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 requirements for strategic defense, would appear dim. Furthermore, without mastering the beam break-up instability—in which the beam opens up roughly in the shape of a horn because of a nonlinear growth of transverse beam motion—the generation of well-collimated and focused electron beams for both free electron lasers and terminal defense, becomes an elusive goal.

The Livermore team developed a technique they call "electrostatic [plasma] channel guiding" with which "the beam break-up instability . . . was reduced by three orders of magnitude." They turned off their solenoid magnets, and used a low-density plasma to focus the beam.

Low-density benzene gas was fed into the accelerator chamber. Then, a short pulse from a low-power krypton-fluoride laser was used to ionize the gas 1%, and transform it into a low-density plasma. As the electron beam passes through the plasma, the plasma acts to focus the beam and dramatically diminish its transverse motions.

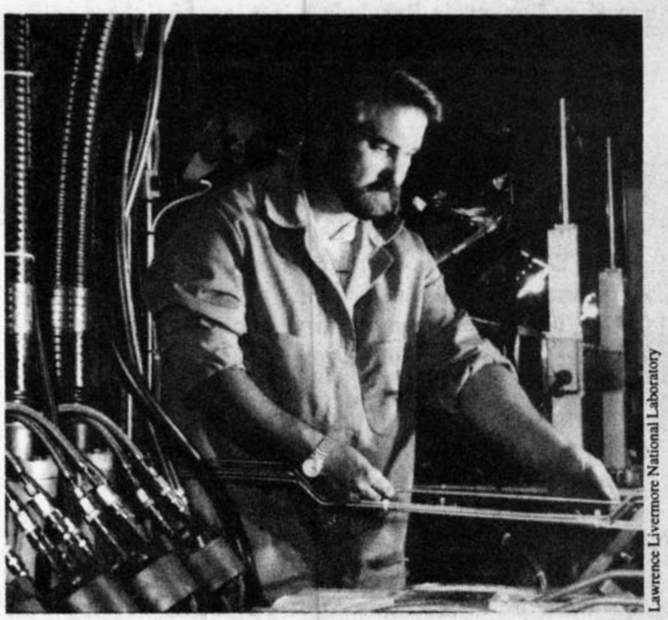
Plasma-electrostatic focusing improved the output of the ATA with a concomitant reduction in operating costs. As Livermore's *Energy and Technology Review* reported in March 1985:

> Upon entering the zone where the strong electrostatic fields [produced by the benzene plasma] are in effect, the electron beam is focused to a smaller radius, since the electrostatic focusing fields are three to four times stronger than the 3,000-Gauss fields of the ATA solenoids. . . . With electrostatic guiding, the full beam current pulse is preserved through the entire length of the accelerator. . . . For the ATA, our 0.4-joule laser is now allowing better electron beam transport than is possible with our conventional axial magnetic solenoids that produced 67,500 joules of magnetic field energy.

The strong electrostatic fields established by the benzene plasma differentially affects the electrons of the beam. The helical "betatron" oscillations of the electrons about the accelerator-plasma axis, increase in frequency for electrons closer to the axis, reported *Energy and Technology Review* In other words, electrons farther from the beam axis, spiral in a helix with a lower frequency than those close to the axis. Through the cross-section of the beam, there is consequently a spread in the betatron frequency or "wave number." Such a frequency spread occurs in water vortices whose angular velocity slows with distance from the vortex center. Electrostatic channel guiding thus appears to transform the beam into a coherent differential-velocity vortex-filament.

This phenomenon is quite significant, reports the LLNL group in *Physical Review Letters*:

> The spread in the betatron wave number, due to the nonlinear restoring force of the channel, has profound implication for the beam break-up instability. Indeed, if the spread . . . is sufficiently great, acceleration to arbitrarily high energy is possible without any BBU growth whatever.



Lawrence Livermore National Laboratory

A Lawrence technician works to assemble the electron injector at the Advanced Test Accelerator (ATA), a $55 million, 50 million electron-volt, 10,000-ampere linear electron beam accelerator.

These advances have yielded a new generation of linear induction accelerator technology. The ATA with electrostatic channel guiding, is not a mere scale-up of the 5-MeV Experimental Test Accelerator that powered the Livermore free electron laser and produced impressive free electron laser gain and efficiency results last spring. The "new ATA" is a machine based in part, on more advanced physical principles of operation. The new Livermore free electron laser driven by this ATA technology, and expected to also include parabolic magnets for improved beam control in the lasing or "wiggler" region of the machine, holds great promise as a second-generation free electron laser.

In light of the Livermore report, there appear to be no limitations on the energy and power (the product of energy and current) for electron beams produced by linear induction accelerators. If beams as finely collimated as Livermore claims it can produce, can be generated with energies on the order of 100 to 200 MeV, gigawatt-power free electron lasers in the visible and even the ultraviolet region, might be achieved in less than a decade. Stanford University's John Madey explained before a Conference of the Society of Photo-Optical Instrumentation Engineers in 1985:

> With a bright enough electron beam, a collective instability occurs in the free electron laser, which results in exponential growth of optical power with interaction ["wiggler"] length.

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