on Harmful Bacteria In Poultry and Meat Products

# Radiation Effects on Food

- **Radiation effects have been observed in all of the major food constituents:**
  - **Carbohydrates, proteins and fat; HOWEVER,**
  - **These effects are so minor that it has taken many years to develop reliable analytical methods for the detection of these effects.**
- **The presentation provides limited details on**
  - **The basic physics and chemistry of determining these effects; and**
  - **Results of some of the studies on effects of radiation on some food components**

# Chemical Effects

- All living matter is composed of elements such as carbon, hydrogen, oxygen, and nitrogen
- Ionizing radiation interaction with any of these atoms could ionize them
- Ionizing radiation could also ionize the molecules
- As ionizing radiation passes through food:
  - Energy is absorbed, absorbed dose
  - Results in the chemical changes in food

# Chemical Effects

## Determining Effects: General Approach

- Steps in Studying the Radiation Effects on Food
  - Understanding Radiation Interaction with Matter and Its Results
  - Determining the Subsequent Chemical Reaction

# Chemical Effects

- **Ionization and/or excitation result in creation of ions**
  - **Ions are "free radicals"**


  - **Free radical are usually highly reactive - chemically**
  - **Compton Scattering of X and Gamma Rays create the most number of free radicals in food**

- **<u>Primary processes</u>, which result in the formation of ions and excited molecules by the passage of radiation through matter, occur in the first <u>$10^{-14}$ s</u> on the timescale for events in radiation chemistry**

# Chemical Effects

- Secondary processes are the various reactions of the primary species that result in ultimate molecular products
  - They are over in approximately $10^{-2}$ s on the timescale of events
- The overall process by which stable end products are produced as a result of irradiation of matter, such as food, is called "radiolysis," and the products thus formed are termed “radiolytic products.”

# Chemical Effects

- An excited molecule (M*) can lose its energy by:
  - Emission of energy as a photon,
  - Internal conversion to heat,
  - Energy transfer to a neighboring molecule, or
  - Via a number of chemical reactions
- Normally, excited species retain their energy for a period of only $10^{-8}$ s and thus do not persist after irradiation.

# Chemical Effects

- An excited molecule can dissociate into two molecules
  - $M^* \longrightarrow M_1 + M_2$; $M_1$ and $M_2$ represent the final products of the irradiation process

OR

  - into two radicals:

$$M^* \longrightarrow \bullet R_1 + \bullet R_2;$$

# Chemical Effects

- If free radicals are formed
  - They may enter into a number of reactions
    - Recombine with each other (radical - radical recombination)

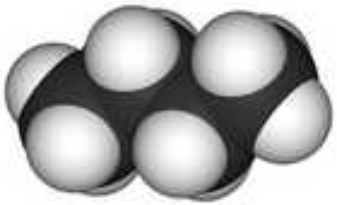
$$\bullet R_1 + \bullet R_2 \longrightarrow M ;$$

- Normally occurs in regions of high radical concentrations such as spurs
- No net effect – on food

# Chemical Effects

- **However, radicals may also combine to form a new molecule, different from M**
  - **Example, ethyl radicals ($\bullet C_2H_5$) formed by dissociation of ethane ($C_2H_6$) could combine with each other (dimerization) to form butane**

$$\bullet C_2H_5 + \bullet C_2H_5 \rightarrow C_4H_{10}$$

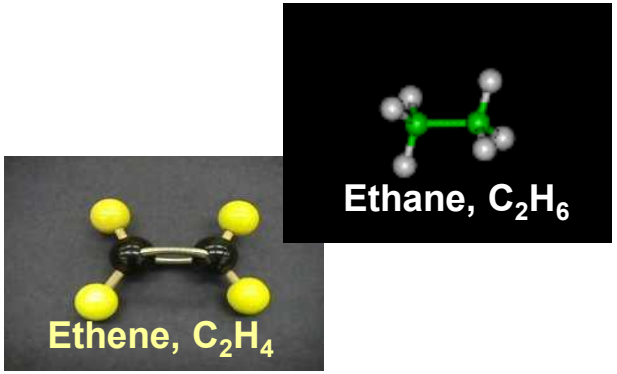


Butane, $C_4H_{10}$

# Chemical Effects

- "Radical-radical disproportionation" reactions can take place, usually with transfer of a hydrogen atom.
  - Example, two ethyl radicals could disproportionate to form ethene and ethane

$$\bullet C_2H_5 + \bullet C_2H_5 \rightarrow C_2H_4 + C_2H_6$$




***Note:*** *It is not necessary for the two radicals to be identical for disproportionation to occur.*

# Chemical Effects

- Free radicals may also react with molecules to abstract a hydrogen atom; this is termed "abstraction"

$$\bullet R + MH \rightarrow \bullet M + RH$$

  - The radicals so formed tend to have a long lifespan and disappear only by radical - radical recombination, radical dissociation, or reaction with radical scavengers.

# Chemical Effects

- "Radical scavengers" have a high affinity for free radicals
  - May react with radicals on almost every collision
- For example, oxygen, which is a diradical (possesses two unpaired electrons), readily reacts with free radicals to form peroxy radicals ($-RO_2$)

$$\bullet R + O_2 \longrightarrow \bullet RO_2$$

- Unsaturated molecules are the most general radical scavengers, since radicals readily add to a double bond.

# Chemical Effects

- **The free radicals produced in food on irradiation have a short lifetime, usually less than $10^{-3}$ s**

- **If food is dried, frozen or contains a hard component such as bone, the free radicals will have limited mobility and consequently a longer lifespan.**
  - This forms the basis of a detection method for irradiated food whereby electron spin resonance (ESR) spectroscopy can be used to detect free radicals in foods containing bone or seeds, with shells attached, or dried foods containing cellulose or crystalline sugars.

# Chemical Effects

- **Free radicals are not exclusive to irradiated Food /material**
  - Can be produced by freeze-drying, cutting, or grinding materials or by heating protein-rich foods
  - Many biochemical reactions, such as those in plant cells and mammalian organisms, proceed via radical mechanisms
- The fate of positive ions generated by incident gamma ray or X ray must eventually be neutralization, and it has been estimated that the time taken for this process in the liquid state is of the order of $10^{-13}$ s.

# Chemical Effects

- **Preceding discussion was an example of how the chemical effects of Irradiation on foods can be studied**

- **This approach has been taken to study chemical effects of radiation on many varieties of foods and their components**

Chemical Effect of Ionizing Radiation on Food Have Been Well Characterized and Understood – No Adverse Chemical Effect of Significance Found

# Water Radiolysis

- **Irradiation of pure water generates a number of highly reactive entities**

$$H_2O \rightarrow \bullet OH(2.7) + e^-_{aq}(2.7) + \bullet H(0.55) + H_2(0.55) + H_2O_2(0.71) + H_3O^+(2.7)$$

where: $\bullet OH$ = hydroxyl radical

$e_{aq}$ = aqueous (solvated or hydrated) electron

$\bullet H$ = hydrogen atom

$H_2$ = hydrogen

$H_2O_2$ = hydrogen peroxide

$H_3O^+$ = solvated (or hydrated) proton

(x.xx) = G values (number of species produced per 100 eV absorbed)

# Water Radiolysis

- Hydroxyl radical (-OH) is a powerful oxidizing agent
- Aqueous electron ($e_{aq}$) and hydrogen atom (●H) are reducing agents
  - Therefore, all foods containing water are likely to undergo both oxidation and reduction reactions during irradiation

# Water Radiolysis

- Hydrogen ($H_2$) and hydrogen peroxide ($H_2O_2$) are the only stable end products of water radiolysis.

- However, as they are largely consumed by the radicals produced on irradiation, as shown below,

$$H_2O_2 + e^-_{aq} \rightarrow \bullet OH + OH^-$$

$$H_2 + \bullet OH \rightarrow H_2O + \bullet H$$

- And they are produced in low yield, even when high irradiation doses are employed.

# Water Radiolysis

- The presence or absence of oxygen ($O_2$) during irradiation can influence the course of radiolysis.
- The hydroperoxyl radical ($\bullet HO_2$) can be formed as a result of the reduction of oxygen by hydrogen atoms:

$$\bullet H + O_2 \rightarrow \bullet HO_2$$

- The superoxide anion radical can also be formed by the reaction of aqueous electrons with oxygen:

$$e_{aq} + O_2 \rightarrow \bullet O^-_2$$

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# Water Radiolysis

- The presence of oxygen ($O_2$) during irradiation can result in the development of rancid off-flavors.
  - By irradiating under anaerobic conditions, off-flavors and odors can thus be minimized.

# Water Radiolysis

## *Effect of Temperature*

- **In a frozen food the reactive intermediates of water radiolysis are trapped, and hence, not free to interact with each other or with other food components**
  - **Under such conditions free radicals can persist for relatively long periods. Therefore,**
- **Freezing can protect food components against the effects of ionizing irradiation.**

# Water Radiolysis

## Dose / Dose Rate Effects

- The yield of a particular radiolysis product will generally increase linearly with increasing irradiation dose
- At low doses, the amount of each product increases but the nature of the products formed does not change
- At elevated doses, however, yields of some products with high reactivity will be sufficient to participate in competitive reactions
  - As a result, their yields will remain constant and the quantities of resulting secondary products will increase linearly with increasing dose

# Water Radiolysis

## Dose / Dose Rate Effects

- In general, dose rate (the energy absorbed per unit time) does not have a critical effect on the irradiation of food
  - Except for very high dose rates
  - At high dose rates, the end products are formed in concentrations that allow recombination reactions to occur in preference to reactions with other entities,
    - Reducing the amount of indirect effects

# Water Radiolysis

## Effects of Radiation Type

- **Amount of radiolytic products formed during irradiation is independent of the type of ionizing radiation utilized**
  - **provided radiation penetrates equally to all parts of the food –** recall the range of different types of radiation in matter

# Intermission