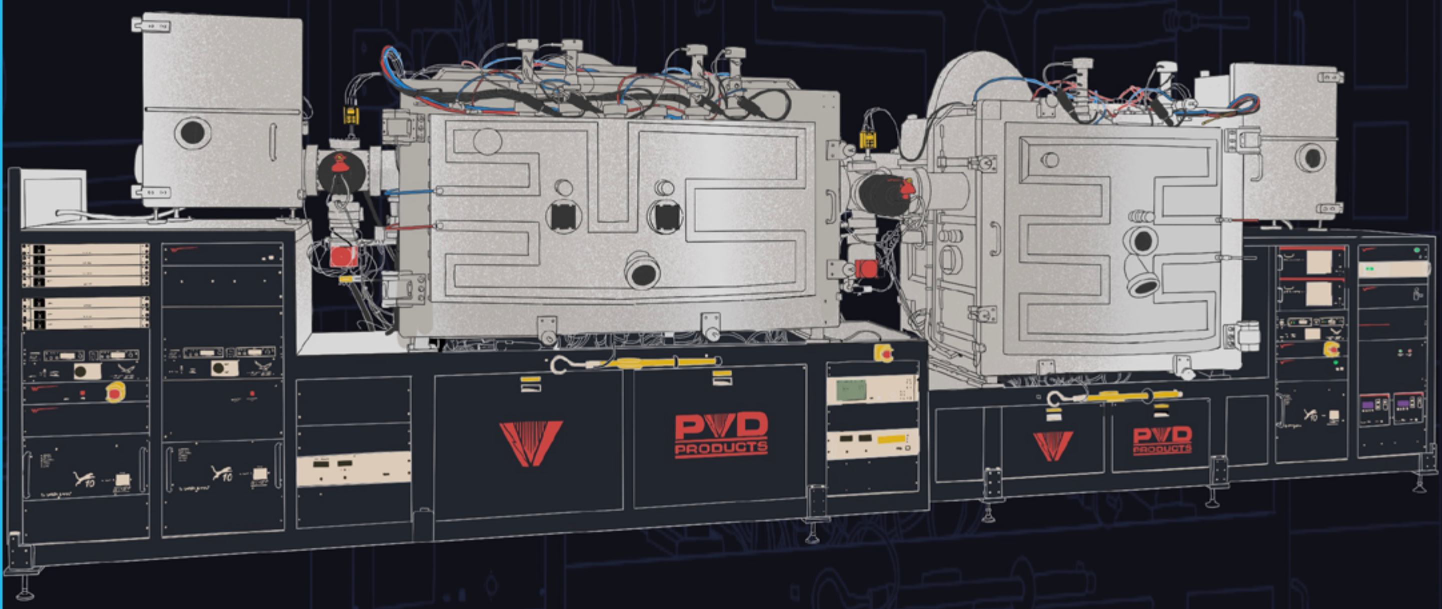
This article is based on an interview with me conducted in late November, 2020, by Sean McEvoy of Superconductivity Week which was published in the December 13th, 2020, issue here at https://www.superconductorweek.com/ .

SUPERCONDUCTOR WEEK



DECEMBER 13 2020

TABLE OF CONTENTS

Spotlight

Paul Grant is an IBM Research Staff Member Emeritus and retired Electric Power Research Institute Science Fellow.

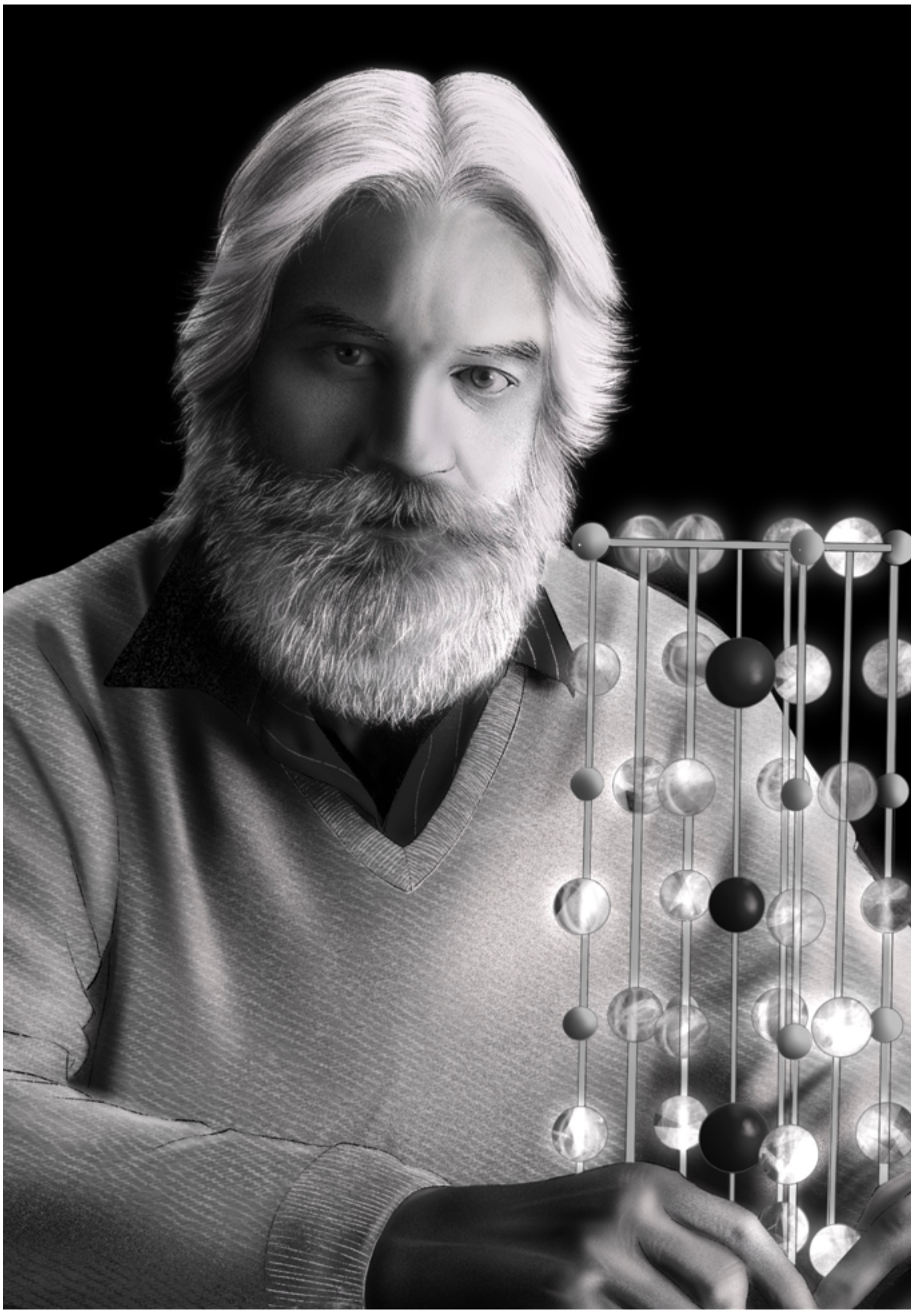
Superconductor Week (SW) : Why don't you start off by telling us about yourself ?

Paul Grant (PG) : Well, let's see. I grew up in the Hudson valley in an IBM family. My dad worked for IBM. My mother was a career woman. She was very political. I'm an only child and I think she was just doing her Irish Catholic duty in having me, but she was really the boss of the family.

On her side, I'm the grandson of Irish immigrants that came over in the 1880s to help dig the sewers in NYC. I was one of four grandchildren that actually were the first to go to high school and get educated. And then all four of us actually went on to obtain advanced degrees in graduate school.

My mom's career started when she was 15 years old as a stenographer at a local utility company, Central Hudson Gas and Electric, later to become one of the major founding utilities of the Electrical Power Research Institute (EPRI). My mother, when she retired, 45 years later, was secretary to the company's CEO. She interacted a lot with attorneys, that's the culture of the regulated utility industry in the United States - in case you haven't noticed. Her ambition for me was to go to Harvard and become a lawyer and it turned out I eventually did go to Harvard but I got a PhD in physics instead, so my mom always considered me the family failure.

I went to work for IBM during my last months of high school, when I was still 17. I started out setting pins in IBM's employee country club bowling alley and when I finally graduated from high school I got promoted, in what turned out to be the biggest break in my life, to be the mail delivery boy in a brand new laboratory that



IBM and the U.S. Air Force had established in downtown Poughkeepsie. It was the first use of computers in an air defense system which became known as SAGE/NORAD - we are talking now in 1952 - so I was trained as a programmer. They found I had some talent for arithmetic.

I was posted out as a member of the SAGE XD-1 prototype service team, organized by IBM and MIT at Lincoln Labs, when I was 19. I had, I like to say, the largest toy in the world to play with, it was the world's biggest computer. When I was 21, IBM decided I was worth educating. They had a program for employees that if you worked in NY state and got accepted to a NY institute or university, and if you studied what IBM wanted you to study, they sent you to college. I thought I'd try it, and I had some difficulty getting accepted because of my miserable high school records my senior year, but eventually Clarkson University in upstate NY accepted me. I went up there under the bar and I was class valedictorian four years later.

▸ When I graduated from Clarkson, I wanted to go to grad school and IBM saw that I was going to quit and they would have lost all their investment in me. It turned out that I got accepted to MIT in the physics graduate program, and when IBM found out that I was going to quit and leave, they said, why don't you go down and talk to this IBM fellow, Rolf Landauer, in Poughkeepsie where the first IBM research lab was built.

Landauer is known for Landauer's Principle from an entropy limit on irreversible computing – when every time a computer switches from a 0 to 1 or a 1 to a 0, the second time around it doesn't remember the state that it was two sets before, so you generate a small amount of entropy. The Landauer Limit has been shown to apply to quantum computers as well.

So Landauer says to me, why the hell do you want to go to MIT, because Harvard is much better in what you want to study, which is solid state physics. I knew that already, but the problem was that I had a national defense education fellowship to attend MIT. Harvard was very anti-militarist in the early 1960s. My national defense education fellowship didn't apply to Harvard, so Landauer convinced IBM to keep me on board as an employee and send me off to what I love to call 'this obscure former divinity school on the banks of the Charles' for my graduate degrees.

IBM had also wanted to know when they sent me to Clarkson what I going to study, and I said I wanted to major in physics. My manager at the time at IBM Poughkeepsie Kingston said, no, we want you to do something useful when you get back here, so you are going to take electrical engineering. So I majored in both. Today, I am one of the advisors on the Clarkson Honors Program, where honors students can get two degrees if they work their asses off and take extra courses and overload themselves. But it was an interesting era. I mean, what other company like IBM today sends employees to school?

SW: It's certainly rarer.

PG: Not out here in Silicon Valley, nowhere that I know of, at least in the United States, so when I got my degree, I escaped from Harvard. IBM had just opened a lab out in California, part of the research division, and I convinced them to transfer me out to the San Jose research lab, so my career has essentially been out here in California.

SW: Was this the same lab where Bednorz and Müller did their research?

PG: No, that's in Zürich.

SW: Is it still an IBM lab?

PG: Yeah, in the 1950s IBM established three labs, one in Poughkeepsie, which was later transferred down to Yorktown Heights; one in Zürich, under the leadership of Alex Müller; and one out in California to essentially do some marketing. But we evolved into hardware development, particularly storage. The research division of IBM was started by someone we called the old man in my time, T.J. Watson, Sr. He was on the board of directors of Columbia University, and he saw that research and engineering in physics could be a valuable asset to IBM, which is why he founded the research division. IBM was a paradigm for the ideal socialistic society, that if you worked hard, behaved, made money for the company, you were taken care of for life - everything, medical, retirement plans, everything, so, that's kind of the culture I grew up in.

SW: Do you think the culture has changed at IBM?

PG: It changed very quickly after IBM had to enter into a compromise of the antitrust suit that had been brought against it by the government in the decades of the 1970s and 80s. You see, the old man would say about IBM, "We sell a service, not machines." and throughout most of IBM's history, throughout the 1950s, IBM owned all of the machines that were in its customers' business sites. They didn't sell the machines, so when you entered into business with IBM, you got the machines sort of for free, and that was considered anti-trust, anti-competitive. Starting in the late 1940s, suits brought by other companies and the government eventually mandated that IBM had to offer their machines for sale, and that's when the company really began to change. In order to economically compete in this new scenario, IBM had to reduce many of the benefits formerly available to its employees.

SW: So you were sent to the lab in California for IBM, what was your primary focus of research over the many years?

PG: My initial work was to continue my thesis work at Harvard, the growth of epitaxial thin films on single crystal substrates, which was brand new at the time.

▸ I started that work at Harvard based upon summer experience I had at Clarkson while working at IBM Kingston. I mentioned magneto-resistive thin films earlier; which earned me and my IBM colleague Bob Penney the first patent on using that effect as memory read-out.

I'm a skier. I'm a mountain guy. My parents taught me how to ski when I was a five-year old in the 1940s, and so when I was in graduate school at Harvard I actually skied on the volunteer ski patrol team at Mt. Snow up in Vermont. I was raising my first family at the time, so my family got to ski for free. My Harvard buddies and I used to fantasize what it'd be like to live in California, where you could go skiing in the morning and surfing in the afternoon, and so that's why I pressured IBM to transfer me to California. That's the basic reason I came out here.

I first heard about superconductivity when I was the mail boy in the Poughkeepsie High Street Lab, the first stage NORAD lab in downtown Poughkeepsie. I was delivering mail and one of the engineers said, hey, kid, come over here; I want to show you something. He took a soldering knife and he splattered some solder, lead tin alloy, of course, on his bench top, scraped it up and wired it up to a current source. He lowered it into a vacuum chamber of really cold stuff - I didn't know what it was at the time, but it was liquid helium, and he measured the resistance going through, and all of a sudden the resistance went to zero, and he said, tell me, what do you think happened? And I said, I think the leads came off, which is stupid because if the leads came off the resistance wouldn't go to 0, it would go to infinity. And he said no, it's called superconductivity.

This engineer became one of my mentors at Clarkson, I worked for him several summers at Kingston. His name was Jim Crowe and he is known as the inventor of the Crowe cell, the first use of superconductivity for computer memory and storage. So that's how I got involved in superconductivity, at a very young age through one of the real pioneers of applications of superconductivity in the digital regime, and then, of course, this is all low temperature stuff.

It was in late 1986 that I heard about an experiment that had been done in IBM's Zürich lab by Alex Müller and his former postdoc Georg Bednorz. I heard about this from one of the people in my department at San Jose Research who had actually visited Zürich and had come back with the news. Alex and I have written about the story in Physics Today and other publications.

There was a lot of competition between IBM's three labs, especially against Yorktown, and I got to know Alex because he was one of the very first IBM fellows and would spend summers with our group in San Jose. And so, this protectionist attitude against Yorktown existed in Zürich as well as in San Jose, but more seriously in Zürich.

And so what did Alex do when he and Georg found zero resistance in an early sample of barium lanthanum copper oxide? They wrote up a manuscript and submitted it to Zeitschrift für Physik. Müller asked its editor not to distribute this paper, but just to read and referee it himself.

Alex had violated a basic tenet of IBM policy in that he did not first publish an internal report, and so I found out about it because one of our at IBM colleagues in San Jose actually came back from a short trip to Zürich and told me. So, at the end of December of 1986, between Christmas and New Year's, I took a quick flight to Switzerland. I didn't tell my managers; I just said I was taking a short vacation. I went down to Zürich, and I went from the airport to the lab. Alex was off skiing; he wasn't there, but I found out where Bednorz' lab was, and I went and talked to Georg and he showed me the experiments.

I carried this back with me, this knowledge, back to San Jose. I didn't inform Yorktown that I found out about what they had been doing, so we were the first group worldwide to replicate Alex's result and it was at IBM San Jose.

SW: Were there any consequences for this insubordination? Long term probably irrelevant because this guy got the Nobel Prize.

PG: Exactly. He got it right away. Alex actually had some friends who were on the Nobel committee, by the way. He had become internationally famous for his basic work on electromagnetism and electrolysis, so he was probably the number one, two or three famous researcher in the general community outside of IBM; he's a great guy .

SW: Wow.

PG: Anyway, that's how we got started in San Jose.

▸ I came back from this trip in the last week of 1986 to Zürich, and that's where the story of HTS superconductivity began in San Jose. There was a lot of internal competition or caution inside IBM about spreading it outside and even inside. Müller did his best to keep everything to himself, and so this affected the initial patent rights to the invention or discovery of high temperature superconductivity, which went to Paul Chu at the University of Houston and the Kitazawa group in Japan. Our group at IBM Almaden Research was awarded the international patent. The whole HTS patent issue will remain unclear until someone finds a real money-making application.

Therefore, I suspect what you may want to talk about is: why isn't superconductivity being used on a large scale?

SW: Yeah, we know where it's being used because we do write about this, and there are a few applications in particular I would like to ask you about. One big question is why haven't there been more applications of HTS wire in power transmission? There are some examples of that happening, most notably AMSC and ComEd's collaboration in Chicago and THEVA's project for power distribution in Munich, which we discussed with their CEO in our last issue. But not such large scale or universal efforts.

PG: I'm aware of all of these. We actually worked with AMSC to use their wire, a distribution cable, which ran from Detroit Edison's rural substation to downtown Detroit, and it all works. And one of the issues that comes up from time to time is why isn't it being more widely applied in the power industry? My offhand opinion has always been that it's because of the utilities.

There is no clear way the utilities can make money using superconducting technology on a large scale. If you really look at the power industry, the electric power industry worldwide, electricity is cheap, and so one of my examples would be, supposing we came up with a superconductor that superconducted at room temperature at zero cost, would it still be attractive to tear down the 1200 mile DC voltage interchange from Seattle to Southern California just to save 6% or 7% in ohmic electricity loss? The answer to the utilities, although nobody verbalizes this, is that obviously there's no real strong economic incentive to do this in cost savings. This is one of the issues that plagues the general application of superconductivity: the electric power industry worldwide.

There are plenty of demonstration projects. They all work; the technology is pretty much mature now. The reason it's not being used, in my observation of the utility culture, is that there is no clear way to make a lot of money. And what would, in my vision, really encourage a large deployment of superconductivity, in particular in power transmission, would be a comeback of nuclear power.

SW: Tearing down a traditional transmission line costs money; however, these things naturally deteriorate and you have to replace them. Part of the reason for the implementation on the Munich grid that THEVA is trying out is because all of their transmission cables now are these old nitrogen pressurized cables that aren't being made anymore and can no longer be maintained. So that has become obsolete infrastructure that they have to replace anyway, which is maybe why they are open to trying something new. This could be an economic incentive.

PG: Near the end of my EPRI career, I served for a couple of years (2012-14) as an advisor to IASS-Potsdam, the Institute for Advanced Sustainability Studies, funded primarily by the German government. I had a pal who was one of the members of what we would call our DOE, but it's in Germany, and I would tease them; I'd say how come you are tearing down your nuclear plants? How many Germans have been killed by nuclear power accidents? Zero.

How many Germans are killed in automobile accidents every year on the Autobahn? About 800. So why don't you go to Frau Merkel - she has a PhD in chemistry - and say, why don't you expand the German nuclear power industry and then we can change all the autobahns to superconducting levitated trains and it will save 800 German lives a year at least? I mean I'm a wise ass American, so, the Germans just look at me and shake their heads, like, 'no, you don't know what we have to deal with'. The antagonism towards nuclear power is justifiable in terms of weapons control, which we can do separately from development as a source of electric power that's cheap and in certain aspects renewable, and certainly in terms of waste disposal is really pretty minimal; it's all a matter of politics and public perception.

SW: In a lot of your presentations, you were focused

▸ on using the same power distribution corridors that would exist in the natural gas industry to incorporate superconducting cables so you can essentially have energy produced at the site where it is collected and then distribute it at zero resistance across very long distances. Nuclear would make more sense; you could distribute it from a nuclear power generation source across wide geographic areas.

PG: Right, that's the continental super grid vision, described on my website at http://www.w2agz.com/PMG%20SuperGrid%20Home.htm. The bottom line is, how do utilities and governments make an attractive return on investment, both financially and societal, from that? That's a very challenging vis-à-vis preserving the present infrastructure and doing things the way it's being done now. When I was on sabbatical at the National University of Mexico, I looked a little bit into the issue of taking electricity generated by fracking on-site, rather than piping it around, and then distributing it by superconducting cables instead of pipelines. That makes technical sense, but I never saw a way, or at least I didn't observe the utility industry, either public or private, looking at this as a way to increase efficiency and save some money, and also environmental protection.

That's what makes the energy business rather unique compared to the computer industry. Improving computer technology makes money for a computer company as you go on in time; but you'll have to wait, in my opinion, for 16 months or until 2024 to see if quantum computers really turn out to be profitable.

There's a lot of hype in quantum computing. Think about quantum computing this way: it's sort of like a return to the era where you build a device that attacks one particular problem. For example, the ones that are currently particularly well known are quantum computers that are good at solving Ising type problems where you actually model in the hardware; the spin systems of a set of interacting spins, one way or another.

To me, quantum computing is a return to the era of analog computers, where you design a machine for a specific problem, where we have today the real revolution in computation that took place with Alan Turing and its implementation by von Neumann. I call them TvN machines, which in principle can solve any problem in physics, given enough time and enough power. Quantum computing is not general computing; however it's very successful at certain types of problems much more quickly.

SW: Problems that are not necessarily realistic or have much practical application?

PG: Well, I would say they are not capable of generalization in the same piece of hardware. D-Wave is very good at solving the Ising model. D-Wave kept everything secret by the way, they were very hard to deal with, I would talk to D-Wave people a lot at physical society meetings, and the answer would be, oh, we can't talk about that. So, I would recommend to the DOE, where I was on the advisory panel for superconductivity, why don't we just buy a D-Wave computer and take it apart and see what they have really done that works. I'm sure that it's a special purpose machine for one particular problem, not general purpose.

Now, it could take dozens of years to solve certain thermodynamic problems on a classical Turing machine, where if you build the registers around a specific physics model, like the Ising models that are my favorite example, then you can solve a problem rather rapidly on that quantum computer, in a matter of hours instead of years. But I think if you come up with something that is the salvation of mankind, you ought to be able to explain how to use it.

SW: So I'm not the only one who doesn't understand everything about quantum computers.

PG: Right. it's important because there are certain kinds of problems that can be solved a lot faster, but it's not general…

SW: Is commercial viability then limited because of limited applications that it has?

PG: Absolutely.

SW: So, going back to your thoughts on power distribution: if there isn't an economic incentive for utilities, the remaining incentives that I can imagine would have be regulatory. What if a government needs to implement environmental protection policies, especially ones that are more focused on climate, as seems to be the way the wind is blowing now? I know for example, speaking with THEVA about their infrastructure in Munich, it's because the EU now has a regulatory mission to reduce CO_2 emissions, so that

▸ could be one incentive. Are you saying the only way this technology could be adopted on a broader scale is with pressure from governments, because otherwise there's no economic incentive to utilities to actually do this?

PG: Yes, the control of carbon emissions is really important. Very critical, to me, in terms of the power aspect, is bringing back nuclear power, big time - it doesn't combust any fuels.

SW: My personal opinion is that nuclear is the best option we have for energy production in terms of cost effectiveness, and that it doesn't involve releasing CO_2 into the atmosphere in a big way. We've been interviewing other companies that are going towards fusion. Do you think that there is something to be done there? Do you think that small fusion reactors are viable and something that we could actually implement in utility grids in the near future?

PG: You are talking about the MIT project and the fallout from that? Because they are the largest progenitors and fans of fusion reactors.

SW: Yeah, Commonwealth Fusion Systems, the spinoff from MIT. And Tokomak Energy in the UK.

PG: Well, we'll see. If you mention nuclear power to the general public, the first thing they think of are bombs. I tease the fusion people at MIT when I see them at meetings - I say 'isn't there something called a hydrogen bomb? That uses fusion? Is that efficient?' And they just ignore me.

SW: One more thing I'd like to ask that I typically ask everyone is, looking back on your career and the experiences and successes you had, what advice would you give to people now that want to get involved in science and in industry? Obviously you come from a different time, and your career started in a way that by and large is no longer possible. That kind of story is special, but it's something from a time in U.S. development and the culture in this country that is no longer around. I can't imagine that sort of thing happening for someone now.

PG: This is some of the advice I give to my mentees at Clarkson: just learn as much physics and math as you can, and then spend your summers with Eastman Kodak or IBM or some company and look around at what problems are holding them back that they need to solve. But concentrate on the basic core elements and skills of engineering and science.

That's what I always like to do. My advice to students, the undergraduates I mentor at Clarkson, is, when you get a summer job at an industry, spend the first couple days going out on the factory floor and see what kinds of problems they need fixing. If you have a proper educational background, you will have the skills and talent to be able to attack those problems. Don't go into a closet; you have to get out there and look around and see what is going on the factory floor. That's what I pretty much did for my whole IBM career. I was rather different from my colleagues in the research division in that regard, but that's how I can best sum it up right now. Haul your ass out on the factory floor and see what problems need solving. Don't become a university professor.

SW: Or don't become one of those managers who are completely unfamiliar with what happens at every level of the company where they work.

PG: I often say, when I retired from IBM, I had probably four or five academic positions available to me. One, for example, was Dean of the Physics Department at UC Davis There were jobs like that, and I probably would have gone to Florida State University. At the last minute, I got a call from a friend of mine that worked at EPRI and we had collaborated when I was at IBM San Jose on certain projects that he was interested in. EPRI offered me a position as a science fellow, with a discretionary budget of five million dollars a year where I could hire university professors to work on projects that I wanted to see worked on, rather than go to a university and have to deal with students and faculty and all of the internal politics of what goes on in those institutions that I became very familiar with over the years. So, yeah, I really owe a big debt to EPRI for giving me this free money.

SW: Yeah, not having to write grants or beg for a budget.

PG: Exactly. So this is why I encourage my mentees to go into industry or government, I mean places like the NRL or national labs, and if you want to teach you can do that off the clock.

SW: Thank you for your comments. ■