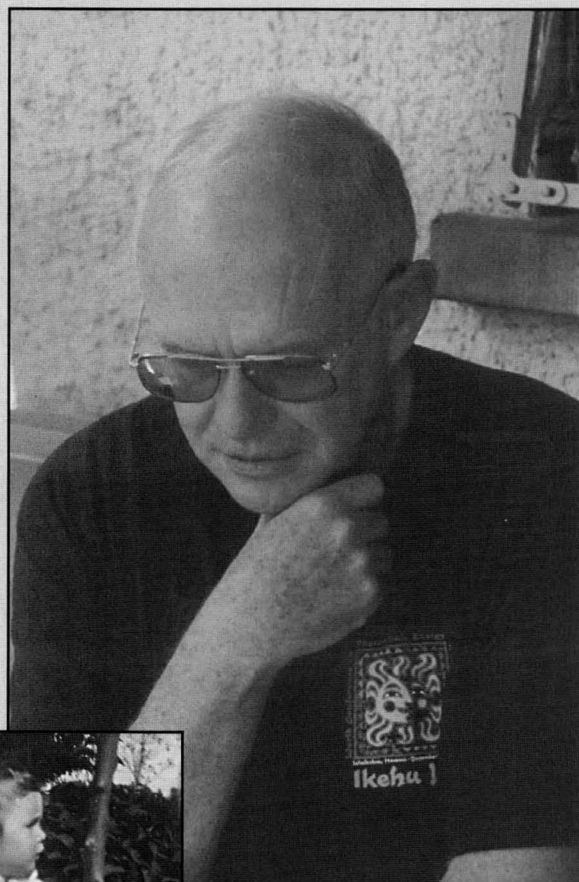
ChE educator

T.W. Fraser Russell

An Appreciation by his Colleagues

T.W. Fraser Russell is a friend, a guide to his younger colleagues at all levels, and a continuous source of good humor and valuable perspective for all who know him. He is the Allan P. Colburn Professor of Chemical Engineering at the University of Delaware and Chief Engineer of the Institute of Energy Conversion, a campus laboratory that is devoted to thin-film photovoltaic research. He is an exceptional teacher who has also served the University as Chair of the Department of Chemical Engineering, as Associate and Acting Dean of the College of Engineering, and as Director of the Institute of Energy Conversion for 16 of the 25 years it has been in existence.

Fraser was born in Moose Jaw, Saskatchewan, and lived in various cities in Saskatchewan and Alberta before obtaining a bachelor's degree in chemical engineering from the University of Alberta in 1956. He put himself through college by working in an Edmonton oil refinery in the summers. Although this was valuable practical experience in both laboratory analysis and refinery operating, he had to turn down a job as lifeguard at the Banff Springs Hotel to complete his third summer at the refinery. This would not be worth mentioning were that not the year *The River of No Return* was filmed in Banff. Thus, while Fraser completed the design of a waste treatment unit for the refinery, his replacement in Banff was hired to teach Marilyn Monroe how to swim. This dedication to the practice of engineering has held throughout Fraser's career.



My...My...My. Where HAVE the years gone?

Upon graduation, Fraser worked for the Research Council of Alberta on fluid mechanics problems associated with the production of oil from the Alberta tar sands. His first job was the collection of a (probably metric) ton of tar sands from a site on the Clearwater River north of Edmonton. He and two colleagues brought the sand out by canoe. This early pragmatic work in mass transport was short term and his principal research effort was directed toward an understanding of the pipeline flow of the very viscous tar sand-crude oil-water mixtures. This research produced the first papers published on liquid-liquid flow in pipes and was accepted by the University of Alberta as meeting the research requirements for a master's degree, which Fraser was awarded in 1956.

Fraser, his wife Shirley, and their two-year-old son Bruce left Edmonton in the summer of 1958 and proceeded to Montreal (in a 1956 Volkswagen "Beetle") to a position as a design engineer with Union Carbide Canada. This firm had just moved into Canada and had assembled a group of Canadian engineers to design and build a petrochemical plant to make ethylene-derived chemicals in Montreal East. Fraser was assigned the task of designing a facility to make ethanolamines and glycol ethers using information from a batch processing unit at the Montreal plant. The preliminary design and economic justification was completed in Montreal, and Fraser and his family were sent to Houston to complete the process design and equipment specification. This was done with the help of Union Carbide International and Brown and Root—the result was a multipurpose continuous processing unit designed to make mono-, di-, and triethanolamines and methyl, ethyl, and butyl glycol ethers—the first multipurpose continuous processing unit built in Canada.

Fraser's career is characterized by a close relationship with industry, and he has always strongly believed that one cannot effectively teach engineering without understanding the art aspect of the profession . . . . He also feels that the techniques required to organize research results into a form suitable for teaching students are the same as those required to prepare information in a form useful for practicing engineers.

Union Carbide's policy to make as much use of Canadian personnel as possible required that Fraser, Shirley, Bruce, and three-month old Brian move to Calgary, Alberta. Fraser supervised the piping design and drafting phase of the job in Brown and Root's office—despite the fact that his undergraduate drawing courses concentrated on drawing bolts in India ink and never mentioned piping (this has always annoyed him). The project was brought back to Montreal in the fall of 1960 and, after a winter of Fraser's construction supervision, the plant was started up in the spring, producing on-spec product within 24 hours. It did so for over 35 years and was just recently decommissioned.

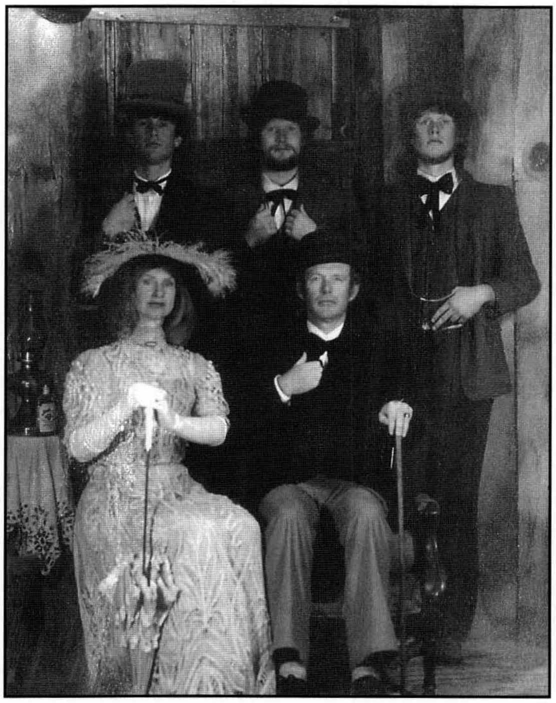
Shirley and Fraser then executed a plan they had developed over several years and began investigating the possibility of graduate education. The presence of Art Metzner and Bob Pigford at the University of Delaware, coupled with its location in a small university town with good schools and a low cost of living, led them to apply to Delaware.

Fraser, together with his family (Shirley, Bruce, Brian, and month-old Carey) came to Newark, Delaware, in the fall of 1961. The adjustment to an academic environment presented many challenges, not the least of which was overcoming failure of two of the three qualifying exams on his first attempt. A supportive faculty, and many study sessions with his fellow graduate students, taught him to effectively integrate his exceptional practical experience with the academic approach to chemical engineering, and he passed the exams laudably on his second try. He is particularly grateful to Jack Hopper, John Gainer, and Don Kirwan, all of whom became chemical engineering faculty.

Fraser was asked to teach the senior capstone design course in his last year as a graduate student, and his success in so doing prompted Bob Pigford to offer him a position as an assistant professor (he is the only person who received his PhD at Delaware who has been invited to stay as a faculty member—and, as Fraser says, "You can analyze that one of two ways."). His experimental thesis on "The Flow Mechanism of Two Phase Annular Flow" was directed by David Lamb, and the degree was awarded in 1964.

His early research efforts at Delaware were driven by a desire to quantify a whole class of reactor design problems in which ethylene oxide was reacted with water, ammonia, and various alcohols. Fraser and one of his early graduate students, David Buzzelli, studied this problem and published "Reactor Analysis and Process Synthesis for a Class of Complex Reactions." At that time, Fraser was also consulting with Union Carbide Canada on the expansion of the multipurpose facility in Montreal, and this gave him and another early graduate student, Robert Anderson, the opportunity to use the Buzzelli paper to design new reactors for this unit. The new reactors gave Union Carbide a distinct competitive edge over its chief rival, Dow Canada. Years later, David became CEO of Dow Canada, and thus had to deal with a competitor that had been wise enough to follow the design procedures he developed as a student. He must have done so successfully because David is now VP and Corporate Director for Environment, Health, and Safety at Dow. In an even more curious turn of events, at the same time that Dave was responsible for Dow Canada, the same Robert Anderson was the Union Carbide manager for the Montreal plant!

Fraser also combined industrial process design experience with work on two-phase fluid mechanics to develop a research program emphasizing experiments that produced essential information for the design and operation of commercial-scale process equipment. This experimental research and modeling effort, resulting in an early series of papers coauthored with Anderson, Schaftlein, Cichy, Ultman, Rogers, Jensen, Arruda, Etchells, and Holmes, was well received by a number of industrial organizations and the findings were incorporated into many of their design procedures. This group's organization of gas-liquid design problems into tank-type and tubular categories proved valuable to both design engineers and students. It also led to a long-term consulting contact with the Engineering Department of the DuPont Company (now in its 26th year) and gave Fraser's students an opportunity to test the conclusions of their experimental work and modeling efforts in the design and operation of commercial-scale equipment.



"Just for fun." Shirley, Fraser, Brian, Bruce, and Carey (January 1980)

Fraser's career is characterized by a close relationship with industry, and he has always strongly believed that one cannot effectively teach engineering without understanding the art aspect of the profession. He defines this as an ability to make decisions within severe time constraints and with uncertainties in the available information. He also feels that the techniques required to organize research results into a form suitable for teaching students are the same as those required to prepare information in a form useful for practicing engineers. This approach to both teaching and engineering practice has earned him several honors, including a University of Delaware Teaching Award, the AIChE Award in Chemical Engineering Practice, and the Thomas H. Chilton Award (from the AIChE Wilmington Section).

A quote from J. R. Balder's presentation of the Chilton Award to Fraser in May of 1988 captures the essence of Fraser's contribution to industrial practice:

> *Dr. Russell has contributed through his research and publications to the solution of a whole class of problems related to multiphase fluid flow. I can speak from personal knowledge about Dr. Russell's industrial contributions, and I am not referring to people just reading his papers and applying his results. For the past twenty years he has spent between a half to a full day each week, as a member of our internal consulting group in heat, mass, and momentum transfer. He consults with our own consultants on their technical problems, and he also has a series of clients at DuPont's manufacturing sites for whom he is the engineering department consultant in multiphase processing. He is on the front line solving problems every week, and in fact one of the strongest impressions that Dr. Russell leaves with those who work with him is his practical orientation to the science of engineering.*

(It is interesting to note that J. R. Balder was a student in the first class in design that Fraser taught.)

Fraser has also had multi-year consulting relationships with the Ethyl Corporation, Pfizer, and over twenty other firms or organizations for shorter periods.

Fraser was promoted to Associate Professor in 1967 and to full Professor in 1970. During this time, he devoted a great deal of effort to redesign of the traditional first course in chemical engineering. Fraser and Mort Denn tackled the problem with the considerable talent and experience they possessed between them (see Mort's comments in the sidebar opposite). For six years they taught the course in two sections so they could compare notes on the classroom effectiveness of the material being developed. This collaboration produced the text *Introduction to Chemical Engineering Analysis,* which has been described in the pages of this journal by two articles, the first in the summer issue, 1973, and more recently in an article about Mort Denn (spring issue, 1996).

Fraser convinced his wife, who was studying for a master's degree in secondary math education at Delaware, that she could not effectively teach math without understanding how it was used. So Shirley registered for the course—attending Fraser's lectures, but with homework and exams graded by Mort. She says she thought she could give Fraser advice on how to be a more effective teacher, and Fraser thought he could get good solutions of the homework problems. In fact, both occurred. Shirley's enthusiasm for the approach and her success in mastering the material (she was one of the top three students) promoted the development of a course in chemical engineering analysis for nonmajors. This course attracted a wide variety of students and was taught both as an on-campus offering of the Chemical Engineering Department and as a Continuing Education course.

A very satisfying sabbatical year in 1972-73 at the Swiss Federal Institute of Technology (ETH) in Zurich produced a collaboration with Irving Dunn and Harvey Blanch. A research effort developed that followed earlier work on sewage treatment in transfer lines and involved designing, building, and conducting experiments in a two-phase tubular loop reactor in the ETH labs. Together they successfully produced C. topicalis and developed a reaction and reactor analysis for the system. At Fraser's urging, the department at Delaware hired Harvey, where he subsequently received

Comments from Mort Denn

For my first teaching assignment, Bob Pigford asked me to develop a new course on mathematical methods to follow immediately after the introductory "mass and energy balances" course. (By a historical accident, a differential equations course was not a formal part of the Delaware chemical engineering curriculum although all our students took differential equations—so there was no campus political issue in removing our students from an existing math course.)

Fraser took an immediate interest, and after the first offering of the new course we decided to work together to integrate the two courses into a year-long sequence. We soon realized that the most serious problem faced by our students was not poor ability in formal mathematics (which certainly existed), but rather a lack of appreciation of how to quantify physical problems. We cut back significantly on the mathematics and began to develop a systematic approach to translation of physical problems into mathematical form. (I'd like to call it "mathematical modeling," which it is, but that term has a negative connotation to many of our colleagues.)

Fraser and I developed our program with a few key ideas in mind; the material covered in basic science and math courses should be used and reinforced in our chemical engineering course (Fraser kept copies of all the textbooks used by our students and cited them frequently in class.) The most easily understood physical processes are those in the liquid phase, and keeping to the liquid phase enables the introduction of dynamics at the start. Chemical reaction and mass transfer can be developed effectively at the introductory level, creating avenues of understanding about the full scope of chemical engineering and enabling students to attack simple design problems in the first course. Fraser's design experience was very helpful in focusing on meaningful problems, which inevitably meant that rate processes had to be included in the problem formulation, since the rate processes play a central role in any real design. (This was a major departure from traditional introductory courses in chemical engineering.)

For a number of years we taught the course in two morning sections, covering the same material in each section and getting together for tea after class to evaluate and plan. In time, the year-long course evolved to the material covered in our text *Introduction to Chemical Engineering Analysis.* With the reintroduction of a formal course in differential equations, much of the later mathematical content became redundant and the analysis course is again a one-semester course, but totally different from the old mass and energy balances course. It is notable that most of the essential concepts are taught with separable first-order differential equations, so calculus is used extensively, but only a first course in calculus is required.

It is not possible to overstate Fraser's contribution to this effort. He has an uncanny understanding of the way in which students learn difficult material, and he defined the pace at which ideas were introduced—very slowly at first, to build confidence, then accelerating rapidly. (A typical Russell comment: "Do you want to cover everything or do you want them to learn something?") While his lecturing style is very low key, he has a wonderful way of relating to each student, and they learn from him. I still recall with chagrin the year in which my students were consistently doing more poorly on exams than Fraser's. Since the material covered in each section was identical, the obvious conclusion was that he had, on the average, better students. But I note sadly, if one is to accept the predictive ability of the freshman GPA, it was I who had the better students!

part of the experience that made him so attractive later on to the University of California at Berkeley. Since Mort also ended up at Berkeley, Fraser often wonders why collaborations with him produce this urge to go west!

In the mid-1970s, Fraser was asked by Irv Greenfield, a newly appointed Dean, to take on the responsibilities of the Associate Dean of the College of Engineering. Fraser claims he accepted so he could have access to his own secretary, but his three years at this task produced the beginnings of what is now a very successful minority engineering program, the introduction of computers into the education programs of the college, a revision of the student advisement process, support for teaching excellence in the College, and an upgrading of the academic program in all the departments. He was also responsible for initiating and supervising an intern program in chemical engineering design, a master's-level program for chemists, a partnership program for chemical process design, and a bachelor's-master's program for exceptional undergraduates.

Fraser's belief that one could not ask students to take the fundamentals exam for professional registration unless someone in the Dean's Office was a registered professional engineer led him to attempt to get the Delaware Association of Professional Engineers to recognize his Quebec registration. He was not successful, and twenty years after he graduated he took and passed both the eight-hour fundamental and eight-hour professional exams in order to reinstate his professional registration. After doing this, he concluded that better exams would be written if all faculty had to take an exam every so often.

It was during his time in the Dean's office that Fraser and Jim Wei, assisted by M. Swartzlander, developed both a research and teaching program in the economics of the chemical process industries. This produced a text, *Structure of the Chemical Process Industries,* as well as a successful course (described in the Fall 1979 issue of this journal). Three papers applying microeconomics theory to process design were also produced as a result of this collaboration, as well as the thesis research of Ricardo Bogaert and Dennis Brestovansky.

Fraser ended his tenure in the Dean's Office by serving a year as Acting Dean. His effective leadership of the College prompted the university administration to ask him to take the directorship of a troubled laboratory devoted to photovoltaic and other renewable energy research. Thus, in the fall of 1979, he became the first Director of the Institute of Energy Conversion (IEC).

Fraser directed the IEC during a critical period in the early 1980s, during which federal support for photovoltaic research was reduced from over $150 million to around $40 million annually. Despite this drop in federal funding, he developed a stable and effective research organization that between 1979 and 1996 received over $20 million in federal funds, over $3 million from industry, and over $600,000 from the State of Delaware. Money was also raised for a new 40,000 square-foot laboratory facility built in 1982.

During his tenure as Director, the IEC research program was reorganized to concentrate on developing, implementing, and analyzing the laboratory experiments required to provide essential information for the manufacture of large-area photovoltaic modules. This integrated approach encompassed materials synthesis, process equipment design and operation, and device design and analysis. It allowed the engineers and scientists at IEC to make many significant contributions to thin film photovoltaic technology. These contributions include

- *Expansion of the number of thin-film photovoltaic materials designed, fabricated, and analyzed at IEC to include cadmium telluride, copper indium diselenide, and amorphous silicon;*
- *Achieving efficiencies of laboratory-scale solar cells of between 10 and 15% for all of the above materials;*
- *Developing twenty-three patents in thin-film photovoltaic technology, along with several hundred technical publications;*
- *Development of a reaction and reactor analysis research program carried out in conjunction with the Department of Chemical Engineering that led to the design, fabrication, and operation of the first pilot-scale reactor for continuous deposition of photovoltaic-grade semiconductor material onto a moving substrate.*

Fraser dubbed the above research effort "photovoltaic unit operations," and it was carried out in cooperation with Bill Baron, a physical chemist at IEC, and a group of students including Rick Rocheleau, Dennis Brestovansky, Ricardo Bogeart, and Scott Jackson. This effort was recognized by the Leo Friend Award for the best paper in *CHEMTECH*, "Photovoltaic Unit Operations," and the ASEE Chemical Engineering Division 3M Lectureship Award.

The editor of *CHEMTECH*, Ben Luberoff, also commented on this in an editorial:

> *But the paper by the University of Delaware's T.W. Fraser Russell—the 1982 Leo Friend Award winner—is a lot more than just another energy paper. I see it as a vane pointing the direction of at least American chemistry. In his Colburn Chair lecture, on which the winning paper is based, Russell opens the door to the kind of technology that will be required as we turn our attention from making "stuff" to making "things"—in this case copper cadmium-sulfide solar cells. Russell's continuous process involves not only classical chemical technology, but lots of surface science.*

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Fraser has recently expanded the reaction and reactor analysis with colleagues N. Orbey and R. W. Birkmire, and students R. Varrin and S. Verma, to include the first reaction analysis of the growth of copper indium diselenide. This is a study essential to a major consortium research and development effort that has as its goal the construction of an integrated pilot line to make copper indium diselenide modules on flexible substrates.

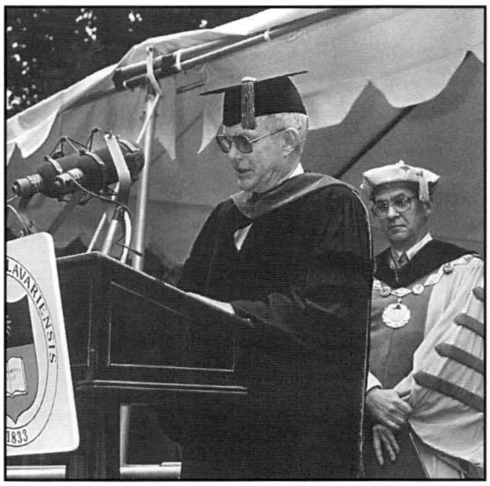
As Director, Fraser strongly supported the educational component of IEC's solar-cell research, and he actively encouraged undergraduate and graduate students to carry on research with IEC's professional staff and faculty. This emphasis on education produced twenty PhD and over fifty MS graduates who have research experience in photovoltaics. In addition, over fifty professionals now active in the photovoltaic industry received their training at IEC.

IEC's significant contributions were further recognized by the United States Department of Energy in 1992 when it designated the laboratory as a University Center of Excellence for Photovoltaic Research and Education, an award given to only two institutions in the United States. IEC is the only University Center of Excellence supported by the National Renewable Energy Laboratory.

Despite the administrative demands of leading a laboratory with between forty and fifty faculty, professional and technical staff, and of his development of the photovoltaic unit operations research, Fraser continued studies of gas-liquid fluid mechanics. These studies were sponsored by the Design Institute for Multi-Phase Processing, an AIChE cooperative research effort funded by the industrial firms in the chemical processing industry. This phase of Fraser's research was carried out in close collaboration with A.W. Etchells, a consultant in DuPont's Engineering Department and Fraser's former student. Jim Tilton, Zenaida Otero, Robert Hesketh, and Fraser produced a series of papers on bubble break-up and design of commercial-scale tank-type mass contactors that have been well received; the validity of the design methods employed was verified using data from a multi-acre sized commercial waste disposal facility.

In 1986, Fraser was asked to become Chair of Chemical Engineering, a position he held for a five-year term while continuing to direct the IEC. Fraser says he could not have dealt with the administrative load if he had not had an

▲ ***Shirley and Fraser take a break at the European Photovoltaic Conference in 1989.***



► ***Fraser accepts the University of Delaware's Alison Award (1990)***

extremely competent staff in both organizations. It is typical of Fraser's concern for his staff that he publicly acknowledged the exceptional efforts of his first IEC secretary, Sheri Barwick, and the IEC Manager of Operations, Margaret Stallings, in his ASEE Award lecture publication in this journal. He is particularly appreciative of the two executive secretaries, Linda Huber in Chemical Engineering and Paula Newton at IEC, who worked closely with him and each other to give him the needed freedom from administrative detail to continue his teaching and research.

Fraser has turned down many opportunities to assume upper-level administrative positions in universities. He has done so because he feels that his most significant impact on chemical engineering has been in the classroom, and over the past few years he has begun to put much more time into these activities. In 1991, he and Nese Orbey supervised a DuPont Teaching Fellow, Linda J. Broadbelt (now an Assistant Professor at Northwestern University), in an undergraduate course in kinetics and reactor design. The DuPont Teaching Fellows Program and the experiences of the six Fellows were described in the Fall 1993 issue of this journal. An excerpt from Linda's write-up regarding her interaction with Fraser reads:

> *Dr. Russell sat in on most of my lectures and gave me excellent feedback about my style and the students' reactions. He was also an invaluable resource during a lecture, providing knowledge and insight from his years of experience. Having such an active and interested mentor was the most crucial element in making my teaching experience so rewarding and successful.*

His colleague, Nese Orbey, describes Fraser as a born teacher who creates a classroom environment (with a relaxed atmosphere) that cultivates participation and self-esteem while promoting higher-level reasoning and creative thinking. His style is much appreciated by colleagues and academic candidates he has mentored. She also notes that perhaps the most difficult part of working with Fraser is to be always reminded—and sometimes forced—to walk at least five miles daily and to "eat your veggies."

Fraser has served the chemical engineering profession through his membership on the AIChE Awards Committee and its Education and Accreditation Committee, where he also serves as an ABET visitor. He and Stan Sandler organized, co-chaired, and raised funds for the support of the 1982 Summer School for Chemical Engineering held at the University of California at Santa Barbara. He has published over ten articles in *Chemical Engineering Education* and other ASEE publications.

Raising three sons always kept the Russell family engaged in various outdoor activities, and time each year was spent hiking, sailing, snorkeling, diving, skiing, and canoeing in locales ranging from the Florida Keys to Baxter Park in Maine, and from the Appalachian Trail to the Colorado and Alberta Rockies. Highlights of those trips include a two-week cruise of the Virgin Islands (sailing their own boat), three months in Western Europe in the 1970s traveling and camping in a VW camper, a fourteen-day trek along the Walkers High Route from Chamoix in France to Zermat in Switzerland, and a one-day, thirty-kilometer hike from the top of Haleakala (Hawaii) through Kapo Gap to the ocean (3500 meters drop in elevation).

The National Academy of Engineering elected Fraser a member in 1990, the same year the University of Delaware designated him as Francis Alison Scholar—an honor held by only 16 of some 1000 faculty. His most recent honor was designation as the ICI Distinguished Lecturer at the University of Alberta. This not only gave him an opportunity to speak on his theme of the critical need for creative laboratory-scale experiments for commercial-scale equipment design, but it also provided an opportunity to visit with his two-year old grandson, Quinn, who was just recently joined by a new granddaughter, Skye. ❒