Food Irradiation Using Electron Beams and X-Rays

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Questions

- What is Food Irradiation?
- Is it Safe?
- Why is it Effective?
- How is it Done?
- What are Important Applications?
- Will it become an Important Food Processing Technique?

What is Food Irradiation?

Definition: The use of ionizing radiation (electrons, x-rays, gamma rays) to decrease the population of, or prevent the growth of, undesirable biological organisms in food.

Radiation Sources:

Radioactive Isotopes (Cobalt-60)
Electron Accelerators (electron beams and x-rays)

Comparison:

1 million curies of Co60 = 15kW (e-beam)
= 185kW (x-rays)

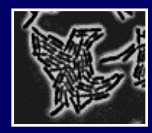
We already buy many irradiated products

- Spices
- Band-Aids
- Pet Treats
- Cosmetics
- Baby Bottles
- Computer Chips
- Feminine Products
- Baby Diapers
- Wound Care
- 50% of all medical devices
- Food Products

Principle Applications of Food Irradiation

- **Enhanced Food Safety**
  eliminate harmful food-borne bacteria (e-coli, salmonella, listeria) (typically 1-2 kGy)
  - **US CDC estimates are**
    - **5,000 deaths**
    - **325,000 hospitalizations**
    - **76 million cases of illness**
- **Disinfestation to kill fruit flies and other pests (typically < 0.5 kGy)**
  - **Eliminate need for chemical fumigation**
- **Reduced food spoilage to extend shelf-life (0.5-10 kGy)**
- **Inhibit sprouting, etc. (0.1-1 kGy)**
- **Sterilization (>42.7 kGy)**
  - **Patients with compromised immune systems; NASA astronauts**

Listeria



E. Coli

Salmonella

Foods Currently Approved for Irradiation in the USA

Product	Approval Date	Max. Dose (kGy)
Wheat & wheat flour	1963	0.50
Dry enzyme preps	1985	10.0
Pork	1985	1.0
Fruits & Vegetables	1986	1.0
Spices & dry seasonings	1986	30.0
Poultry	1992	3.0
Red Meat (fresh/frozen)	2000	4.5/7.0
Shell eggs	2000	3.0
Seeds for sprouting	2000	8.0
Animal Feed & Pet Treats	2001	50.0

Petitions Under Review by FDA/USDA

- **Processed Foods**
  - Submitted by NFPA in Aug. 1999
  - Hot dogs, deli meats, RTE meat, processed fruits & vegetables, fruit juices
- **Molluscan shellfish**
  - Submitted by NFI in Oct. 1999
- **Crustaceans**
  - Submitted by NFI in Feb. 2001

International Approvals

- 42 countries have issued approvals
- 140 foods have been approved by at least one country
- Conflicts of dose or food descriptions among countries
- Harmonization is progressing by region
- Doses vary greatly by region and country

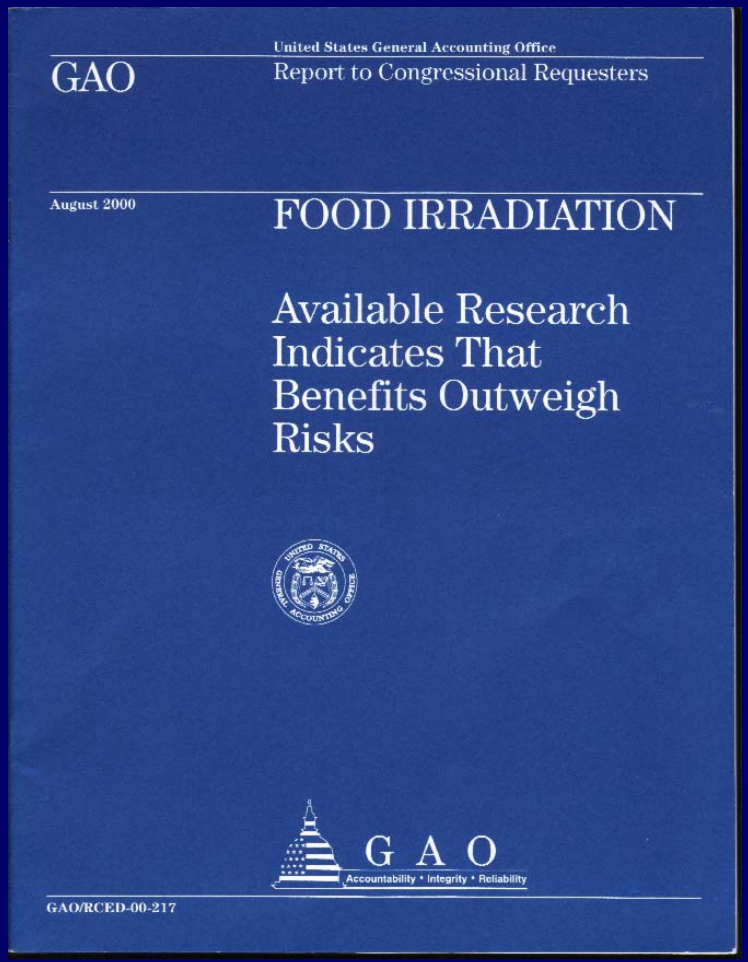
Label Regulations

- Labeling

  - Retail
    - Radura, plus “Treated with / by Irradiation” – (Irradiated for food safety)
    - Claims: Reduced, Eliminated, or Free (OK if substantiated)
    - If treated product used as an ingredient, identify in Ingredient Statement

  - Foodservice
    - On case to establishment
    - No requirement to inform consumer

Is Irradiated Food Safe?



- Induced radioactivity is of no concern, provided:

  $E_e < 10MeV; E_x < 5$ MeV
- Compounds formed by irradiating food are essentially the same as those produced by other preservation methods (i.e., cooking)
- "The Study Group concluded that food irradiated to any dose appropriate to achieve the technological objective is both safe to consume and nutritionally adequate." - WHO TR 890, 1999
- No evidence exists that pathogenic bacteria become more virulent when irradiated
- "there is no other known means to kill deadly bacteria such as E. Coli 0157 H:7 in raw ground beef" - USDA

Support for Irradiation Technology

Prominent health and medical organizations support the use of irradiation technology

American Medical Association

AMERICAN DIETETIC ASSOCIATION

NFPA
The Food Safety People

CDC
Centers for Disease Control and Prevention

mayo

FDA

AUSTRALIAN FOOD AND GROCERY COUNCIL

USDA UNITED STATES DEPARTMENT OF AGRICULTURE

WHO OMS
WORLD HEALTH ORGANIZATION - ORGANISATION MONDIALE DE LA SANTÉ

FOOD AND AGRICULTURE ORGANIZATION of THE UNITED NATIONS

AMI
AMERICAN MEAT INSTITUTE

Two Supporting Points of View

- **"An overwhelming body of scientific evidence demonstrates that irradiation does not harm the nutritional value of food, nor does it make the food unsafe to eat. … Food irradiation is a logical next step to reducing the burden of foodborne disease in the United States." (US Centers for Disease Control)**

- **"Food irradiation is possibly the most significant contribution to public health to be made by food science and technology since the pasteurization of milk." (World Health Organization's Food Safety Unit)**

Opposing Viewpoint (Organic Consumers Association)

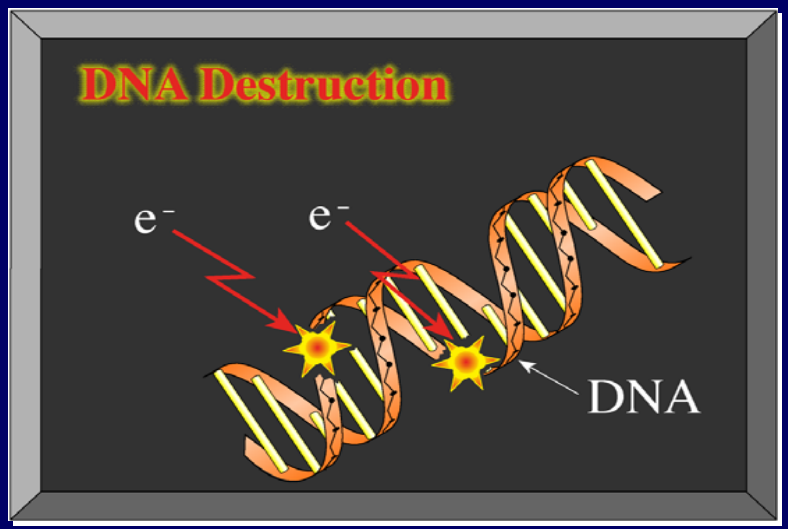
- **Irradiation damages the quality of food.**
- **Science has not proved that a long-term diet of irradiated foods is safe for human health.**
- **Irradiation covers up problems that the meat and poultry industry should solve.**
- **Irradiation doesn't provide clean food.**
- **Irradiation using radioactive materials is an environmental hazard.**
- **Electron-beam irradiation today means nuclear irradiation tomorrow.**

What does organically grown mean? Where do the plants get their nutrients?

Effects of Ionizing Radiation on Micro-organisms

Effects are stated in terms of the absorbed "dose"

- **Dose = Energy absorbed per unit mass**
- **Dose is typically measured in kiloGray**
  - **1 kGy = 1 kJ/kg**
  - **Temp. rise is 0.25 ^{o}C.**



Number of interactions per molecule depends on molecular size

$$N_m = 10^{-7}\, G M_w D(kGy)$$

G = "G-Value" – number of events per 100 eV
M = molecular weight
= 180 for glucose; 10^9 for DNA!

Ionizing radiation preferentially disrupts DNA because of its enormous size.

(Much smaller food constituent molecules are largely unaffected.)

Effects on Food Constituents

- **Carbohydrates**
  - Weakening of large structural molecules (cellulose) at high doses (>10 kGy)
- **Lipids (fats and triglycerides)**
  - Oxidation of fats can lead to off-odors (>3-5 kGy)
- **Proteins**
  - Weakening of structural proteins at high doses (>10 kGy)
  - Denaturation at high doses (> 10 kGy)
- **Vitamins**
  - 20% loss of thiamine at 3 kGy

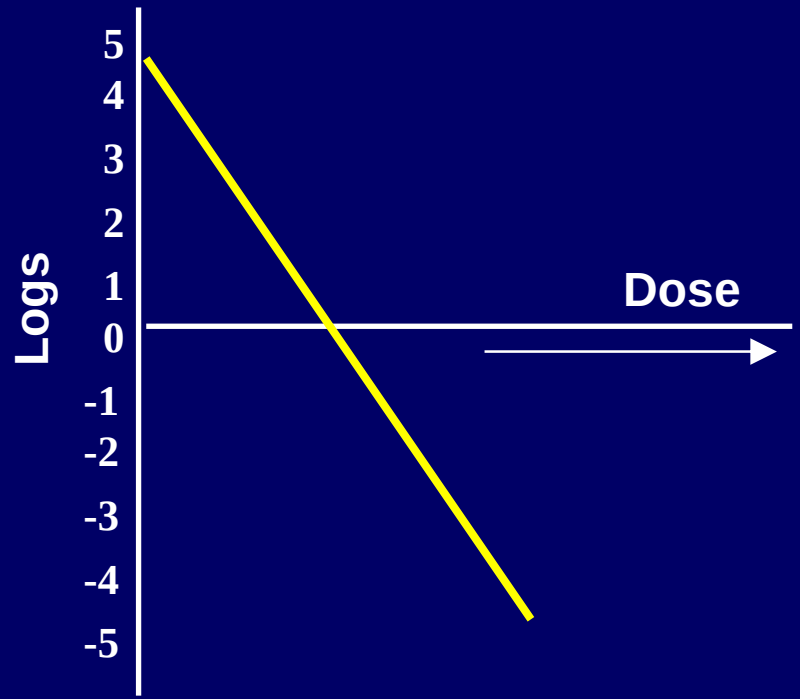
➢ **Far less impact than most other food processing techniques (cooking, pasteurization, freezing, dehydration, etc.)**

Establishing Target Dose Values

- **Effects of ionizing radiation are characterized by absorbed dose.**
  - **1 kGy = 1 kJ/kg**

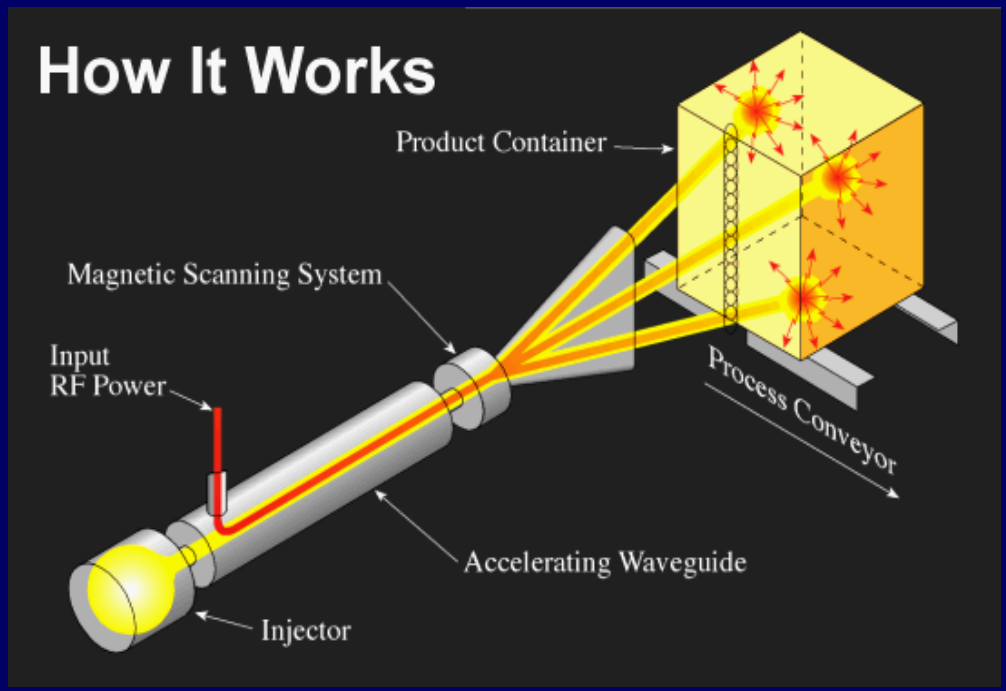
- **D-value = The dose required to achieve a 1 order of magnitude reduction in the microbial population. (Established by scientific testing.)**
  - E.Coli 0157:H7, Salmonella, Listeria ≈ 0.25 – 0.70 kGy

- Typical food safety doses = 5 log reduction (99.999%) = 1.25 kGy minimum required dose for e.coli



Electron-Beam / X-Ray Technology

The primary goal is to deliver the minimum required dose to all parts of the product. There are three essential pieces of technology:



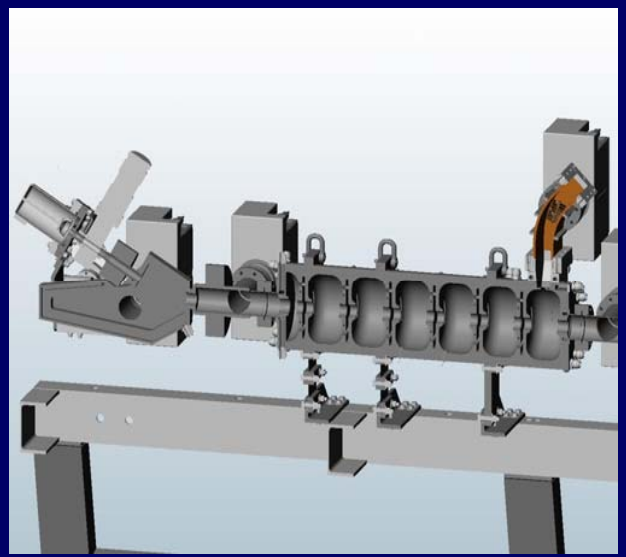
- A high-energy electron beam is generated by the accelerator system
- The beam is uniformly swept across the product using a magnetic beam scanner
- A thin exit window (Ti) is used for direct electron irradiation; x-rays are generated with a high-Z converter
- Product is passed through the scanned beam in a highly controlled manner by the material handling system

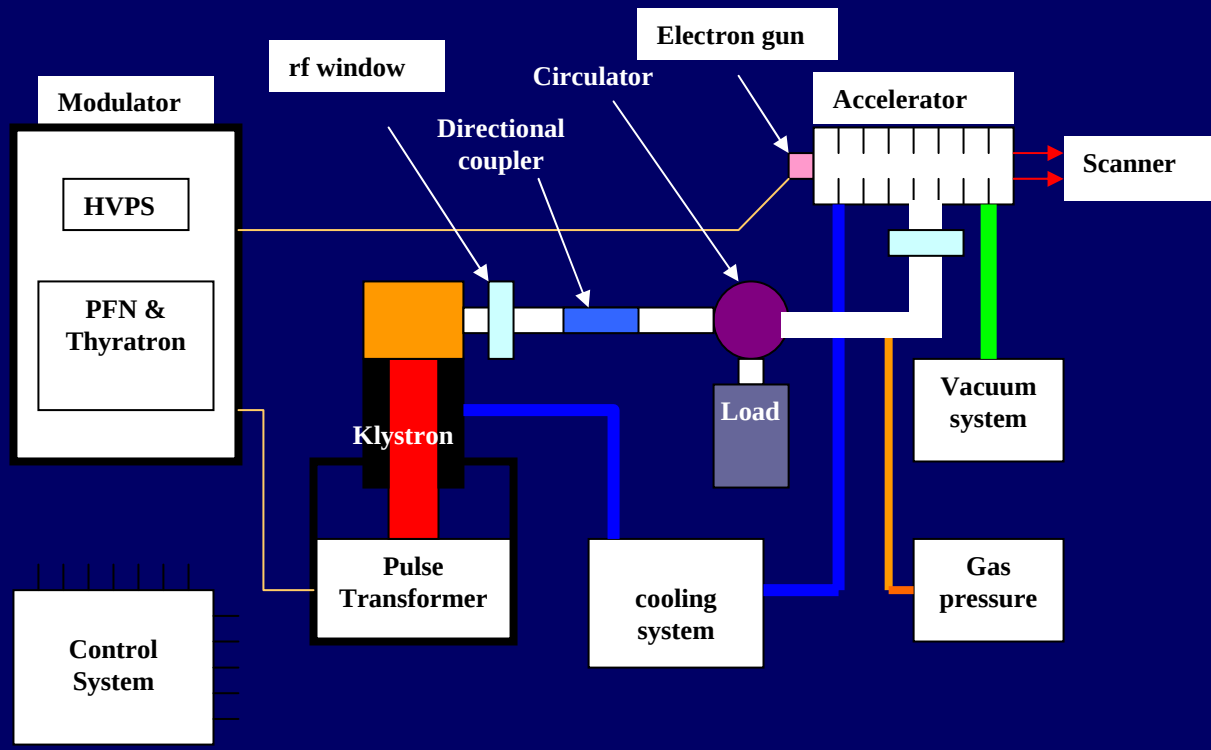
Kinetic Energy Considerations

- To avoid food activation, the electron kinetic energy is limited to 10 MeV for electron beam processing, and 5 MeV for x-ray processing.
- For electron beams, penetration depth scales linearly with kinetic energy.
- For x-rays, the generation efficiency scales linearly with kinetic energy. (8% @ 5 MeV)
- (Usually) operate at the maximum permissable energy.
- (Usually) implies a microwave accelerator.

Accelerator System Key Components

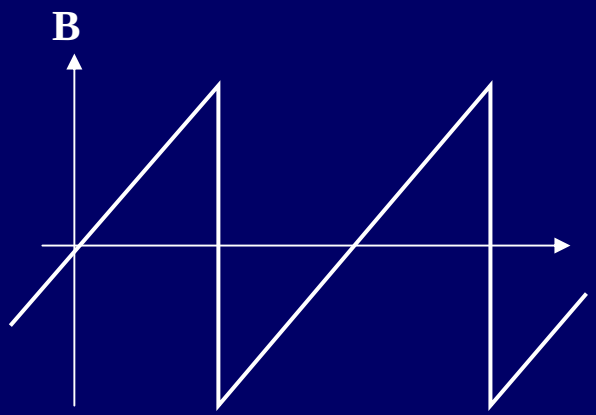
High-Power (SB5/150) Linac

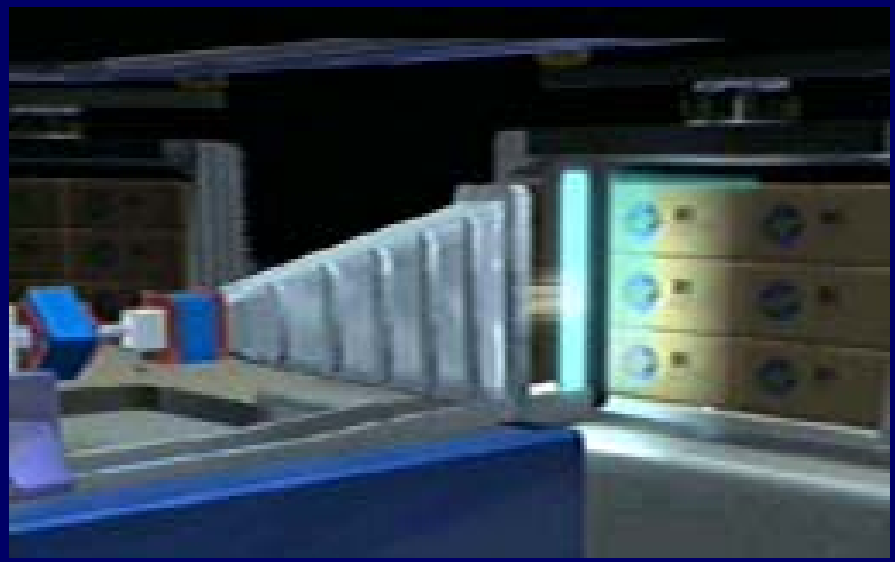




Beam Scanning System

- **Beam is “uniformly” scanned over the product using magnetic deflection.**



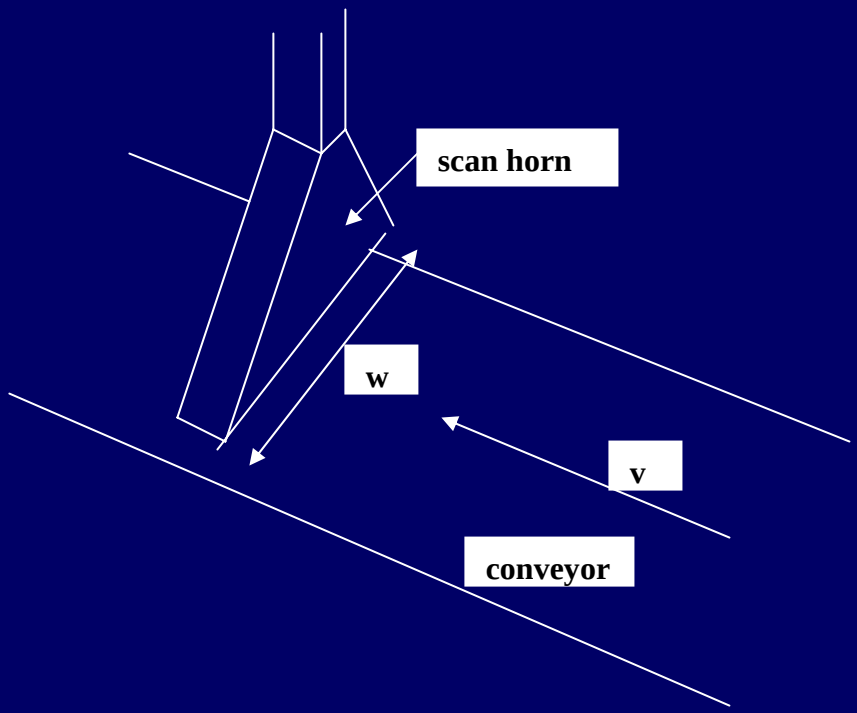


Material Handling System Description

- MH system moves product at a constant rate through the irradiation zone with minimal space between product carriers or packages.
- There can be three conveyor elements in the MH system
  - High speed feed conveyor (flexible loading and unloading)
  - Closing conveyor (minimizes space between product carriers)
  - Process conveyor (moves product carriers through the irradiation zone at a precise rate)
- The product flow is monitored and controlled by a process control system.

Front Surface Dose

- **Dose is the key parameter that links the accelerator system, the scanner and the conveyor system.**



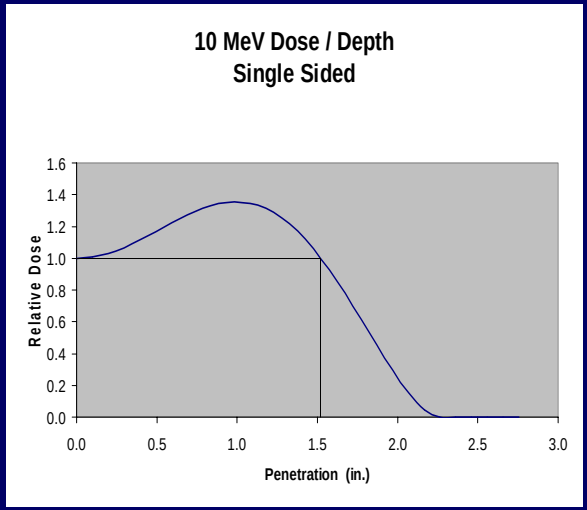
Electrons (10 MeV):

$$D_{fs} = 1.8 \times 10^{6}\ I(A) / [v(cm/s)w(cm)]$$

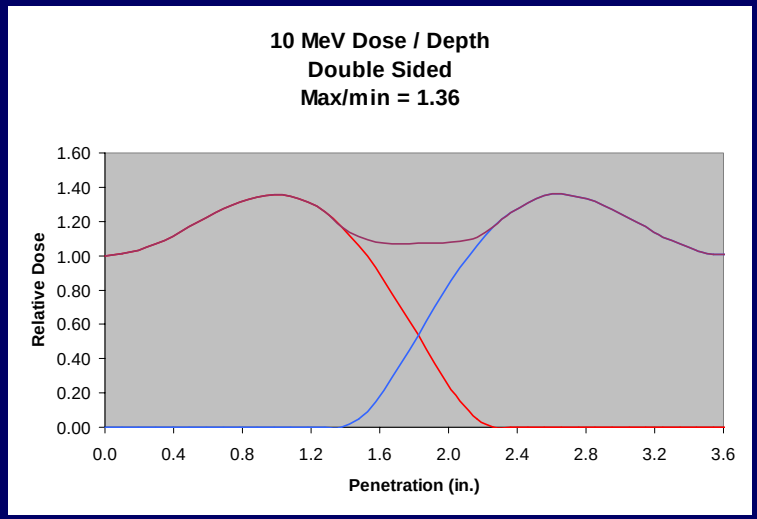
X-Rays (5 MeV):

$$D_{fs} = \{3.4\ P(kW) / [vw]\}\ e^{-0.012 z_c(cm)}$$

Depth-Dose Distributions

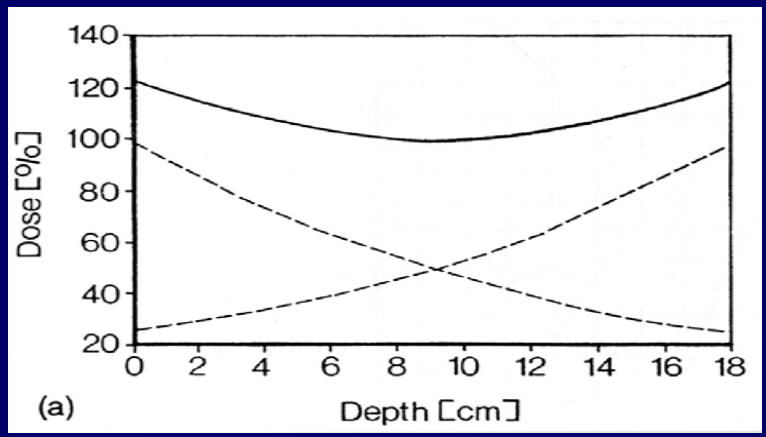


Single-Sided E-Beam Irradiation at 1.0 gm/cc Density



Double-Sided E-Beam Irradiation at 1.0 gm/cc Density

- If the areal density (density multiplied by thickness) exceeds 8.5 g/cm^2 , must use x-rays (> 20 g/cm^2).



Double-Sided X-Ray Irradiation at 1.0 gm/cc Density

Product Throughput Rate Estimates

- **Processing rate (mass per unit time)**
  = effective rate of energy absorption (power) divided by the required dose.

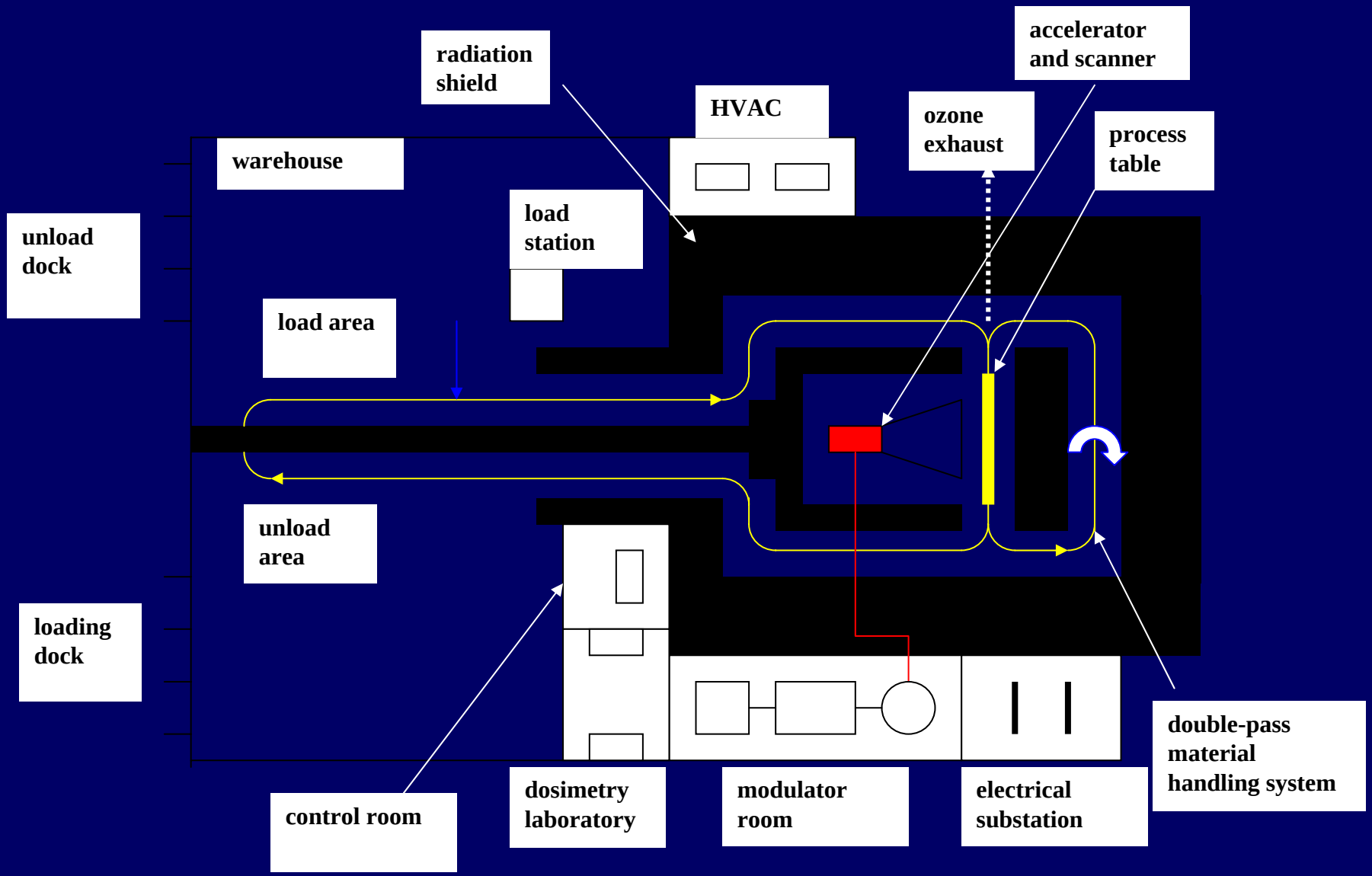
$$dM/dt\ (kg/s) = \eta \times P(kW) / D(kGy)$$

η **(efficiency) = 0.5 (e-beam, 10 MeV)**
= 0.03 (x-ray, 5 MeV))

- **Example 1: P = 15 kW e-beam, D = 1.5 kGy (ground beef)**
  dM/dt = 5 kg/s = 40,000 lbs/hr!

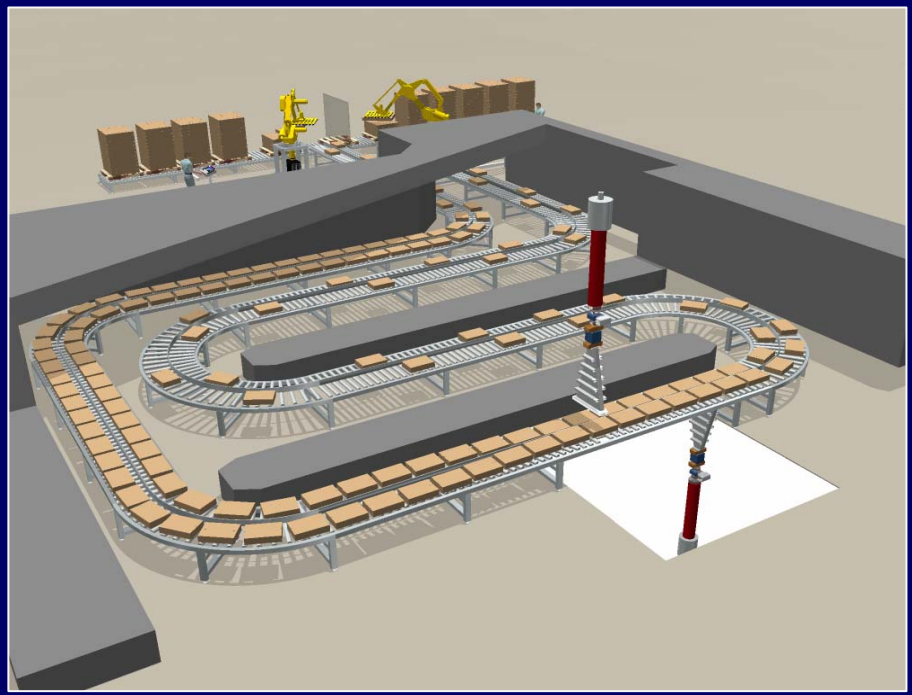
- **Example 2: P = 150 kW x-ray, D = 5 kGy (spices)**
  dM/dt = 0.9 kg/s = 7000 lbs/hr

Food Processing Facility Overview



E-Beam and X-Ray System Configurations

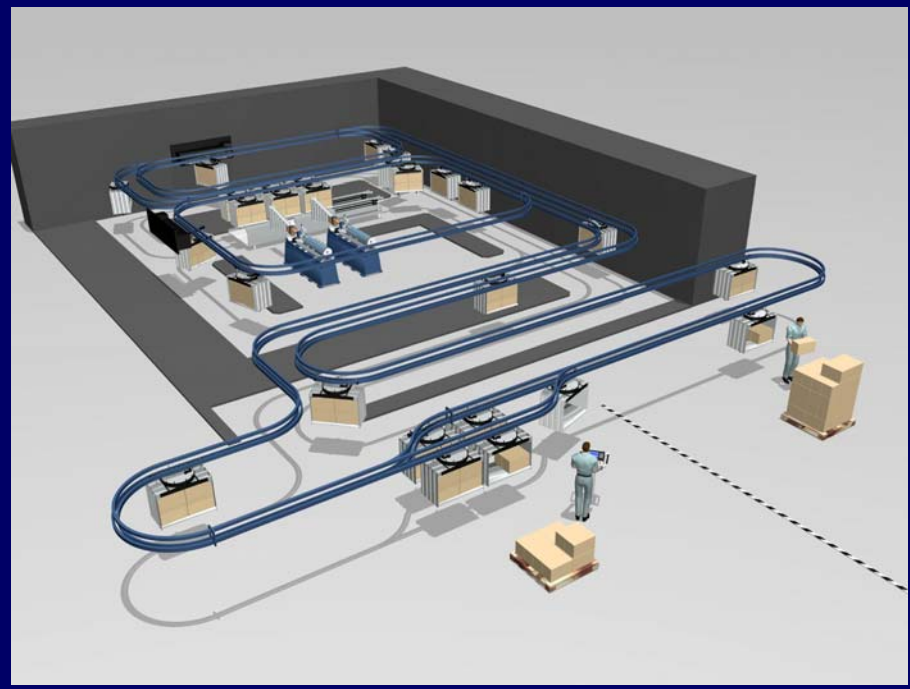
E-Beam



Vertical Beams;

Roller Conveyor

X-Ray



Horizontal Beams;

O/H P&F;

Roller w/ Translation

Electronic Food Irradiation Facilities

Location	Accelerators (KE/P)	Material Handling	Throughput (lbs/hr)	Application
Sioux City	10/15 (x2-u/d) 5/15	Roller 2-p w/ transl.	60,000@2kGy 1500@2kGy	Food Safety
Hawaii	5/15	O/H P&F 2-p w/rot	6000@0.5 kGy	Disinfest.
Viet Nam	5/150	O/H P&F (x) 2-p w/rot	6000@5kGy	Food Safety
Los Angeles	10/15 (x2-u/d) 5/15 (x2)	Roller (e) O/H P&F (x) 2-&4-p w/rot	60,000@2kGy 1200@5kGy	Food Safety
Texas A&M	10/15 (x2-u/d) 5/15	Roller 2-p w/ transl.	-	Research

Costs/Pricing

- Capital investment is significant
  - Accelerator systems in range of $1-2M
  - Total facility costs in range of $5-10M
  - Amortization of capital investment is usually the largest yearly cost item. (Dwarfs cost of electricity.)
- Breakeven processing price is usually in the range of $0.01 – 0.10 per pound.

What Does The Future Hold?

- Market Size
- Consumer Acceptance
- Government Regulations
- Impediments to Industry Growth
  - Anti-nuclear lobby (isotopes)
  - Equipment reliability (machine sources)
  - Large Food Producers/Users
  - Cost/Pricing

Estimated Market Size

Estimated Worldwide Food Production Volume (millions of pounds)

Product	US	International	Total
Ground Beef	9,000	10,000	19,000
Poultry	35,000	100,000	135,000
Processed Meats	25,000	N/A	25,000
Seafood	12,000	250,000	262,000
Fruits/Vegetables	65,000	1,300,000	1,365,000
Total	146,000	1,660,000	1,806,000

Business opportunity depends on "public acceptance."

Modest adoption of food irradiation could require significant capital investment.

Some of the implied opportunities will not represent good business ventures.

Opinions on Irradiated Foods

- Awareness is high but understanding is low
- Informed consumers are more accepting
- Purchase intent is relatively high
- Meat & poultry seen as the likeliest candidates for irradiation
- Consumers are turning to the government for broader use of irradiation for food safety

Product Acceptance

- Consumers cannot differentiate between irradiated and non-irradiated foods
- Strong evidence of commercial success where irradiated foods are available in restaurants

Government/Regulatory Factors

- **FSIS considers e.coli O157:H7 to be an adulterant – no organisms permitted!**
- **“there is no other known means to kill deadly bacteria such as E. Coli 0157 H:7 in raw ground beef” – USDA**
  - **Irradiation of fresh ground beef is not mandated.**
- **Seafood and Ready-to-Eat petitions are languishing – their approval is not a high priority**
- **Congress is sensitive to letter-writing campaigns of the “anti-nuclear” lobby**
- **Irradiation is still considered a food “additive,”, instead of a process.**

Waiting on government regulations to spur industry growth is a losing strategy.

Who is the Preferred Customer for Food Irradiation Services?

- **Large producers/users are not so interested.**
  - **Irradiation will not increase their market share**
  - **They can handle recalls and lawsuits**
  - **Irradiation disrupts their traditional ways of doing business.**
- **Passive resistance**
  - **studies**
- **Active resistance**
  - **High surcharges to consumers because food is "safer"**

Suggested Path Forward

- **Technology**
  - Get costs under control
  - Improve processing efficiency
  - Improve machine reliability
- **Marketing**
  - Concentrate on markets in which irradiation provides an economic incentive
  - Quarantine treatment opens new markets
  - Extended shelflife allows longer shipping times, and access to new markets
  - Strong, active support of the Ready-to-Eat petition.

For Further Questions or Discussion

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