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Understanding Radiation Energy and Its Use in the Preservation of Seafoods

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THE NATURE OF RADIATION

Radiation can be defined as the transfer of energy from one place to another through space. Good examples of this are the transfers of light and heat, two different forms of energy, from the sun to the earth. The earth also receives other types of radiant energy from the sun as well as from other radiating bodies in outer space. Cosmic rays and Xrays are two more examples of these external radiations. Now, it must be made clear from the start that there would be no life on earth if it were not for most of the radiations it receives. For example, without light, all photosynthesis would cease. To put it simply (Fig. 1), photosynthesis is the process by which plants grow by the action of the sun's light on the green substance (chlorophyll) they contain. Of course, without the sun's heat, the earth would steadily grow colder and all things would finally become completely frozen.

On the other hand, the amount of radiation which is directed toward the earth is greater than we actually receive. In fact, it would be harmful if all of it were to reach us. Fortunately, our atmosphere acts as a screen, stopping much of the radiation (Fig. 2) and we get just enough to sustain life on the earth. While we are on the subject, it might be informative to point out that our bodies have a built-in mechanism to protect us from the harmful effects of the normal radiation we receive. Cosmic rays reach the earth from outer space incessantly, and it is estimated that each person receives about 50 cosmic ray hits every second. It would seem that this radiation rate is tied in to our natural ability, as an evolutionary development to withstand a certain amount of radiation. Of course, when we receive too much radiation, we become ill, and when the excess is great enough, the radiation becomes deadly.

RADIATION IN OUR NORMAL DAILY ROUTINE

Besides the radiations which we have just discussed, it is pertinent to note that we make other encounters with radiation in our normal daily routine. One example is vitamin D, which is added to ordinary milk. Vitamin D is first produced by converting a chemical, which we can call provitamin D, into vitamin D by irradiating it with ultraviolet or gamma rays. The same effect can be had by exposing it to the sun. This is then added to milk as a supplement. As a matter of fact, vitamin D is normally produced in our bodies in exactly the same way. This chemical, which we called provitamin D, is situated just beneath our skin, and when we are exposed to the sun, its rays cause a chemical change producing vitamin D (Fig. 3). Vitamin D is necessary to maintain a balance of certain minerals in the body to prevent a disease called rickets.

Some of the more familiar types of radiation are ultraviolet rays (we see these used to sterilize glassware), radio and television rays, and Xrays. Differences in the length of these and of those of other radiations are shown in Table 1.

In some ways, Xrays, gamma rays, and cosmic rays are similar to the other forms of radiation we have mentioned, but they have one property which makes them different from most—they are highly penetrating. As we know, Xrays can be used to photograph the inner parts of our bodies. (Some might remember when Xray machines were used by shoe salesmen to make sure that a prospective customer was properly fitted). However, it has been found through experience that unrestricted exposure to Xrays can be

CARBON DIOXIDE + WATER + SUNLIGHT = SUGAR + OXYGEN

Carbon dioxide, a gas in air, is a by-product of man, animals, combustion processes, etc.

Water exists in air as a vapor and is plentiful as a liquid in fertile soil.

Sunlight is the energy source for this reaction.

Sugar produced in plants can then be converted to starch or fat in the plants. By adding nitrogen, the plant can then produce proteins.

Oxygen, a by-product of plants, is necessary for life in man and animals, and it is necessary for combustion.

Figure 1.—The basic reaction in photosynthesis.

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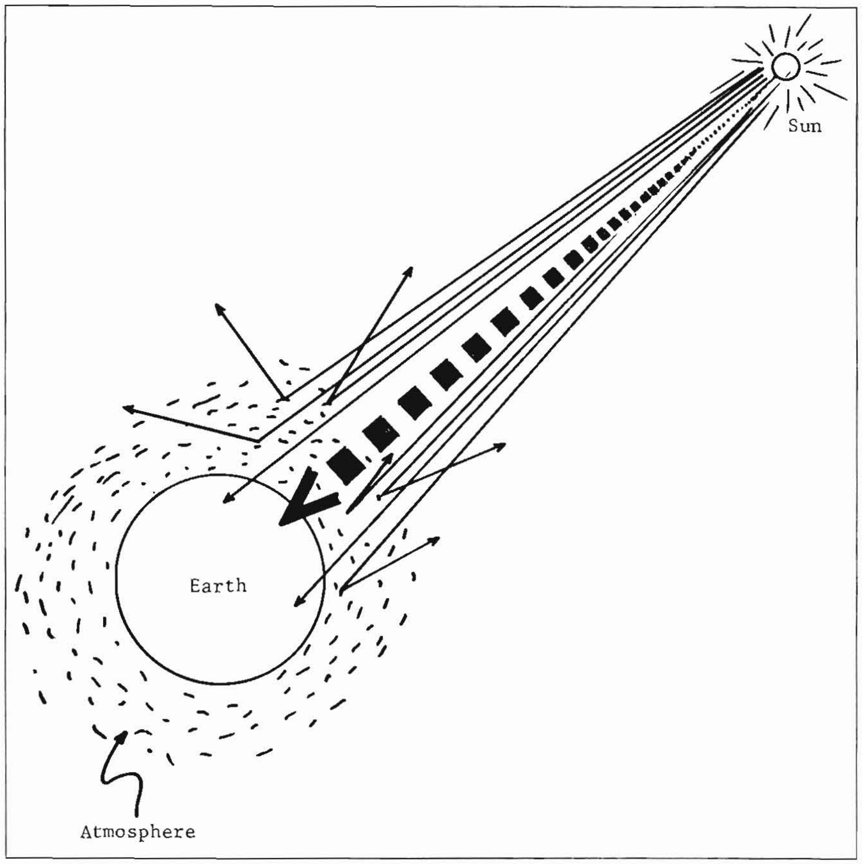
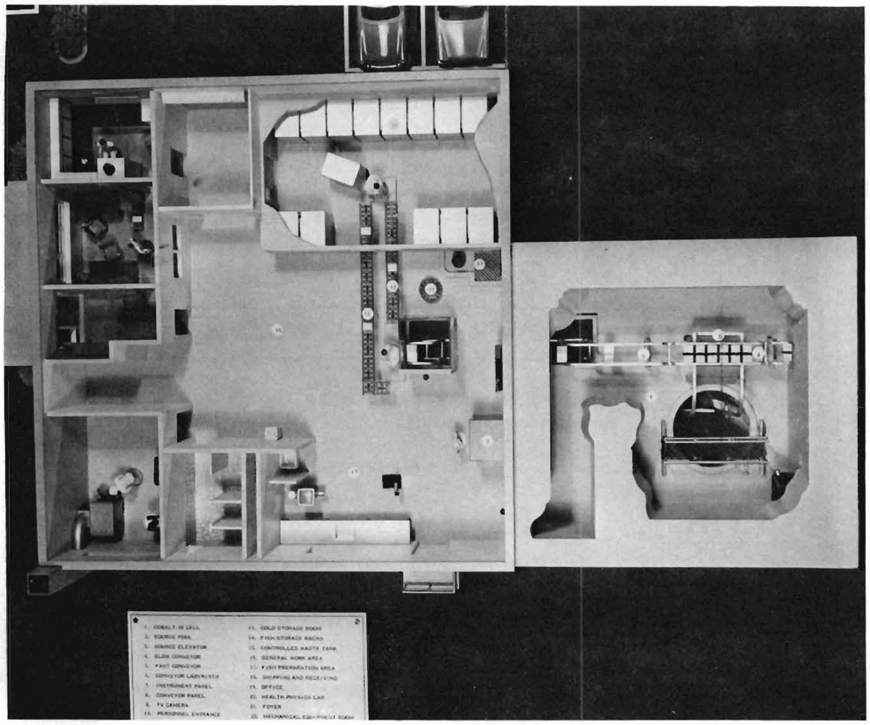


Figure 2.—Much of the radiation from the sun is deflected by the earth's atmosphere.



Floor plan of the irradiation facility at the Northeast Utilization Research Center.

dangerous, and there are now strict controls to protect both the patients and the medical people who use the Xray equipment. Of course, these findings eliminated the shoe Xray machine and other unnecessary exposures to Xrays.

For some time now, however, cancer patients have been treated with radiation. Since cancer is a mass of fast-growing new cells, and since radiation attacks new cells more easily than it attacks old cells, we can understand that when a thin beam of radiation is made to hit a cancerous tumor, the radiation will destroy it. We must recognize that the radiation will also cause some harmful effects to the good cells it unavoidably must pass through, but the harmful effects are considered to be minor compared to the beneficial effects. For the treatment of cancer, we mainly use gamma rays from radioactive cobalt.

We should mention that there exist on this earth natural radioactive elements. Perhaps the most important is carbon 14 (a radioactive form of carbon) believed to be largely produced by the action of cosmic rays on ordinary carbon. Since carbon is an essential element of all living things, as well as all things made from them, all animals and plants continue to add radioactive carbon throughout their normal life cycle. Measurements of radioactive carbon are used for estimating the age of bones, fossils, etc. because when a living thing dies, it stops adding radioactive carbon to its body, and consequently, there is less and less of it as time passes. Because all radioactive elements continually decay with the passing of time, radioactive carbon becomes ordinary carbon when it loses its radiation energy. Man also carries other radioactive elements, potassium for one, which can be found in the teeth and in the bones.

HOW RADIATION PENETRATES

One might wonder how an Xray, a gamma ray, or a cosmic ray can penetrate something solid, as a brick or a piece of wood, especially since we can see no evidence that this takes place. The explanation for this apparent mystery is that we can't see the detailed structures of the brick and the wood because of their extremely small sizes. It is the same as looking at a cloud. We can see its shape, but because of the distance, we can't see the droplets of moisture of which the cloud is made. Down in the range of sizes, much too small for the eye to see, even with the help of a microscope, solid materials can be found to be made of very small particles with a lot of space between them. In fact, solids are really mostly empty space. A brick, as other solid materials, appears to us to have a shape because the particles of which it is made are held together in a sort of weave or pattern. It is similar to the weave in a cloth, but on a much, much smaller scale. The structure of such solid substances as a brick is so small that even the point of the sharpest needle cannot pierce it. In Figure 4, we can see represented a piece of finely woven cloth (top left), a needle (middle left), and a part of a brick (lower left). The dimensions of the parts in Figure 4 are not to exact scale. They are intended only to illustrate a message. The point of the needle is shown magnified one million times on its right. A point of the brick equal in size to the point of the needle is magnified one million times, and it is shown on its right. Likewise, a point between the fibers of the cloth is shown to the same magnification. Note that the top circle on the right is empty. It represents empty space among fibers in the fabric, which can hardly be seen with the naked eye. The circle in the middle represents the point of the needle. Notice that it is mainly empty space, but contains many particles. These are atomic particles of which the needle is composed. The bottom circle, representing the point on the brick, shows the detailed composition of the brick which is also mostly empty space. We can see that the entire middle circle could pass through the upper circle, because the upper circle is completely empty. However, the whole of the middle circle could never pass through any of the spaces among the particles of the bottom circle. On the other hand, gamma rays and Xrays, as well as cosmic rays, are much smaller than the smallest specks shown in the magnifications, so we can see that it is very easy for these rays to pass through the spaces among the particles.

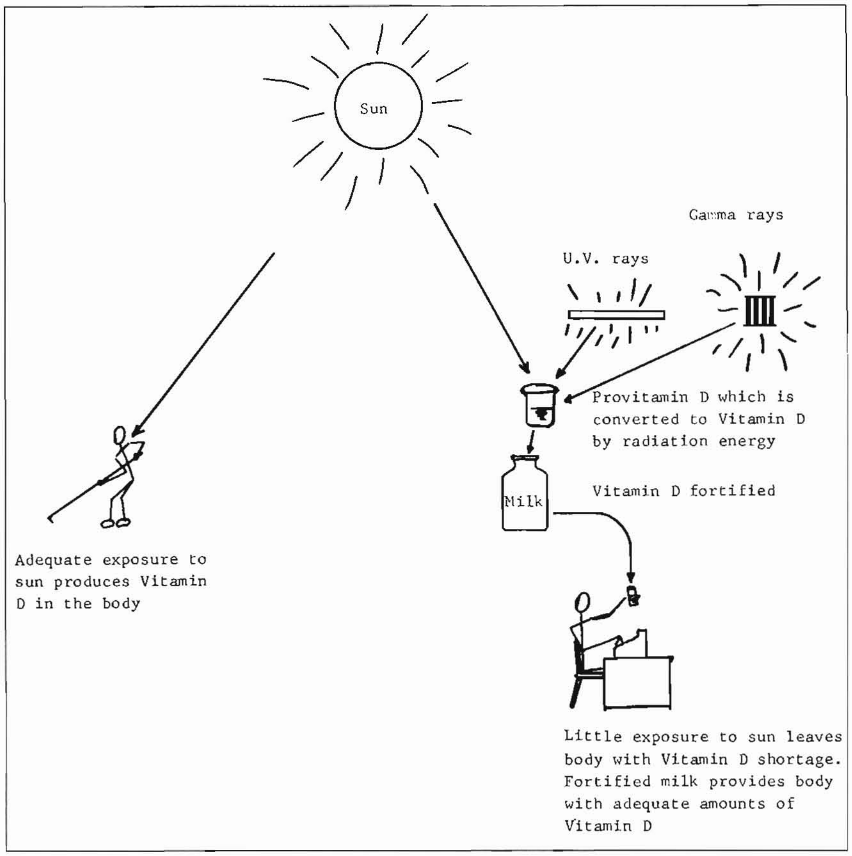
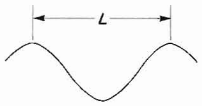


Figure 3.—The body can get vitamin D directly from the action of the sun's radiation or indirectly by drinking fortified milk.

Table 1.—Wave lengths[1] of different energies.

Energy	Wavelength (approximately)
Electricity	1,000 to 10,000 miles
Radio	100 yards to 1 mile
Television	1 to 10 yards
Radar	1 inch
Infrared	1/1,000 inch (1 mil)
Visible light	1/10 mil
Ultraviolet	1/1,000 mil
Xray	less than 1/1,000,000 mil
Gamma	a little shorter than most Xrays
Cosmic	shorter than gamma or Xrays

[1] These energies are believed to follow a wave-like path as shown below. The length of the wave (*L*) is the distance between 2 peaks.



These rays strike matter at the speed of light and although matter is mostly empty space, the rays eventually strike a particle, whereupon they lose some of their speed and are deflected from their course much like a cue ball which strikes one or more pool balls before it comes to rest. The thicker an object is, the more particles are available to block the rays which strike the object, and when the object is thick enough, the rays are slowed by too many collisions with particles and finally stop.

Because of their high speeds, however, these high energy rays are very penetrating. For example, it takes as much as 5 feet of solid concrete to hold back the gamma rays of the cobalt 60 source used in the research laboratory of the Northeast Utilization Research Center in Gloucester, Mass.

MEASURING THE RADIATION DOSE

Depending on the amount of radiation being produced, we can say that it is intense or not so intense. As with all other things that vary in intensity or strength, it makes it convenient to be able to measure radiation. For most applications, radiation is measured according to amounts received by a target. These amounts depend on the time of exposure as well as on the intensity of the radiation. The unit which has been chosen to measure the amount of radiation received is called a "rad", from the term radiation-absorbed-dose. The unit "rad", to measure radiation, is used in the same way that we use calories to measure heat, inches to measure length, and ounces to measure weight. A rad is an extremely small unit, and it might help to see how small if we compare it with a more familiar unit, the calorie. Radiation energy is largely converted to heat energy when it is absorbed, and it has been found by actual measurements that the amount of heat produced when 500,000 rads are absorbed is equal to about one calorie. However, radiation does other things besides producing heat, so we cannot really use rads and calories interchangeably.

PRESERVATION OF FOOD

In order to understand how radiation preserves foods, we need to know how food spoils, and it might be helpful to consider other preservation methods. The most important type of food spoilage is caused by bacteria. Bacteria are very tiny living things, much too tiny for the naked eye to see. They are so tiny that thousands can grow in the space taken up by the period at the end of this sentence. Because of their tiny size, bacteria and other very tiny forms of life are called "microorganisms". Some of these bacteria are capable of producing poisons which can make people sick or can even cause their deaths when they eat infected foods. Most bacteria are not considered to be poisonous, but many of them are responsible for the production of foul odors when they decompose the infected foods making them unappetizing.

All raw foods contain bacteria, so in order to prevent spoilage by bacteria and other microorganisms, much of the food we eat is preserved. Obviously, foods to be consumed within a short time do not need to be preserved. They should, however, be kept as cool as possible until they are consumed. To preserve foods, it is necessary to destroy the bacteria or to prevent their growth. The use of heat is one of the most effective means of preserving foods, because when enough heat is applied, the bacteria can be killed. Foods preserved by heat must be packaged in airtight containers, usually cans, beforehand so that no bacteria can reinfect them after they have been heat-processed. Examples of heat-processed foods are corn, peas, string-beans, etc. When foods are heat-processed in cans, they will last for years without any refrigeration.

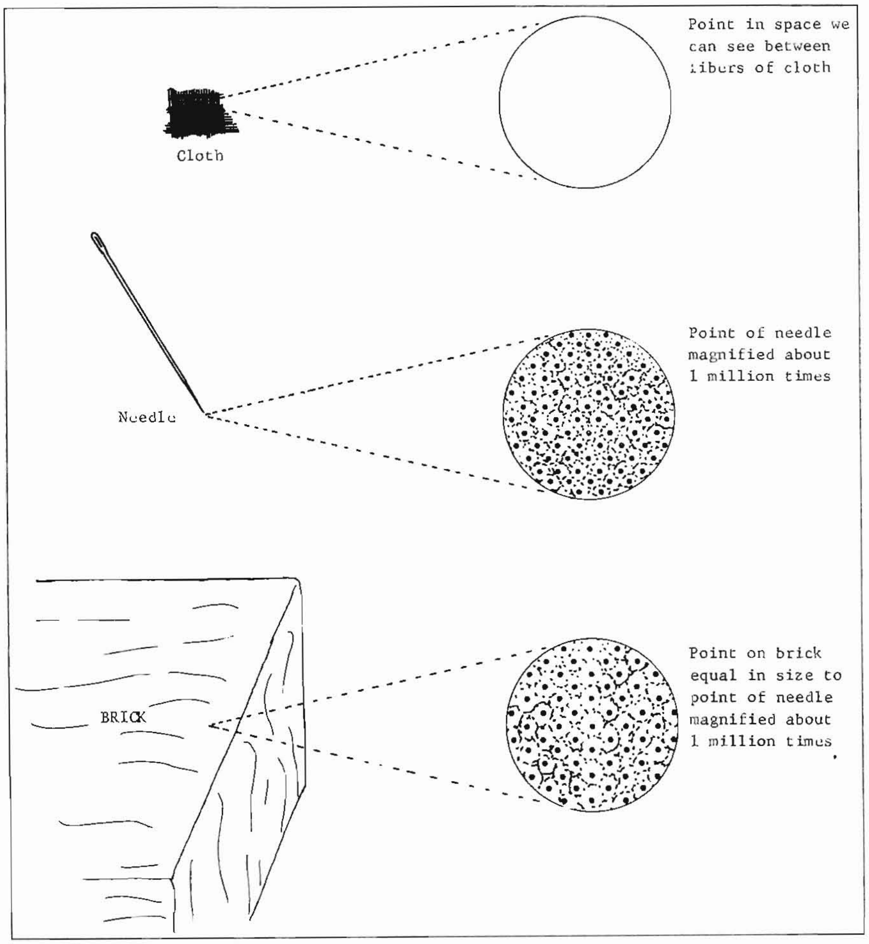


Figure 4.—Million-fold magnifications of point of needle, point on cloth and point on brick.

Although many foods can be heat-processed, there are some which cannot tolerate much heat. Examples of these more delicate foods are milk and most fish. In the case of milk, it is "pasteurized" using smaller amounts of heat. By pasteurization, we mean that most of the bacteria are destroyed (about 99 percent), and the food is made safe to eat. However, since some bacteria remain in the food, it will eventually spoil within one to a few weeks. Furthermore, it is necessary to refrigerate the food to attain even that shelf life, because bacteria grow faster when the food is stored in a warm place. We can see the result of storing fish for just 12 hours at 42°F against storing it in ice by looking at Figure 5. The figure shows that for every 12 hours, one bacterium of a particular species forms two bacteria at 32-33°F, but at 42°F, one bacterium forms 64 bacteria. (Bacteria of other species have different generation times.)

Canned fruits can be preserved with less heat than corn or peas because fruits are classified as acid foods. Acid can be considered to be a preservative because it does not allow harmful bacteria to grow. This brings up the subject of preservation by preventing bacterial growth as opposed to preservation by killing the bacteria.

We can prevent the growth of bacteria by removing something the bacteria need or by adding something that they cannot tolerate. To begin with, we need to recognize that there are many different types of bacteria which vary widely from one another as to their requirements and as to the conditions they can tolerate. Some grow well in cold as well as in warm environments. Others grow well in warm environments rather than cold ones. Still others grow well in salt or sugar or acid, and so on. Fortunately, nearly all of the bacteria that grow in acid or in salt are not harmful to us.

The growth of poisonous bacteria is stopped when a food has a high acid

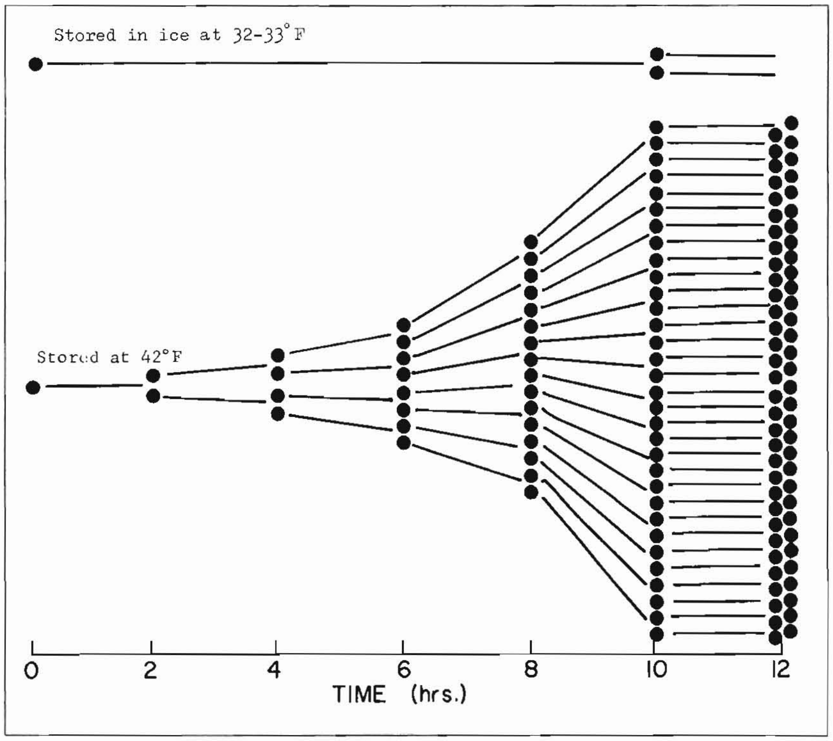


Figure 5.—The increase in number of bacteria on fish stored in ice (time between generations about 10 hours) and at 42°F (time between generations about 2 hours).

content, as in fruits, or when the salt concentration is high enough, as in salted fish. One way of stopping most of the bacterial growth is to remove the water from the food because bacteria need water to grow. Examples of this form of preservation are dried beans, dried milk, dried potatoes, etc. Another preservation method is to add chemicals that bacteria cannot tolerate, such as sodium benzoate, sodium nitrite, etc. In all preservation methods the object is the same—to prevent bacterial growth.

HOW RADIATION PRESERVES SEAFOODS

We discussed earlier how Xrays and gamma rays were able to penetrate even solid materials, at times colliding with atomic particles. For our purposes, we can think of gamma rays as microscopic bullets streaking through matter, hitting anything in their path and continuing on their way until they are finally stopped after many deflections. When a ray hits a bacterial cell, the impact is so damaging that it results in the death or crippling of the microorganisms. The details of radiation destruction of bacteria are complex and will not be discussed here.

Of course, the greater the amount of radiation passing through a food, the more hits there will be on the bacteria. Enough research has been carried out to show that a food has to receive about 5 million rads of gamma radiation in order to be sterilized (kill all the bacteria) and about 200,000 rads to be pasteurized (kill about 99 percent of the bacteria). Figure 6 shows bacterial contents of unprocessed, pasteurized, and sterilized fish.

It might be puzzling to learn that it takes 25 times as much radiation to kill the last 1 percent of the bacteria as it takes to kill the first 99 percent. This can be explained by the fact that bacteria are of different types, some more resistant than others. Some bacteria can form a hard shell called a spore, which is extremely resistant to radiation, heat, and other preservation methods, and requires all of the extra energy before they are destroyed.

WHY RADIATION IS DESIRABLE FOR PRESERVING SEAFOODS

We noted in an earlier section that many seafoods are too delicate to preserve by heat-processing. Of course, we know that some seafoods can be satisfactorily heat-processed; these include tuna, sardines, anchovies, and herring. Lobster, crab, and other shellfish are also heat-sterilized, but are not considered to be as acceptable as the fresh products, especially to consumers who are familiar with fresh lobster, crab, etc. Except for a few seafoods, we find that heat-sterilization is too drastic for preserving them. This is true for the fillets and steaks of many species of fish—in fact, even heat pasteurization is too harsh.

Fish can be preserved by salting, drying, smoking, pickling, freezing, and by combinations of these treatments. Except for freezing, each of these treatments changes the eating quality of seafoods considerably, so that they are not necessarily appetizing to anyone not accustomed to them. Freezing is theoretically the best of the conventional processes from a quality retention standpoint. Unfortunately, this theory is not completely supported by experience.

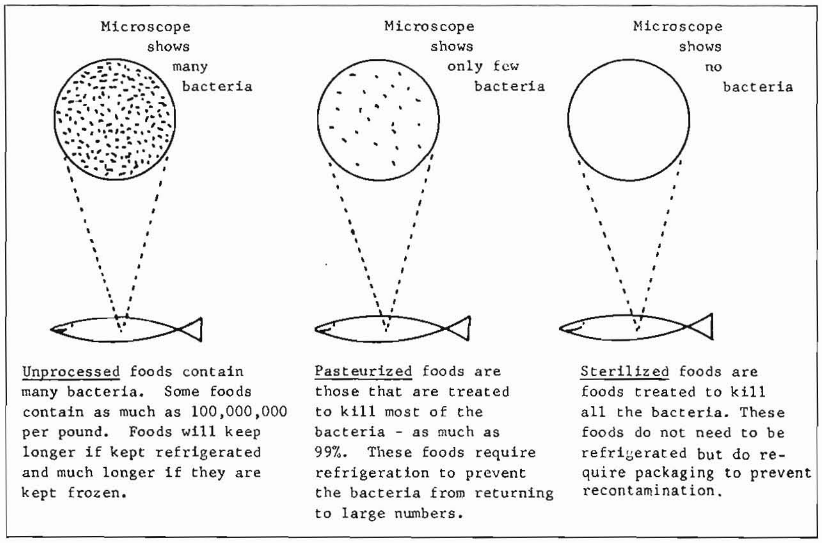
Since it first became recognized that radiation could be used to preserve foods some 20 years ago, food scientists have tested this processing method. It was found that the amount of radiation needed to sterilize fish was more than their quality could tolerate. However, seafoods could be pasteurized with low amounts of radiation without damage to their quality. Research laboratories of NMFS, as well as those in a number of universities, have conducted comprehensive research, under contracts to the U. S. Atomic Energy Commission, to show that most fish and shellfish can be satisfactorily pasteurized with a treatment of about 200,000 rads of gamma radiation. The most experienced food tasters could not detect any difference between the qualities of irradiated and nonirradiated fish. The researchers found that the shelf life of any conventionally-packed seafood could be doubled or tripled by treating it with 200,000 rads of radiation, which destroyed over 99 percent of the bacteria normally found in the fish. This type of treatment does not make the fish radioactive. When fish were tested for radioactivity afterwaves, none could be detected.

Using regular chemical analyses, the scientists found that radiation has little effect on the quality of seafoods. So, it is not surprising to find that fish preserved by radiation look and taste like fresh nonirradiated fish, whether they are compared raw or cooked, and the only difference is that the irradiated fish have at least double the shelf life of nonirradiated fish. The scientists further found that the sooner fish are treated, the longer and better they will keep. In special experiments, some fish were irradiated at sea just after they were caught. Because fresh-caught fish have relatively few bacteria, it was found that only 50,000 rads were necessary to preserve them. This has motivated some scientists to investigate irradiation at sea more thoroughly.

In many undeveloped countries, good quality fish are available only to coastal inhabitants. If the fish could be preserved in a manner which would not alter their quality, they could be transported long distances inland to those areas or countries where protein is scarce. Irradiation preservation is a potential process for this type of situation where refrigeration is generally unavailable.

While the use of ionizing radiation has demonstrated a potential as a processing method in certain applications, it cannot be applied until approval for its use is given by the FDA. The reason for this is that the FDA has declared ionizing radiation to be a food additive and by law all food additives are used only under the approval and regulation of the FDA. Under normal circumstances the FDA requires proof of safety and this is usually demonstrated by animal feeding studies involving generations of specific species of test animals over a specified minimum of time. The most advanced animal testing program presently underway that has the promise of gaining FDA approval for the radiation process is presently being conducted at the U.S. Army Natick Development Center, Natick, Mass.

For additional information, readers are invited to write the Director, Northeast Utilization Research Center, National Marine Fisheries Service, NOAA, U.S. Department of Commerce, Emerson Avenue, Gloucester, MA 01930.



Unprocessed foods contain many bacteria. Some foods contain as much as 100,000,000 per pound. Foods will keep longer if kept refrigerated and much longer if they are kept frozen.

Pasteurized foods are those that are treated to kill most of the bacteria - as much as 99%. These foods require refrigeration to prevent the bacteria from returning to large numbers.

Sterilized foods are foods treated to kill all the bacteria. These foods do not need to be refrigerated but do require packaging to prevent recontamination.

Figure 6.—Bacterial content of unprocessed, pasteurized, and sterilized foods.

Pool of clear water at the bottom of which is stored the cobalt 60 (in the containers at the bottom of the track).

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