The Gamma-Ray Gourmet

Scientists cook up tests for irradiated food

By RICK WEISS

What do you get when you irradiate an apple with 100,000 rads of gamma rays? Unfortunately, nobody knows for sure. And it is precisely this uncertainty that is stimulating a nationwide debate about the safety and usefulness of food irradiation.

Proponents see irradiation as a safe replacement for many pesticides, a way to reduce spoilage and a blessing for the world's hungry. Opponents point to potentially carcinogenic by-products in irradiated food, possible losses in nutritional value, and the problems inherent to nuclear facilities and the disposal of radioactive wastes. The debate involves farmers, food technologists and nuclear weapons activists.

If there is one thing that all factions can agree upon, however, it is that research into the chemical effects of high-energy food sterilization is still incomplete. So behind the din of antinuclear activists arguing with food industry representatives, such research, mostly funded by the Department of Agriculture (USDA), is quietly being done.

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The technology in question involves the irradiation of fresh foods with gamma rays as a means of extending shelf life. Doses ranging from 20,000 to 3 million rads (the equivalent of up to 150 million chest X-rays) for each item of food are useful for killing spoilage-promoting bacteria or to delay ripening. Although spices are the only irradiated edibles currently being marketed in the United States, the Food and Drug Administration (FDA) has already approved irradiation for use on produce and some meats. FDA regulates irradiation not as a process but as an additive.

But what exactly is "added" to irradiated food? Irradiated food looks and smells better for an extended time, but little is known about the chemical changes induced by the process. This mystery is of concern to scientists and consumers for two reasons: First, without a reliable chemical "marker" to test whether food has already been irradiated, the technology is difficult to regulate. There is the possibility of nonirradiated food being sold fraudulently as irradiated food. Or food could be illegally re-irradiated — either inadvertently or as a substitute for maintaining hygienic practices between harvest and packaging. Over-irradiated food can be invisibly damaged.

A second concern is that even small doses of irradiation may destroy nutritionally important compounds or create potentially dangerous chemicals in food. Food chemists seeking to identify and characterize such "radiolytic" changes, however, are hindered by the chemical complexity that is typical of most foods.

"Food is not a defined substance," says Richard Piccioni, a senior staff scientist with Accord Research and Educational Associates, a public health research group in New York City. "You don't know what's in food to begin with, and when you expose food to radiation you have no idea what the changes are," he said at a recent food irradiation debate in Washington, D.C.

But while scientists agree that it is difficult to identify and measure such changes, several say the task is by no means impossible.

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Michael Simic, of the Radiation Chemistry and Chemical Dosimetry Group at the National Bureau of Standards in Gaithersburg, Md., is working to identify altered amino acids that could be used as markers in irradiated foods (SN: 7/12/86, p.27). His group has already identified an altered form of tyrosine that is produced when meat is exposed to ionizing radiation.

Simic is also using electron spin resonance (ESR) to detect food-borne free radicals — highly reactive chemical compounds that appear in bone or cuticle (such as shrimp shell) after exposure to irradiation. Simic says the latest generation of ESR machines can detect food that has been irradiated with as little as 1,000 rads.

Meanwhile, researchers in Germany are having some success with the detection of thermoluminescence, or the emission of very small amounts of light that are "trapped" inside the matrix of irradiated food. In those experiments, the food is heated in a laboratory and emissions are measured with a spectroscope.

Other researchers are measuring the amount of hydrogen gas that is generated inside irradiated food. And still others are measuring the reaction products resulting from the bonding of DNA-thymin (a chemical component of DNA in food) with the hydroxyl radicals formed by the irradiation of water in food.

Some of the more promising research into irradiation markers is being performed by Wassef Nawar, a professor in the Department of Food Science and Nutrition at the University of Massachusetts at Amherst. Lipids produce the greatest number of detectable by-products in irradiated foods, Nawar says. In particular, he has found, radiation-induced cleavage of lipids tends to occur in a certain region of the fat molecule called the ester-carbonyl region. This results in the accumulation of compounds with a characteristic shortage of carbon atoms relative to the major fatty acid in the food — compounds he says can be measured simply and rapidly using gas chromatography.

In related research, Dan Schwartz, at the USDA's Agricultural Research Service in Philadelphia, is looking for naturally occurring markers in irradiated chicken. Working with chicken livers, he and his colleagues found a compound that is a degradation product of cholesterol and that may prove to be diagnostic of irradiation. The compound increases in concentration by about 100 micrograms for every 300,000 rads of exposure, making it a possible quantitative indicator as well.

Further tests are needed, however, to ensure that the marker is in itself nontoxic. Even if the compound is safe, Schwartz adds, scientists will have to see if its concentration changes significantly over time. They'll also have to confirm that the compound doesn't occur in traditional forms of processing that do not involve irradiation.

Indeed, one of the major disappointments in the search for irradiation markers is that many of the "unique" by-products of irradiation have subsequently been found in nonirradiated food as well.

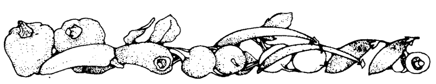
"The trouble is not that it is difficult to detect these changes, but that it's hard to prove definitively what caused them," says George Pauli, a safety review coordinator for the FDA's division of food and color additives. Free radicals, for example, which have been detected in large quantities in irradiated dry foods, can also be formed by simple heating or even grinding.

In addition, identification of markers often requires sophisticated equipment not generally available to food inspection services. To detect Schwartz's cholesterol by-product, for example, requires a gas chromatography column and a mass spectroscope. The procedure is too complicated for everyday use.

For compounds that do prove to be good markers, there is always the hope that simpler tests might be designed. Some researchers say it may be possible to develop ELISA immunoassays — sensitive, enzyme-based biological tests — to detect the presence of suspected irradiation markers.

Equally difficult is the problem of quantitative analysis. An ideal marker would be produced in amounts proportionate to the amount of irradiation, and would remain relatively stable over the shelf life of the product. Many of the markers tested so far, however, have been found to disappear over time, making measurement inaccurate unless it is done immediately after processing.

"The quantitative [aspect] will be a real beast," Pauli says. "For example, I can look at a piece of meat and tell whether or not it's been cooked. But I can't tell you what temperature it was taken to or how long it was roasted." Indeed, he says, radiolytic products will vary in concentration depending on wavelength of radiation used, dose, temperature, time elapsed since irradiation and the conditions of storage. In addition, free radical concentration will depend in part on the amount of oxygen surrounding the product when it is irradiated. All of these variables make it difficult to devise a test that would tell to what degree, if any, certain foods have been irradiated.



Even more troubling, many scientists say, is that aspects of the irradiation process itself make it difficult to determine the health risks of irradiated food.

Under normal conditions, very small quantities of irradiation-caused by-products accumulate in food. Traditionally, scientists have tested the safety of low-concentration, nonirradiated food additives by giving unusually high doses to test animals and looking for such things as tumor formation, chromosomal abnormalities or birth defects. But how does one obtain large doses of these rare breakdown products? Counterintuitively, more radiation doesn't necessarily produce more radiation by-products.

"You simply can't *get* high doses of the stuff," says Piccioni, "because if you increase the radiation level 1,000 times, then you don't have food anymore — you have carbon dioxide and water." And for obvious reasons, he adds, you cannot simply irradiate food at normal doses and then force a test animal to eat 30 times its normal diet.

The impossibility of testing large doses of radiolytic products on animals puts government regulators in a difficult position. Additives are subject to the FDA's "Delaney clause," which requires that any additive shown to be carcinogenic *in any dose* must be kept off the market. It is difficult to see how the standard can be fully applied to irradiated food when no method exists to implement high-dose tests. In fact, some opponents argue, since gamma rays themselves are known to be carcinogenic, the wording of the Delaney clause could be interpreted to forbid their use altogether as food additives.

That argument ignores the fact that irradiation is not actually added to food in any traditional sense of the word. But it is representative of the somewhat strained logic that, in the absence of definitive scientific tests, has come to dominate both sides of the food irradiation debate.

Indeed, says one irradiation supporter with unintended irony, "Food irradiation is so good for food *because* it is so dangerous for everything that lives." □

A primer in food radiochemistry

Most food irradiation is accomplished with gamma rays, a form of electromagnetic energy similar in wavelength to X-rays. The process usually involves exposure to radioactive cobalt-60 in a heavily shielded processing facility. Radioactive cesium-137, retrievable through the reprocessing of nuclear waste, has also been used as a source of gamma rays.

Electron beam machines capable of accelerating electrons to high-energy states have also been used, but have limited usefulness as irradiators. Such beams fail to penetrate more than a few centimeters, and unlike radioactive gamma sources they produce unwanted heat in the food being irradiated. A new generation of electron beam X-ray irradiators looks promising, however, according to researchers at the Lawrence Livermore (Calif.) Laboratories.

A single gamma ray-energized electron may produce 30,000 to 40,000 individual ionization reactions in food, and may excite as many as 80,000 other electrons in the first 10^{-14} seconds of the radiation process. These secondary electrons, called delta rays, can in turn produce further chemical changes in food.

In dry foods, chemical changes may occur as a direct result of irradiation energy acting on organic molecules. In most foods, however, radiation is absorbed by water molecules. Electrons are knocked off of some water molecules, and these electrons may in turn disrupt surrounding chemical bonds with the subsequent formation of charged, highly reactive "free radicals."

Irradiation of fats, for example, results in a free-radical "chain reaction" that creates an immense variety of hydrocarbons, aldehydes, ketones and esters. In many cases, these are impossible to differentiate from the large variety of compounds that result from cooking.

Looking at proteins, researchers have found that sulfur-containing amino acids seem to be especially sensitive to irradiation, making them potential irradiation markers. Unfortunately, their destruction by gamma ray-propagated hydroxy radicals can give meat a rancid flavor. Other potential markers are equally undesirable, and ideally their production would be minimized. Of the many radiolytic products from carbohydrates, for example, there is some concern about the apparent production of small quantities of malondialdehyde, a chemical that has been shown to be deadly to cells.

Meanwhile, researchers are also looking into the effects of irradiation on various types of food packaging. In addition to concerns about gamma damage to plastics, scientists want to know if packaging residues can be transferred to prepackaged food that is subsequently irradiated. — *R. Weiss*