

# Meat Irradiation and Meat Safety

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## Introduction

In September, 1994, the Food Safety Inspection Service (FSIS) of the U.S. Department of Agriculture declared *Escherichia coli* O157:H7, which had previously been considered to be a natural contaminant, an adulterant in fresh meat. In January, 1995, FSIS issued proposed regulations that, for the first time, mandated microbial testing of fresh meat which would be used to establish microbial standards. The Center for Disease Control is developing new methods to better estimate the number of cases of food borne diseases. The awareness of food borne diseases by consumers will increase and therefore, pressure to improve the safety of the food supply will also increase.

While not a new technology, irradiation has the potential to eliminate pathogenic bacteria in fresh meat. Before widespread adaptation of irradiation occurs, issues regarding quality changes and packaging must be more thoroughly addressed.

## Regulatory Status

In the U.S., poultry and red meat are approved for irradiation. Refrigerated or frozen poultry is approved at dosages between 1.5 kGy and 3.0 kGy (9 CFR Part 381, 1992) for control of pathogenic bacteria. These dose ranges are more restrictive than most other countries (IAEA, 1995) where poultry has been approved. Maximum irradiation doses for poultry are 7 kGy in seven countries with only one other country having a maximum dose of 3 kGy. The low maximum dose approved by the U.S. Food and Drug Administration (FDA) was based on the concern about the survival of *Clostridium botulinum* spores and the loss of competitive spoilage organisms at irradiation doses above 3 kGy, which would allow the *C. botulinum* spores to germinate and produce toxin undetected without competition. The same concern about *C. botulinum* toxin production in an anoxic environment has prevented the use of

vacuum packaging or modified-atmosphere packaging on irradiated poultry.

Red meat (beef, pork, lamb, goat, and horse) is approved with a maximum dosage of 4.5 kGy for refrigerated product and 7 kGy for frozen product (Federal Register, 1997). USDA rules for the implementation of irradiation in red meat have not been issued as of May 15, 1998. Maximum doses are slightly higher than approved for poultry, higher doses for frozen meat than for refrigerated meat and the use of anoxic packaging. If USDA sets the minimum dose at 1.5 kGy, (as it did for poultry) the higher maximum doses would move the ratio of maximum to minimum dose to 3:1 compared with 2:1 approved for poultry. The higher ratio would enable full pallet loads of product to be irradiated in a gamma facility. Microorganisms are more resistant to irradiation in frozen product than refrigerated, hence a higher minimum and maximum dose would be needed for frozen product to achieve a microbial kill equivalent to the lower doses approved for refrigerated product (Murano, 1995a). No packaging environment restrictions were included in the approval. Use of vacuum or modified atmosphere packaging would reduce oxidative changes in the product thus minimizing quality changes in the product.

## Microbiology of Irradiated Muscle Foods

Radiation is used to "pasteurize" raw meat by reducing or eliminating pathogenic bacteria. As with cooking, where higher temperatures kill more bacteria than lower temperatures, higher radiation doses kill greater bacterial numbers. D-value is a measure of the death rate of a microorganism at a given radiation dose necessary to destroy 90%, a decimal reduction, of the microorganisms present. The D-values of several of the important pathogenic bacteria found in raw meat are shown in Table 1. *Salmonella* is the most resistant non-spore forming pathogen, having a D-value in the range of about 0.6 kGy. For poultry, the approved radiation dose is 1.5 kGy to 3.0 kGy (9 CFR Part 381, 1992). Hence, about 99.9% (3 logs) to 99.999% (5 logs) of *Salmonella* present would be destroyed within the limits of the poultry irradiation regulations. In addition, all of the other pathogenic bacteria listed in Table 1 would be controlled except for the spores of *Clostridium botulinum*.

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**Table 1. D values of some important food borne pathogens and spoilage organisms.**

Organism	D values (kGy)	medium	Suspending temperature (°C)	Irradiation References
<i>A. hydrophila</i>	0.14 - 0.19	Beef	2	Palumbo <i>et al.</i> , 1986
<i>C. jejuni</i>	0.18	Beef	2 - 4	Clavero <i>et al.</i> , 1994
<i>E. coli</i> O157:H7	0.24	Beef	2 - 4	Clavero <i>et al.</i> , 1994
<i>L. monocytogenes</i>	0.45	Chicken	2 - 4	Huhtanen <i>et al.</i> , 1989
<i>Salmonella</i> spp.	0.38 - 0.77	Chicken	2	Thayer <i>et al.</i> , 1990
<i>S. aureus</i>	0.36	Chicken	0	Thayer <i>et al.</i> , 1992
<i>Y. enterocolitica</i>	0.11	Beef	25	El-Zawahry <i>et al.</i> , 1979
<i>C. botulinum</i> (spores)	3.56	Chicken	-30	Anellis <i>et al.</i> , 1977

The D-value for *E. coli* O157:H7 is about 0.24 kGy. At a minimum dose of 1.5 kGy, at least 6 logs of *E. coli* O157:H7 would be destroyed. Therefore, radiation, would be extremely effective at eliminating this microorganism from raw meat which is critical since it is listed as an adulterant in ground beef.

While the primary objective of food irradiation is to destroy pathogenic bacteria, substantial reduction of spoilage organisms also occurs. Niemand *et al.* (1983) reported over a four log reduction in total aerobic counts and almost a five log reduction in anaerobe counts in chilled ground beef irradiated to 2.5 kGy. They found an extension in shelf-life of nine days before counts reached seven logs when stored at 4°C. With vacuum-packaged beef sirloin cuts irradiated to 2 kGy, refrigerated shelf-life more than doubled from about four weeks for non-irradiated product stored at 0°C to 10 weeks for irradiated product stored at 4°C (Niemand *et al.*, 1981). Lefebvre *et al.* (1992) found a three log reduction in psychrotrophic aerobic bacteria in ground beef irradiated at 2.5 kGy. The irradiated ground beef had a shelf-life of ten days before counts reached seven logs compared to the non-irradiated control which lasted only one day.

Lambert *et al.* (1992) found pork loin slices packaged under nitrogen and irradiated to 1 kGy had a 26-day shelf-life (21 days more than the control) stored at 5°C. Thayer *et al.* (1993) found uninoculated ground pork, irradiated at 1.9 kGy, had no surviving bacteria when stored at 2°C for up to 35 days.

The predominant food spoilage organisms are Gram-negative psychrotrophic microorganisms which are very susceptible to radiation (Monk *et al.*, 1995). Several researchers have shown that irradiation of food at dosages of 1 kGy and higher virtually eliminates Gram-negative microorganisms with a much smaller effect on Gram-positive lactic acid-producing microorganisms (Dempster, 1985; Ehioba *et al.*, 1988; Lambert *et al.*, 1992; Mattison *et al.*, 1986; Niemand *et al.*, 1983; Thayer *et al.*, 1993). Pseudomonads and enterobacteriaceae, which are common spoilage bacteria, are easily eliminated even with low dosages of radiation. However, in all of these studies at dosages in the range of 1 to 5 kGy, Gram-positive microor-

ganisms survived and caused spoilage conditions after prolonged refrigerated storage.

### Quality of Irradiated Muscle Foods

Irradiation can significantly reduce microbial contamination of meat. However, irradiation may affect the quality of meat by processes other than caused by the presence and growth of microorganisms. Meat exposed to ionizing radiation results in the formation of radiolytic products from free-radicals that are formed during treatment. These radiolytic products can cause oxidation of myoglobin and fat, leading to discoloration and rancidity or other off-odor or off-flavor compounds (Murano, 1995b). Development of an off-odor, off-flavor, or off-color in irradiated raw meat can be affected by a number of factors including temperature, packaging environment and material, radiation dose, and condition of the raw meat before irradiation.

After irradiation, raw meat has been shown to develop an off-odor or irradiation odor compared to the non-irradiated control (Lefebvre *et al.*, 1994; Lynch *et al.*, 1991). Irradiation odor threshold dose ranged from 1.5 kGy for turkey to 6.25 kGy for lamb (Sudarmadji and Urbain, 1972). The irradiation odor produced by low dose irradiation of raw beef was found to be detectable but not objectionable (Niemand *et al.*, 1981). Low molecular weight volatiles have been found in irradiated pork patties (Ahn *et al.*, 1998a) and in irradiated beef patties (Ahn *et al.*, 1998b) that were not present in the non-irradiated patties. These volatiles may be responsible for off-odors but they were not identified. Total volatiles increased as thiobarbituric acid reactive substances (TBARS) increased with correlation of 0.95 (Ahn *et al.*, 1998a).

Cooking appears to lessen or eliminate the irradiation induced odor (Kropf *et al.*, 1995; Luchsinger *et al.*, 1996; Luchsinger *et al.*, 1997a). Thus, changes in odor due to irradiation may be important only in raw meat. More research is needed to fully characterize the odor and factors or conditions that may increase or decrease its presence. Irradiated meat will be successful in the market place only if consumers are satisfied with its sensory quality. It is important that irradiation processors choose conditions, such

as oxygen exclusion and packaging materials, which avoid the presence of objectionable off-odors or off-flavors.

Radiation can also cause some color changes in meat, which are greatly influenced by the packaging environment. Meat packaged under vacuum and irradiated can develop a fairly stable brighter red or pinkish color in pork, beef, and turkey breasts (Lebepe et al., 1990; Lynch et al., 1991; Niemand et al., 1983). However, the color changes appear to be affected by muscle fiber type. No differences in Hunter "a" values were found between irradiated and non-irradiated whole muscle beef (Luchsinger et al., 1997b), ground beef patties (Luchsinger et al., 1997c) and ground pork (Ahn et al., 1998a). However, whole muscle pork loin chops and turkey breasts became redder due to irradiation (Nanke et al., 1998b; Ahn et al., 1998b). In pork muscles that have different levels of red fibers versus white fibers, the dark muscles with more red fibers did not change in "a" values, but the light muscles with more white fibers had increased "a" values due to irradiation.

In the presence of oxygen, irradiated meat can become discolored (Grant and Patterson, 1991; Ahn et al., 1998a, 1998b; Zhoa et al., 1996; Luchsinger et al., 1997c; Nanke et al., 1998a). During food irradiation, the strong oxidizer ozone is produced from oxygen. It is likely that ozone interaction with myoglobin oxidizes the pigment, causing the bleaching discoloration. It is apparent that irradiation of meat products must be done in the absence of oxygen to eliminate the discoloration of the products at the surface of the products. While oxygen is needed to maintain the desirable bloom appearance, it is detrimental to the color of the product during irradiation.

## Packaging

To obtain the full benefit of eliminating pathogenic bacteria and reducing the total microbial load, meat should be pre-packaged prior to irradiation to prevent post-irradiation contamination. Consequently, the packaging material is irradiated while in contact with the meat and must not be adversely affected by the treatment (Lee et al., 1996).

Packaging materials must be accepted by the U.S. Food and Drug Administration according to indirect food additives regulation. There is a list of acceptable materials in 21 CFR—Part 179.45. Most of these packaging materials were accepted in the 1960's and do not include modern packaging structures. This list of materials cannot be extended to unlisted co-extruded or laminate films which are in common use in the industry; therefore, film manufacturers must seek acceptance for each multicomponent film.

Radiation has the potential for chemically changing packaging films. Irradiation of film could result in evolution of gases, such as hydrogen, and production of low-molecular weight hydrocarbons and halogenated polymers (Kilcast, 1990). At doses accepted for food, only low-molecular weight polymers and gases have the potential for

migrating into the product, which may have some potential for influencing the quality of the product.

Polyvinylchloride (PVC), commonly used as a fresh meat overwrap, has been shown to have some taint-transfer problems when irradiated at 3.9 kGy (Kilcast, 1990), however, it is not listed by FDA as an accepted material. Antioxidants used in packaging films can also be significantly degraded, although there is no indication of any migration of the antioxidants into the product (Buchalla et al., 1993). More research is needed to determine the suitability of new types of polymeric packaging material, including co-extrudates and laminates, for food irradiation. In addition, additives, adhesives, and printing materials should also be screened (Kilcast, 1990).

Research is needed to determine the threshold level of migration of film components, resins, and additives that will lead to an expansion of the availability of FDA approved polymeric films. With FDA approval of individual film components, film manufacturers would be able to develop film structures that would have defacto FDA approval without having to petition for approval of each new film structure developed.

## Summary

Irradiation of meat and poultry effectively reduces or eliminates pathogenic bacteria. This technology must be used under conditions that minimize or eliminate objectionable changes in quality. Packaging materials, accepted for contact with food to be irradiated, are very limited and do not include multilayer and co-extruded films that are commonly used.

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