Superconductivity Centennial

T.G. Berlincourt

Editor's Note: The following is an adaptation of a presentation made at the Gordon Research Conference on Superconducting Films, Tilton, New Hampshire, July 20, 1989. The predictions in this speech, both fanciful and serious, are those of the author and do not represent any official position of the Department of Defense. Moreover, in his irreverent treatment of science, technology, industry, politics, activism, ethnicity, gender, and locale, his professed intention is only to entertain and not to offend.

Well, here it is, the year 2011, and we're here to celebrate the 100th anniversary of the discovery of superconductivity. The arrival of this centennial means, one way or another, I've now had a hand in superconductivity for 61 years. Actually, at the age of 85 it's a pleasure to be here at all.

But I wouldn't be, were it not for medical magnetic resonance imaging, or MRI. Progress in the performance of those MRI imagers has been really spectacular. We were lucky to get three millimeters resolution when they first came into use back in the '80s. Now they're good for a couple tenths of a millimeter, and so they've really proliferated. I understand there are currently more than 20,000 of them in use worldwide.

It's all so routine now; you just go in periodically for a complete body scan. The radiologists—they're still called that ...should be called magneologists—they don't have to know anything anymore. The computer does all the anomaly detection and just shunts you into a processor, which does the necessary repair work. That all happens so fast you hardly know it.

It's done mostly with superconducting accelerators zapping the faulty parts from all different directions. Afterwards, you undergo some superconducting quantum interference device (SQUID) diagnostics which sense the magnetic fields that emanate from the heart and the brain. The magnetocardiography scan determines if your pump is still functioning according to specs. And the magnetoencephalography section checks out your brain function. I had a little problem on that one and a few others, and so they shunted me over to rework, but I'm O.K. now. The way I feel, I think they replaced a few more parts though. In fact, it's getting so I can't even remember which of my parts are original anymore.

> Now space is full of those high Tc superconducting oxide focal-plane arrays put up there in the days of the SDI...but they're almost beside the point now.

Anyway, back to the MRI machines ...they're still using liquid-helium-cooled superconducting Nb-Ti alloy windings in the magnets. I take perverse pleasure in that, after all that talk back in the '80s about how those blankety-blank oxide ceramic superconductors were going to do this and they were going to do that.

Of course, they are taking over in some areas.

You can make pretty good, small-size oxide supermagnets now, but you have to protect them from corrosive attack, and you can put them through only a certain number of thermal cycles before you run into trouble.

Aside from little research magnets, the first real supermagnet application for the oxides was for gyrotron microwave and millimeter wave generating tubes. They appeared first in radar sets around the turn of the century. As power levels were raised, they were very useful for heating plasmas in controlled thermonuclear reactor experiments. With still higher power, they could be useful for anti-aircraft, anti-missile, and anti-satellite applications, but there's not much call for that sort of thing these days.

Of course, the oxides are pretty widely used today for sensors, all the way from dc magnetic fields to radio frequency, to microwave, to millimeter wave, to infrared.

There was a real battle between the oxides and the semiconductors for the infrared role back in the '90s. The oxides won—not that their performance is that much better. Well, their bandwidth is better, but the big factor was that they turned out to be a lot less expensive to process.

Now, space is full of those high-temperature superconducting oxide focal-plane arrays put up there in the days of the Strategic Defense Initiative...but they're almost beside the point now...hasn't been much use for them since Gorbachev catalyzed the democratic and capitalistic conversions of the U.S.S.R. and Eastern Europe. (Incidentally, have you noticed how obnoxious those nouveau riche, wealthier-than-thou Soviet capitalists can be?)

Anyway, those orbiting oxide infrared sensors still find use in environmental monitoring, and in spotting forest fires and the occasional drug rocket lifting off from Cuba.

The oxides have also shown up prominently in analog electronics devices and circuits. The basis for all that was pioneered with low-temperature Nb and NbN technology back in the '80s for the first-generation terahertz communications and surveillance systems. Most of that's now been pretty well duplicated in oxide technology, at least the passive elements like

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delay lines and chirp filters—the ones that don't need a lot of Josephson or Giaever tunnel junctions.

Those oxide tunnel junctions are still hard to process in large numbers with uniform switching thresholds, and so they aren't making much headway in digital computer electronics. That appears to be pretty well sewn up by superconducting NbN technology. Not only does the NbN technology now dominate the digital supercomputer market, but it has worked its way down into the business computer market as well. This displacement of semiconductor technology in the medium- to high-capacity computer market should've been widely foreseen, but the semiconductor industry fought it tooth and nail nonetheless.

They made a little progress by using oxide superconductor interconnects on semiconductor chips operating at liquid nitrogen temperatures, but, in the end, the transistors still dissipated too much power. That meant they couldn't be packed close together, and signal propagation between switches took too long. On the other hand, the NbN switches operate 10 to 100 times faster and dissipate 1,000 times less power, and so they can be packed very close together. In computer switches, small size and low power ultimately triumph. (Insect wings flap faster than eagle wings, and you can pack insects closer together!) But the smaller a device, and the lower the switching power, the more susceptible it is to thermal upset. So whether it's a superconducting device or any other small, low-power device, it has to be operated at low temperatures.

The NbN supercomputers are now a lot faster than the old '80s-vintage Crays. Those Crays dissipated 200 kW, while the NbN computer power requirement is only 5 kW, and most of that's for the ultra-reliable, closed-cycle helium refrigerator, which operates at 8 K.

Now, as you know, after that revolution in the supercomputer arena, it didn't take long for NbN technology to take over the business computer market as well. Of course, in the beginning, most of the NbN computers went into military systems, but that market dropped off as world tensions eased. Now most are used in business, engineering, R&D, economics forecasting, global environmental modeling, and medicine.

Incidentally...all that fancy MRI medical diagnostics I described earlier...relied on NbN computers.

Actually, the transition to NbN digital computers was pretty traumatic for the semiconductor and computer industries—a little like what happened to the electronics companies during the shakeout that took place when we went from vacuum tubes to transistors. Although IBM did the pioneering development in superconducting digital electronics, they disengaged in 1983, and Japan picked up where they left off.

What saved our shirts in this area were measures the Department of Defense took to reactivate U.S. efforts. It was clear that the U.S. semiconductor and computer industries weren't about to do it on their own.

But low-temperature superconducting digital electronics technology turned out to be a tough nut to crack, and it wasn't long until both the U.S. and Japan knew they needed each other's help. As you know, this spawned the AT&T - Fujitsu - Hitachi - Hypres - IBM Superconducting Supercomputer Consortium, which has been so spectacularly successful and has served as the prototype for a whole series of other international consortia. A century ago, they'd have been outlawed as cartels, but now their time has come.

So much for superconducting digital electronics. Now I'd like to mention some of the latest developments in power systems.

Remember the Arab oil embargo in 1973? It caused so many energy conservation measures that electric utilities stopped buying central-power-station electric generators. General Electric and Westinghouse virtually dropped out of that business...and the Electric Power Research Institute cancelled their 300 MW superconducting generator project.

Well, the Japanese never faltered...their superconducting generator development went ahead full speed, and they were ready for the market surge that began in 2005. That's when older, conventional units began to wear out and, at the same time, power demand began to surge with the worldwide economic expansion that arrived with the vanishing of trade barriers and the new emphasis on consumer markets as opposed to military ones.

Well, we swallowed a very bitter pill and bought a whole raft of those very elegant Japanese supergenerators. I had a good look at one a few months ago down at the TVA Gallatin Generating Station. It's about one-fourth the weight and volume of the old conventional machines, has better efficiency, responds better to fault conditions ...and all this for less than one-half the installed cost of a conventional generator.

They're still using liquid-helium-cooled Nb-Ti windings though. The field coils are still a bit too big to allow use of oxide superconductors, but I expect that transition will take place in another five to ten years.

Well, we may have bought generators from the Japanese, but they've bought superconducting magnetic energy storage systems (or SMES installations) from us. You recall that the Strategic Defense Initiative Organization pioneered that technology for dual use, both for electric utility load leveling and for a rapid-discharge mode to energize free-electron lasers for missile defense applications. The new SMES installations use Nb-Ti windings too, and you can be sure they will for a long time to come. All those thermomechanical and magnetomechanical stresses and strains dictate use of ductile materials.

The first big SMES, about 100 meters in diameter, was built in 1995 and it worked like a charm. The only trouble was (pardon the expression) it "attracted" all the anti-magnetic-field activists, or magnetophobiacs as we call them. Now, admittedly, in the extreme, at very high magnetic fields, the Zeeman splittings, which the magnetophobiacs have never heard of, will doubtless alter atomic energy levels enough to perturb chemical and biological processes. But, to date, there's no hard scientific evidence of any biological hazard at SMES magnetic field levels. Try to tell that to the magnetophobiacs, though!

Anyway, back in the '90s, the magnetophobiacs did a lot of demonstrating at MRI clinics, trying to shut them down. Thank goodness they're nonviolent demonstrators! But I have to tell you they do bruise easily, and they were no match at all for the patients. Those patients were going to exercise their rights to MRI diagnosis no matter what, and they hadn't made any pledge of nonviolence.

But a SMES...now here was a really big magnet, and there weren't any MRI patients around to challenge the rights of magnetophobiacs to demonstrate. So magnetophobiacs from all over the U.S. converged on the first SMES, and their dogged but peaceful demonstrations ever since have slowed the development of SMES installations in the U.S. It's a little reminiscent of what happened with nuclear power.

Anyway, the rest of the world just loves SMES and hasn't coddled the magnetophobiacs the way we have in the U.S. So, there's a large export market, which we dominate because of the early U.S. lead and experience in SMES technology. The new models really dwarf the old Mark I model that started it all.

But I still can't account for the different reactions to SMES in different countries. For example, in the Soviet Union, magnetic fields are believed to intensify amorous liaisons, and so there's a lively and illicit resort business around Soviet SMES

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installations. Perhaps it's because SMES is a Russian word, although not a particularly noteworthy one.

In any event, the reaction to SMES in Japan is just as inexplicable. I recently traveled there by aerospace plane to inspect their SMES installations, and, quite by chance, I happened to witness some of the highly illegal antics of a cult of magnetophilic kamikazes, or magnekazes as they're now called. Note that I said they're magnetophiliacs, not magnetophobiacs.

What they do is a little like sky diving and surfing combined, and the timing has to be just right. They have to guess the state of charge of the SMES, taking into account the time of day, the day of the week, and other factors such as the extent of air conditioner use. Then, standing atop their liquid-nitrogen-cooled superconducting ceramic levitation disks, they drop out of helicopters high above the SMES.

If they've figured everything just right, they free fall for a while, then they're gradually slowed by the SMES magnetic field and eventually come to rest levitated just a few feet above the ground. Still levitating, they can pole themselves around and and play all kinds of games.

Of course, if they've misjudged the charge on the SMES, and they launch from too great a height, they end up plastered all over the landscape. That possibility has introduced a certain asymmetry into their choice of launch height. As you might expect, they tend to launch at a rather modest altitude. That, too, posed some problems until they replaced the ferromagnetic parts in their helicopters with nonmagnetic ones. The authorities used to leave the wrecks in place as warning to others who might come in too low.

Of course, if the SMES is fully charged, the magnekaze is marooned at high altitude, either until the SMES discharges or until the liquid nitrogen coolant in his or her ceramic levitation disk system is depleted. In the latter case the disk normally loses levitating capability rather gradually as it warms, and the landing is uneventful. But if, at the same time, the SMES is in a rapid discharge mode, say if it's feeding the big free-electron laser that's used to vaporize hazardous reentering space debris, things can get pretty dicey.

Needless to say, novice magnekazes are usually pretty securely tethered to their levitation disks, but it's really considered bad form to be seen hanging from one as if it's a parachute.

There's some talk now in Japan of legalizing and regulating magnekaze activity and thereby reducing risk. Under regulated conditions, any magnekaze wishing to make a legal drop could, for a fee, query the SMES data bank by radio for information on the state of charge of the SMES and the appropriate launch altitude for his or her weight and levitation disk model. As you might expect, most magnekazes believe that if it gets this routine, the thrill will be gone, and of course that's just what the authorities are hoping.

In any event, I was so unnerved from watching the magnekazes that, instead of returning from Japan by aerospace plane, I decided to take a leisurely cruise ship. That was a most pleasant and interesting experience because the ship used superconducting electric drive, and I had ample opportunity to inspect it as a guest of the propulsion officer. For those of you too young to remember, that technology was pioneered by the U.S. Navy back in the '70s.

The prime power source is a gas turbine which turns at about 10,000 rpm, much too fast to connect directly to the ship's propeller. In the older ships, cumbersome and inefficient reduction gears were used to lower the rotation rate to the few hundred rpm appropriate for the propeller. The turbine and gears all had to be located deep in the ship, and the turbine's long intake and exhaust ducts intruded on the interior space.

> Despite that little problem with the fire ants in Waxahachie, Texas, they've pretty well completed the experimental program laid out when the 20 TeV superconducting supercollider accelerator was activated back in 1999.

With electric drive the turbine is located high in the ship, where it requires very little ductwork. The turbine drives a high-rpm superconducting generator which feeds a low-rpm superconducting motor, deep in the ship, which turns the propeller. Overall, the system saves a lot of space, weighs much less, and is far more efficient than the old reduction-gear approach. The superconducting-electric-drive ships still use the old workhorse liquid-helium-cooled Nb-Ti alloys, because their supermagnets are still a bit too large for ceramic superconductors.

However, since the turn of the century, the U.S. Army has been testing a gas-turbine-driven main battle tank which uses liquid-nitrogen-cooled ceramic superconductors in its electric drive system. I don't know if this tank will ever see production, though, because world tensions have eased to the point where tank warfare seems anachronistic, and besides it's hard to conceive of a peacetime use for a tank. Nevertheless, as an aficionado of all things superconducting, I did take a trip out to the Army Systems Test Center for a ride in one.

The tank itself performed very well, but the driver seemed to have a lot of trouble getting the hang of it. He was awfully indecisive, and the approaches to the obstacles were made at bizarre angles, always from the far right, and I mean the *far*, far right. It was only afterward that I had a chance to get a good look at the driver, and you guessed it—none other than Governor Dukakis, trying to do it *right* this time in his bid for the presidency in 2012.

While at the test center I also had a chance to look at the first helicopter to use superconducting electric drive. The liquid-nitrogen-cooled superconducting ceramic generator and motor are marvels of light weight and efficient design and promise to have significant impact in military helicopter operations, which are now mostly just drug interdiction. I wouldn't be surprised, though, to see this technology appear in civil and commercial helicopters by 2015.

Incidentally, have any of you been down to Waxahachie, Texas lately? On my last visit I was told that, despite that little problem with the fire ants, they've pretty well completed the experimental program they had laid out initially when the 20 TeV superconducting supercollider accelerator was activated back in 1999. And so it appears that the supercollider itself and the scientific program have both been smashing successes. In particular, a number of scientific questions originally posed have been answered very definitively indeed.

Uh, well, that's not quite all...there do seem to be just a few little odds and ends still begging to be cleared up...nothing that a little 200 TeV accelerator couldn't handle very nicely I'm told.

Well, you can imagine how Congress is going to react to that, after that little budget overrun on the supercollider back in the '90s. I suspect that the Congressional statutes banning protons with energy greater than 20 TeV could soon face a Constitutional test.

In fact, it's no secret that high-energy physicists have been holding clandestine meetings to explore design concepts for a 200 TeV accelerator. But if they really want it, sooner or later they'll have to come out into the open. I wouldn't be surprised to see them win the Constitutional test of their right to develop design concepts, but getting construction funds out of Congress will be quite a different matter. Their only hope is the discovery of much-higher-performance superconducting materials, which could be used to upgrade the old supercollider ring. That appears rather unlikely, and even if such materials were to be found, the discoverer would doubtless be reluctant to talk very openly about them for fear of provoking a magnetophobiac demonstration outside his laboratory.

But enough of that...

Now, I'd like to say a few words about the maglev train, the one that makes the run between Washington and Boston. As you know, our introduction of maglev transportation back in 2001 was the product of a joint manufacturing agreement with Japan. That agreement was a kind of inversion of the 1989 FSX fighter aircraft agreement in which the U.S. supplied most of the technology. Those original maglev units, which use liquid-helium-cooled Nb-Ti supermagnets, have established an enviable record for safe, dependable, quiet, and comfortable transportation.

So on my way to the maglev station in Washington this morning, I was rather looking forward to another very pleasant trip. I arrived at the station early enough to take a window seat with good visibility in the middle of the car. Incidentally, this particular car was a new one and looked different somehow, but I put that out of my mind and settled down comfortably to review my notes for this talk. Then all of a sudden there was a disturbance caused by a late-arriving passenger. I was told it was a magnetophobiac, making a scene because the only remaining seat was directly over one of the magnets.

Now, normally I have very little patience with the "phobies," as we call them, but this one was, how shall I say it, uncommonly attractive. I might even say that on a scale of one to ten she was about 20 Tesla! Her delicate beauty, style, and noble bearing were all reminiscent of the legendary Audrey Hepburn in her heyday.

As her plight became apparent, several males in the car fell all over each other in their coldly calculated and feigned gallant maneuvers to offer her their seats. After some chaos, order was restored.

To my surprise, and through no design on my part (I'm above such things) she found refuge in the seat next to mine, which was about as far as you can get from the magnets. Well, I did my best to calm her fears, and soon her story came out.

It seems she doesn't normally react magnetophobically, but she had suddenly become very uneasy when she realized what I had failed to comprehend...namely, that this very car was making the first-ever regularly scheduled passenger run equipped with the new ceramic superconducting magnets. They're being introduced entirely without fanfare so as not to evoke the very response I had just witnessed.

I continued my attempts to reassure her, explaining that these new magnets were no more intense than the old ones, just lighter and warmer. With this revelation, the fear which veiled the dark beauty of her eyes gradually underwent a metamorphosis to trust. (And was there also a glimmer, if ever so slight, of affection?) It was then that an amorous crescendo, powerful and wavelike, enveloped my whole being. Yes, I know I'm 85, but, as I earlier recounted, several of my essential components were replaced after my last MRI scan.

But, alas, such a love could never be...I could never live a lie.

Someday, sooner or later, she would have to know that, back in the '60s at the dawn of the high-magnetic-field superconductivity age, I was not only there, but, as an addicted magnetophiliac, I was among the most active participants in the great kilogauss race.

Emerging from this reverie, I gradually became aware that we were gliding along swiftly and smoothly at 200 mph. Only then did I notice the near silence achieved through use of the more modest refrigeration system made possible by the higher operating temperature of the ceramic supermagnets. This greater quiet had a further calming effect on the exquisitely beautiful and vulnerable creature at my side. Taking me still further into her confidence, she confessed that the ceramic magnets had been only part of the source of her discomfort.

What really distressed her was a press release, which had come into her possession only this morning. With a trembling hand she proffered it.

Now, I know that you've been isolated at this conference here in Tilton for the past several days, and doubtless you've not heard this news...so I'll quote from the release:

"Today a research team composed of organic chemists and physicists, led by Dr. Boris Sverkprovodimost of the Institut für Organischen Supraleitern announced the discovery of a new organic chemical material which exhibits superconducting properties at unprecedentedly high values of temperature, magnetic field, and current density.

The new material is composed of inexpensive ingredients and is easily synthesized, formed, and fabricated in all configurations of interest for both small-scale and large-scale applications.

The isotropic, ductile, high-modulus, durable, and corrosion-resistant character of the material assures its suitability for applications in which extremes of magnetomechanical, thermomechanical, and environmental stresses are encountered.

Measurements have revealed a transition temperature of 450 K, and a critical current density of one million A/cm^2 at a temperature of 350 K and in a magnetic field of 100 T.

The composition, structure, and techniques for synthesizing the new organic superconductor are all being fully disclosed in an article simultaneously being published in the *Interplanetary Journal of Organic Chemistry*."

Imagine that...a *plastic* superconductor!

Now, you're doubtless as curious as I was about where in the world this remarkable development took place, for depending upon that factor, this advance could either reinforce the new era of international sharing and cooperation, or it could intensify old rivalries and rekindle nationalistic greed. Unfortunately, the location could not be easily ascertained. The dateline on the press release was badly smudged and stubbornly resisted our most diligent efforts to decipher it.

We puzzled over the research team leader's name—Sverkprovodimost—which is simply the Russian word for superconductivity. And we wondered about the obviously German name of his institute. Then, in an inspired move, my companion seized the press release, and, leaning across close in front of me, she placed it against the maglev car window, where the sunlight streamed through. In that way she could view the release in transmitted light.

The delicate scent of her perfume permeated my senses, and the sunlight diffracting in her hair formed a thousand rainbows. I watched, hypnotized, as in slow motion her incredibly sensuous lips form the letters U-T-A-H, followed by the word "Utah."

This revelation triggered a glimmer of hope in her countenance and then a smile, at first enigmatic but finally joyous and ecstatic! As her spirits soared, mine plummeted...and visions of warm plastic superconductivity vanished, obliterated totally by the specter of unrequited cold fusion. □

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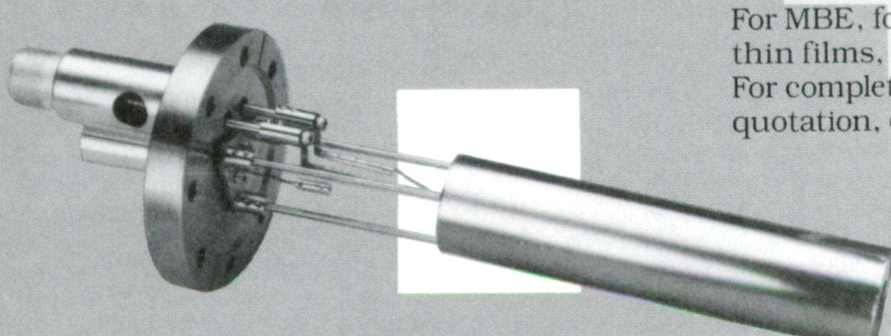

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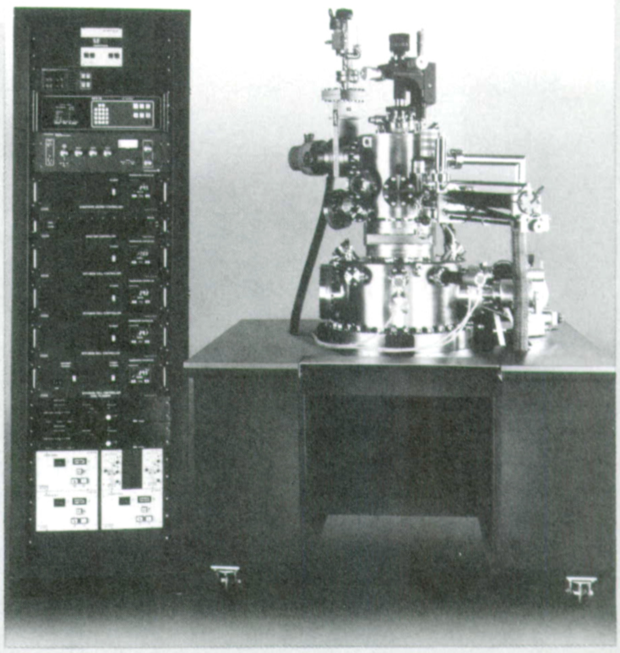

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