A college-level interest in friction blossomed into a career that ranged from wear standardization for ASTM to experimenting with new tribomaterials for Oak Ridge National Laboratory.
When and how did you become interested in tribology?
Back in 1976 I was nearing the end of active duty military service and decided to take a few graduate courses in metallurgy at Wright-Patterson Air Force Base through an Air Force Institute of Technology program with Ohio State University. I suppose that was how professor Dave Rigney found my name. I received a letter from him saying that he was looking for several graduate students to work on a new project involving friction and wear.

His offer intrigued me, and I became his first doctoral student in tribology. At that time graduate studies in materials aspects of friction and wear were uncommon in the United States, and tribology research was a departure from the usual topics. In fact, I’ve always been fascinated by subjects that are somewhat off the beaten path. That’s why I enjoyed my master’s degree work. There were few metallurgists working in NASA’s Apollo Lunar Sample Examination Program, and along with my thesis advisor, professor Joe Goldstein at Lehigh, I had to learn a whole new vocabulary to communicate with the mineralogists and geochemists. While my work on the origins of lunar soil particles probably had no practical engineering use, it was great fun to study metal fragments that were collected on the moon by the astronauts.

Later, during my time in graduate school at OSU, I came to appreciate the uniqueness of our field. There are so many facets of tribology that I’ve stayed involved in the subject for almost 30 years. Unfortunately, though, there is a disappointing lack of public understanding and appreciation for our profession. It’s hard enough explaining to people what a metallurgist is, let alone a tribologist. As a working definition, I prefer to think of tribology not as a distinct discipline, but, rather, as a set of interdisciplinary problems that happen to concern friction, wear or lubrication. The challenge we have as tribologists is to select which scientific and engineering tools are appropriate for each new problem we face.

Is there any particular aspect of tribology that you find most interesting?
Yes. I’ve had an abiding interest in transient, non-linear phenomena like running-in and other transitions in friction and wear behavior. I suppose that my interest started during graduate studies at OSU. I noticed that initial transients in friction and wear were repeatable in many cases and especially when you take extra care in setting up the experiments. Often, even relatively small fluctuations in the friction force could be replicated. At the same time, having spent many hours looking at wear surfaces under a microscope I realized that rarely could a single model or a limited set of mechanisms fully account for what I was seeing. So I became increasingly interested in the evolution of synergistic, non-steady-state interfacial processes.

My first research position after graduating from OSU was at the National Bureau of Standards. I still call it NBS because the name didn’t change to the National Institute of Standards and Technology (NIST) until a few months after I left. My group leader, Dr. Bill Ruff, and his colleague, Lew
Ives, were excellent people to work with, and I had the opportunity to pursue studies on combined wear processes, including running-in phenomena.

During the early 1980s I began to systematically categorize the characteristics of friction and wear transients. I wanted to know how the various changes in surface morphology, interface composition and subsurface microstructure all worked together to create the changes in friction that we experimentalists so often observe. I think that “frictional signatures” contain a lot of information about the evolution of steady-state processes if only we can learn how to interpret them. I hoped that categorizing such behavior would lead to a better understanding of how to stabilize friction and wear mechanisms in different kinds of tribosystems, and that interest led me to write a book called *Friction and Wear Transitions of Materials*, which was published by Noyes Publications in 1989.

More recently, and with support from the U.S. Department of Energy, I’ve had the opportunity to participate in the development of lightweight materials for the next generation of heavy truck brakes. Friction braking is a rich area of study for those like me who have an interest in complex tribosystems and transitions. For example, you start with multicomponent composite materials (brake linings) and apply them to either traditional cast iron or to candidate, lightweight materials like ceramics, carbon composites or coated titanium alloys. Then you apply intermittent loads, accelerations and decelerations and varying times of sliding while trying to understand physically what happens to the materials in the interface.

The stabilization and control of friction in truck brakes has to be of great concern to drivers. I’ve had the occasion to study what happens to friction braking characteristics when aggressive road de-icing chemicals, like magnesium chloride and sodium chloride, attack cast iron brake surfaces. Through friction transient analysis of intentionally rusted cast iron (see photo), we’ve seen that oxide scales first act as an abrasive, then become incorporated into the fine structure of the transfer layer to behave much like solid-lubricating fillers. Ultimately this process can reduce friction for a period of time, making braking less effective.

At Oak Ridge National Laboratory, we’ve also recently completed a program for the U.S. Department of Transportation to develop a standard code for marking aftermarket heavy truck brake linings. That was not only a technical challenge but also a challenge in reconciling the divergent interests of trucking associations, regulatory agencies and industry groups like lining manufacturers.

**How did you become interested in wear standardization?**

As I mentioned, I had the privilege of working with some great people at NBS, so it was natural to join them in participating in ASTM activities. I was hooked from my first meeting in Williamsburg, Va., in 1979. The impression that a lot of people seem to have of standards work is that it’s a dull process, comprised of tedious meetings and piles of marked-up documents. While I admit that there is a lot of paperwork—recent trends toward internet-based balloting notwithstanding—I dispute the notion that standards work is boring.

In fact, some of the debates I’ve had while defining terms or working out the sources of variations in test data have been extremely
stimulating. I’ve made a lot of good friends in ASTM over the years, and I always leave meetings having learned something new and having made new contacts. While serving as the chairman of ASTM Committee G-2 on Wear and Erosion, I’ve witnessed a steady need for standards in tribology, but it’s becoming increasingly difficult to find people with the level of commitment and dedication needed to see the standardization process through to its completion. I don’t like to hear people complaining that there should be more standards in this or that area but who themselves are unwilling to commit to doing something about it.

In fairness, I have to say that using standards is not always the best course in tribology R&D—especially if the tribosystem of interest doesn’t happen to resemble any of the standardized testing configurations. On the other hand, standard test methods were developed and refined over the years by some very diligent people and can provide a solid basis for developing new tribomaterials and lubricants. I’m a firm believer that you can’t fully understand the results of a friction or wear test unless you understand the test itself. In fact, a few well-conceived, yet relatively simple experiments can be illuminating. As I’ve often reminded my son, David: “There are those who look but do not see.”

Tell us about Oak Ridge National Laboratory and its tribology program.

Oak Ridge National Laboratory came into being after World War II and gradually evolved into the large, diversified U.S. Department of Energy facility that it is today. There’s an excellent history of the lab on the public website, www.ornl.gov. Materials science has always been a core technical area at ORNL. In fact, Oak Ridge scientists contributed significantly to understanding the metallurgy of plutonium, uranium and similar materials to support the Manhattan Project in the early 1940s.

Today, more than 3,800 people and thousands more guest workers and visitors annually provide a diverse workforce. The Metals and Ceramics Division in which I work is one of ORNL’s largest divisions with 15 research groups, seven program offices and three major user facilities. We are a matrix-type organization, and I serve both as a senior member of the Surface Processing and Mechanics Group and as Leader of the Machining, Inspection and Tribology User Center.

I sometimes refer to Charlie Yust, who retired in 1994, as the father of tribology at ORNL. When I joined ORNL in 1987 as task leader for the tribology project, I was following in Charlie’s footsteps. Together with Carl McHargue, who is now director of the materials processing center at the University of Tennessee, Charlie began the lab’s tribology effort in the early 1980s by studying the low friction of diamond sliding against ion-implanted titanium diboride. Later, he conducted groundbreaking studies of high-temperature friction and wear of ceramics.

That effort was in support of low heat-rejection engine concepts being advanced by the Department of Energy to improve the energy efficiency of ground vehicles. Back then it was believed that structural ceramics were naturally slippery and therefore would work in engines without additional lubrication. Wrong! Nevertheless, Charlie and I investigated a variety of ceramics, whisker-reinforced ceramic composites and novel intermetallic alloys that ORNL metallurgists had developed. That work laid the foundation for our continuing strength in materials tribology.

Today we maintain a diverse portfolio of projects, most of which concern saving energy or controlling energy dissipation in transportation system components—from cermet injectors to new standard tribo-tests for diesel engine cylinder components to light-weight materials for the next generation of truck brakes. We keep busy evaluating, characterizing and modeling the behavior of a spectrum of tribomaterials. We’re also working collaboratively with other national laboratories, universities and industry to open new avenues of research in surface engineering. It seems to me that we’re always in the process of improving, modify-

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ing or building tribometers as we reinvent ourselves to meet new project needs.

In parallel with the multiyear projects, we conduct shorter-term collaborations with U.S. industry and universities that are made possible through the High Temperature Materials Laboratory (HTML) User Program (http://www.ms.ornl.gov/htmlhome/). Tribology user facilities are contained within six HTML user centers. These facilities offer outstanding instrumentation and expertise for characterizing the structure, composition and properties of materials—all under one roof. HTML user projects keep us on our toes and broaden our experience base. And experience is a valuable asset in tribology. Solving tribology problems is rarely as easy as looking the answer up in a handbook. And I can attest to that, having chaired the ASM handbook on Friction, Lubrication and Wear Technology.

What do you see in the years ahead for our field?

That’s a tough one, and I want to qualify my answer as being a personal perspective rather than ORNL’s. I believe that, on the whole, tribology knowledge will continue to advance, but advances will occur at different rates in different technology sectors (industrial, aerospace, ground transportation, energy, biomedical, MEMS, etc.).

Some areas may not advance much at all, due to reduced funding. For example, it’s fashionable now for government agencies to fund research whose subjects are prefaced with the terms nano or bio. Sometimes I worry that a great deal of intellectual talent is expended in explaining subtle experimental artifacts in nano-probe devices while important macroscale problems remain unaddressed by the best and brightest talent. There needs to be a reasonable balance between science for the sake of science and science for the benefit of engineering.

Support for research in areas like high-temperature erosive wear, two- and three-body abrasive wear, impact wear and other more traditional tribology topics has eroded despite the fact that major problems in these areas have scarcely gone away. Difficult problems that involve combined wear modes such as impact plus fretting and the like are common in machinery but have largely been ignored by the research community. Where will we find people with broad research experience in macrotribology to tackle such practical problems in the future?

In fact, with a push toward higher energy density in propulsion systems, the use of lighter weight structures and the need to decrease dependence on sources of energy from troubled parts of the world, many new macroscale tribology problems will rise up to challenge us. You can bet on it.

Do you have any thoughts on tribology education?

From time to time I get calls with tribology questions, and it’s evident that there is a great need for tribology basic training within the engineering community. I had hoped that my second book on Friction Science and Technology, published in 1996, would provide a logical bridge between high-school tribology, like wood blocks sliding down inclined planes, and engineering tribology that includes advances in tribophysics, surface engineering and instrumentation. Unfortunately, most people—even practicing engineers—fail to recognize the important distinction between a material’s properties, like its melting point, and its system-dependent characteristics, like friction and wear. We tribologists have got a lot of work to do educating engineers who have a critical need to understand such things.

I’d like to close by thanking the editors of TLT for this wonderful opportunity to talk to my colleagues. And I’d like to acknowledge the friendship and support of many fine teachers, mentors, program managers and research collaborators who’ve enriched my experience in our fascinating, interdisciplinary field. Some say tribology is mature and that there is little research left to be done. Obviously they haven’t been talking to the engineers down in the trenches who are designing future mechanical systems on which our society will come to rely.

You can contact Peter Blau at blaupj@ornl.gov.