Interview: Dr. Stephen Matthews

Electron beam accelerator can boost food irradiation, help feed the world

The first generation of commercial food irradiation plants will use cobalt-60 or cesium-137 as the source of radiation. But if this technology is to fulfill its promise and increase the world food supply by lengthening the shelf life of produce and eliminating the spoilage caused by insects and fungi, these radionuclide sources will not be able to keep up with the demand.

Thanks to the beam defense program, a new type of electron beam accelerator—an induction linear accelerator—is being developed. It has a modular design and can be mass produced; it can operate with a 1-megawatt portable generator; and it can process food efficiently and cheaply at a rapid rate. Lawrence Livermore National Laboratory is now collaborating with the University of California at Davis to develop this accelerator for use in commercial food irradiation.

Dr. Stephen M. Matthews, a senior physicist at Lawrence Livermore who has been working on the development of this beam defense spin-off, is interviewed here by Marjorie Hecht, managing editor of *Fusion* magazine.

Hecht: What's most exciting to me is that this food irradiation project is a spin-off of the beam defense program. Two years ago we did a study that showed that if the United States applied the technologies from the beam defense program to industry, this would create an enormous increase in productivity. What you have done is actually quantify this process in the area of food irradiation.

Matthews: That's true. Any time one deals with new technology, there are all kinds of spin-offs. I believe that's the way it's been throughout the history of mankind, starting with the invention of bronze.

To me, it's an evolution of an old idea: that is, that man is driven to learn how to control the forces of nature. That's very constructive work for him. And with these beam technologies, we now have the capability to control, for the first time, unprecedented amounts of power. Of course, the driving force to develop these technologies—as was the driving force to develop bronze or many of the other things we've developed—is to protect ourselves from hostile invaders. It's always been that. But if we can put the threat of nuclear war behind us, then I see these technologies as providing a new opening for doing things that could not be done before. . . .

Hecht: What is your technical background?

Matthews: I'm a physicist and my background is very varied; I have spent periods of time in different subfields. I have had a lot of experience in designing and building detectors and detection equipment for various types of nuclear radiation. I have been involved with some very advanced technologies, which are the types of things that we're looking at now, and I have always been interested in ways of utilizing these technologies for commercial benefit.

Hecht: As you calculated in a paper you presented in November 1983 at a food irradiation conference in Hawaii, an electron beam accelerator of the sort Lawrence Livermore Laboratory is developing can mass process irradiated food at a cost of $5.98 per ton.

Matthews: I've just done a reevaluation of that. . . . Dr. Manuel Lagunas-Solar at the University of California at Davis and I have gone over the costs of processing food with cobalt and cesium as the nuclear sources compared to doing it electrically—with electron beams. It turns out that the price electrically, according to the assumptions we've made, is significantly better than the $5.98. . . . For using a portable electron beam accelerator facility, we've now found that the operating cost of processing a ton of produce at 100 kilorads is $3.25 per ton. That's a little more than half of what we had before, because we now have a better estimate of the accelerator cost.

Hecht: That makes it much cheaper than current chemical methods of disinfestation and fumigation for grains, for example, and for fruits.

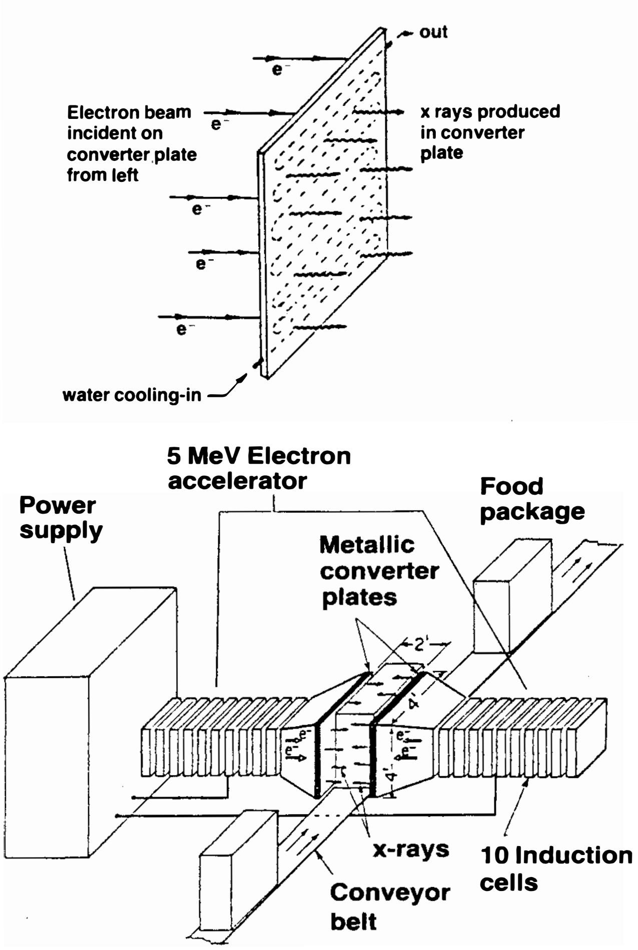
Matthews: Yes. I'll give you some details from a table in our current paper titled "Comparative Processing Costs for Pest Control in Raisins." We picked raisins because there is available comparative data in a University of California report on alternative processing techniques for raisins.

When EDB, ethylene dibromide, was removed from use by the EPA, the growers went into a little bit of a panic here. They have compared the costs of alternative fumigants—methyl bromide, phosphene, low-oxygen atmospheres, and nitrogen atmospheres—and we just added to that table the cost of doing it with radiation. For the current processes, methyl bromide is $8.37 a ton, phosphene is $10.75 a ton, and the other alternatives go way up to as high as $17.83 using liquid nitrogen. The fumigation costs include a charge of $5.42 per ton to stack the raisins so that the processing atmosphere can circulate through the stack. Stacking is not required with radiation processing.

For the radiation technologies, even the cobalt is cheaper than the bromide. It's possible that people may disagree with some of the assumptions we've used. Nevertheless, I think the costs are reasonable here.

Hecht: How does the accelerator differ from the electron beam accelerators that have been used in the past for testing with food irradiation?

Matthews: There are a number of different types of electron accelerators. The types that have been used in the past for commercial applications have been radio frequency linear accelerators—they're called RF Linacs. These linacs have a resonant cavity, which is basically a metal box—a waveguide, if you like. A radio frequency standing wave, an electromagnetic wave, is placed inside the box, and this wave accelerates electrons down the length of the box, and they come out one end.



Electron beams can be used directly for food processing or to produce x-rays for the processing. Shown here is an induction linear accelerator design, where electrons from two accelerators are stooped in a metal plate and converted to x-rays. A two-foot-wide conveyor belt moves pellet-sized containers through the radiation zone.

This type of machine has been used very successfully in the past. However, it has certain problems if you try to make the beam intensity high, which arise from the fact that the accelerator has a resonant cavity. All cavities have what is called the Q factor, which is how well they can support the wave before it damps out. Since the cavity for a high-intensity machine will have to have a very intense radio frequency wave, the Q factor has to be very high.

This means that the mechanical tolerances for building the cavity are severe. You have to build that cavity just right; it has to be precisely the right size, and you can't handle it too roughly. Also, the material out of which the box is built has to have a very high conductivity. Otherwise the Q begins to drop, and this means that some of the energy goes into heating up the walls of the accelerator and you lose energy from the propagation of the beam.

Now, at let's say 5 megavolts—which is the voltage you'd want to have an electron beam accelerator to drive an x-ray machine—a typical accelerator machine that you can buy will put out a power on the order of 1 to 2 kilowatts, and that machine will cost about $1 million. For the same price, we can build a machine that will put out 1,000 times the power at 5 megavolts and has far better commercial properties.

For example, an induction linear accelerator doesn't depend upon a resonant cavity. There are no high voltages that are built up inside the machine. The machine is made out of a modular construction, so that all you have to do is put together a bunch of parts and then link them together.

Hecht: Can the accelerator therefore be mass-produced?

Matthews: It can be mass-produced.

Also, the vacuum tolerances are very relaxed. For example, a radio frequency accelerator has to have extremely good quality vacuums; otherwise you get a breakdown and you get an arcing inside the machine. Since relatively low voltages are used inside this machine, the vacuum tolerances are relatively mild, and you can have what is called a commercially obtainable vacuum. A dirty vacuum, so to speak, something like 1 micron is perfectly sufficient. You can obtain this with a mechanical pump; you don't need fancy oil-diffusion pumps or vac-ion pumps.

Hecht: Did this new accelerator come specifically out of the beam program?

Matthews: It was an outgrowth of the beam program, that's right. We needed to have an accelerator that could produce intense beams to study, and this is what came out of it.

Hecht: How does the induction linear accelerator work?
Matthews: It works as a series of one-to-one transformers. You have a group of modules, and each module will increase the voltage of an electron beam that passes through it by 500 kilovolts, half a megavolt. In exactly the same way that a transformer works, you have a primary and a secondary circuit. In this accelerator, the primary circuit is a 500-kilovolt pulse, which is placed through the module.

The secondary circuit is the electron beam itself passing through the module. You hook up a whole bunch of these modules—one module for each 500 kilovolts that you want to increase the beam energy. For a 5-megavolt machine you need 10 modules. You hook up the 10 modules and launch an electron pulse at one end of the accelerator. Every time the electron pulse passes through a module, you then pulse that module with an external current. In this way, the electron beam will be increased in energy by 500 kilovolts, or by half a megavolt at each of the 10 modules.

Hecht: How high is your outside current?
Matthews: The outside current is delivered by a capacitor through a switch that puts a pulse into the external circuit. The pulse is 10 kiloamps. So you've got a 1/2-megavolt, 10-kiloamp pulse which increases the energy of the electron beam by half a megavolt. Now you have to fire these modules in succession. You have to fire the first module when the electron pulse gets to that module, and then a very short time later you fire the second module, and then the third module—exactly the same way that the lights on a theater marquee march down the marquee. You fire the modules one after the other, as the electron pulse gets to the particular module.

When the electron pulse gets to the far end of the machine, it has picked up the energy it has accumulated after traveling through all these modules.

To make 5 million volts, you only need voltages of half a million volts, and you just keep building it up. Then you have to launch one pulse after the other in rapid succession, so that you have a whole bunch of pulses coming out of the end of the machine.

In order to do that, you have to have a special type of switching technology called *magnetic modulators*—a magnetic switch. It's a new type of switch—actually it's a very old type of switch but uses new materials—that enables the linear accelerator to deliver pulses in very rapid succession. That's what gives it the very high average power.

You see, the idea of a linear accelerator has actually been around since about 1968, and we built linear accelerators here around that time. The problem with them was that they could only put out one pulse at a time. Now, with the magnetic switches, the accelerator can put out 1,000 pulses per second, for long periods of time.

Hecht: What dose will you use for food irradiation?
Matthews: We are considering applying doses of 100 kilorads to fresh produce. And in order to do 100 kilorads, we had considered a little portable machine that was rated at 100 megarad/tons per day. This is what we presented in a paper last year in Hawaii. Now we've upped that to closer to 200 megarad/tons per day, and the only reason we can't make it higher is that we're limited to a 1 megawatt portable generator. If you could get a bigger portable generator, we could run the thing higher; the limit on it now is how much electricity we can feed through it.

Hecht: Why are you limited to a 1-megawatt generator?
Matthews: A 1-megawatt portable generator is what's easily available. And if you use a 1-megawatt portable generator, then the machine will put out half a megawatt of electron beam. And 8% of that energy gets converted to x-rays. It sounds like a very wasteful thing, energetically, but it turns out that even that amount, even 8% of the energy converted to x-rays, is far, far better than what you can do with radioactive isotopes.

For example, let's take the portable accelerator that I just described, with a 1-megawatt generator. Even suffering the fact that half the energy is lost when you convert from the electrical energy to the electron beam, and that of the energy in the electron beam only 8% is converted to x-rays—even then, the amount of x-rays available for processing is equivalent to 4.5 megacuries of cobalt, which is something like 5% of the world's supply.

Hecht: You mentioned that if all the cobalt and cesium available in the world were used to irradiate food, we would be able to process only 6 ounces per person in the United States—hardly enough to do anything with.
Matthews: That's right. Now, I have so far described only the portable facility. A fixed electron beam accelerator in a fixed location could irradiate the food so fast that you could not move it through the machine fast enough—almost a ton per second. In other words, the limitation with a fixed facility is not in the radioactive material nor in the radiation source: The limitation now is how fast you can move the food through the machine!

Hecht: One other thing that impressed me was that you are able to give a uniform dose to a much thicker quantity of food.
Matthews:: That's true, but there's also a problem here. The Food and Drug Administration (FDA) has limited the energy of the radiation to 5 megavolts, no higher. And at 5 megavolts, you're still limited somewhat by the penetrability of the radiation through the food. We are now in the process of calculating the maximum/minimum dose ratios in pallet-size containers of various thickness and density.

Although the 5 megavolts of electron beam radiation is superior to cobalt, and certainly superior to cesium, it's still not really good enough, I think, for doing pallet-size containers. The FDA has said you cannot put any more than 100 kilorads into most food. Now, using this technology, you have to ask yourself, if you put no more than 100 kilorads at the surface of the pallet, what is the dose deposited deep inside the pallet, at the center of the pallet. It turns out that it could be only about 20 kilorads, depending on density and pallet thickness, using 100 kilorads at the surface.

If you're going to do pallets of grapefruit or oranges, then you want to be able to put more than 20 kilorads in the center of the pallet without exceeding 100 on the surface.

Hecht: And how would you do that?
Matthews: In order to do that, 5 megavolts might not be enough. We would like to argue with the FDA to do one of two things, or maybe a combination of both: We would like to be able, number 1, either to raise the 100 kilorad limit, or to increase the energy of the x-rays from 5 megavolts, to, let's say 10 megavolts, so that we would get a much more uniform dose. Whether the FDA will allow that or not is an open question; we don't know.

Hecht: The FDA still hasn't given final approval on 100 kilorads.
Matthews: I know they haven't, and I'd like them to go with that. The World Health Organization already allows 1,000 kilorads.

Hecht: It seems that food irradiation technology is near to commercialization, after 40 years of research.
Matthews: I believe that when and if food irradiation comes of age in this country, it certainly will start off with radionuclide sources—cesium and cobalt. When people see the benefit of that, there'll be a tremendous demand for cobalt. Now, already, the cobalt people are having a hard time just keeping up with the supply. It's very difficult to see where new cobalt will come from. There is cesium that is available, but that will get used up very quickly. And although I think the radionuclide sources will initiate food irradiation, when the technology really takes off, it's going to have to be the electric sources.

For example, these machines that we are considering at 5 megavolts, 10 of these machines, at a cost of a million dollars each, can equal the entire world capability of cesium and cobalt combined.

Hecht: That's an incredible statement! How long do you think it would take to produce one of those machines?
Matthews: They should be able to be built very rapidly: For a 10-megavolt machine, you bolt 20 modules together; for a 5-megavolt machine you bolt 10 modules together. All you have to do is get a company that makes modules, and bolt them together. It's exactly the kind of thing that lends itself to mass production.

Hecht: Will you be actually testing 10 megavolts versus 5 on fruit and vegetables?
Matthews: The first thing that we're going to be doing is testing the 2 megavolts on fresh produce—grapefruit, oranges, whatever California produces; and we will check to see how that works compared to cobalt. There is a lot of history on cobalt. And there is a difference between the radiation that comes from these machines and the radiation that comes from a nuclide source.

A nuclide source puts its radiation out in a continuous manner; the accelerator machines put their radiation out in pulses. You may have, for example, 1,000 pulses a second, but each pulse is on only for about 80 nanoseconds—a nanosecond is a billionth of a second. So although you may have 1,000 pulses a second, the amount of time that the machine is on, compared to the amount of time that it's off, is really very small.

This means that the food is actually being irradiated by extremely intense radiation for very short periods of time. We don't really know what the effect of the extremely high dose rate is on the food. You see, cobalt food irradiation, if it is done commercially, will irradiate at something like 1 kilorad per second. These beam machines will irradiate the food at tens of *megarads* per second.

This intense radiation in a very short time may create a different photon interaction in the food that may alter the radiolytic chemistry, so that the food might behave differently at a 100-kilorad dose of high-dose-rate irradiation than it would with a 100-kilorad dose of cobalt. Some people believe that by using such intense radiation, you actually do a much better job on the food, making fewer undesirable radiolytic products than with cobalt. However, this is an open question which can only be determined by experiment. This question is the first issue to be addressed in our joint study with the University of California at Davis.

Hecht: Is Lawrence Livermore going to promote this application as well as the food irradiation?
Matthews: The laboratory never seems to do these things itself. It always has to wait for somebody on the outside to come in, and it's always been done in a rather haphazard manner. It has always been true that the most effective way to transfer technology is for people who work for the lab to get up and leave and go work somewhere else.

When I came here and started trying to get the laboratory interested in food irradiation, they thought I was a crackpot. Physicists know even less about food technology than the food people know about irradiation. But during the past two years there has been an increasing interest, not only in food irradiation but in other applications as well. Now we have reorganized the technology transfer department. We are going to have, sometime later in the year—possibly in February or March—a workshop for the commercial aspects of induction linear accelerators.