Pros and Cons of Commercial Irradiation of Fresh Iceberg Lettuce and Fresh Spinach: A Literature Review

Introduction

On August 22, 2008, FDA published a final rule for the safe use of ionizing radiation (also termed irradiation, irradiation pasteurization, cold pasteurization) of fresh iceberg lettuce and fresh spinach for control of foodborne pathogens, and extension of shelf-life. A few weeks later, the US Government Accountability Office (GAO) released a report entitled, “Improvements Needed in FDA Oversight of Fresh Produce.” This report states that FDA’s intervention efforts for reducing the risk of contamination during the processing of fresh-cut produce have been limited. Interestingly, the GAO reviewers only briefly mention irradiation, and brought little context to the implications of introducing irradiation as a potential control (“kill”) step during produce processing.

In 2008, serious outbreaks of *E. coli* O157:H7 continued to be documented and linked to fresh lettuce despite major efforts by the industry to instigate science-based good agricultural practices (Table).. Since 1995, the FDA has documented at least 22 other *E. coli* O157:H7 outbreaks traced to leafy greens likely contaminated before retail distribution, including a number of outbreaks involving fresh iceberg lettuce and spinach. Clearly, there is a need for improved methods to prevent contamination of produce before it reaches the consumer.

Most food safety experts would agree that there is no silver bullet (defined by Webster’s dictionary as “a magical weapon ; especially : one that instantly solves a long-standing problem”) to guarantee protection of any food from contamination. The use of comprehensive “farm-to-table” approaches is well accepted as the best way to combat the complex problems in food safety.

Where does irradiation of food fit into this evolving continuum including the new rule in the United States for lettuce and spinach?

Irradiation is probably the most studied, and the most controversial, food processing method in history. Several years ago, two renowned food safety leaders, Drs. Robert Tauxe (2001) and Michael Osterholm (2004), published elegant summaries describing the role of irradiation in food safety and protecting the public health. They did not promote irradiation as a silver bullet, but their commentaries suggested the process is one tool in the toolbox, and may be a silver lining (defined as “a hopeful side of an otherwise desperate or unhappy situation”) in the burgeoning problem of foodborne disease.

I. Historical Perspective and Definitions

Irradiation as a processing method for food is not a new technique. Indeed, research into using ionizing radiation to improve food quality and shelf-life began in the late 1800’s. In 1905, scientists received the first patents for application of ionizing
radiation as a food preservation process to kill bacteria. In the 1940’s, the term “irradiation” was first used in the literature, but some have since questioned using this language to describe the technology. Molins (2001a), an expert in the field of radiation, characterized the term as: “a most unfortunate occurrence because it brought a direct and conceptually misleading association of a food processing technique with the nuclear establishment.” He suggested use of the word “irradiation” was inappropriate because “it does not describe the actual process of applying ionizing radiation in ways that would set it apart from other processes used in the food industry. Thus, microwaves and infrared light – both of which generate heat – are also forms of radiation, and their use in cooking, heating foods in a microwave oven, or simply keeping the food warm under infrared light – as is customary in many restaurants – could just as properly be termed “food irradiation.”

Fifty years ago, the FDA defined food irradiation as a “food additive” in the Food, Drug, and Cosmetic Act. Tauxe (2001) made this comment on the classification in his review paper: “By an historical quirk, the use of irradiation on food was formally approved as though it were something added to food, rather than a process to which the food is subjected.”

Regardless of the potential pros and cons of food irradiation, poor terminology is a disservice to the scientific community, industry, and the public; furthermore, the “mystery” surrounding food irradiation has potentially lead to unnecessary controversy and miscommunication. Before beginning this review into the potential advantages and limitation of food irradiation, it seems critical to review some definitions and basic chemistry behind the process.

**How does food irradiation work?**

Food irradiation is based on the principle of using energy to ionize a material, in this case food. Ionizing irradiation treatment involves chemical reactions with microbes, but these reactions are not dissimilar to chemical reactions induced by cooking, canning, curing, drying, freezing, or other food processing techniques. There are pros and cons to every food processing technique. In food irradiation, high speed particles or rays are harnessed by a machine. The particles used for this purpose are common in nature, and part of the energy that comes from the sun. These particles are focused in the process to penetrate the food, and result in the creation of free radicals that damage the DNA of organisms, especially microbial contaminants at the doses used for food. Depending on the organism and irradiation dose, this process is capable of enhancing food safety and quality of the food (the nature of this process as it applies to food safety and comparison with other food processing methods such as cooking, and effects on food quality such as nutrients, are described in subsequent parts of this review).

**There are 3 sources of ionizing radiation approved in the context of food processing:**
1. Gamma rays
2. X-rays
3. Electronic beams (E-beams)

Only gamma rays require the use of radioactive material (Cobalt 60), but the levels required are too low for creation of “radioactivity” in the food or packaging. Thus, the food or packaging are not radioactive. In contrast, X-ray and electronic beam applications do not involve the use of radioactive material. For example, with E-beam technology, electricity is the source for generating electrons that damage DNA of certain microbes that contaminate food. Photons are generated by gamma and x-ray technology, and these methods provide deeper penetration into the food compared with E-beam, but the difference in penetration is not significant in the context of fresh lettuce and spinach. None of these methods for food irradiation create neutrons, the particles associated with nuclear technologies.

The “dose” applied to the food is an important consideration in understanding the chemistry of food irradiation. There are three general categories for irradiation dose in food processing. The dose of ionizing radiation is measured in units called gray.

1. Low (< 1kGy) is used mostly to kill insects that infest foods
2. Medium (1-10 kGy) is used primarily to reduce pathogens and prolong shelf-life of foods
3. High (>10 kGy) is used to reduce organisms resistant to low-medium doses, or to sterilize food

FDA currently permits food irradiation in the “medium” dose range to control pathogens (primarily bacteria and parasites) for the following foods:

• Fresh, non-heated processed pork
• Fresh or frozen, uncooked poultry products
• Refrigerated and frozen, uncooked meat products
• Fresh shell eggs
• Seeds for sprouting
• Fresh or frozen molluscan shellfish
• Fresh iceberg lettuce and spinach

The susceptibility of organisms to different doses of irradiation varies based on the biology of the organism. Damage is greatest in more complex organisms that may be a problem in food. The required dose to reduce or eliminate pests, pathogens, or spoilage organisms is generally in decreasing order as follows:

Insects < parasites < molds/yeasts < vegetative (non-spore forming) bacteria < spore forming bacteria < viruses < prions

II. Food Safety: The Problem of Foodborne Pathogens in Fresh Lettuce and Spinach
Before embracing a potentially expensive and controversial new control method in processing such as irradiation, it is imperative to consider the scope of the problem being addressed. Consumer confidence in the safety of fresh fruits and vegetables has been shaken in recent years due to high-profile and sometimes deadly outbreaks linked to produce contaminated with foodborne pathogens. Experts in nutrition agree unanimously that fresh produce is an important component of a healthy diet; therefore, production of safe produce free of harmful pathogens is critical.

Outbreaks associated with fresh leafy green vegetables including iceberg lettuce and spinach are increasing. Herman (2008) presented data at the International Conference on Emerging Infectious Diseases showing a 9% increase in consumption of leafy green vegetables from 1996-2005, compared with a 38.6% increase in leafy green-associated outbreaks during the same time period. These results suggest that the proportion of foodborne disease outbreaks due to leafy greens cannot be explained by increases in consumption alone. Unfortunately, there is evidence that consumers may be at risk from produce that is contaminated prior to purchase, and recommendations to “wash” their fruits and vegetables before consumption may not always be adequate to prevent foodborne illness. In a study of E. coli O157:H7 outbreaks from 1982-2002, the authors estimated that half of the produce-associated outbreaks were due to produce already contaminated with E. coli O157 before purchase by the retail store or consumer (Rangel et al, 2005).

Examples of foodborne disease outbreaks and recent recalls linked to salad greens are shown in the Table below. The table includes only outbreaks/recalls believed to be due to contamination before the produce reached the retail level (e.g., grocery store, restaurant, kitchen). The fact that lettuce, spinach and other raw or minimally-processed produce can be contaminated with foodborne pathogens on the farm, or during harvest, transportation, or processing is a daunting problem for public health and industry. The risk is increased because fresh lettuce, and often spinach, is not subjected to a “kill” step such as cooking prior to consumption. Other unique challenges with microbial contamination of lettuce and spinach have been documented in the literature.

- The purpose of sanitizers used to wash leafy greens (for example, chlorine solutions) is to eliminate microbial contamination of the wash water, not the plant leaves. Many studies have shown the limitations of routine protocols for chemical washing of lettuce and other leafy greens in reducing pathogen levels. The low infectious dose (very few bacteria) of pathogens such as E. coli O157:H7, other STECs, and Shigella increase the threat.
- Researchers have found that plant lesions (such as those caused by harvesting and processing, including “fresh-cut” processing) can promote the rapid multiplication of E. coli O157:H7 (Brandl, 2008)
- Bacteria may internalize into the plant tissue and be protected from chemical sanitizers. Giron from the University of Arizona described preliminary results from high-resolution electron microscopy showing E. coli O157 internalized within the “stomata” of spinach leaves, and the bacteria were not destroyed by chlorine wash solutions.
Could any of these outbreaks or recalls have been prevented by use of irradiation as a control step during processing in the US and other countries?

An analysis by Tauxe (2001) suggests that the answer to this question would be “yes.” He analyzed the potential benefit of irradiated meat and poultry and estimated that 900,000 cases of infection, 8,500 hospitalizations, over 6,000 catastrophic illnesses, and 350 deaths could have been prevented each year. A similar analysis of the potential impact of irradiation in preventing illnesses due to contamination of lettuce, spinach, and other leafy greens would be interesting. Nine of the outbreaks and 1 recall (Table) were from contaminated fresh iceberg lettuce or spinach. Additionally, several outbreaks involved institutional settings such as hospitals, children’s camp, and nursing homes, which serve populations that are especially vulnerable to severe illness or death from foodborne pathogens.

Notably, the pathogens most commonly implicated in leafy green-related outbreaks and recalls are bacteria and parasites; these organisms are also the most susceptible to control using medium (1-10 kGy) dosage of irradiation. For example, research indicates that *Campylobacter*, *Cyclospora*, *E. coli* O157/STECs, *Listeria*, *Salmonella*, and *Shigella* are reduced by 3-5 logs. Additionally, raw or “minimally processed” fresh-cut, pre-washed leafy greens have unique risks that irradiation as a control step could potentially address. Specifically, an advantage of irradiation is its ability to penetrate the leaf tissue and reach bacteria internalized in the lettuce or spinach tissue. For example, Niemira (2007) showed that “ionizing radiation but not chemical sanitizers effectively reduced viable *E. coli* O157:H7 cells internalized in leafy green vegetables.”

The irradiation dose (up to 4 kGy) approved by FDA is not meant to sterilize (kill all living organisms) iceberg lettuce or spinach. Thus, irradiation is not a replacement for good agricultural practices and management practices on the farm and during harvest, transportation, and processing. Use of irradiation also does not prevent post-processing contamination during transport or by the retailer or consumer during food preparation and handling. Murano summarizes the issue in her chapter on microbiology of irradiated foods:

“Irradiation, however, should not be used to make “dirty” products (those heavily contaminated with microorganisms) clean again. To attempt to do so would require doses much higher than those needed to eliminate normal background levels. This would result in significant damage to the quality of the product, and in high costs to the processor in terms of energy.”

Additionally, at the approved dose for iceberg lettuce and spinach, irradiation may not effectively reduce viruses (e.g., norovirus, hepatitis A), spore forming bacteria such as *Clostridium botulinum*, and it does not eliminate toxins. However, it is worth noting that these causes of foodborne illness and intoxication are rarely linked to fresh lettuce and spinach. All forms of food processing including ionizing radiation may introduce “resistance” into the microbial pathogen. Likewise, processing techniques may lead to
mutations in bacteria. There is a theoretical risk of irradiation-induced mutations leading to increased virulence in a bacterial population, but no evidence of this phenomenon with food irradiation could be found in the literature.

**Food Irradiation and Toxicology**

Considerable debate about the safety of irradiated food products in terms of potential “side effects” has ensued since the inception of this technology. The primary concerns raised include: 1) potential for “radioactivity” of the food or packaging, and 2) production of toxic elements or “unique radiolytic products” in the food or packaging that may have long-term health consequences for consumers such as cancer or reproductive problems.

An extensive review of the literature revealed no significant health risks for consumers at the irradiation doses approved for food processing. Indeed, the research by preeminent scientists in the fields of physics, biology, nutrition, and medicine overwhelmingly provide data that refutes concerns about food irradiation leading to long-term negative health outcomes. Additionally, respected public health organizations worldwide have reviewed the data, and every major group has stated that food irradiation is a potential tool to protect the public health. In addition to FDA, these groups include but are not limited to: American Academy of Pediatrics, American Dietetics Association, American Medical Association, Centers for Disease Control and Prevention, and the World Health Organization.

Given the massive amount of work by experts already dedicated to addressing the two questions above, only a brief summary and selected citations are provided in this review.

First, it is physically impossible to create radioactivity in food or packaging at the approved energy created by food irradiation dosages using gamma ray technology; as discussed in the previous part of this series, gamma rays are the only food irradiation technique that require a radioactive substance (Cobalt 60). X-ray and electronic beam (E-beam) technology do not use radioactive substances, and therefore cannot create “radioactivity” in food or packaging.

The second concern about potential toxic substances created by irradiation, and subsequent effects on human health, has been the subject of intense research for four decades. A few preliminary studies suggested possible risks that prompted more research; the original findings could not be reproduced in later studies, which lead experts to conclude that food irradiation is safe.

One substance is worth mentioning as it is the only chemical described as a potential “unique radiolytic product” in food following irradiation: 2-alkylcyclobutanones (2-ACBs). Scientific evidence indicates that 2-ACBs do not pose a health risk for consumers. The substance is created by a chemical reaction with lipids (fats), and most research has focused on food with fat content (e.g., meat, poultry). Since iceberg lettuce
and spinach contain virtually no fat content, 2-ACBs are not relevant in the discussion of food safety and use of irradiation to reduce foodborne pathogens.

In summary, food irradiation is not a “silver bullet” for food safety. However, the increasing problem of illnesses and deaths associated with consumption of fresh produce, including lettuce and spinach, emphasizes the need for an intervention. It is critical that scientists, policy makers, industry, and the public consider carefully the implications of this technology, and its potential role in food safety.

III. Ionizing Radiation as a Food Preservation Technique

Irradiation is one of many food preservation techniques. As discussed previously, food irradiation is not new, but the application of this technology to fresh lettuce and spinach was only recently approved in the US. Before delving into the details of food quality in the context of food irradiation, it is worthwhile to consider the historical perspective of food preservation, and how food irradiation fits into this picture.

The quality of any fresh food deteriorates after harvest, in part, due to the action of spoilage organisms (e.g., bacteria, fungi). Spoilage leads to loss of nutrients and negative effects on the flavor and appearance of fresh food over time. The negative effects of deterioration could be avoided if consumers were able to prepare and eat foods almost immediately after the food leaves the farm. But, for most consumers this scenario is not practical on a year-around basis. The search for efficient and effective methods to preserve the safety, quality, and nutritional value of perishable foods during transportation and storage, while simultaneously maintaining the benefits of the original fresh product, has been an ongoing challenge across the ages of civilization.

The earliest examples of food preservation include cooking/boiling, cold storage (refrigeration/freezing), drying, and salting. To this day, these traditional methods remain a cornerstone in the prevention of food spoilage and waste, worldwide. Examples of more recent historical developments in food preservation include pasteurization and canning.

In the modern age, the food processing industry has addressed the unique food preservation challenges associated with fresh produce by introducing novel approaches such as the use of modified atmosphere packaging (MAP) and wash water disinfectants, especially for fresh-cut, minimally processed produce. Temperature control (refrigeration) continues to be the most important approach to preserving the quality and safety of fresh produce. Irradiation of fresh lettuce and spinach represents a new tool in the produce preservation toolbox. The following are examples of current approaches to achieve food quality preservation of fresh produce that may be used individually, or in combination, depending on the specific product.

- Refrigeration
- Freezing (spinach)
- Heat treatment – cooking and canning (spinach)
- Wash water sanitizers (e.g., sodium hypochlorite, hydrogen peroxide, chlorine dioxide,
ozonated water, etc.)
• Modified atmosphere packaging (MAP), a procedure that packages fresh-cut lettuce/spinach in high CO2 and low O2 to control spoilage organisms
• Ionizing radiation

Irradiation and the Fresh-Cut Produce Industry

It is worth noting that many of the produce-related papers in this review address “fresh-cut” fruits and vegetables. Fresh-cut (also termed “minimally processed” or “value-added”) is defined as ready-to-eat, raw fruits and vegetables that have been peeled, chopped, shredded, or similarly processed. Fresh-cut leafy greens are usually pre-washed with a disinfectant (e.g., chlorine) and are packaged, sometimes in a modified atmosphere (reduced oxygen) to preserve the food quality. The packages range from individual containers that consumers purchase at the grocery store to institutional size packages sold to restaurants, hospitals, correctional facilities, and other facilities that serve large populations. Fresh-cut is differentiated from raw commodities such as whole lettuce heads and mature bunch spinach.

Application of Ionizing Radiation to Control Spoilage Organisms: The Shelf Test

Most retailers and consumers have experienced the disappointment of discarding spoiled fresh lettuce and spinach that was not sold or consumed, respectively, before the “use by” date. The “shelf-life,” defined as the length of time a product can be stored without becoming unsuitable for consumption, is relatively short for fresh produce (for example, 10-14 days for fresh spinach), which can lead to food waste. Plant bacterial and fungal pathogens are a major cause of lettuce and spinach spoilage during storage. Spoilage results in off-odors, “slimy” or “rotten” textures, and leaf deterioration. Because fresh-cut lettuce and spinach processing, in particular, introduces plant wounds/lesions, these products may be more vulnerable to microbial growth of spoilage organisms. The most important spoilage problems and species involved for lettuce and spinach include:

• Bacterial soft rot: *Erwinia, Pseudomonas*
• Watery soft rot: *Sclerotinia* (fungal)
• Gray mold rot: *Botrytis cinerea* (fungal)

Similar to foodborne pathogen reduction, the approved dosages for irradiation of lettuce and spinach significantly reduce spoilage bacterial levels (3-5 logs), and the process thereby extends shelf-life. The mechanism for control by irradiation is the same for spoilage organisms and foodborne pathogens. Thus, a major advantage to using ionizing irradiation as a microbial control step is its simultaneous impact on reducing food spoilage organisms and foodborne pathogens. However, the effectiveness of irradiation in controlling both plant and human pathogens depends on the initial quality of the iceberg lettuce or spinach coming from the field and processing plant prior to irradiation. As discussed previously, irradiation is not a replacement for good agricultural practices and good manufacturing processes; furthermore, irradiation does not “sterilize” the lettuce/spinach, and eventually the product will spoil. Everyone across the food chain,
including the consumer, must still take precautions to prevent spoilage through proper handling, especially temperature control (refrigeration).

**Effect of Ionizing Radiation on Nutrient Content: The Popeye Test**

Popeye the Sailor is the iconic symbol of the benefits of eating spinach. The cartoon legend purportedly gains his superhero strength from iron in canned spinach. Indeed, there is no doubt that spinach (fresh, frozen, or canned) is highly nutritious, and the Reference Daily Intake (RDI) value for spinach is classified as “good” for iron (and calcium, fiber). Spinach is also considered an “excellent” source of vitamins A, C, K, and folate. In contrast, iceberg lettuce is only an “excellent” source of vitamin K.

Every food processing technique is subjected to intense scrutiny by nutritionists in the academic and regulatory world to determine the positive and negative effects on nutrient content. Food irradiation is no different, and there is an abundant amount of studies in the scientific literature describing the effect of ionizing radiation on nutrient quality of specific foods under specific conditions.

Prior to analyzing the results of these studies for any food, it is critical to consider two general key questions:

1) Is the nutrient sensitive to ionizing irradiation in the food product?
2) If so, how important is the food product as a source of the nutrient(s) in the overall diet?

Nutrients are divided into two broad categories: macronutrients (carbohydrates, protein/essential amino acids, fats/lipids, water) and micronutrients (vitamins and minerals). Notably, water is the largest component of iceberg lettuce (96%) and spinach (92%). Lettuce and spinach are not major contributors to macronutrients (carbohydrate, fat/lipid, protein) in the diet, and are therefore not significant in the nutritional evaluation of irradiation effects. Likewise, irradiation does not significantly impact minerals (including Popeye’s iron).

Vitamins are divided into two groups based on their solubility in water. The water soluble vitamins are more sensitive to destruction by irradiation. Specifically, radiation can break bonds in some vitamin molecules causing inactivation. Also, irradiation produces free radicals that can combine with antioxidant vitamins and cause the vitamin to lose its activity. Below is a summary of the impacts of ionizing radiation on the four important vitamins in fresh spinach and/or lettuce.

- **Vitamin A** (pro-vitamin carotenoids): this fat soluble vitamin is relatively resistant to radiation. An older study by Richardson (1961) found no significant loss at doses up to 14 times (56 kGy) the maximum approved FDA dose (4 kGy) for spinach. Evaluation of carrots, an important source of this vitamin, also showed minimal effects from radiation on this nutrient.
- **Vitamin C** (ascorbic acid): this water soluble vitamin is sensitive to irradiation and may
undergo a reaction to produce dehydroascorbic acid; however, the reaction is reversible. Fan and Sokorai (2008) compared irradiated and non-irradiated fresh-cut iceberg lettuce and spinach and found the loss of vitamin C was similar in both groups; they concluded that most vitamin C loss related to deterioration over time during storage.

- **Vitamin K:** this fat-soluble vitamin is particularly resistant to radiation and studies have found no significant losses following medium-dose treatment.

- **Folate:** this water-soluble vitamin has some sensitivity to radiation. Muller (1996) documented a 10% loss at 2.5 kGy. Similar to vitamin C, the folate losses in spinach appear to be much more significant from storage time compared with radiation.

Overall, the vitamin losses following medium-dose irradiation of fresh iceberg lettuce and spinach are relatively insignificant, especially compared with losses due to storage time and temperature abuse. As perspective, researchers from Pennsylvania State University published a study in 2004 showing more than 50% of the folate and carotenoid (vitamin A) content of spinach was lost after 8 days of storage at refrigeration temperatures, and after only 4 days with temperature abuse.

**Sensory Evaluations: The Taste Test**

“Sensory science” is a field of “psychophysics.” It is the scientific study of the senses and psychological responses to stimuli, for example: taste/flavor, appearance/color, texture, and aroma/odor of food. Although consumers will differ in opinion when evaluating these subjective qualities of food, sensory science utilizes trained “panelists” and statistical analyses to quantify the sensory attributes. Additionally, qualities such as texture and color can be measured using objective criteria such as electrolyte loss (associated with “sogginess”) and chlorophyll loss (color changes) in lettuce and spinach leaves under different conditions.

Fan and his research team at the USDA ARS Eastern Regional Research Center have been on the forefront of irradiation research of fresh-cut produce and food quality. In 2002, Fan and Sokorai documented a dose-response for ionizing radiation of fresh-cut iceberg lettuce in MAP; higher radiation doses (> 2 kGy) correlated with increased sogginess. A subsequent study (2003) showed that the combination of warm water treatment and MAP could reduce the negative effects of radiation on iceberg lettuce appearance and texture. Zhang et al (2006) found a similar dose response: “experimental results showed that the number of aerobic mesophilic bacteria on fresh-cut lettuce irradiated with 1.0 kGy was reduced by 2.35 logs and sensory quality was maintained best during storage for 8 days at 4°C.” Increasing the dose to 1.5 kGy resulted in a 3 log reduction in spoilage bacteria, but also caused some damage to leaf tissue appearance.

In 2008, Fan and Sokorai describe the results of a comprehensive study of food quality effects of irradiation on 13 fresh-cut vegetables including iceberg lettuce packaged in air, iceberg lettuce in MAP, and spinach in MAP. Based on previous studies, they chose a dose of 1 kGy, and compared quality characteristics over 14 days of storage in two groups: irradiated vegetables and non-irradiated/control vegetables. They found:
• No significant differences in texture between the irradiated and control groups for iceberg lettuce and spinach during 14 days of storage.
• No significant differences in appearance for irradiated or control group spinach during 14 day storage.
• Irradiated iceberg lettuce packaged in air showed irradiation-induced enzymatic browning during storage compared with the control group
• Irradiated iceberg lettuce packaged in MAP had a better appearance score than the control group, which suggests that MAP may be an approach to mitigate the irradiation browning effect for iceberg lettuce.
• Irradiated iceberg lettuce had an off-odor due to the packaging material used in the study

Notably, there were few studies in the literature comparing different packaging materials, styles (e.g., bag, clam shell), and sizes (individual, institutional) specific for fresh iceberg lettuce and spinach. This research will be needed to fully evaluate the effects of radiation on food quality, and optimize the dose for commercial processing of fresh iceberg lettuce and spinach.

In summary, the food quality literature relating to irradiation of fresh iceberg lettuce and spinach suggests that the process has the following pros and cons with regard to food quality:

**Food Quality: The Pros (Limitations) of Food Irradiation for Fresh Lettuce and Spinach**

• Reduction of spoilage microorganisms, which may translate into increased shelf-life and less food waste
• Minor to no significant loss of important nutrients in lettuce and spinach, especially compared with nutrient loss following other common food preservation techniques (e.g., boiling and freezing) and losses during storage
• At the low-end of the approved dose range for fresh lettuce and spinach (1 kGy), there was limited to no detectable problems with sensory qualities (appearance, taste, texture, and aroma)

**Food Quality: The Cons (Limitations) of Food Irradiation for Fresh Lettuce and Spinach**

**Cons**

• In general, as the dose increases, the log reduction of susceptible spoilage organisms (and foodborne pathogens) also increases, but the increased dose (especially over 2 kGy) may have negative effects on nutrients and sensory attributes
• Some packaging material may not be appropriate (or FDA approved) for irradiation processing as shown in a recent study (Fan and Sokorai, 2008) where the packaging material caused “off-odors” in fresh-cut iceberg lettuce
Taken together, the food safety and food quality literature review shows that the pros can be balanced against the cons of ionizing radiation with optimization of the process. In other words, the technology is not “one size fits all,” and each type of product and packaging material must be evaluated to identify conditions that both promote food safety and preserve food quality. The experts frequently recommend a “hurdle approach” that employs a combination of treatments designed to minimize the radiation dose while maximizing the positive effects on microbial control and food quality.

IV. Consumer Confidence and Acceptance

Two major and intertwined challenges might limit or delay the application of this processing method in the marketplace for fresh iceberg lettuce and spinach despite FDA’s approval: 1) consumer acceptance of the technology and 2) costs to the leafy green industry to implement the process. Given the gravity of the situation with outbreaks from fresh iceberg lettuce and spinach in recent years, it is imperative to examine carefully these challenges, and potential solutions including food irradiation.

Fresh-cut (minimally processed) produce has grown to a $15 billion dollar per year industry in North America, and salad greens comprise a significant portion of that market, including iceberg lettuce and spinach (Palumbo et al, 2006). Likewise, a disproportionate number of the produce-related foodborne disease outbreaks have been linked to contaminated fresh-cut lettuce and spinach (Table). As a result, consumer confidence in this market has been shaken, which severely hurts the US economy, as well as the consumers who enjoy these products as fresh, healthy, and nutritious food sources.

For example, a survey conducted by the Food Marketing Institute of the US Grocery Shopper trends (2007) found that “safety concerns prompted 38 percent of consumers to stop purchasing certain foods in the past 12 months — up from 9 percent in 2006. Among those who stopped buying products, the items most often mentioned were spinach (71 percent), lettuce (16 percent), bagged salad (9 percent) and beef (8 percent). The survey was conducted in January 2007, when the outbreak linked to spinach was still in the news and illnesses associated with other foods were starting to make headlines.”

Based on these findings, one may ask: does food irradiation represent an opportunity to improve consumer confidence in the safety of fresh iceberg lettuce and spinach?

The answer would appear to be a resounding, “yes,” given the strong scientific evidence that irradiation is an effective and safe approach to reduce the levels of the most important foodborne pathogens in combination with other approaches such as GAPs and HACCP, as discussed in the earlier parts of this series. NASA has been irradiating astronauts' food successfully since the 1970s, but acceptance and availability of the technology for approved foods such as ground beef and poultry in the civilian market place has been limited despite the benefits recognized by the scientific and medical communities. A review of consumer surveys provides insight into some of the complex
reasons that this technology has not been widely adapted in the US and other parts of the world.

**Historical perspective on consumer acceptance of food irradiation**

Prior to FDA’s new rule for fresh iceberg lettuce and spinach, food irradiation at similar medium-level doses was approved in the US for numerous applications including control of foodborne pathogens in other fresh and processed foods. A large body of literature exists on the issue of consumer acceptance of food irradiation, especially for beef and poultry products. Notably, many of these consumer surveys took place 10-20 years ago, and similar studies on perceptions relating to the use of ionizing irradiation in fresh lettuce and spinach processing have not appeared in the literature as of the time of writing this review.

Dr. Christine Bruhn at the University of California, Davis published many of the pioneering studies on consumer acceptance, and recently made this comment about consumer acceptance of food irradiation in a series on the new FDA rule published by Jim Prevor’s Perishable Pundit (2008):

“My work and that of other researchers over the last 20 years has found some people are ready to buy irradiated product right now....This group of consumers represents maybe 10 percent of the population. At the other side of the spectrum, 10 percent of consumers are appalled by irradiation. They believe it makes the product less safe and less nutritious and wouldn’t touch it with a 10-foot pole. The majority of the population is in the middle. They don’t know very much about irradiation, or how it would benefit them.”

Clearly, the target audience for education (pros and cons) about food irradiation and FDA’s new rule concerning fresh iceberg lettuce and spinach, should be the 80 percent “in the middle.”

DeRuiter and Dwyer (2002) published a review article on consumer acceptance of irradiated food. Although slightly older, Sapp (1995) also provides an excellent review of the literature on consumer acceptance in the book, “Food Irradiation: A Sourcebook.” Some research highlights and selected original papers from these reviews and other sources are summarized below.

- Most consumers know little about food irradiation (American Meat Institute, 1993; Bruhn, 2001)
- A survey conducted at FoodNet sites in 1998-1999, indicated that the primary reason consumers would not buy irradiated foods (meat, poultry) was due to insufficient information about the risks and benefits; the survey also showed 50% of those asked were willing to buy irradiated meat and poultry and among those, 25% were willing to pay a premium price (Frenzen et al, 2000)
- Numerous studies have shown that consumer acceptance increases after they are given educational information about food irradiation, and many consumers have reported that they would prefer irradiated over non-irradiated meats after given science-based
information (Bord and O’Connor 1989; Bruhn and Schutz, 1989; Fox et al, 1998; Resurreccion et al, 1995)

- The use of audio and/or visual materials on food irradiation such pamphlets, slide shows and videos shifts consumers toward a positive attitude on food irradiation (Bruhn et al, 1986b; Hashim et al, 1995; Pohlman et al, 1994)
- Labeling is important to consumers, and strongly influences their acceptance of food irradiation; in one survey, 80% of US consumers indicated they would buy products with the approved Radura label and a statement: “irradiated to destroy harmful bacteria” (Bruhn 2001)
- Consumers have expressed more concern about foodborne illness than irradiation “safety” (Bruhn et al, 1986)
- In a survey of 250 dieticians employed in health care facilities, the responses were surprisingly receptive to irradiation (Giamalva et al, 1998)
- Surveys indicate that military consumers, in particular, may be amenable to irradiated food (DeRuiter and Dwyer, 2002; Pohlman et al, 1994)
- Consumer confidence depends on making food clean first, and then using irradiation to make it even safer (DeRuiter and Dwyer, 2002)
- Consumers indicate they trust information most from health professionals (Bruhn 2001; American Meat Institute 1998); but, also trust in government and industry are the important factors affecting acceptance of irradiation (Bord and O’Connor, 1990)
- An interesting and innovative educational campaign was launched in Florida to promote food irradiation (Bruhn 2001; Hunter 2001), that engaged the state and local county health department and multiple media outlets. They used billboards with pictures of mothers and children to draw a comparison between pasteurized milk and irradiation. The billboard read:

PUBLIC HEALTH NOTICE:
Pasteurization, Safer Milk.
Irradiation, Safer Meat.

Additionally, the state health officer (a physician) made a statement directed at consumers and retailers (restaurants, grocery stores): “I hope you will purchase irradiated chicken and ground beef as they become available. This combination will afford your family maximum protection against foodborne illness.”

The role of the Internet in acceptance of food irradiation

It is worth noting, that since many of these studies were conducted more than a decade ago, the potential influence of the Internet, including anti-irradiation activist websites, has not been factored into the consumer acceptance equation. An informal survey on the web during this review showed a preponderance of mostly non-science groups against food irradiation, and a relative paucity of recent web-based information from scientists, industry, and government about the potential benefits. It is also difficult to predict how increased consumer demand for “organic” and “natural” foods will affect acceptance of food irradiation of fresh produce such as lettuce and spinach. Irradiation of organic food is currently prohibited. There is an urgent need to conduct new studies in
today’s marketplace including assessments of consumer attitudes toward irradiation of leafy greens and other produce. Additionally, it would be useful to examine consumer demand in different types of markets (e.g., chain restaurants, institutional settings such as hospitals, long-term care facilities, and prisons).

**Economic Costs and Commercial Viability**

Similar to the literature review on consumer acceptance, most of the papers that address economic costs and potential benefits (from reduced outbreaks and recalls) relating to food irradiation are outdated, and not specific for fresh lettuce, spinach or other leafy greens. Nevertheless, there are common themes that can be applied today when weighing the costs and benefits of radiation to control foodborne pathogens and spoilage organisms in fresh iceberg lettuce and spinach.

**The Human Costs**

The type of costs that accrue for individuals and society due to foodborne diseases and recalls include but are not limited to:

- Physician and emergency department visits
- Hospitalization
- Outpatient medication
- Productivity loss
- Long-term complications (e.g., HUS)
- Premature death
- Loss to industry from recalls and highly publicized outbreaks
- Loss of consumer confidence and market share
- Liability (lawsuits) and increased insurance premiums

As previously discussed, Tauxe (2001) analyzed the potential benefit of irradiated meat and poultry and estimated that 900,000 cases of infection, 8,500 hospitalizations, over 6,000 catastrophic illnesses, and 350 deaths could have been prevented each year. Similarly, Morrison et al (1992) conducted a cost:benefit analysis for irradiation of poultry products, and concluded that the savings from decreased foodborne illness would be greater than the small increase in cost passed on to consumers. Although similar studies have not been conducted for lettuce and spinach-related illnesses, it is reasonable to assume that irradiation would also result in reduced human illnesses and associated costs.

**The Facility Costs**

There is no debate concerning whether or not irradiation is technically feasible for fresh iceberg lettuce and spinach. The technology has been shown to be safe and effective. The major disincentive for implementing food irradiation processing in the leafy greens industry relates to economic feasibility.
The fresh iceberg lettuce and spinach industry faces unique challenges with this technology. First, there is a geographic challenge. The majority of fresh iceberg lettuce and spinach is grown and shipped from the west coast (mostly the Salinas Valley, California). This region does not currently have a facility to accommodate radiation of fresh produce at the dose approved by the FDA for foodborne pathogen control; therefore, it is necessary to either 1) build stand-alone or in-line unit(s) in the major lettuce/spinach production region or 2) ship the packaged products to irradiation facilities in other distant parts of the country. There is potentially less financial risk in utilizing an offsite location given the uncertainty of consumer demand (see below); however, shipping to an out-of-state irradiation facility increases costs, and adds another layer in the distribution system where contamination could be introduced, especially if there is an accidental failure in temperature (refrigeration) control.

Second, it may be necessary still to optimize the conditions for ionizing radiation processing for specific facilities and product types/sizes (including packaging) to maximize the food safety benefits and minimize the potential negative effects on food quality such as off odors; this is a relatively simple problem to address once a facility is in place.

Several excellent reviews of the costs associated with irradiation facilities are available, but they are outdated (Cleland et al, 2001; Frenzen et al, 2001; Hayes, 1995; Kunstadt, 2001a; Kunstad, 2001b; Morrison et al, 1992; Morrison, 1989).

There are three major components that factor into costs for industry (and that may be passed on to consumers):

- Capitol costs (hardware and land/property)
- Annual operating costs (type of product and radiation source/dose, personnel maintenance, tax/insurance, regulatory requirements)
- Annual throughputs

Cleland et al (2001) summarize the critical importance of annual throughput: “total cost per unit of product decreases as the throughput rate increases because the fixed costs (e.g., capitol amortization, utilities, maintenance) are then spread over a larger market of units.” In other words, the financial success (economic feasibility) of building an irradiation facility is closely associated with the demand for the product.

Thus, the uncertainty of the market place with regard to the number of consumers (including retailers) that will purchase fresh iceberg lettuce and spinach treated with radiation for food safety and quality is perhaps the greatest challenge in implementing FDA’s new rule.

**Consumer Willingness to Pay**

Although the actual number of potential customers remains unclear for irradiated fresh iceberg lettuce and spinach, numerous surveys have indicated that once consumers
are educated about the food safety benefits of the process, most are willing to pay an increased price (Bruhn 2001; Frenzen et al, 2001; Hayes, 1995; Sapp 1995). Furthermore, published studies indicate that the increased cost per pound for meat and poultry products amounts to only a few cents. Although current numbers are not available in the literature for lettuce/spinach, Sadex Corporation estimated the increased cost for food irradiation at the medium dose level would be approximately 10 to 20 cents per pound using e-beam technology (personal communication). This seems like a small price to pay for increasing food safety, but as reviewed exhaustively in this series, many complex scientific, social, economic, and policy factors influence the decisions surrounding acceptance and use of food irradiation.

V. Conclusions

“Never confuse movement for action.”
Ernest Hemingway

Pros (Advantages)

• Like pasteurization, food irradiation has widespread, worldwide endorsement by nearly every major medical and scientific organization

• Enhances food safety and can prevent illnesses, outbreaks, and recalls. The new FDA rule allows a maximum dosage of 4 kGy, which is effective at reducing or eliminating the major foodborne pathogens such as E. coli O157:H7 and Salmonella associated with recent lettuce/spinach outbreaks and recalls (see Table). Fewer outbreaks and recalls translates into:

  o less direct and indirect costs to individuals and society due to medical bills and other expenses
  o less litigation
  o increased consumer confidence in leafy greens

• Unlike other sanitation methods for raw or minimally processed lettuce/spinach, irradiation will kill bacteria adhered to the outside or internalized within the edible plant tissues (for example, E. coli O157:H7 inside pores or stomata); regular washing by the consumer likely will not eliminate these bacteria

• Conducive to use by companies that supply institutions (restaurants, hospitals, nursing homes, long-term care facilities, schools/colleges, prisons and jails) with large quantities of bagged, minimally processed, pre-washed iceberg lettuce and spinach, which historically appear more vulnerable to serious foodborne disease outbreaks

• Enhances food quality by extending product shelf-life and promoting less food waste. Similar to foodborne pathogen reduction, the approved dosages for irradiation of lettuce and spinach significantly reduce the levels of spoilage bacteria and molds.
• Minor to no significant loss of important nutrients in lettuce and spinach, especially compared with nutrient loss following other common food preservation techniques (e.g., boiling and freezing) and losses during storage

• Limited to no detectable problems with sensory qualities - appearance, taste, texture, and aroma - especially at lower dosages (1 kGy)

• No chemical residues left on the product, and a consensus within the scientific community that the technology is safe and does not produce any “toxic substances” or “radioactivity” in the food or packaging. Indeed, the three specific sources (gamma rays, x-rays, e-beam) specifically approved by the FDA for food irradiation were approved because they do not make the food radioactive.

• Includes a Radura label that allows consumers to make a choice to buy or avoid irradiated product, depending on their assessment of the pros and cons.

**Cons (Limitations)**

• Lack of irradiation facilities near major lettuce/spinach production regions such as the Salinas Valley, and substantial costs associated with building new facilities; alternatively, the leafy green industry could ship product to existing facilities in other parts of the country, but this also adds costs that will likely be passed to the consumer

• Uncertainty about consumer acceptance of irradiation, especially for produce items. Some consumers fear of the word “irradiation,” which may be incorrectly associated with the words “atomic” or “nuclear.” Studies indicate that the primary reason consumers might not buy irradiated foods is due to insufficient information about the risks and benefits, thus underscoring the considerable need for education efforts

• Strong opposition to the use of irradiation in organic food production; FDA’s rule would not apply to organically produced lettuce and spinach since irradiation at the medium dose range is not allowed by USDA standards that define “certified organic” (Note: the 2006 *E. coli* O157:H7 outbreak was traced to bagged baby spinach grown organically)

• Not a replacement for good agricultural practices (GAPs) and good management practices (GMPs) on the farm and during harvest, transportation, and processing

• Does not prevent post-processing contamination during transport or by the retailer or consumer during food preparation and handling

• At the approved dose, irradiation may not effectively reduce viruses (e.g., norovirus, hepatitis A); spore forming bacteria such as *Clostridium botulinum*, and it does not eliminate toxins. However, these causes of foodborne illness and intoxication are rarely linked to fresh lettuce and spinach
• Some packaging material may not be appropriate (or FDA approved) for irradiation processing

From Movement to Action

Coincident with starting this series last fall, an outbreak of *E. coli* O157:H7 involving over 40 illnesses and numerous hospitalizations was linked to bagged, fresh-cut iceberg lettuce shipped to institutions in Michigan and Illinois. Earlier in 2008, Washington State reported an outbreak of *E. coli* O157:H7 among patrons that consumed Romaine lettuce at a Mexican restaurant. These outbreaks appear to have happened despite substantial efforts by the leafy green industry to implement stronger control measures to prevent contamination in the fields and processing facilities, especially in the Salinas Valley of California. Both of these outbreaks have resulted in lawsuits.

Stearns (2006) wisely notes in his chapter on the legal perspectives of food irradiation:

“*Food irradiation has the capacity to substantially reduce not only the risk of lost sales that result from an outbreak or recall but also the lawsuits that inevitably follow.*”

He goes on later in the chapter to say:

“*Because it is clear that the size of the highly susceptible population [elderly, preschool age children, persons with AIDS, persons on chemotherapy, etc.] is certain to grow, the food industry has no choice but to take this increasing risk into account when making decisions about what, if any, additional steps to take to prevent a parallel increase in the incidence of foodborne illness attributable to its product.*”

Given the gravity of the situation with continued illnesses and deaths linked to fresh produce, the “cons” (such as uncertainty about consumer acceptance and potential costs to implement irradiation), should not paralyze the effort to go from movement to action. The following are some suggestions for first steps to maximize the benefits of FDA’s new rule:

• All professionals in the food safety arena should work with experts in food irradiation companies to conduct a modern assessment of the estimated costs and benefits associated with implementation of the FDA rule for fresh iceberg lettuce and spinach. Specifically, these professionals should look closely at potential niche markets or at-risk groups that could benefit from the technology. For example, irradiation could have a significant impact (reduction of illnesses and outbreaks) if applied to products shipped to institutional settings (schools, hospitals, nursing homes, long-term care facilities, prisons) where populations are especially vulnerable to foodborne diseases.

• Government, industry, academia, health care providers, legal professionals, consumer groups, and other stakeholders need to provide and advertise an honest and balanced assessment of the pros and cons (advantages and disadvantages) of food irradiation including application of the FDA rule for fresh iceberg lettuce and spinach. This
information should be readily available to the public via multiple sources including the Internet to allow the public to make an informed choice. Pszczola suggested that the medical and scientific communities “develop closer relationships with the media so emotionalism is not overemphasized compared with scientific facts.”

• The label for irradiated fresh iceberg lettuce and spinach (plus other approved foods) should include the Radura, and a general or incentive statement on the purpose of irradiation such as, “to kill harmful pathogens,” or “to reduce Salmonella and *E. coli* O157:H7.” It would also be worthwhile to consider phasing out the word “irradiation” and adopting a new term for this processing technology such as “cold pasteurization” or “electronic pasteurization (for e-beam processing),” which are still descriptive, but not associated with the words “nuclear” or “atomic.”

• FDA should expand the rule to include approval of other high-risk salad greens linked to foodborne disease outbreaks, especially Romaine lettuce. Public and private funding agencies should continue to provide support for research into the optimal conditions for use of ionizing radiation in different types of leafy greens and packaging materials that promote both food safety and food quality.

**References**


45. GAO. Improvements needed in FDA oversight of fresh produce, U.S. Government Accountability Office, September 2008. Available at:


Table. Examples of outbreaks and recalls of E. coli O157:H7 and Salmonella linked to leafy greens believed to be contaminated at the production or processing level, 1995-2008.

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Page 29
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<th>Year</th>
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**RECALLS (no illnesses)**

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*Unpublished data was acquired from the CSPI, FDA and/or CDC foodborne disease outbreak resources.

**Preliminary data.