Senior Leader Notes

Message from the Director
by Mrs. Joan Ma Pierre

This year marks the 4th birthday of the Defense Threat Reduction Agency’s basic research program. DTRA initiated the program in 2007 to promote the development of the future science and engineering workforce for combating weapons of mass destruction. Today the agency sponsors more than 160 research teams representing over 90 universities, government laboratories and private research institutions.

Hundreds of students are being trained in science and engineering disciplines that support DTRA’s mission.

A new “community of interest” with the diverse talents needed to address the unique scientific challenges presented by WMD threats is beginning to coalesce. This past October, close to 400 professors, students, federal sponsors of basic research, and extended members of the government and industry research community attended the 2009 DTRA Basic Research Technical Review in Springfield, Virginia.

continued on page 8

Research Corner

Quantification of uncertainty for dispersion models through computer experiments

by Dr. David C. Woods

The simulation of physical and engineering systems via complex mathematical models has become a vital technique for gaining knowledge and understanding when physical experimentation is too time consuming, costly, or hazardous to perform. Transport and dispersion (T&D) models are important examples of such systems and are used to predict the downwind hazard generated by a chemical or biological (CB) release, and to provide crucial information for command and control decisions. Uncertainty in the source of the release and...
meteorological conditions requires collections of combinations of model input variables, or runs, to be performed, with each combination describing a different threat scenario. This is an example of a computer experiment, where data gathered from a careful choice of runs, or a design, is used to investigate and interrogate the computer model.

This DTRA-funded project is developing methods of investigating T&D models through the effective application of computer experiments. The research team brings together investigators from three UK centers, the University of Southampton, the Defence Science and Technology Laboratory (Dstl), and the Met Office, to provide expertise in design of experiments and statistical modeling, transport and dispersion, and meteorological forecasting.

When a computer model is computationally expensive to run, relative to available resource, it may be necessary to build a statistical approximation, or emulator, of the model. Such emulators, typically constructed using Gaussian stochastic processes, allow fast prediction of model outputs and quantification of associated uncertainties caused by the inevitable inadequacies in the emulator and the underlying computer model. For T&D models, building an emulator is complicated by the functional nature of outputs from each computer run, e.g. a two-dimensional CB dosage surface, and the highly nonlinear relationships between the inputs and outputs of the computer model. Research so far has focused on two key areas: the optimal design problem of selecting combinations of input variable values at which to run the computer model, taking account of prior uncertainties and dependencies between input variable; and the construction of an emulator for dosage using results from function approximation (thin-plate splines), multivariate statistics (principal components) and hierarchical Bayesian models, see Figure 1.

Emulators are particularly useful when there is uncertainty in the model inputs, as they make feasible Monte Carlo-based uncertainty and sensitivity analyses. A major component of our research is to understand, describe and incorporate the uncertainties in the meteorological variables. Our aim is to achieve these goals through statistical analysis and model fitting of ensemble meteorological forecasts to quantify their uncertainty and propagate it through the T&D model via the emulator.

This basic research project is providing underpinning methodology that will contribute to the effectiveness of risk-based warning systems. The goal is fast and accurate prediction of dispersion, with an associated measure of uncertainty which is induced a variety of

Figure 1: (left) Actual CB dosage surface from a transport and dispersion model and (right) predicted dosage using a hierarchical statistical model and principal components. In both plots, a log scale is used for dosage.
variables. Tools built on this research have the potential to enable warfighters and commanders to make informed decisions in a timely manner and thus facilitate mitigating courses of action.

Dr. David Woods is a Lecturer in Statistics at Southampton Statistical Sciences Research Institute and the School of Mathematics at the Univ. of Southampton UK. Research interests focus on the design and analysis of both physical and of computer experiments, Bayesian methods, and the application of Statistics to science and technology. Much of his work is interdisciplinary and involves collaborations with researchers from other disciplines (Chemistry, Engineering, Computer Science), and with government and industry (Dstl, Met Office, Lubrizol, GlaxoSmithKline, Pfizer). He is a member of the editorial boards of Technometrics and the Journal of the Royal Statistical Society: Applied Statistics.

Multi-metal ion catalyzed alcoholysis reactions of neutral & anionic organo-phosphorus compounds in alcohol media
by Dr. R. Stan Brown

There is a growing consensus that the active sites of enzymes, Nature’s catalysts, have effective polarities and dielectric constants resembling organic solvents rather than water. A major thrust of our work is aimed at testing the hypothesis that the rates of enzyme-catalyzed reactions of organophosphates can be attributed such a solvent effect. Indeed, previous work from our labs indicated that methanol, which has a lower polarity and dielectric constant than water, provides unprecedented catalytic enhancement of catalytic degradation of phosphate esters mediated by metal ions. For example, neutral organophosphates such as the nerve agents soman, tabun and VX are degraded in seconds in neutral methanol at room temperature in the presence of lanthanum ion (La$^{3+}$).

Our present DTRA-funded project aims to understand if this unusual medium effect can be used to enhance the reactivity of other man-made catalysts that are modeled after the active site constituents of metal-containing enzymes that cleave phosphate diesters and monoesters. The generic phosphate diester shown below (upper-left: labeled 1) is extremely stable toward P-OR’ cleavage, which makes it an ideal linker to hold together RNA and DNA genetic material.

Many of the enzymes that cleave RNA and DNA contain two catalytically essential Zn$^{2+}$ ions in their active sites. In order to mimic the activity of these two-metal ion containing enzymes, we have synthesized a dinuclear catalyst (labeled 2) and investigated its ability to cleave a series of RNA models (labeled 3) and DNA models (labeled 4) in both methanol and ethanol. The process follows Michaelis-Menten type kinetics (Cat. + substrate $\leftrightarrow$ Cat.:substrate $\rightarrow$ product) giving extremely large catalysis in both solvents, for example, by factors of $10^{14}$ for the DNA models in methanol and $10^{17}$ for the RNA models in ethanol relative to the respective background reactions.

The natural substrates of many of the enzymes that cleave phosphate esters generally have leaving groups (the OR’ group in 1) which are poorer than the O-aryl groups in the model substrates 3 and 4, yet enzymatic cleavage of such natural substrates is very fast. It has been postulated that the enzyme provides some sort of “leaving group assistance” during the departure of the OR’ group. Since that group generally departs as an anionic alkoxide (-OR’), one way to assist its departure is to have the enzyme position a positively charged metal ion (M$^{2+}$) in such a way that it that would partially neutralize the negative charge as P-OR’ cleavage occurs. To test this hypothesis we are investigating the reaction rates for Cu(II)-assistance of

![Dr. David Woods](image)
the cleavage of a contiguous set of phosphate tri-, di- and monoesters (see figure below with substitutions labeled 5, 6 and 7) with the expectation that strong binding of the anionic leaving group to it’s embedded Cu(II) will offset the energy required for P-O leaving group departure. Work to date indicates that in the case of the mono and diesters (7, 6) the rate acceleration for the decomposition of the Cu(II) bound species are at $10^{12}$ to $10^{14}$ fold faster than the background reactions, providing convincing evidence that leaving group assistance can be an important tool from enzymes and other catalysts to employ to increase the reaction rates of poorly reactive substrates.

There is a long-standing interest in understanding how enzymes achieve their remarkable rate accelerations for difficult reactions, in the hope that such understanding might lead to the development of man-made catalysts of increased efficacy. The present work indicates that a combination of metal ion catalysis and a reduced polarity/dielectric constant medium such as is produced in the light alcohols, offers a new paradigm from which new catalytic processes might be approached.

Acknowledgement. These studies were made possible through the generous past funding from the United States Department of the Army, Army Research Office, Grant No. W911NF-04-1-0057 and the Defense Threat Reduction Agency, Joint Science and Technology Office (06012384BP) as well as present funding from the United States Defense Threat Reduction Agency Joint Science and Technology Office, Basic and Supporting Sciences Division through the award of grant # HDTRA-08-1-0046.


R. Stan Brown is a Professor of Chemistry at Queen’s University, Kingston. He received his undergraduate B.Sc. (Hons) in chemistry from the University of Alberta in 1968, and subsequent M.Sc. and Ph.D. degrees from the University of California, San Diego in 1970 and 1972. Following a two year NSERC PDF period at Columbia University in New York, he joined the University of Alberta as an Assistant Professor in the Dept. of Chemistry. In 1995 he moved to Queen’s University as Head of the Chemistry Department.

Prof. R. Stan Brown

Quotes

“The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them.” William Bragg

“Out of intense complexities intense simplicities emerge.” Winston Churchill
Questions and Answers

By Professor Robert Feigelson on Materials, Crystal Growth, and Research Perspectives

Could you give us an overview of the research you are currently pursuing for DTRA?

Our research involves developing an understanding of the relationship between grain boundaries and other crystalline defects in transparent scintillator ceramic materials on their transparency and performance. Scintillator materials are an important component of radiation detecting devices, and high efficiency; low cost materials are necessary for the practical deployment of large-scale equipment throughout the country and elsewhere. To date most inorganic materials used or being proposed for these applications are in the form of single crystals. These are generally expensive to prepare and have problems with size, uniformity, and activator ion concentration. Optical ceramic materials have slowly emerged over the last two decades as potential competitors for single crystal scintillators. Ceramics do not undergo component segregation during processing as do single crystals, and can be produced in near-net shapes and scaled up to large sizes more readily and at lower temperatures than single crystal components. Until recently, only highly transparent ceramics of cubic crystal structure materials have been prepared. The optically isotropic grains and refractive index continuity at the grain boundaries makes light scattering from the randomly oriented crystallites nonexistent. The trick is to make highly transparent ceramics from birefringent materials (phases with non-cubic crystalline symmetry) since the most efficient scintillator materials have this type of structure, including LaBr₃, YAlO₃, Lu₂SiO₅, Bi₄Ge₃O₁₂, and SrI₂.

Our research program involves a study of the relationship between both macro- and micro-scale defects on scintillator properties using model optical ceramic material systems. Macro defects include grain boundaries, porosity and solid phase inclusions, while micro-scale defects include various atomic-scale lattice imperfections. Our program was structured to progress from the study of scintillator compounds having a simple chemistry and crystal structure (such as binary cubic materials) to the study of more complex materials (non-cubic binary and ternary compounds) including exciting new materials of interest to the radiation detector community.

What are the knowledge gaps in fundamental sciences that present a challenge for your research effort in this work?

This is not such a prominent issue in our research work. There is an already extensive body of theoretical and experimental literature to draw from concerning the formation and energetics of crystalline defects in solids, their structural and chemical nature, as well as densification mechanisms. The most challenging part we face in our research relates to determining and controlling defect type, concentration and distribution and how they interact in a particular solid to lower the total energy of the system and ultimately affect light yield. These defects can be strongly influenced by the choice of processing conditions employed, and can be manipulated to some extent by additional processing steps such as annealing. Unlike single crystals, ceramics have the additional complexity of containing small single crystal grains and hence grain boundaries. The grains can vary both in degrees of miss-orientation and in size, the latter influencing the grain boundary area (defect concentration). Crystal defects can interact with these boundary regions in complex ways.

The issue that is least understood at this time is how these various individual defects or defect complexes affect scintillator performance. One of our surprising results, for example, was that light yield in highly transparent Eu:Y₂O₃ ceramics could be improved over 3-fold by annealing for unexpectedly long periods of time in the presence of oxygen, thereby reducing oxygen vacancy concentrations, oxidizing...
Eu from divalent to trivalent and probably affecting other defects such as impurities and defect complexes.

Another issue of great importance is how the spatial distribution of activator ions or trapping sites across a grain and through the grain boundary affects scintillator performance. To address this problem my graduate student, Steven Podowitz, is using several techniques to probe these micro-scale variations in composition and scintillator output. These include cathodo-luminescence transport imaging (CLTI) and X-ray radioluminescence microscopy (XRLM). This work is in collaboration with Prof. Nancy Haegel’s group at the Monterey Naval Postgraduate School and the X-ray microprobe beam line “2-3” at Stanford’s Synchrotron Radiation Light Source (SSRL) within the SLAC National Accelerator Laboratory.

What are the current challenges in fabricating high-optical grade ceramics?

First let me put the optical ceramics field in perspective. Until the late 1950’s most of the high-density ceramics were opaque and even achieving densities up to 99.9% of theoretical was a significant challenge. The ceramic community was stunned therefore when Robert Coble from the GE Research Laboratory in Schenectady, New York reported that they had produced theoretically dense, highly translucent aluminum oxide ceramics for the first time. The breakthrough involved both the use of sintering additives (In this case MgO) and a reducing sintering atmosphere to eliminate all porosity. In later years this technology was exploited for other window materials such as spinel, MgF₂, and aluminum oxynitride. In the 1990’s research on scintillator ceramics began at the GE laboratories and transparent (Y,Gd)₂O₃:Eu ceramics for medical detectors were developed. During this same period several Japanese groups successfully prepared large, water clear YAG ceramics for laser applications. Optical ceramic research was greatly stimulated by these successes.

While the previous processing technologies can guide our way in preparing a high-optical grade ceramics, there is still no general formula that is applicable for all classes of materials. The thermodynamic properties of the material, crystalline defects and extrinsic influences such as impurities, dopants, and processing variables can all affect both the transparency and properties. This will necessitate processing modifications that have to be empirically determined.

The first step in fabricating high performance transparent ceramic scintillators is to promote transparency without creating detrimental defects that would degrade its performance (i.e. color centers, impurities, trapping centers, etc.). The use of sintering aids for example, may introduce such harmful defects and their avoidance would be useful. We need to develop a quantitative relationship between ceramic processing variables, defect structure and scintillation performance. In our DTRA program we have discovered that in the Eu:Y₂O₃ system, the europium is reduced from 3+ to 2+ during hot pressing creating oxygen vacancies that enhances sintering without extraneous sintering aids. Also that grain boundaries facilitate re-oxidation and that light yield was an unexpectedly strong function of oxygen annealing time.

That said, I believe that the single biggest challenge in the ceramic detector materials field is being able to prepare very transparent ceramics of compounds with non-cubic structures. To date a certain degree of transparency has been produced in a number of interesting materials, including SrI₂ (in our Laboratory), but grain boundary scattering from randomly orientated grains in birefringent materials is a major issue. The best way to solve this problem will be to prepare ceramics with not only minimal porosity but with oriented grain structures as well. Few studies on how to enhance grain alignment in scintillator ceramics have been undertaken to date.
What do you see as the opportunities as well as challenges for young scientists to work in this research area?

I think opportunities will be very good for thoroughly trained young scientists who want to pursue a career in radiation detector materials technology. Both the defense and medical applications involved are very important and while funding can be rather mercurial, I anticipate that it will be increasing over the next decade due to the importance of this technology to our country. As a result, an increase in job openings in both industry and our national laboratories should arise.

If this prediction is correct, one of our challenges will be to attract future scientists to this field. First we need to alert them of the interesting science, engineering and job opportunities available. This will require some targeted outreach programs to educate undergraduate or even high school science students on the scientific and engineering opportunities available, as well as the substantive way this research contributes to societal needs. Then we need to be able to provide them university graduate programs to train them adequately on the fundamentals involved and how to carry out high-level research work.

Otherwise I do not think that young scientists working in this field will have challenges much different than in other research fields.

In your professional opinion, what major trends do you see in basic research?

Of the two important trends that come immediately to mind, the first is the explosive growth in nano-scale research. The unusual physical and chemical behavior of nano-sized materials, and the novel engineered structures made from them, have given rise to very exciting areas of research, both with respect to unraveling new property-structure relationships as well as the development of new devices and devices with significantly improved properties. It is important, however, that we do not tilt too far, nor too fast in this direction and lose sight of other more conventional areas of macro-scale materials, which are important for many applications such as radiation detector and laser systems.

The second trend is the increasingly more interdisciplinary nature of science and engineering education and research. The more collaborative nature of our research benefits both students and research programs. When scientists from different disciplines collaborate, they provide perspectives and valuable insights that are not afforded by the other research workers.

Prof. Robert Feigelson is a member of the faculty of the Stanford University Materials Science and Engineering Department and the Geballe Laboratory for Advanced Materials. He received his Ph.D. from Stanford, and for over 35 years directed the Crystal Science Laboratory in their Center for Materials Research. His principal research areas have been in crystal growth and materials processing, his work spanning a broad range of compounds and processing technologies. He was the recipient of the International Organization for Crystal Growth's 1995 Triennial Laudise Prize, for outstanding achievements in experimental crystal growth, is a current Editor of the Journal of Crystal Growth and was President of the American Association of Crystal Growth and other regional societies.

Introducing Dr. Michael Robinson

Dr. Robinson was promoted to chief of the Sciences division and reports directly to Mrs. Pierre, Director. He is responsible for leadership and oversight of the DTRA basic research portfolio that addresses the complex and unique spectrum of counter-WMD challenges.

Michael Robinson began with DTRA in 2009 as the thrust manager for the radiological and nuclear sensing portfolio in the basic and applied sciences directorate. He holds a doctorate in atomic physics.
from the University of Virginia, specializing in laser cooling and trapping of atoms; he also holds a master of science in business administration from Boston University. Prior to joining DTRA, Mike was a science advisor in the counter improvised explosive device (C-IED) and asymmetric warfare community ensuring technical quality in initiatives from basic research through fielded technology demonstrations including quick reaction capabilities. Mike began his career on the bench with the Air Force Research Laboratory, building and managing a basic research laboratory investigating ultra-cold atoms as sensitive inertial force sensors.

Mrs. Joan Ma Pierre…continued from page 1

Principal investigators for all the grants in progress presented their research to an audience that included peers and government program managers. The attendance survey reflected overwhelming support for continuing this practice. Those of you who attended the plenary presentations heard first-hand from DTRA senior leaders. Col Michael Baehre, acting directorate chief of the Nuclear Technology Directorate, and Mr. Stephen Dowling, directorate chief of the Counter WMD Technologies Directorate, offered perspectives on research needs to support their mission areas. (See Spotlight on Science articles “Active Detection of Special Nuclear Material”, July 2009 and “Advanced Energetic Materials for Counter-WMD Applications”, July 2008). It was my pleasure to meet many of you at the review and share with you the latest information about DTRA’s exciting research opportunities in basic and early applied sciences. Keep posted to this newsletter for additional insights and announcements throughout the year.

On behalf of the DTRA team, thank you for your support of DTRA’s basic research program.

Events Calendar


DTRA Chemical and Biological Defense (CBD) Science and Technology Conference: This conference seeks to identify and examine interrelated CBD areas of basic and applied research that are relevant to the medical and physical science disciplines; 15-19 November, Orlando, FL.

DTRA Basic and Applied Sciences Technical Review: Basic and Applied Sciences Annual Technical Review will be held from 9-13 and 16-20 August, Springfield, VA.

Spotlight Submissions

Spotlight on Science welcomes your articles, announcements, and submissions on research topic areas in sciences of sensing and recognition, cognitive and information sciences, sciences for protection, sciences to defeat WMD, and sciences to secure WMD. Articles should be approximately 350 to 500 words and may be edited for space and clarity. Submissions should be sent to Scott at scott.brady_contractor@dra.mil •