Paper No.: 02

Paper Title: The Principles of the Food Processing & Preservation

Module No. : 24

Module Title: Food Irradiation

24.0 Introduction

Food safety is widely recognized as an increasingly significant public health concern world wide. Recent history has included too many examples of recalls necessitated by the presence or suspected presence of foodborne pathogens such as *E. coli* , *Listeria* , and *Salmonella* . In the face of growing concern about food-related illness, food irradiation has entered the picture. Irradiation is not a "new" technology by any measure. In modern society, irradiation is routinely used to sterilize medical equipment, including most of the disposable items used in hospitals every day. Nor is irradiation of food itself a new development. FDA has approved irradiation of food for limited purposes since 1963, and NASA has used irradiated food on its space missions for decades as a precaution against foodborne pathogens. But it is only within the last 20 years that irradiation has been approved for the types of usage that would have a substantial impact of the presence of foodborne pathogens.Despite its conceded effectiveness against foodborne pathogens, the use of irradiation is still uncommon in the food industry.

24.1 The technology of food irradiation

The term "food irradiation" may be applied to any process that exposes food either to electromagnetic radiation or to high-energy particles. Electromagnetic energy can be generated by radioactive isotopes, as in the case of gamma ray irradiation, or by bombardment of thin metal films with high-energy electron beams to produce radiation, as in the case of X-ray irradiation. Alternatively, a high-energy electron beam ("e-beam") can be directed at the food itself. In all of these cases, the radiation is absorbed by the food, and more particularly, by the microbial organisms in the food. This absorption disrupts the complex organic molecules of the microbes, either preventing the microbes from reproducing or killing them outright. The effectiveness of the treatment varies based on the type of radiation used, the intensity of the radiation, and the microbe in question. The relative advantages and disadvantages of the three forms of food irradiation (gamma ray, X-ray and e-beam) used today are discussed below.

24.1.1 Gamma Ray Irradiation

The simplest form of irradiation, at least in concept, is gamma ray irradiation. In this form of irradiation, the source of radiation is a radioactive element that emits photons in the gamma ray range of the electromagnetic spectrum. Gamma ray photons have a higher frequency (and therefore energy) than either ultraviolet or X-ray photons. Gamma rays can penetrate a target food (or medical product) to a depth of several feet and reach microbial contaminants anywhere within that range.

While simple in concept, gamma ray irradiation can be difficult in practice. The first difficulty is selecting a radioactive source element. In addition to radiating gamma rays, many radioactive elements also produce alpha rays (helium nuclei), beta rays (high- energy electrons or positrons) and/or high-energy neutrons. Alternatively, they might decay into another radioactive substance that generates these other forms of radiation. The other forms of radiation are undesirable because they have the potential to make the target food (or medical product) radioactive. To date, the only radioactive isotopes approved as having the proper radiation profile are Cobalt 60 and Cesium 137, with only Cobalt 60 being actually used for food irradiation at the present time. These radioactive isotopes are produced by exposure of the ordinary element to a nuclear reactor core, and their availability may be conditioned on the continued availability of nuclear power.

Even after a source is selected, there are logistical complications in gamma ray irradiation. Radioactive elements do not have an "off" switch, nor do they come equipped with directional or intensity controls. Gamma rays can be contained by immersion of the source in a sufficient quantity of water, but the source must be removed from the pool in order to irradiate the target food. In order to prevent inadvertent gamma ray exposure, the source must be insulated from the outside world by several feet of concrete.

24.1.2 E-beam irradiation

E-beam irradiation, though it uses the same term as gamma ray irradiation, is a completely different kind of treatment. High-energy electron beams are produced in an electron gun, a larger version of the cathode ray gun found in devices such as televisions and monitors. The electrons can be directed by a magnetic field to a target food. The term "irradiation" is really a misnomer, since the food not exposed to electromagnetic radiation or beta rays (electrons produced by a radioactive source). Nevertheless, the process has a similar effect to that of gamma ray irradiation. E-beam irradiation requires shielding as well, but nothing like the concrete bunkers used in gamma ray irradiation. The disadvantage of the e-beam is its short penetration depth (about an inch), preventing its application to many foods and limiting the amount of food that can be processed in bulk.

24.1.3 X-Ray Irradiation

X-ray irradiation is a relatively new technique that combines many of the advantages of the other two methods. Like gamma ray irradiation, X-ray irradiation consists of exposing food to high-energy photons with a long penetration depth. In this case, however, bombarding a metal film with a high-energy electron beam produces the photons, allowing the radiation to be turned on and off. The device is a more powerful version of the X-ray machines used in medical offices. The device still requires heavy shielding, although the amount of shielding required is less than that for gamma ray irradiation. No radioactive substances or by-products are used in, or result from, the process.

Regardless of form, food irradiation is fundamentally about how much energy is absorbed by the target food. It is helpful to have a measurement for what dosage of radiation will be required independent of the amount of food to be irradiated. For this reason, radiation doses are measured in *kiloGray* (kGy). A dosage of one kGy indicates that the target sample receives 1000 Joules (metric units of energy, abbreviated J) per kilogram of sample mass.When measuring the effect of radiation on the microbe population of food, it is useful to have a measurement that does not depend on the number of microbial organisms in a particular sample of food. For this reason, the effect of radiation on microbes is measured by a dosage called the *D value* . The D value is the dosage of radiation required to reduce the microbe population of a sample by 90%.If a particular organism has a D value of 0.5 kGy in a particular kind of food, then exposing a 1 kg sample of that food containing the organism to 500 J of radiation will kill 90% of the population of that organism. An additional amount of dosage equal to the D factor will reduce the remaining microbe population by 90%. Thus, exposing the sample in the example above to 1000 J of radiation would reduce the microbe population by 99%; 1500 J would remove 99.9% of the microbe population; etc. Varying the power of the source or the duration of exposure controls the amount of radiation the target receives. The energy of electron guns used for e-beams and X-rays is typically measured in electron volts (eV), units of energy convertible to J.

The D value will depend primarily on the type of food irradiated and the type of organism to be eradicated by irradiation. Generally, the more complex the organism, the more sensitive the organism will be to radiation, since the operation of complex microbes is easier to disrupt. Viruses, the simplest form of life, are most difficult to destroy. Many bacteria collapse into a dormant state known as a *spore* (as contrasted with the *vegetative* state) when conditions are unfavorable to growth (e.g., when the oxygen or temperature levels are too low). The D value for spores is higher than the corresponding D value for the vegetative state.

Other factors that affect the D value are the strain of organism involved, the state of the food (frozen or unfrozen), ambient oxygen and temperature. The difference between frozen and unfrozen food is particularly important, since one of the most effective ways of controlling microbial pathogens in food is to keep the food below a temperature at which the pathogen can grow. More radiation is required to kill microbes in frozen food, and the slight heating that results from incidental absorption of radiation by the food has the danger of raising the food to a temperature that would allow pathogenic organisms to grow. Consequently, temperature effects must be carefully monitored in most foods.

24.2 Effect of irradiation on Foodborne Microbial Pathogens

One of the biggest problems with the acceptance of food irradiation in society is that few people are fully aware of how serious the problem of foodborne illness can be. In a way, this reflects well on our existing food safety measures, since it presumably indicates a great deal of consumer confidence in the quality of the food they purchase. Even given the relative safety of the food supply, the harm created by food-related illness is nothing short of staggering. There are five common food borne pathogens which can lead to loss in productivity. They are *Salmonella*, *Escherichia coli*, *Listeria monocytogenes*, *Campylobacter jejuni and Vibrio.* FDA and USDA have approved doses of 3.0 kGy for poultry, 4.5 kGy for other unfrozen meats, and 7.0 kGy for other frozen meats. Comparing those doses to the D value reveals the percentage of the microbe that will be killed by irradiation at the allowed dose.

Salmonella: Depending on strain of bacteria and other factors, the D value of *Salmonella* ranges from 0.4 to 0.8 kGy. At the 3.0 kGy dose approved for poultry, irradiation would kill over 99.9% of the most radiation-resistant strains of *Salmonella* .

E. coli: E. coli is even more radiation sensitive that *Salmonella* ; it has a D value ranging from 0.2 to 0.4 kGy. Exposure of beef to a 4.5 kGy dose would reduce the amount of *E. coli* in the sample by a factor of 100 billion. Considering that *E. coli* is not ordinarily present in beef, food irradiation could effectively eradicate the problem of *E. coli* in beef products.

Listeria: Listeria in beef, pork and lamb has a D value ranging from 0.40 to 0.48 kGy. Using the 4.5 kGy approved dose would reduce the *Listeria* population by a factor of one billion. Unfortunately, irradiation has not yet been approved for processed meat products such as hot dogs, a common source of *Listeria* .

Campylobacter: Campylobacter is one of the more radiation-sensitive bacteria, with the *C. jejuni* species having a D value ranging from 0.18 to 0.24 kGy. The approved poultry dose of 3.0 kGy would leave only one trillionth of the original *Campylobacter* population. Considering that *Camplylobacter* 's effects are often chronic and difficult to trace back to food, food irradiation could prevent a great deal of food-related illness that might be undetectable and effectively unavoidable otherwise.

Radiation-resistant microbe: Most of the discussion thus far has been confined to the most common non-viral pathogens. For the sake of completeness, a few more organisms should be mentioned. *C. botulinum* , for example, is one of the more deadly pathogens (although not quite so virulent as *Vibrio vulnificus*); nearly 8% of hospitalized cases of botulism result in the patient's death. *C. botulinum* also happens to be quite radiation-resistant in its spore phase, having a D value of between 2 and 4 kGy. Irradiation, at least at conventional doses, would have a limited effect on *C. botulinum* .

Viruses also play a significant role in food-related illness, and they are much more resistant to radiation that other microbial pathogens. Since people exposed to a virus can often develop immunity to the virus, much of the incidence of food-related viral illness is found in children. Hepatitis A is the most notorious of the viral food-related illnesses. About 5% of all cases of hepatitis A are traced back to food, but since 50% of all hospitalized cases have an indefinite source, the actual number of food-related cases may be significantly higher. Again, irradiation at conventional doses is unlikely to have a significant impact on hepatitis A, and sufficient irradiation could have undesirable effects on the characteristics of infected food (e.g., it might kill raw oysters, reducing shelf life).Another class of disease unlikely to be affected by irradiation is bovine spongiform encepalopathy ("mad cow disease"). Although the cause of the disease is still under study, scientists currently believe the culprit to be *prion particles*, simple collections of protein lacking DNA. Their simple structure makes them resistant to disruption by radiation.

24.3 History of Food Irradiation

Excluding ultraviolet radiation, the first approved use of food irradiation took place in 1963, when FDA approved the use of irradiation in doses from 0.2 kGy to 0.5 kGy to control mold and insects in wheat flour. In the next year, FDA approved limited doses of radiation (0.05-0.15 kGy) to inhibit sprouting in white potatoes. Somewhat surprisingly, food irradiation would not be approved for use against parasites and microbial pathogens for nearly 20 years. Around this time (in the period from 1953-1980), the U.S. Army and Atomic Energy Commission conducted studies of food irradiation under the National Food Irradiation Program. Also during this time, NASA used food irradiation in order to protect its astronauts from the possible dangers resulting from food-related illness during space missions. Much of the data concerning the safety of food irradiation for humans comes from studies conducted on astronauts who consumed irradiated food.

The next wave of approvals for food irradiation did not come until the eighties. In this period, FDA finally began to approve food irradiation in order to control parasites, insects and microbes for a substantial number of foods. Starting in 1983, FDA approved doses of up to 10 kGy for the control of insects and microbes in spices and other dried vegetables (later raised to 30 kGy in 1986). Also in 1986, FDA approved irradiation at doses up to 1 kGy to control Trichina parasites in pork. That same year, FDA approved irradiation of fruits as a desirable alternative to pesticides for controlling insects and as a means to increase shelf life.

In the nineties, food irradiation continued to expand, particularly into areas in which the products went directly to consumers. In 1990, FDA approved poultry irradiation at doses up to 3 kGy for bacterial pathogen reduction. Two years later, USDA approved a like rule for doses ranging from 1.5-3.0 kGy as necessary. Sprouts gained increasing notoriety as a source of foodborne pathogens among food safety experts in the late nineties. Although much of the contamination in sprouts comes from the point of service (e.g., at salad bars), sprouts pose a particular health hazard because they are too fragile for the vigorous washing used to clean other vegetables. Because chemicals cannot be washed off of sprouts, there is a limit to how much chemical treatment can be applied. Historically, then, it had been virtually impossible to reduce significantly the natural microbial population of sprouts. Irradiation of seeds from which sprouts are grown provides a valuable alternative solution to the problem which is widely being used world over.

24.4 Labeling Requirements

Since food irradiation is classified as a food additive, its presence must be disclosed on a label as per regulations. According to those regulations, the product must bear a legend saying either "Treated with radiation" or "Treated by irradiation." The legend must be accompanied by a symbol known as a *radura*, an international symbol designed specifically to indicate food irradiation.

24.5 Scientific Concerns about Irradiaiton

Although food irradiation is an effective tool, there are legitimate scientific arguments that can be made against food irradiation. Even though the arguments have been substantially refuted, they are still often recited by those unfamiliar with the science of food irradiation.

24.6 Nutrition Effects of Irradiation

Macronutrients (proteins, fats and carbohydrates) and minerals (e.g., iron, phosporous and calcium) are substantially unaffected by radiation doses at approved levels. Some vitamins, particularly thiamine, undergo an appreciable reduction when exposed to radiation. The maximal use of food irradiation on meat would result in a decline in the amount of B vitamins consumed in the average person's diet. Irradiation under approved conditions has been demonstrated to have no dangerous effects on food, either chemical or microbial in nature. Although irradiation does reduce non-pathogenic spoilage bacteria (thereby increasing shelf life), the population of spoilage bacteria still exceeds that of pathogenic bacteria, so that the ordinary characteristics of spoiled food will still been present before the food has reached a dangerous state. Irradiation can have undesired side effects on sensory qualities of the food, but such effects tend to be minimal, especially when manufacturers take conscious steps to avoid them.

24.7 Conclusion

The first salient point is that the scientific evidence in favor of the safety and efficacy of food irradiation is overwhelming. Scientists have data from direct observation of the food products themselves, as well as theoretical analyses and experimental verification through animal testing. The second major theme that emerges is that education can play a pivotal role in the future of irradiation. Much of the economic inefficiency that interferes with the widespread acceptance of irradiation can be explained by lack of information on the part of the consumers. The flip side is that irradiation may prove fruitless if not accompanied by consumer education. If consumers view irradiation as a magical solution to problems of food safety, they may become careless in their own food safety habits. If manufacturers are permitted to use irradiation as an excuse for carelessness in other phases of processing, the end result may be a less sanitary product. Last but not least, there are optimistic signs for the future of irradiation. The regulatory climate has been, and continues to be, hospitable to food irradiation as a food safety technique. X-ray irradiation in particular seems to be a promising technology that is on the verge of a commercial breakthrough.With all of the positive indications, however, it seems that irradiation will eventually expand to the scale that its considerable benefits would justify.