In our Autumn issue we highlight the research of Professors Craig Criddle, Jim Leckie, Visiting Professor Tom Curtis, and the ambitious and successful new program Leadership for Sustainable Development and Global Competitiveness (SDGC) under executive director Jie Wang. SDGC works with senior management in China’s public and private sectors to support efficient, sustainable use of environmental resources. The Criddle group is developing innovative techniques for removing uranium from polluted groundwater at their field research site in Oak Ridge, TN. Curtis, who is from the University of Newcastle-on-Tyne and worked closely with Criddle during his time at Stanford, is studying biological treatment of wastewater and its importance to sustainable development worldwide. Leckie and his exposure group are making impressive contributions to the study of children’s exposure to toxics in the environment. Through these and other programs EES is continuing to advance CEE’s goals and support its vision of a sustainable future through the cooperative efforts of scientists, engineers, managers, and local and national leaders around the globe.

Early this year, however, EES suffered a great loss with the death of Professor Paul Roberts, one of EES’ most respected and beloved members. We will miss him.

Latest USNews Ranking…

Environmental Engineering at Stanford is still number 1! Civil Engineering moved from number 4 to number 3. The School of Engineering is number 2 just behind MIT.

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EES Newsletter

Edit: Julie Stevens
Design: Molly Quan
The best strategy to realize this transition is to employ the sustainable development paradigm where short term and long term economic, social, cultural, and environmental issues are carefully coordinated, balanced, and governed.

This principle is based on the belief that future economic and business development and competition will be conducted in the context of increasing environmental concerns and limited natural and human resources. Building competitive advantages in a global economy requires addressing the needs of smart business development and innovation in a rapidly changing business ecosystem, while fulfilling social responsibility and trust as a long lasting endogenous foundation for development.

To help educate a new generation of leaders who can carry out sustainable business development in a global economic and business environment for China, we launched an executive training program, the “Stanford-China Executive Leadership Program for Sustainable Development & Global Competitiveness” in conjunction with the Development and Research Center (DRC) of the State Council of China. The mission of the program is to empower business leadership with a new mind set for sustainable development. The program focuses on:

- **A systematic framework** for leadership, decision making and strategic planning in a competitive, fast-changing, knowledge intensive global political, economic, and business environment
- **Adequacy** of information and knowledge and the capacity for obtaining new knowledge
- **Efficiency** in use of natural and, human resources, and lifecycle management
- **Innovations**, assessment, and portfolio management in new technologies and new processes
- **Responsibility** in business ethics, social trust, and collaboration among enterprise leaders and government leaders

Stanford professors and researchers from the Departments of Civil and Environmental Engineering, Management Science and Engineering, Economics, Electrical Engineering, and Computer Science will lecture in the program together with Chinese scholars and policy makers organized by the DRC of the State Council, China. The program is offered through The Stanford Center for Professional Development (SCPD) as a Stanford University certified program.

This program started in March, 2006 with a first cohort of 22 students. Most of the students are top executives from well-known Chinese and Hong Kong enterprises including the vice president of the Three-Gorge Dam Corporation and the director of Hutchison Ports, Hong Kong. Program Director, Professor James Leckie, Executive Director Dr. Jie Wang, and Dr. Richard Dasher, Director of US-Asia Technology Management Center at Stanford, attended the opening ceremony for the program and Professor Leckie gave the keynote speech on sustainable development and global competitiveness. Two ministers, Mr. MengKui Wang and Mr. QingTai Chen from the DRC State Council also attended the opening ceremony.

This program has been well accepted by the Chinese business community and the second class of the program will open in September, 2006. Our goal is to help the participants study sustainable development from the combined perspectives of cultural, social, economic, business and engineering, thus providing them with effective, practical means to put the vision of sustainability into execution in future business development in China. Moreover, by offering this program, we are also carrying out Stanford University’s mission of contributing to the larger world community.

http://www.stanford.edu/group/sdgc/
Seeking a way to resolve the problem of uranium contamination in groundwaters...

By Craig Criddle and Julie Stevens

The Environmental Remediation Sciences Division of the United States Department of Energy (DOE) (http://www.er.doe.gov/ober/ERSD_top.html) sponsors field research that is expected to yield strategies for management of contamination from past radionuclide mining, enrichment and disposal practices. One of these field research sites is the Y-12 National Security Complex in Oak Ridge, TN. In ponds at Y-12, millions of liters of waste from uranium enrichment operations were discharged into unlined lagoons then paved over with asphalt to form a parking lot. The solids under the asphalt cap were contaminated with high levels of uranium (up to 800 mg/kg) and other contaminants. Groundwater that percolates through these solids becomes loaded with contamination. As a result, plumes of contaminated groundwater stretch out from the source zone carrying contaminants into surface waters. Development of strategies to decrease surface water contamination to safe levels is expected to lead to a generic approach that can be adapted for use at other sites.

Stanford involvement at Y-12 began in 2000, when the DOE funded Craig Criddle (EES), PI, and Peter Kitanidis (EFMH), Co-PI, along with partners at Oak Ridge National Laboratory (ORNL) led by Phil Jardine, to conduct a field project entitled: Field-Scale Evaluation of Biostimulation for Remediation of Uranium-Contaminated Groundwater at a Proposed NABIR Field Research Center in Oak Ridge TN. The Stanford/ORNL team proposed the preparation of a region of the subsurface near the source zone for U remediation, to be followed by periodic ethanol additions that stimulate microbial activity and U(VI) into sparingly soluble and immobile U(IV). This biconversion would remove uranium from the groundwater and immobilize it in situ.

A key first step was identification of treatment zone. This involved detailed characterization of the site: its geological, hydrological, andgeochemical characteristics. Characterization is a major challenge: rock type, permeability, strike, extent, flow rates, directions of flow, and its relationship with geological structure of the area are all features that influence flow of groundwaters. There is also the added difficulty of characterizing and controlling conditions in the subsurface. Environmental conditions are not always predictable. In wet climates, such as Tennessee, changes can come about rapidly, the result of sudden rainstorms that introduce water into the subsurface.

After site characterization, the next step is to develop a model for design of the treatment zone. Because the site was so heavily contaminated with substances that would interfere with remediation, the team used injection and extraction well pairs to create an inner recirculation loop nested within an outer recirculation loop. After removing inhibitory and clogging agents, growth of naturally occurring microorganisms within the inner loop was stimulated by addition of ethanol. This created an underground bioreactor within the inner loop. Sampling wells within the inner loop enabled process monitoring. A major challenge was overcoming mass transfer limitations. Most of the flow at the site passes through small fractures surrounded by a sponge-like matrix. Contaminants diffuse slowly from this matrix, and this slow release can limit the rate of remediation. A contaminant of particular concern was nitrate, which was initially present at very high concentrations and had penetrated deep into the matrix.

An additional mass transfer issue was the challenge of chemical delivery, in particular, delivery of ethanol and base to different locations within the subsurface. This can change with time. Some flowpaths from the injection to extraction well are direct while others are circuitous, so not all organisms experience the same level of stimulation. There can thus be differences in the kinds of organisms present. Certain organisms, such as methanogens, appear to interfere with the U removal process, so operational conditions were maintained to select against them.

In the early years of the project, laboratory feasibility studies were used to preview proposed field operations. These studies evaluated denitrification for removal of nitrate, U(VI) reduction and reaction kinetics (2001 and 2002). Column studies using sediment cores were used to evaluate U reduction. In 2002, flow meter tests and tracer studies were performed using bromide to evaluate subsurface flow patterns and release of contamination from the sediment. Construction then began of below ground wells and above ground treatment units for conditioning of the groundwater. This was completed in August 2003 and clean water was flushed through the system to remove substances that could interfere with controlled uranium reduction, such as nitrate, calcium, and VOCs. This flushing process, which continued through January 2004, also removed clogging agents such as aluminum. From January 2004 through August 2005 in situ denitrification and uranium reduction and immobilization continued. Since August the group has periodically introduced oxygen into the subsurface to determine the stability of the reduced/immobilized uranium in situ.

In retrospect, the group can now point to several major achievements: in situ U(VI) reduction and sulfate reduction occurred two months after biostimulation; as early as 14 months after the initiation of bioremediation, aqueous phase U concentrations dropped below the EPA drinking water standard (<0.03 mg/l), despite the presence of very high levels on the solid phase; reduced and immobilized uranium has been shown to be stable under anoxic conditions; and the microbial com-
munity associated with the remediation has been analyzed using 16S rDNA and shown to be Geobacter spp (Fe(III) reducing species) and Desulfobulbus spp (sulfate-reducing species). The value of hydrogeological models has been further reinforced: at every stage in the project, model simulations have informed design and operation.

Participation in a major field research project is definitely a “learning experience”, but the lessons learnt are not only scientific. They can be about the nature of research itself; the surprises, sometimes unpleasant, that are always possible; the risks involved in making high stakes decisions based on available data, then making predictions. The diversity of skills and knowledge of the Stanford and Oak Ridge groups has helped them deal with these challenges. Members of the Stanford team include Professor Scott Fendorf who joined the team as a Co-PI in 2002, seven graduate students, a Senior Research Engineer, and two subcontractors, Dr. Olaf Cirpca now at EAWAG, Switzerland, and Drs. Robert Hickey and Raj Rajan both now at Ecowater, Inc. All have made significant contributions to the project. Kitanidis and his graduate students Mike Fienen and Jian Luo have used their geological, mathematical and modeling skills to help predict and simulate field experiments. Criddle and his graduate students Margy Gentile and Jenny Nyman designed and conducted experiments in the lab to understand the microbial ecology and reaction kinetics needed for the field models. Fendorf and his graduate student Matt Ginder-Vogel applied their knowledge of mineralogy to explore and predict reactions, especially relating to iron species.

At the site, Dr. Wei-Min Wu, Senior Research Engineer, directed daily operations of the above and below ground systems, working closely with Jack Carley, an environmental engineer at Oak Ridge. Phil Jardine and his team at ORNL handled site geophysics, a large initial tracer study, much of the routine sampling and sample analysis, and complementary bench-scale experiments. Dr. Baohua Gu's lab provided critical analytical chemistry support. David Watson, Manager of the Field Research Center, provided logistical support including sample analyses, well construction and obtaining permits. Dr. Jizhong Zhou (formerly at ORNL, now at Univ. Oklahoma) and Dr. Matthew Fields (formerly at ORNL, now at U. Miami Ohio) and their research teams have provided high-level microbiology support.

The research has been a team effort from the start. Risks involved in making decisions on the fly are lessened by the democratic nature of the decision making process - the wisdom of the team as Criddle calls it. Though credit for success is diffused among members of the group, so is responsibility for mistakes. The project sinks or swims on the merit of the ideas produced in the lively discussions at the weekly group meetings at Stanford, in the hundreds of e-mails exchanged, and the frequent, lengthy telephone calls. Five of the graduate students will receive Ph.D. degrees this summer. Criddle views participation in a team such as this a valuable experience for all, and especially the new graduates. They have experienced first hand the messy process of field research, the mutual dependency; the need to speak out and “puncture” bad ideas; the need to deal with uncertainties; the understanding that lack of experience can sometimes trump experience by bringing fresh, unbiased viewpoints to the table.

And the project is continuing. Current and future studies include:

- Long-term stability of reduced/imobilized U
- Microbial community dynamics and its impact on U remediation
- Mineralogy of reduced/imobilized U under variable environmental conditions
- Expansion of the treatment area to test different and improved remediation approaches such as development of thermodynamic and kinetic models for U reduction/imobilization and the development of hydrogeochemical models for remediation and long-term stability.

Field research such as the Oak Ridge project is addressing fundamental scientific questions, how does nature work? It will add to our knowledge of geochemistry, bio-availability, community structure, community ecology and how certain organisms behave. With this knowledge, the group hopes to alleviate contamination at Oak Ridge, and contribute to the fundamental science and know-how needed to address other similar challenges.

The money from the Dean of Research was used to support Valerie Zartarian, a graduate student at the time, as she began developing a time-series based stochastic dermal exposure model. It became apparent that there was very little detailed data on what children actually come into contact with during daily activities. At the time, researchers observing child behavior would use counters or log sheets to track the number of times a child touched an object. This method, however, would be very difficult to extend to multiple objects, and did not record the sequence of activities, an important factor because it accounts for both loading and removal mechanisms, e.g., washing of hands.

Leckie and Zartarian videotaped children at the Bing Nursery School on the Stanford campus and began assessing the best way to quantify the children’s activities. Colin Ong (EES), an associate with the Stanford-Singapore Partnership (SSP) program, was a collaborator and it was he who developed VideoTraq software, now known as Virtual Timing Device, which has revo-
Environmental regulatory programs stemming from accurate exposure have led to great improvements in public health. The Exposure Research Group (ERG) has been conducting research on children’s exposure to pesticides since the early 1990’s, when Professor James Leckie (EES) the Dean of Research to form the Exposure Research Group pesticide exposure of the children of farm workers. Leckie’s human exposure showed him that very little research had been previously conducted on this subject. Adult white men were the subjects of most of the studies, and their bodies are still developing may have greater dermal exposure on the floor playing and crawling. In particular, the children for pesticide exposure due to spray drift and contamination clothing, shoes or skin.

Over the years the method has been used in a number of studies at Stanford and around the country to investigate dermal contact activities, especially hand to mouth behavior, of rural, urban, suburban, and autistic children. An early, far-reaching goal of ERG was to use the micro-activity data with concentration data as inputs to a total human exposure model for quantifying total pesticide exposure. This goal has not yet been achieved, partly because human exposure and subsequent health effects arise from a complex of physical, chemical and biological processes that are difficult to model. However, Paloma Beamer, a Ph.D. student in the group is combining previous models and adding modules to develop a total human exposure and dose model that will allow researchers to estimate exposure via all routes (inhalation, dermal, dietary, and non-dietary) and subsequent dose. Outputs include metabolite concentration values in the urine, which can be validated with concentrations measured in children. The model may serve as a tool to determine the contribution of each exposure route and to evaluate alternatives intended to reduce pollutant exposures and subsequent dose. It will also provide a link between environmental concentrations and subsequent health effects.

Teaching has also been an important focus for Leckie and the ERG. They have developed an introductory course on human exposure analysis focused on quantitative estimates of exposure and the receptor. Instructors focus on their particular areas of expertise and the long list of those involved includes: Professor Lynn Hildemann (EES), Consulting Professor Wayne Ott (CEE), Dr. Andrea Ferro, now an assistant professor at Clarkson University, Dr. Jeffrey Cunningham, now an assistant professor at the University of South Florida, and Ph.D. students Viviana Acevedo-Bolton and Qing Chen. The course is designed to give students an appreciation of the physical, chemical and biological issues relevant to estimating exposure. It has grown from a seminar to include lectures, laboratories, and an exposure assessment project, reinforcing material presented in classes dealing with fate and transport and the physics and chemistry of air pollution. A textbook, edited by Wayne Ott, has also been developed as a result of this course.

Former members of the group are continuing to work in the exposure field. Valerie Zartarian is based at the US EPA National Exposure Research Laboratory; Alesia Ferguson is an assistant professor in the Dept. of Environmental & Occupational Health at the University of Arkansas; Robert Canales has recently completed postdoctoral training at the School of Public Health at Harvard and is returning to Stanford as an acting assistant professor. Willa AuYeung and Paloma Beamer hope to graduate within the next year and continue as postdoctoral researchers with ERG. The group now has a new member, Tim Julian, a Ph.D. student, who plans to research pathogen risk using the microactivity database, and modify the chemical, non-dietary ingestion exposure model to assess children’s exposure to rotavirus in day care centers.

Over the years ERG has grown as a research program, a teaching program and as a major contributor to the field of exposure research. Six Ph.D. students have been members of the group and four have been selected for best student research poster at the annual conference of the International Society for Exposure Analysis. With continual involvement from students in the bachelors, masters, engineering, and Ph.D. programs, ERG is continuing its groundbreaking contributions. This research has been presented at annual conferences held by the International Society for Exposure Analysis (ISEA) and the International Society for Environmental Epidemiology (ISEE) and published in journals such as the Journal or Exposure Science and Environmental Epidemiology, the Journal of Children’s Health, and Environmental Science and Technology. Students in ERG have won awards for their research on human exposure, including the ISEA Joan Daisey Outstanding Young Scientist Award (Valerie Zartarian in 2000) and the Best Student Paper Award presented at the ISEA annual conference (Valerie Zartarian, 1995; Alesia Ferguson, 1996; Robert Canales, 2000 and Paloma Beamer, 2004.)
Tom is a Royal Academy of Engineering Global Research Fellow who arrived at Stanford July, 2005 to spend a year of research with Professors Craig Cridde, EES, Brendan Bohannon, Biological Sciences and Chris Francis, Geological & Environmental Sciences. He shares our belief in the central importance of biological treatment to the sustainable development of both the developed and developing world, and at Stanford found “… peace and quiet, and the opportunity to collaborate with excellent microbial ecologists and engineers with experience in turning hard science into real design.”

Research in biological treatment systems is often highly empirical and heuristic. Few would deny the importance of empiricism and heuristic in solving engineering research. However, there are limitations to such an approach, both for researchers and practitioners. Researchers in biological treatment must confront the possibility that such research is simply hitting the laws of diminishing returns. Moreover, research is yielding less and less information. The solutions we do develop are often situation bound and difficult to generalize with any confidence. As a consequence, practitioners live with the daily possibility of failure, failure that is often difficult or impossible to explain. Worse still, the scientific basis for the explanations offered within the industry might appear flawed or even fallacious when judged by the standards of contemporary scientists in other areas.

The engineering of open biological systems in the 21st century is, in many ways, at a stage akin to that of traditional engineering over 150 years ago. Rankine, then professor of Civil Engineering at Glasgow University, devised new physics for new design challenges. Thus, where the existing physics was inadequate (for example to design a steam engine) he actively improved the science to permit design. Biological treatment plants represent assemblages of many different interacting organisms, so we must look to theoretical ecology to describe biological treatment plants.

Measurement is a very important driver in the tradition of empiricism in the engineering of biological treatment systems. There was therefore a great deal of optimism about a new generation of tools in microbial ecology that permitted, for the first time, the detection and quantitation of the microorganisms in real environments (as opposed to test tubes and laboratory pure cultures). My colleagues and I have been at the forefront of the application of these techniques to wastewater treatment plants, using quantitative techniques to determine the numbers of specific key organisms as well as defining patterns in the prokaryotic diversity using a variety of tools. These new tools are neither cheap nor easy to use and considerable technical difficulties must be overcome if they are to yield usable results. The new tools have revealed new, almost inexplicable, patterns. We have foreseen these difficulties, and called for, and begun developing, a body of theory to support design (Curtis et al., 2003). We have made a good start. As a baseline we have established that the quantitative Monod based predictions of McCarty and Downing agree with the quantitative measurements we can make using quantitative molecular tools (inspired by Bruce Rittman’s group). We have then gone beyond the size of the system and started looking at its composition, developing a simple theoretical approach to estimate the maximum possible diversity of biological wastewater treatment systems. Latterly, working together with Bill Sloan (Department of Civil Engineering in Glasgow) we have developed stochastic model that can predict the diversity of any wastewater treatment reactor.

Theories that will describe any biological wastewater treatment system will describe any microbial system, engineered or not. Thus this work places research on the theory not just at the vanguard of engineered biological systems, but at the vanguard of biological theory as well. I have just returned from a presentation to the Royal Society in which I used theories and parameters developed for use on wastewater treatment plants to ponder the microbial diversity of the world. However, tools to measure a system and theory to describe it are not design. Design is now our greatest challenge. This requires a good grasp of the theory and measurement, an appreciation of the realities an engineer faces on the ground, as well as elements of design philosophy exemplified by Henry Petroski, Vesic Professor, Department of Civil and Environmental Engineering at Duke University.

There are, of course, grounds for scepticism. Some doubt that the application of further theory can have a useful effect on design or practice. This is a fair comment, but we will not know unless someone tries. Rankine himself was dogged by such criticism, and sufficiently stung by it to write his famous essay “On the harmony of theory and practice in mechanics”. I was very encouraged to learn that, in the 1960s, Professor (then Dr) Perry McCarty found that his seminal theoretical work was not always considered the province of environmental engineers, though now it forms the basis for most rational modeling of wastewater treatment plants.

Selected References

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Colleagues throughout the university and alumni and friends everywhere mourned the death of Professor Paul V. Roberts from leukemia February 12 at his home in Cupertino. He was 67 years old. Widely respected for his achievements in research and teaching, and loved by his students for his warmth and the hospitality he and his wife, Inge, extended over the years, he is remembered for his love of life, his enjoyment of music, and his deep regard for nature. At the memorial service held in his honor February 22 in Memorial Church, Professor Richard Luthy, Chairman of the CEE Department, spoke of the esteem and affection his colleagues held for him: “Paul was one of the very best and admired environmental engineers of my generation. He was drawn to environmental engineering both philosophically and intellectually, for he had discovered in himself a deep affection for the natural environment. He was a role model for me and many others for his approach to environmental research and his commitment to democratic ideals and peace.”

Roberts was the first person to hold the C.L. Peck, Class of 1906, Professorship of Engineering. He received an M.S. degree from Princeton in 1960 and Ph.D. from Cornell in 1966, both in chemical engineering. After teaching in Chile for two years he worked at Chevron and then SRI before enrolling in the Stanford School of Engineering’s Honors Cooperative Program and earning a masters degree in 1971. His move to academia was prompted by a lifelong interest in nature and increasing concerns about industrial pollution. During the next five years he was a highly valued staff member of the Swiss Federal Institute of Water Supply and Water Pollution Control, but in 1976 he decided it was time to return to the US and accepted an offer as research professor in Stanford’s environmental engineering program.

He was the author of more than 200 publications, also a member of the Swiss Academy of Sciences, and was elected to the National Academy of Engineering in 1997. Other honors included the 1989 Scientific and Technical Achievement Award from the EPA and the 2003 Founders Award from the Association of Environmental Engineering and Science Professors.

Roberts was recognized as an outstanding teacher who contributed greatly to the growth of the EES program and its eventual standing as the premier program in the country. Professor Emeritus Perry McCarty expressed a commonly held feeling: “The esprit de corps that developed in the Environmental Engineering & Science Program with Paul’s warmth and generosity helped in creating an exceptional teaching and research atmosphere for us all.” He was a pioneer in the environmental research field specializing in wastewater reclamation. It was he who organized an international team of scientists to carry out field experiments in Canada in 1980. This is now recognized as the definitive study of the processes affecting the movement and fate of hazardous chemicals in groundwater. He also pioneered the concept of using treatment processes to reclaim wastewater and then inject and store the reclaimed water in the aquifer below San Francisco Bay wetlands.

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EES was proud to host the Annual AEESP Distinguished Lecture jointly with UC Berkeley this year. Rene Schwarzenbach, Professor of Environmental Chemistry at the Federal Institute of Technology (ETHZ), Zurich, Switzerland, was the honoree.

The title of his lecture given at Stanford Friday, March 17 was “Use of Stable Isotope Fractionation to Assess Organic Pollutant Transformation in Contaminant Hydrology”. In the lecture, the possibilities and limitations of the application of isotope fractionation data to assess organic pollutant behavior in natural and engineered systems was discussed using a variety of practical examples including chlorinated solvents, gasoline components (BTEX), MTBE, and nitroaromatic explosives.

Schwarzenbach is Professor of Environmental Chemistry at the Federal Institute of Technology (ETHZ) in Zurich and head of the Institute for Aquatic Sciences and Water Pollution Control at EAWARE. He earned his diploma (1970) and his Ph.D. (1973) from the Chemistry Department at ETHZ and spent 2 years as a postdoctoral researcher at Woods Hole Oceanographic Institute. His research and teaching focus primarily on the distribution, fate and effects of organic pollutants in the natural environment.

Dr. Eduard Hoehn, Senior Research and Expert Consultant Hydrogeologist at EAWARE, the Swiss Federal Institute of Water Science & Technology, has just returned to Switzerland after a 3-month sabbatical working with Professor Martin Reinhard and his group. During his stay at Stanford, Hoehn participated in the Reinhard group’s field study at an experimental site along Upper Silver Creek in San Jose researching the “…natural attenuation of emerging (unregulated) contaminants during a planned augmentation of the creek with recycled water.” Hoehn’s areas of expertise include exchange between groundwater and surface water; radon in groundwater; and groundwater quality and tracer studies.