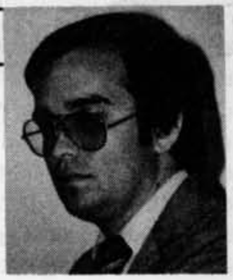
Interview: John Cox



# X-rays offer a new approach to the irradiation of food

*Dr. John Cox is president of FutureTech Industries, Inc. in Gainesville, Florida. He was previously a research scientist at the University of Florida and worked for U.S. Army Ballistic Missile Defense and for the National Aeronautics and Space Administration to develop high-energy nuclear-powered lasers. He has also developed a comprehensive college course on lasers available on video cassette. Mrs. Hecht interviewed him on Sept. 17.*

**Q:** When did you begin working on the idea for food irradiation with x-rays?

**Cox:** It was even before I started FutureTech, in November 1984. I was sitting around the cafeteria with two other faculty members and we were kicking around the idea about food irradiation. We had just gone to a seminar given by the Florida Citrus Council at our department, and we were discussing the idea of a continuous-duty x-ray machine, similar to that used at airports to scan luggage. We thought an x-ray machine poised over a conveyor belt, irradiating food, would be a very good idea because it would mitigate some of the logistical and economic problems associated with dealing with a radioisotope source. Another device that is being studied for this use is a high-energy electron accelerator.

We formed a company called Citrex Technologies, Inc., and wrote a grant proposal in March 1985 to the U.S. Department of Agriculture under the Small Business Innovative Research program (SBIR). They accepted the proposal, and by September 1985, we were under way. We got a $50,000 Phase I research grant. For six months, we did a study of the disinfestation of Florida grapefruit.

**Q:** You've had about a year of research now on your idea; how far have you come?

**Cox:** There are several things. First of all, you can control an x-ray source to a far greater degree than you can control a cobalt source. You can't really control the emission from the radioactive source, you can't control things such as the energy of the particles and so forth that come out.

**Q:** I think with cobalt-60 irradiation, all that they can do is put the food closer or farther away from the source.

**Cox:** Right. But with an x-ray source, you can can control not only the intensity of the source, but also the x-ray energy. And the energy from the source will dictate on a macroscopic level the way in which the radiation is absorbed in the food.

**Q:** What is the difference between the intensity and the energy?

**Cox:** To give you an example, it's like the photoelectric effect where you can shine all of the red light that you want on metal and it won't eject an electron. In other words, you can increase the intensity as much as you want; it won't cause any ionization. But, if you go from red to blue light—it doesn't matter how weak the blue light is—as soon as one blue photon hits the metal, it will eject an electron. So it's the photon frequency (which is proportional to energy) that makes a difference. This is a very rough analogy, because in the context of absorption of the x-rays at various energies in matter, it's not quite that spectacular a difference. Ionization occurs with all x-ray energy. The higher the energy, the greater the penetration depth to the food or into anything really, no matter what it is.

For example, if you wanted to take an x-ray of a human chest, you would probably use something on the order of a 100,000-electron-volt x-ray. But if you wanted to shoot through steel, you might want to use a 1-million-electron-volt x-ray. There is another curious thing. All the electromagnetic charts that show the spectrum always show gamma rays as being more energetic than x-rays. Well, that's not true; you can make x-rays with 10 million electron volts if you want. In other words, there's very little in the way of limitations in terms of forming x-rays. X-rays and gamma rays are identical from the context of what they do to matter when they interact. It's just a definition: X-rays are defined as originated by electrons and gamma rays are defined as originating in the nucleus. Other than that definition, there is virtually no difference in how they interact with food; they interact on an equal basis.

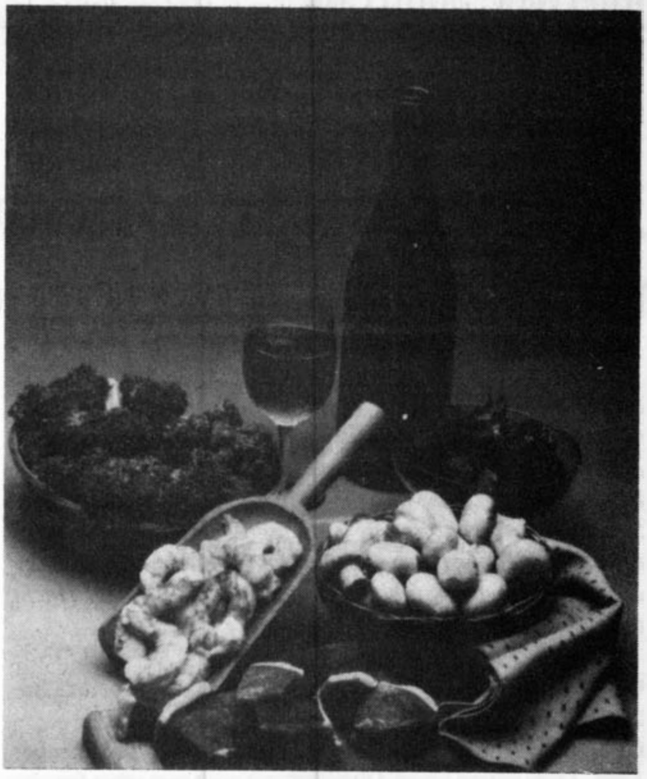
**Q:** So you are really saying that you can create x-rays of certain frequencies that will act in the same way as the gamma irradiation from a cobalt source.

**Cox:** Yes. For instance, suppose that you had a cobalt source that was emitting 1-million-electron-volt gamma rays. You could concoct an x-ray source that would produce the same sort of energy—1 million electron volts—that's commonly done. Now, as far as the food is concerned, it doesn't matter if it is being hit by an x-ray or a gamma ray; there is no qualitative nor quantitative difference between them. Now, one of the main differences we wanted to focus on is that a cobalt source would produce a mono-energetic spectrum. In other words, they make only one energy or two discreet energies, in contrast to the x-ray, which produces a broad spectrum containing many x-ray energies. Utilizing a spectrum of energies, you can get different effects than you can by using a mono-energetic source. This is another reason that you can control the effect with x-rays better than you can with cobalt.

**Q:** With the x-ray source, would you have a computer that would set the emission for whatever the particular food product?
**Cox:** You wouldn't even need a computer to do that. You would study each food group and once the correct emission was known, it would never change; you would just turn a knob on a set for treating bacon, or cooked stew, or potatoes, and so forth. It would all be established up front after a year or so of study, and each food group would have to be studied separately.

I was talking earlier about the inability to control what the cobalt, of course, does to the food. With the x-ray machines, not only can you jump from one food to another, but you can also control the amount of dose that is delivered to the skin of the food versus what is delivered to the bulk. This is a significant advantage. Especially with fruit, where you don't want to damage the peel trying to go after something in the core. Or maybe you only want to treat the skin, to get rid of fungus or bacteria on the skin only, then you don't want to deliver any dose to the middle, to the inside. You can greatly reduce the x-ray energy and just treat the skin. So that is another significant advantage that we have that is not practical or possible with cobalt or accelerator sources.

**Q:** It was my understanding that the food groups had been thoroughly studied for the cobalt and cesium sources, perhaps a little less thoroughly studied for the electron accelerator sources, but what about x-rays?
**Cox:** X-rays fall in that broad sort of category. You can make a general statement; that is to say, the effect of the radiation on the food is not done by the primary particle, it is done by the secondary particles generated by interactions. For instance, a 1-million-electron-volt gamma ray will generate maybe 10,000 ion pairs in matter. An x-ray of the same energy will do the same thing. It is those secondary particles (ions) that do all of the work. So it really doesn't matter what you hit it with (when it comes to x-rays or gamma rays). What does matter is the density of the hits, how many particles are interacting and the density of the object as to how far the particles will go before they slow down. For example, x-rays interacting in lead will generate those 10,000 ion pairs in a cubic millimeter, whereas in water it might be a cubic centimeter. So the density of the absorbed radiation is different depending on the density of the matter.



*Low doses of radiation have destroyed trichinae in the pork cubes picture here, extended the shelf life of the strawberries by delaying mold growth, delayed spoilage of the highly perishable shrimp, and delayed maturation of the mushrooms and broccoli, without changing the texture and flavor or significantly reducing nutritional quality.*

Now, the primary reason for going with x-rays was a logistical one and an economical one, as well as a psychological one. There are many different facets. The idea is to build a quasi-portable device, one that could be brought to the packing house. That is, we are going to reverse the role of the food irradiator. Currently, if you have an accelerator or a cobalt source, you need a multimillion-dollar facility. In order to justify the cost of that facility, you need to have a high throughput. You have to bring the food to the facility, which means extra handling, and so forth. We have always thought that food irradiation is really going to have a tremendous impact on the Third World. It's going to have very little impact in this country, since here you can pull out a frozen dinner from your freezer, throw it into your microwave, and in five minutes you've got a dinner. That dinner was prepared in the Midwest somewhere, it was delivered frozen to the grocer, and you put it in your freezer. The food was able to be grown on the farm, processed, packaged, delivered frozen, and you eat it five minutes from the time when it was frozen solid. So that is one alternative to food irradiation. In the Third World countries, there is no alternative.

There is also a psychological hurdle that you have to overcome, and as long as people have alternatives, they are less likely to take to any new thing. There are two things against it: For one thing, people don't really like new things; and second, people still don't understand the difference between food that was contaminated at Chernobyl and food that has been irradiated. So, as long as there is an alternative, people just aren't going to flock to food irradiation. However, in the Third World nations with no alternative, it's that or nothing. And that's where it's really going to make a big impact. In order to transfer this technology to the Third World, you've got to have something that's cheap, inexpensive, and user friendly. We are hoping that we can design this x-ray machine with those design criteria in mind.

**Q:** You are thinking of a portable machine that could be trucked or put on a barge and taken to the place of harvest, so that you don't have to take the product of harvest to a central facility.

**Cox:** That's right. A centralized facility is not practical in nations where they don't have road systems and machines to load and unload tons of food. A lot of times, the food is processed in one place, at great distances from where it is grown; these distances would seem much nearer distances here, but are great distances there because there are no roads. These devices wouldn't be truly portable in the sense that you could just plug them in anywhere; you'd have to permanently mount it, put some shielding around it, and have an electric power generator with it, but it would at least be amenable toward moving around from growing season to growing season, establishing it in different places. One machine could treat many different types of food.

**Q:** What is your ballpark dollar estimate on this? I know that a cobalt-source food irradiation centralized plant that can handle a high volume, from start to finish can be built for between $4 and $5 million.

**Cox:** Right. But there is an enormous overhead maintaining the facility. If you want to evaluate all of these different technologies—that is to say, the cobalt source, the accelerators, and our machine—you have to come up with a figure of merit. And the figure of merit that everyone has agreed to is the dollars it takes to irradiate or produce a given amount of radiation to a given amount of food: dollars per megarad ton. What does it cost to irradiate a ton of food at a given megarad? In more bite-size figures, how much does it cost to irradiate a pound of food? We are talking about a penny per pound.

**Q:** What are the comparative figures for a cobalt source, an accelerator source, and your x-ray source?

**Cox:** They are going to be on a par. However, that's not the whole picture. Once again, you've eliminated all of the extra things such as the initial tremendous investment, the need to transport and do the central packing. So it's not going to beat it dollar for dollar. It's going to beat it in the intangibles. In the ease of handling, the training, the ability to move it around and not to have to transport the food: Those are the kinds of things in which it is going to win. Economy-of-scale is hard to beat. We are going to be irradiating 10,000 pounds an hour, where cobalt irradiators can do many times that, about 2,500 pounds per minute. We will never be able to have that kind of throughput. That's why we can't beat them economically.

**Q:** Why can't the x-ray source have that kind of throughput?

**Cox:** Even to process 5 tons an hour you need a megawatt of electricity. Now, we are trying to get that down into the 100 kilowatt range by coming up with a novel x-ray source, but right now, if we are stuck with just a small departure from current technology, we are talking about enormous power consumption. Now to make a generator that produces a megawatt, all you need is soy bean oil or peanut oil [fuel] to run the generator. It's that simple. It's very energy-intensive.

. . . The United States has been studying food irradiation for 30 years, maybe longer. It is that fact that gives us the most encouragement that we'll be able to slug through the legal and psychological implications of this project. If there were some significant health risks—and many of those do take 30 years to become established—that would have been evident by now. The evidence is clear that there are none. And if we were starting from scratch now, trying to promote food irradiation without that body of knowledge, we would have a hopeless case.

**Q:** There are still people who believe in magic, not reason, who think that the technology itself is harmful.

**Cox:** There are people who believe that we didn't go to the Moon yet. You can always find that. But the psychological aspect of this whole thing cannot be ignored. That's why I am convinced that it's the Third World that is going to utilize this technology, and that it will come back to us in the United States later.

**Q:** In the developing sector they see that they need this technology because they don't have food—50 to 60% of their crops go to waste.

**Cox:** We're trying to design this x-ray system with that in mind: the idea that it can be moved around, that it can be operated with virtually no skill, that it doesn't require all of the highly skilled technicians that it takes to operate either a cobalt source or an electron accelerator.

**Q:** Can you explain what happens when the food moves by the x-ray source on the conveyor and in your prototype machine. How much power would it use and what would it look like?

**Cox:** It would look like a bank of fluorescent light fixtures.

It would be a rectangular box, if you will, the width of the packing house line, and maybe several meters long. The x-ray units would be mounted several inches above the conveyor belt, stacked up, so you might have 10 or 15 of them in a line. The food rolls by on the conveyor belt after it is washed or waxed or whatever. It would then be irradiated on the fly, and at the end of the conveyor belt it would be sealed and put in a box for shipment or whatever was required.

In my opinion, it is the advances in packaging technology that have really given food irradiation a boost. Without the packaging technology, food irradiation technology is of little use and benefit. It is the fact that we can hermetically seal food or anything—a medical instrument, for example—in plastics with machines which make it a much simpler process than a canning process. It also takes less energy. In my opinion, that is the main reason why the interest in fool irradiation is being revived. Food irradiation alone is not the key; it's the marriage of the technologies between packaging and food irradiation that has really gotten things rolling.

**Q:** I know when they were beginning to work on food irradiation in the army laboratory at Natick, Massachusetts, one of the first things they did was work on materials for packaging and get those approved by the FDA.
**Cox:** Now it turns out that the medical community has gone to that technology for sterilization purposes, and a packaging technology has been developed for that. The good thing about that is that it takes maybe a hundred times more radiation to sterilize than it does to process food, and the packages are designed for radiation dose levels 100-fold greater, so I am convinced that we can expect that a very inexpensive packaging technology for food is available on the shelf. With that in mind, and knowing that the USDA and FDA have finally approved food irradiation—it used to be considered a food additive, now it is considered a food process—I believe that the legal implications will be mitigated to some extent and we can move ahead.

**Q:** I think that the permit for food sterilization by irradiation is expected to be issued soon in the Federal Register.
**Cox:** That is fortuitous, that all those things are coming together at the same time.

**Q:** Let's go back to the food on the conveyor belt. You have about 15 of these x-ray units lined up horizontally, and the food moves underneath them at a steady rate.
**Cox:** These things would not take up enormous room in the processing plant, they would sit up over the conveyor belt in a line, and there would be a shielding box built around them, just like the shielding box around the conveyor belt systems at the airports. You don't really need a bunker as you would with an accelerator. The shielding could be expressed in terms of inches of lead, 1 inch or something like that, of metal.

Now, we're not trying to irradiate an entire pallet of food. That's the part that people don't understand. A lot of people say x-rays, you're crazy, you can't do that, it's impossible. It is impossible if you try to irradiate a pallet of food at once, but since you are only trying to irradiate one layer of food at a time, then you have enough energy to penetrate through that.

**Q:** The difference is that, in the other sources, they do irradiate the whole pallet, so the food moves by in great volume, very quickly. With the x-ray irradiation, you just have one layer moving by at a time.
**Cox:** That's right. And if you're doing it on the fly, it's not really causing a bottleneck in the process. It moves through there at about a centimeter per second or something like that. It's a typical conveyor belt speed, optimized for whatever machines or devices that are sorting or culling the produce.

**Q:** If you had something that was greatly dense—for example, if you were doing a whole side of pork—would you have to change the setting on it?
**Cox:** Oh, yes, we would have to increase the energy tremendously. We'd have to go up to half of a million electron volts or greater to punch through a big piece of meat. Whereas, if we were to irradiate bacon, we could get by with probably 100 kilovolts.

**Q:** So really, the system that you have described can do anything just at the turn of a dial.
**Cox:** Yes. Now, of course, we've got to design a new type of x-ray machine. That is the premise we started with when we got the grant and decided to form the company: Somehow we were going to innovate, we were going to come up with a new machine, maybe an order of magnitude more efficient. We haven't done that yet, but we have a lot of good ideas. I expect with the talent that we can bring to bear on this idea, we'll solve it. If not, the whole concept may fail if we can't get the x-ray machine to be more efficient. But I feel confident that we are not going to violate any laws of physics along the way in trying to get it up there. It's not that we have to make some kind of magic trick. We'll stretch the limits of technology, but we're not going to violate some natural law of physics. We are studying new ideas, very novel and counter-intuitive methods of producing x-rays. It's a great departure from current x-ray production technology.

**Q:** It sounds good. I can't wait for the technology to become commercialized in the United States.
**Cox:** All of those things will come to pass; it's a question of when. It's going to take a champion, a corporation or an entity to promote this. It's going to take a marketing effort. Just like selling tissues or anything else, it's got to be sold.

**Q:** In other countries, when they put irradiated products on the market, in Israel or China, for instance, those things sold out because people wanted the clean produce. When they irradiated onions in Bangladesh, for instance, those onions sold out so fast that nobody had a chance to show that they could stay on the shelf for months without sprouting.

**Cox:** Right. I have a feeling that by brute force it will overcome opposition and people will accept it. Right now, we are studying the disinfestation of grapefruit from the Medfly and the Caribbean fruit fly. We are also looking at eradicating pests from tobacco. (I don't like tobacco, but I am a business man.)

ing. And we are also considering mangoes as well. Meanwhile, we are continuing to strive to produce a new type of x-ray generator that will be configured for the job.

**Q:** What is your deadline on this?

**Cox:** I'm hoping that, in a year, we will have a prototype of a working device that can be scaled up into a food irradiator-type application capable of processing 5-10 tons of food per hour.

**Q:** What are the background of the people working with you?

**Cox:** There are two nuclear engineers with Ph.D.s, two food crop specialists with Ph.D.s, two entomologists with Ph.D.s, an organic chemist with a Ph.D., a microbiologist with a Ph.D., and electrical engineers as well. So we've pretty well got the bases covered, most of them are faculty from the University of Florida. I expect we have enough firepower to solve the problem. Right now we are getting into Phase II of the SBIR program, with $200,000 in funding, giving us a total of a quarter of a million dollars of USDA money. We are also going after other grants to study other foods, grants from the particular food producers or the USDA.

**Q:** Is the fish industry in your area interested?

**Cox:** Well, it turns out that you need about 10 times or even greater amount of radiation to treat meat than you do to treat vegetables. So, while I can see how we can easily treat the fruit and vegetables, meat is another challenge to me. Meat is going to be 10 times more difficult for us to compete with processing, than it will be to do fruits and vegetables.

**Q:** Even if your machine could only process fruits and vegetables, and maybe grain, that would be a tremendous boon for the Third World.

**Cox:** You can't be everything to everyone. On the other hand, if we do solve the problem and we can get an order of magnitude increase in efficiency, that will be a major breakthrough. I do need to mention that typical electron efficiencies using traditional bremsstrahlung emission devices are about 1% efficient. The accelerators can move that up to about 10%, using 10-million-electron-volt electrons to produce them. We are trying to produce a bremsstrahlung x-ray spectra at 100 kilovolts energy with 1% efficiencies. If we can do that, that will be a major breakthrough in the science of x-ray production. . . .

# Livermore announces accelerator advance

We are

by Robert Gallagher and Charles B. Stevens

A research team at Lawrence Livermore National Laboratory (LLNL) reported an important breakthrough in the technology for acceleration of electron beams in the Sept. 29, 1986 issue of *Physical Review Letters*. They declare that their recent work with the Livermore Advanced Test Accelerator (ATA), "should permit the extension of high-current [electron] induction accelerators to arbitrarily high energies." The ATA is an experimental accelerator for driving free electron lasers, or for an electron beam terminal defense system.

Previously, the energy (or speed) to which high-current electron beams could be accelerated by the linear induction accelerator pioneered at LLNL, appeared limited by the growth of a beam-accelerator interaction instability known as "beam break-up" (BBU), which grows as the beam is accelerated to higher and higher energies. Beam focusing with external magnets is insufficient to prevent the beam from literally thrashing against the walls of the accelerator, unless monstrously large solenoid magnets whose engineering feasibility is questionable, are applied. Experiments in beam propagation conducted in the ATA, indicated that the machine could not achieve its design specifications of producing a 10,000-ampere-current, 50-million-electron-volt (50 MeV) electron beam. Beam break-up destroyed the beam before it ever reached those power levels. As the LLNL team reports:

> It is clear that operation of ATA at its design value of 50,000-amperes with 3,000-Gauss solenoid focusing, is not possible. . . . [In] an attempt to propagate a 7,000-ampere beam through ATA by use of solenoidal guiding, BBU grew to such an extent that it caused the tail of the pulse to hit the beam pipe. As a result, only half of the injected [electron] charge survived through the accelerator, and the large, transverse centroid displacement [from the accelerator axis] as a function of time at the accelerator exit, rendered the beam totally unusable.

If high energies cannot be achieved with high current, the prospects of using linear induction accelerators to drive free electron lasers at the power and wavelength require-