SCHOOL OF ENGINEERING

CRESP

Short Course
Introduction to Nuclear Chemistry and Fuel Cycle Separations

Vanderbilt University School of Engineering
Department of Civil and Environmental Engineering
Nashville, TN

December 16-18, 2008

Speakers Affiliations

OSU Oregon State University

Syracuse University Founded A.D. 1870

NWTRB U.S. Nuclear Waste Technical Review Board

ANA

INL Idaho National Laboratory

Lawrence Livermore National Laboratory
Science in the National Interest

Los Alamos National Laboratory

Oak Ridge National Laboratory
Managed by UT-Battelle for the Department of Energy

Pacific Northwest National Laboratory

SRNL
We Put Science To Work

Acknowledgements

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David S. Kosson, Vice-Chair, Vanderbilt University
Cynthia Atkins-Duffin, Lawrence Livermore National Laboratory
David DePaoli, Oak Ridge National Laboratory
Kathryn Higley, Oregon State University
Terry Todd, Idaho National Laboratory

SPEAKERS:

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Allan Croff, ORNL, ret., and USNRC
David DePaoli, Oak Ridge National Laboratory
B. John Garrick, NWTRB Chairman
Mark Gilbertson, Department of Energy
Mike Goff, Idaho National Laboratory
Clarence Hardy, Nuclear Fuel Australia, Ltd
Kathryn Higley, Oregon State University
Gordon Jarvinen, Los Alamos National Laboratory
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Randi Hall, Administrative Assistant
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About CRESP

CRESP

Consortium for Risk Evaluation with Stakeholder Participation III

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About CRESP

The Consortium for Risk Evaluation with Stakeholder Participation CRESP III is primarily a five year (2006 - 2011) Department of Energy cooperative agreement awarded to Vanderbilt University. The multi-university consortium is working to advance cost-effective, risk-based cleanup of the nation's nuclear weapons production facility sites and cost effective, risk-based management of potential future nuclear sites and wastes.

CRESP III Mission

The mission of CRESP III is to advance cost-effective, risk-based cleanup of the nation's nuclear weapons production facility sites and cost effective, risk-based management of potential future nuclear sites and wastes. This will be accomplished by seeking to improve the scientific and technical basis for environmental management decisions by the Department of Energy and other public entities and by fostering public participation in that search.

Scope

The CRESP III projects help define and assess the technical and regulatory scope and approaches useful for the nation as it strives to undertake its cleanup and stewardship responsibilities in a protective and cost-effective manner at contaminated sites, and plan and manage potential future nuclear sites and wastes. The project effort focuses on supporting independent and collaborative research, reviews, methods, data gathering and stakeholder participation needed for effective evaluation and communication of DOE related health, environmental and other risks. The effort seeks responsively to address on important cleanup-related challenges at the sites, on the end states which cleanups seek to achieve, and planning and management challenges for potential future nuclear sites and wastes. CRESP III is committed to accomplishing these outcomes by:

- performing targeted studies on specific risk related issues important to the long-term management of environmental problems;
- contributing to risk evaluation and assessment, or to the development of related methodologies, relevant to risk issues at a number of DOE sites;
- focusing on the collection and analysis of data needed for effective risk evaluation, and on the definition and assessment of relevant technical and regulatory approaches valuable in resolving risk-related issues;
- providing an independent mechanism to support the assessment of DOE'S needs for research, to critique current research, and to develop data relevant to the concerns of the public, to support planning and to be responsive to evolving regulatory commitments; and
- supporting efforts to improve working relationships and communications with the public and stakeholders at sites and across the DOE complex.

The CRESP Membership

The CRESP III consortium member universities, led by Vanderbilt, now include Howard University, New York University School of Law, Oregon State University, Robert Wood Johnson Medical School, Rutgers, The State University of New Jersey, University of Arizona, the University of Pittsburgh and the University of Washington.

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Course Agenda

Introduction to Nuclear Chemistry and Fuel Cycle Separations

December 16 – 18, 2008

Topics and Speakers:

Tuesday December 16

7:45 – 8:15 Registration and Continental Breakfast

1. Welcome and Course Introduction — David S. Kosson, Vanderbilt University
2. 20 Years of Progress in Processing Nuclear Waste — Mark Gilbertson, Department of Energy
3. Nuclear Fuel Cycle Fundamentals — Frank L. Parker, Vanderbilt University

   a. The Nuclear Fuel Cycle (milling, additional refinement including conversion, enrichment, reprocessing, waste management, and waste disposal), b. Fission yields, c. Actinide elements, d. Important fission products, e. Problems created during Cold War (Waste tanks, Site Contamination-radioactive and non-radioactive, Stewardship of abandoned sites).

Break

4. Mining, Milling, Conversion and Enrichment of Uranium Ores — Clarence Hardy, Nuclear Fuel Australia, Ltd

   a. Ore processing (By ore type-sub-surface, By method – acid, alkaline carbonate, Other) b. conversion, c. Enrichment (Calutron, Gaseous diffusion, Centrifugation, Metal-aqueous phases – Li isotope, Laser).

5. Nuclear Radiation — Robert Sindelar, Savannah River National Laboratory

   a. Radiolysis; b. Radiation induced reactions; c. Considerations in materials selection.

12:30 – 1:30 Box Lunch

6. Reactors and fuels — Allan Croff, ORNL, ret., and USNRC

   a. LWR, b. BWR, c. LMFBR, d. HTGR, e. CANDU.

7. Spent fuel reprocessing — Robert Jubin, Oak Ridge National Laboratory

   a. Separations (Head-end treatment (chop/leach), Purification by solvent extraction (Pu, U, ^{237}Np, ^{241}Am, Cm), Ion exchange – organic/inorganic) b. Distillation (Vacuum, Steam stripping, Acid recovery) c. Off-gas treatment (Iodine, Noble gases, $^{14}CO_2$, ^{3}H, v) Other (Ru, et al.)).

Break

8. Non-aqueous Processes — Mike Goff, Idaho National Laboratory
   a. Volatility/vaporization: (UF6 (Reprocessing, Purification of UF6), Molten salt systems, Liquid metal systems) b. Electrolytically-driven processes (Electrolytic dissolution, Electro-deposition, Electro-reduction, Electrolytic decomposition).

5:00 Adjourn

5:30 Reception at The University Club of Nashville (See Map on page 14 for directions.)

Wednesday December 17, 2008
8:00 – 8:30 Continental Breakfast

9. Precipitation/crystallization/sorption — Gordon Jarvinen, Los Alamos National Laboratory
   a. $Pu_3(PO_4)_4$, b. $Pu(C_2O_4)_2$, c. Hydroxides, d. Carbonates of divers elements, e. Sorption on solids (MnO_2, Al_2O_3, $Fe(OH)_3$).

10. Complexation Reactions — Raymond G. Wymer, Vanderbilt University
    a. Carbonates - uranyl tricarbonate, b. Thiocyanates – actinides, c. Chlorides and sulfates, d. TBP adducts (Uranium, Plutonium, Technetium).

Break

11. Separations equipment — Jack Law, Idaho National Laboratory
    a. Pulse columns, b. Mixer-settlers, c. Centrifugal contactors.

12:30 – 1:30 Box Lunch

12. Waste forms — John Vienna, Pacific Northwest National Laboratory
    a. Glass, b. Grout, c. Metal, d. Other.

13. Environmental Transport — Kathryn Higley, Oregon State University
    a. Natural barriers, b. Engineered barriers, c. Other.

Break

14. The Role of Modeling — David DePaoli, Oak Ridge National Laboratory

5:00 Adjourn

Thursday December 18
8:00 – 8:30 Continental Breakfast

15. Sorbent development and analysis for column separations — Lawrence Tavlarides, Syracuse University

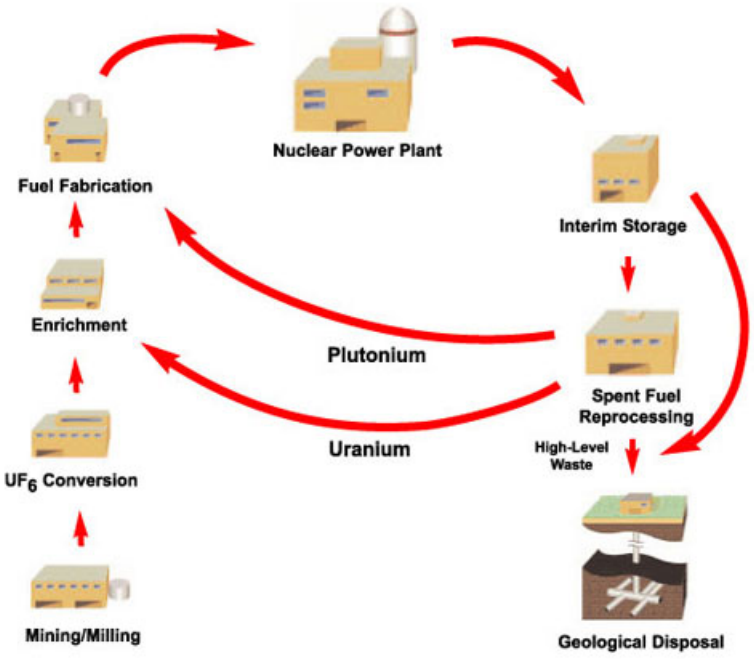
16. The Role of Risk Assessments — B. John Garrick, U.S. Nuclear Waste Technical Review Board
    a. Risk Assessment Principles; b. Risk Assessment in Spent Fuel Reprocessing

17. Nuclear Proliferation and Safeguards — Cynthia Atkins-Duffin, Lawrence Livermore National Laboratory

12: 00 Course Adjourned

The Nuclear Fuel Cycle Diagram

The nuclear fuel cycle for the light-water reactor (LWR), the most prevalent in use, is illustrated in the figure. The cycle consists of a "front end" that comprises the steps necessary to prepare nuclear fuel for reactor operation and a "back end" that comprises the steps necessary to manage the spent nuclear fuel, which is highly radioactive. It is possible to extract the unused uranium and plutonium from spent nuclear fuel through chemical reprocessing and to recycle the recovered uranium and plutonium as nuclear fuel, as shown.



The front end of the cycle is divided into the following steps:

Exploration: Ore bodies containing uranium are first located by drilling and other geological techniques. Ores in known deposits for which enough information is available to estimate the quantity, and which are considered to be economically minable, are called reserves. Ores inferred to exist but as yet undiscovered are called potential resources.
Mining: Uranium-bearing ores are mined by methods similar to those used for other metal ores. The uranium ore is removed from the ground by underground mining, open-pit mining, or by *in-situ* recovery.
Milling: At uranium mills, usually located near the mines, uranium-bearing ores are crushed and ground, and the uranium oxide is chemically extracted. The mill product, called uranium concentrates or "yellowcake," is then marketed (and sold as pounds of U3O8 or kilograms of uranium content. Uranium can also be extracted as a by-product of other mining operations, in association with gold, copper, or phosphate fertilizer.
UF_6 Conversion: Next, the U_3O_8 is chemically converted to uranium hexafluoride (UF_6), which is a solid at room temperature but changes to a gas at slightly higher temperatures. This is a necessary feature for the next step, enrichment.
Enrichment: Natural uranium cannot be used as fuel in LWRs because its content of fissile U-235 is too low to sustain a nuclear chain reaction. The process of uranium enrichment currently consists of two different technologies. The first (gaseous diffusion) consists of forcing UF6 gas under pressure through a long series of barriers that pass U-235 at a slightly faster rate than the heavier U-238 atoms. This differential treatment progressively increases the percentage of U-235 in the product stream. Another enrichment technology (gaseous centrifuge) uses spinning centrifuges to separate the heavier U-238 atoms from the lighter U-235 atoms. The work required to perform enrichment, and the units in which it is sold, is measured in terms of separative work units (SWU).

The back end of the cycle is divided in to the following steps:

Interim Storage: After its operating cycle, the reactor is shut down for refueling. The fuel discharged at that time (spent fuel) is stored either at the reactor site, or potentially, in a common facility away from reactor sites. If on-site pool capacity is exceeded, it may be stored in modular dry storage facilities at the site or at a facility away from the reactor site. The spent fuel rods are usually stored in water, which provides both cooling (the spent fuel continues to generate heat as a result of residual radioactive decay) and shielding (to protect the environment from residual ionizing radiation).
Reprocessing: Spent fuel discharged from LWRs contains appreciable quantities of unused U-235, Pu-239, and other radioactive materials. These materials can be chemically separated and recovered from the spent fuel. The recovered uranium and plutonium can, if economic and institutional conditions permit, be recycled for use as nuclear fuel.
Waste Disposal: A current concern in the nuclear power field is the safe disposal and isolation of high-level radioactive wastes in the form of either spent fuel rods or, if the reprocessing option is used, wastes from reprocessing plants. These wastes must be isolated from the biosphere until the radioactivity contained in them has diminished to a safe level. Current plans generally call for the ultimate disposal of the wastes in solid form in deep, stable geologic structures. Source: Http://www.uranium.info

Speakers Biographies

CYNTHIA ATKINS-DUFFIN

Cynthia Atkins-Duffin, Ph.D., is an authority on physical and chemical behavior of actinide and fission product elements. She is the E Program Manager (Energy, Environment and Non-Proliferation) in the Global Security Directorate at Lawrence Livermore National Laboratory. Prior to this assignment she was the Deputy Associate Director for Strategic Planning and Resources in the Energy and Environment Directorate. Previously she has served as the Applied Energy Technologies program leader and the Yucca Mountain Program deputy program leader. In addition, she was deputy materials program leader in the Chemistry and Materials Science Directorate from 1999 to 2002, and deputy director of the Glenn T. Seaborg Institute for Transactinium Science from 1996 to 1999. Earlier she was principal investigator in the hydrology and radionuclide migration program within the nuclear weapons programs. Dr. Atkins-Duffin's honors include the Chemistry and Materials Science Directorate Award, 2001; the Energy Directorate Award, 2000; and the American Institute of Chemists Aware for Outstanding Undergraduate in Chemistry. She has authored or coauthored more than 40 referred publications and given about 80 presentations. Dr. Atkins-Duffin received her Ph.D. in inorganic chemistry from Purdue University and her B.S. in chemistry from Worcester Polytechnic Institute.

ALLEN G. CROFF

Allen G. Croff has a BS in chemical engineering from Michigan State University, a Nuclear Engineer Degree from the Massachusetts Institute of Technology, and a MBA from the University of Tennessee. He worked at Oak Ridge National Laboratory (ORNL) for 29 ½ years and retired in 2003. While employed at ORNL, Mr. Croff was involved in technical studies and program development focused on waste management and nuclear fuel cycles, including development of the ORIGEN2 computer code and study of actinide partitioning-transmutation. Mr. Croff chaired a committee of the National Council on Radiation Protection and Measurements that produced the 2002 report titled "Risk-Based Classification of Radioactive and Hazardous Chemical Wastes" and the Nuclear Energy Agency's Nuclear Development Committee from 1992 to 2002. He was also vice-chairman of the U.S. Nuclear Regulatory Commission's Advisory Committee on Nuclear Waste and Materials from 2004 until its merger with the Advisory Committee on Reactor Safeguards in 2008. Mr. Croff was a member of the DOE Nuclear Energy Research Advisory Committee from 1998 to 2005 and seven previous committees of the National Academies. He is currently a member of the National Council on Radiation Protection and Measurements, the National Academies' Nuclear and Radiation Studies Board, and a National Academies committee on a development of a DOE cleanup technology roadmap.

DAVID W. DEPAOLI

David DePaoli is currently Group Leader of the Separations and Materials Research Group, Nuclear Science and Technology Division at Oak Ridge National Laboratory. David has worked at ORNL for over 23 years and has been involved in a wide range of chemical- and energy-related research and development projects, including demonstration of environmental-cleanup and waste-treatment technologies, basic research on separations employing external fields, and development of separation processes to recover materials for medical isotope production. For the past 12 years, he has been group leader of the Separations and Materials Research Group in the Chemical Technology and Nuclear Science and Technology Divisions at ORNL, which conducts fundamental and applied R&D aimed at applying chemical engineering principles to develop energy-related technologies. He is currently involved in efforts to develop advanced materials for electrochemical double-layer capacitors, devise new routes for production of chemical feedstocks from renewable sources, improve centrifugal contactor

performance models for solvent extraction, and demonstrate real-time characterization tools for nanomaterials production processes. David has also been active in recent roadmapping activities for Nuclear Energy Advanced Modeling and Simulation (NEAMS) in the Department of Energy's Office of Nuclear Energy.

David is Associate Editor for the journal *Separation Science and Technology*, and has acted as General Chairman for the 11th through 15th Symposia on Separation Science and Technology for Energy Applications. David was an Adjunct Associate Professor in the Department of Chemical Engineering at the University of Tennessee from 1999 through 2006, and a director of the Separations Division of the American Institute of Chemical Engineers from 2003 through 2007. David received a BS in chemical engineering from the University of Michigan, and a Ph.D in chemical engineering from the University of Tennessee. He is author of over 40 peer-reviewed publications, and holds four patents.

B. JOHN GARRICK

B. John Garrick is an independent consultant currently serving a presidential appointment as Chairman of the U.S. Nuclear Waste Technical Review Board. He has an active consulting practice in the development and application of the risk sciences to systems in the nuclear, space, chemical, and marine fields. His research interests include the quantification and importance ranking of catastrophic risks to support societal decision making.

Dr. Garrick has served on or chaired numerous National Research Council committees, including the Committees on the Waste Isolation Pilot Plant, Assessment of Options for Extending the Life of the Hubble Space Telescope, Combating Terrorism, Reviewing NASA's Applied Sciences Program, and the Committee on End Points for Spent Nuclear Fuel and High-Level Radioactive Waste in Russia and the United States. He was appointed to the U.S. Nuclear Regulatory Commission's Advisory Committee on Nuclear Waste in 1994. Dr. Garrick was elected to the National Academy of Engineering in 1993.

Dr. Garrick received his Ph.D. in Engineering and Applied Science from the University of California, Los Angeles.

MARK GILBERTSON

Mr. Mark Gilbertson is currently the Deputy Assistant Secretary for Engineering and Technology within the Office of Environmental Management (EM). The objective of this organization is to reduce the technical risk and uncertainty in the Department's clean-up programs and projects. To reduce those risks, the Program provides technical solutions where none exist, improved solutions that enhance safety and operating efficiency, or alternatives that reduce programmatic risks (costs, schedule, or effectiveness).

Up until 2003, Mr. Gilbertson was the Director of the Office of Basic and Applied Research within the EM Program at the Department of Energy charged with providing the fundamental knowledge necessary to correct problems associated with the cleanup of the nuclear weapons production complex. The program was given a "Hammer" Award by the Vice President's National Performance Review Team in 1998. In his first five years with the EM Program, Mr. Gilbertson was responsible for the development of policy, requirements, and guidance to ensure that risk analysis theory and processes were integrated into coherent decisionmaking processes in the Department of Energy's multi-billion dollar environmental cleanup program. From 1988 to 1994, Mr. Gilbertson worked in the Department's Office of Environment, Safety and Health (EH) and was responsible for the integration of EH concerns into Departmental planning processes, and managing and conducting EH's Progress Assessment and Tiger Team programs. He received a Silver Medal for Meritorious Service in 1991 and was promoted into the Senior Executive Service in May of 1992. Mr. Gilbertson spent four years at the U.S. Environmental Protection Agency (EPA). In his last year at EPA, he served as Director of EPA's Hazardous Waste Ground-Water Task Force Investigation Activities, created to investigate the adequacy of ground-water monitoring at facilities that disposed of hazardous waste on land. During his first three years at EPA, he supported the development of Resource Conservation and Recovery Act regulations and technical guidance and training in the areas of corrective action,

waste management, and environmental monitoring. He received a Bronze Medal for Commendable Service in 1987. He also spent three years in the private sector with an environmental engineering consulting firm. Mr. Gilbertson received a B.S. in Chemical Engineering from the University of Wisconsin in 1981.

MIKE GOFF

Mike Goff is the Nuclear Science and Technology Deputy Associate Laboratory Director for Operations at Idaho National Laboratory. In this role, he is responsible for operations of the Directorate's laboratories and interactions with INL's operations organizations to enable execution of the Laboratory's programmatic mission. Prior to becoming Deputy ALD, Mike was Director of the Fuel Cycle Programs Division. This organization performed research associated with nuclear chemical processing. Mike has worked in the nuclear fuel cycle for almost 20 years at INL and Argonne National Laboratory. His work has focused on development of advanced fuel cycles for treatment of spent fuel, development of high-level wastes, and implementation of safeguards for the nuclear fuel cycle. Mike holds a PhD in nuclear engineering from Georgia Institute of Technology. He is the past Chair of the Fuel Cycle and Waste Management Division of the American Nuclear Society and was Technical Program Chair for Global 2007. He has served as Co-Director of the Idaho University Consortium's Academic Center of Excellence for the Fuel Cycle.

CLARENCE HARDY

Dr. Hardy has distinguished qualifications and experience in the nuclear field. He has two doctorates, has published over 100 scientific papers, and has given over 100 talks to technical and non-technical audiences in Australia.

Dr. Hardy retired in 1991 after a 35-year career in nuclear science and technology in senior positions in three national nuclear laboratories in the UK (Harwell), USA (Oak Ridge National Laboratory) and Australia (Lucas Heights). He worked for 20 years as a Division Chief and Chief Scientist at the Lucas Heights Research Laboratories in Sydney and his history of the Australian Atomic Energy Commission was published in 1999.

Dr. Hardy set up a consulting company in 1991 and also took on voluntary work. He is currently the Secretary of the Australian Nuclear Association (a non-profit, non-government, Scientific Institution which provides information on all aspects of nuclear science and technology) and President of the Pacific Nuclear Council, which represents over 60,000 nuclear scientists and engineers in the Pacific Region. He is also Managing Director of Nuclear Fuel Australia Ltd. He travels the world giving invited talks on many aspects of nuclear science and technology and he organises national and international conferences.

KATHRYN A. HIGLEY

Dr. Higley is a Professor and Assistant Department Head in the Department of Nuclear Engineering and Radiation Health Physics in the College of Engineering at Oregon State University. She holds a B.A. in Chemistry (1978) from Reed College; an M.S. in Radiological Health Sciences (1992) and a Ph.D. in Radiological Health Sciences (1994) from Colorado State University. Her fields of interest include environmental transport and fate of radionuclides; radioecology; radiochemistry; radiation dose assessment; neutron activation analysis; nuclear emergency response; and environmental regulations.

She has held both Reactor Operator and Senior Reactor Operator's licenses, and is a former Reactor Supervisor for the Reed College TRIGA reactor. She has held research positions at three research reactors including Reed College, Washington State University (Pullman), and Oregon State University. She has fourteen years with Battelle, Pacific Northwest Laboratories as an environmental health physicist at the Hanford Nuclear Reservation and three years experience in environmental radiation monitoring at the Trojan Nuclear Power Plant in Oregon. She has been a consultant to the U.S. Department of Energy's Office of Air, Water and Radiation Protection. She is a member of

the Health Physics Society and a certified Health Physicist. She has served on National Council of Radiation Protection and Measurement (NCRP) subcommittees and on National Academy of Science committees. She has recently been appointed to the newly formed Committee 5 of the International Commission on Radiological Protection. Dr Higley has been at Oregon State University since 1994 teaching undergraduate and graduate classes on radioecology, dosimetry, radiation protection, radiochemistry, societal aspects of nuclear technology, and radiation biology.

Her research at OSU has included the use of nuclear track detectors for determination of plutonium, americium, and uranium particle size in soils, analysis of the micro-morphological distribution and association of these contaminants with soil structural features; kinetics of radionuclide movement in environmental systems; development of novel methods for estimating radiation dose to non-human biota; relationship of morphological characteristics of radiologically-contaminated surfaces on radiation detector efficiency, and effects of scanning speeds for radiological survey systems on detector efficiency.

GORDON D. JARVINEN

Gordon D. Jarvinen is the Associate Director of the G.T. Seaborg Institute for Transactinium Science, Los Alamos National Laboratory (LANL). He received a B.S. Chemistry, 1973, from the Massachusetts Institute of Technology, Cambridge, MA and, a Ph.D. in inorganic chemistry, 1979, University of California, Los Angeles, CA. Dr. Jarvinen's 29 years at LANL include: postdoctoral fellowship 1979-1981, Staff Member 1981-1989 in the Inorganic and Structural Chemistry Group, Isotope and Nuclear Chemistry Division; Technical Staff Member 1989-2006, Nuclear Materials Technology Division, Process Chemistry Team Leader 1991-1994 Nuclear Materials Process Technology Group, and Development Team Leader 1994-1996 Advanced Technology Group. Dr. Jarvinen's research & development interests include: actinide and lanthanide coordination chemistry and separation technology, design and synthesis of ligand systems for improved separation and analysis of metal ions, development of chelating and ion exchange polymers, membrane separations. Dr. Jarvinen has over 50 publications, 5 patents, 1 patent pending. He is a Member of the American Chemical Society, American Association for the Advancement of Science, Chair of the Separation Science and Technology Subdivision of the Industrial & Engineering Chemistry Division of the ACS, 2000, and on the Editorial Advisory Board of the Journal of Industrial & Engineering Chemistry Research 2002-2004. His awards include the R.D. Baker Award in Science & Technology 1999, Nuclear Materials Technology Division, LANL; and the G.T. Seaborg Actinide Separations Award 2008.

ROBERT T. JUBIN

Dr. Robert T. Jubin is currently the segment lead for the Waste Materials and Processing within the Advanced Fuel Cycle Initiative (AFCI) Coupled-End-to-End Demonstration at Oak Ridge National Laboratory. He is responsible for the recovery, conversion, and packaging of the key radionuclide products streams from the demonstration and is responsible to provide these feed materials to a number of other DOE facilities to support the waste form development activities. He is also the lead author for the Volatile Gas Recovery and Waste Form portion of the Baseline Document for the GNEP Integrated Waste Management Strategy.

Dr. Jubin has an extensive background in all aspects of nuclear fuel reprocessing. He was selected for an extended assignment in France working with the French Atomic Energy Commission at Fontenay-aux-Roses. This assignment was focused on the development of the DIAMEX process for separation of actinides and lanthanides from high level liquid wastes. He has also worked on the implementation and improvement of new solvent extraction equipment and processes with primary attention on the application of advanced centrifugal contactors. His work in this area has included the design of centrifugal contactors for use in the Idaho National Laboratory and in the US DOE Oak Ridge Y-12 uranium recovery areas. He has authored a number of reports and papers in the area of solvent extraction and holds two patents for improvements to the centrifugal contactors. Other technical fields of expertise include management of volatile radionuclides and gaseous radioactive waste management. He led team

in the design and implementation of an advanced off-gas recovery system for the AFCI. He has co-authored a book chapter on the recovery and retention of radioactive Iodine and NO_x from nuclear facilities.
Dr. Jubin retired in 2007 from the U.S. Air Force Reserve in the rank of Colonel.

He received his Bachelor of Science degree in chemical engineering from the University of Akron. He completed his Master of Science degree in engineering management from the University of Tennessee, and received his Doctor of Philosophy in chemical engineering from the University of Tennessee.

DAVID S. KOSSON

David S. Kosson is Professor and Chairman of Civil and Environmental Engineering at Vanderbilt University. He currently holds joint appointments at Vanderbilt as Professor of Chemical Engineering, and Professor of Earth and Environmental Sciences. He received a B.S., M.S. and Ph.D. degrees in Chemical and Biochemical Engineering from Rutgers University, where he also was Professor of Chemical and Biochemical Engineering prior to joining Vanderbilt. Professor Kosson has published extensively on contaminant mass transfer in soils, sediments and wastes, subsurface remediation process development and optimization, and leaching assessment approaches. Professor Kosson serves as Co-PI for the Consortium for Risk Evaluation with Stakeholder Participation (CRESP). As part of CRESP, Professor Kosson has carried out review and research regarding many aspects of the DOE complex, including evaluation of disposition of the calcine wastes at Idaho, closure of the single shell tanks at Hanford, reaching consensus on closure for Amchitka, and long term performance of waste forms. Professor Kosson previously served for more than a decade on National Academy committees focused on the development and implementation of processes for demilitarization of chemical weapons. His service included chairing the congressionally mandated National Academy oversight committee for destruction of the U.S. stockpile of chemical weapons.

JACK LAW

Jack Law earned a Bachelor of Science Degree in Chemical Engineering from Montana State University in 1984. He has worked at the Idaho National Laboratory for 25 years. Jack's primary areas of expertise are with the development and demonstration of aqueous separation processes to support nuclear fuel reprocessing and radioactive waste treatment. He has also been extensively involved in the design and testing of solvent extraction equipment, primarily pulse columns and centrifugal contactors. Jack has been responsible for the design, construction and testing of four centrifugal contactor pilot plants of various sizes, including a 2-cm centrifugal contactor pilot plant setup and operated in a shielded cell facility. Jack has been extensively involved in the DOE-NE Global Nuclear Energy Partnership and Advanced Fuel Cycle Initiative for the last five years. As part of these programs he was responsible for the development and demonstration of two new solvent extraction processed for the separation of Cs and Sr from used nuclear fuel. He was also responsible for development of a remotely operable/maintainable commercial 5-cm centrifugal contactor as well as hydraulic and mass transfer efficiency testing of commercially available 5-cm and 12.5-cm centrifugal contactors. Jack has been awarded two U.S. patents, three Russian patents, and has over 45 peer reviewed publications. Jack was recently appointed Manager of the Aqueous Separations and Radiochemistry Department at the INL.

FRANK L. PARKER

Frank L. Parker, Distinguished Professor of Environmental and Water Resources Engineering, and member of the National Academy of Engineering, is a pioneer in nuclear waste management and environmental protection. Over the past five decades, he has served as head of the Radioactive Waste Disposal Research Section of Oak Ridge National Laboratory, Head of the Radioactive Waste Disposal Research Program at the International Atomic Energy Agency, Senior Research Fellow of The Beijer Institute of The Royal Swedish Academy of Sciences and Senior Research Fellow, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria. At IIASA, he was the head of the Radiation Safety of the Biosphere Program that investigated radioactive contamination in the

Former Soviet Union and in the Peoples Republic of China. Professor Parker has chaired or been a member of many national and international advisory committees including U.S. Department of Energy's Environmental Management Advisory Board, Scientific Advisory Board (DOD, DOE, EPA) of Strategic Environmental Research and Development Program, Project Officer of the Arctic Military Environmental Cooperation, (DOD), National Research Council's Board on Radioactive Waste Management, many National Academy studies and many national laboratories of the Department of Energy. Professor Parker has also served as consultant to international bodies and countries including IAEA, WHO, UNSCEAR, World Bank, Belgium, France, Israel, Italy, Pakistan, Sweden and Switzerland.

ROBERT SINDELAR

Dr. Sindelar is a senior research staff in the Materials Science & Technology Directorate at the Savannah River National Laboratory. He has held a variety of senior technical and management positions since joining SRNL in 1986. Dr. Sindelar has experience in a broad range of technical disciplines related to Nuclear Fuel Cycle – life cycle management of nuclear fuel cycle operations including canyon, spent fuel, and waste management systems. Dr. Sindelar led the experimentation and analysis task in programs to develop the technical basis for safe storage of aluminum-based fuels in wet and dry storage systems, and to develop the fuel form characteristics information base needed to support repository disposal for spent fuel owned by the U.S. Department of Energy. Dr. Sindelar also developed the fuel-specific performance basis for containment of aluminum-based monolithic fuel in transportation casks. Dr. Sindelar has supported the international community through the International Atomic Energy Agency as the technical expert for spent nuclear fuel management for the Region of Latin America, and for water quality management in research reactor systems. Dr. Sindelar also has experience related to Life/Aging Management of Nuclear Systems - structural integrity demonstrations of DOE nuclear systems, including system service life estimations, for materials and systems subject to environmental degradation. Dr. Sindelar led the experimentation and analysis tasks in programs to predict and extend the service life of the Savannah River Site production reactors and co-led tasks to demonstrate the structural integrity of the high level waste tanks at SRS. The tasks included detailed degradation/degradation rate evaluations including radiation effects, mechanical and corrosion property development, localized structural and fracture analyses, demonstration of structural safety margins, and development of in-service inspection programs to monitor degradation and provide acceptance criteria. Dr. Sindelar has published 90+ papers and publications in the areas of radiation and environmental effects in nuclear systems; structural integrity/life management; spent fuel interim management in wet and dry storage; and DOE spent nuclear fuel disposal.

Dr. Sindelar received a Ph.D. in Nuclear Engineering (Technical Minor - Mineral & Metallurgical Engineering), University of Wisconsin - Madison, WI 53706, 1985; M.S. - Nuclear Engineering, University of Wisconsin - Madison, 1981; and a B.S. - Physics and Mathematics, University of WI - Eau Claire, 1978.

Dr. Sindelar's affiliations include: expert for International Atomic Energy Agency on Spent Nuclear Fuel Management and Reactor Systems' Water Quality; Member of Advisory Board for Department of Nuclear Engineering & Radiological Sciences, University of Michigan; Adjunct Professor and Lecturer for the course on Nuclear Materials at the University of South Carolina; Member of ASTM C26.13 Subcommittee on Nuclear Fuel Cycle, Repository Waste and a member and past chairman of the ASM/TMS Nuclear Materials Committee.

LAWRENCE L. TAVLARIDES

Professor Tavlarides received his degrees in chemical engineering at the University of Pittsburgh and did postdoctoral studies at the Technical University of Delft, Holland. He was on the faculty of Illinois Institute of Technology resulting in the Professorial rank and came to Syracuse University as Chairman of the Chemical Engineering Department in 1981. His awards include the North American Mixing Forum Award for Excellence in Research and the Chancellors Citation Award for Excellence in Academic Achievement at Syracuse University. He is

a Fellow of AIChE. Dr. Tavlarides research interests include synthesis and analyses of adsorbents; solvent extraction; dispersed phase mixing; supercritical fluid separations, diesel fuel combustion, and biodiesel fuel processes; and indoor environmental air chemistry among others. He has published over 130 papers in archival journals, 16 patents, and 1 book, and has given over 250 presentations. Dr. Tavlarides has been a consultant for major chemical industries, the Department of Energy for the last two decades, and the Nuclear Regulatory Commission.

JOHN D. VIENNA

Dr. Vienna began his career as a research associate in the Materials Science Division at Argonne National Laboratory. In 1993, he joined the Glass Development Laboratory at Pacific Northwest (National) Laboratory (PNNL) as a Research Scientist. He's been a Senior Research Scientist in PNNL's Materials Science, Environmental Molecular Sciences, and Process Technology Departments and currently serves as Chief Scientist in the Glass Development Laboratory. He conducts research in waste processing and waste form testing. He served as the principal investigator in PNNL's waste glass development projects for the Idaho National Laboratory, Hanford, and Savannah River sites, since 1997. He is an adjunct faculty member of Chemistry at Washington State University where he regularly teaches graduate courses. Dr. Vienna currently leads waste form technology development projects for the U.S. Department of Energy's Offices of Environmental Management and Nuclear Energy.

Dr. Vienna has published over 150 journal articles, conference papers, and technical reports in materials science and it's applications to waste management. He has performed independent research in basic waste form materials chemistry, nucleation and growth kinetics, waste form processing, and thermodynamics of multi-component, multi-phased waste forms. Dr. Vienna had developed waste forms for excess nuclear materials and wastes at several U.S. and international nuclear waste sites. He is a Fellow of the American Ceramic Society, a founding member of the "Nuclear Waste Vitrification" technical committee of the International Commission on Glass, and is an active member of the Materials Research Society, and the American Society for Testing and Materials. Dr. Vienna received a B.S. in Ceramic Engineering, and M.S. Ceramics Engineering and Science at Alfred University, Alfred, NY; and a Ph.D. in Materials Sciences, Washington State University, Pullman, WA.

RAYMOND L. WYMER

Raymond G. Wymer, PhD, is former Director of the Chemical Technology Division, Oak Ridge National Laboratory and is now a consultant for Oak Ridge National Laboratory, the U.S. Department of Energy, and its contractors on all aspects of the nuclear fuel and radioactive waste management. He is an Associate Member of the National Academies and is a member of the National Academies Board on Nuclear and Radiation Studies. He served on a United Nations UNSCOM team to Iraq in the mid-1990s evaluating Iraq's uranium enrichment capability by chemical exchange. He is co-author of a book "Chemistry in Nuclear Technology" and co-edited a book on "Light Water Reactor Fuel Reprocessing." He was an editor of the journal Radiochimica Acta for more than ten years until his retirement. Dr. Wymer is an Adjunct Professor in the Department of Civil and Environmental Engineering of Vanderbilt University. He has received recognition for his contributions in the nuclear area, including the Robert E. Wilson Award in Nuclear Chemical Engineering from the American Institute of Chemical Engineers for Outstanding Work on the Nuclear Fuel Cycle. He received a B.A. from Memphis State University and an M.A. and Ph.D from Vanderbilt University.

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Logistics

***Printing Boarding Passes*:** A Computer and printer will be available in the Student Life Center for printing boarding passes. Location of computer will be announced

***Transportation to the Airport*:** There will be a signup sheet for travel arrangements to the airport. Location of the signup sheet will be announced.

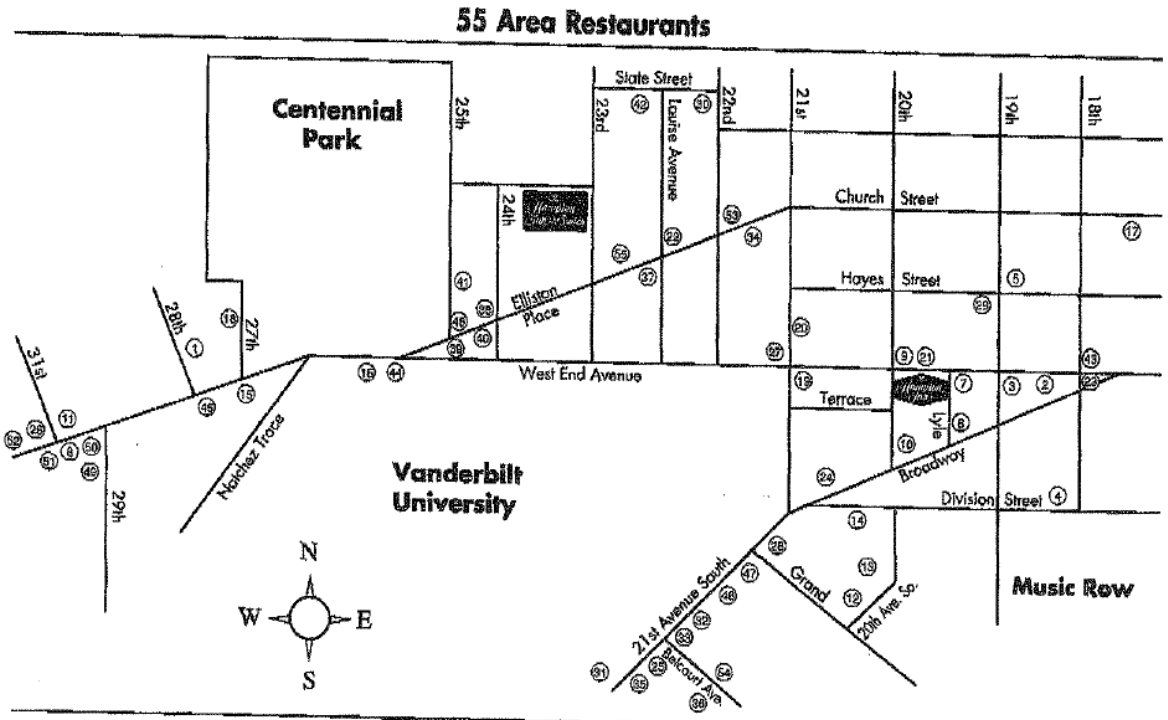
Map

1. Head **northeast** on **W End Ave/TN-1/US-70S** toward **Natchez Trce**	0.2 mi
2. Turn **right** at **25th Ave S**	0.2 mi
3. Student Life Center 310 25th Ave South	0.3 mi

Distance from Holiday Inn to Student Life Center .7 mile

Course Reception will take place at the University Club.

Local Restaurant Suggestions



1. The Acorn
114 26th Ave. N.
320-4399
2. Arby's
1609 West End Avenue
327-1076
3. Midtown Cafe
102 19th Avenue South
320-7176
4. Virago
1811 Division St.
320-5149
5. DaVinci's Gourmet Pizza
1812 Hayes Street
329-8098
6. Longhorn Steaks
110 Lyle Avenue
329-9195
7. Valentino's
1907 West End Avenue
327-0146
8. Stoney River
3015 West End Ave.
340-9550
9. Amerigo's
1920 West End Avenue
320-1740
10. The Nashville Delicatessen
1918 Broadway
329-6674
11. Brick Tops
3000 West End Ave.
298-1000
12. The Boundry
913 20th Avenue South
321-3043
13. South Street Restaurant
907 20th Avenue South
320-5555
14. Mario's Ristorante
2005 Broadway
327-3232
15. J. Alexander's
2609 West End Ave.
340-9901
16. PF Chang
2525 West End Avenue
329-8801
17. Chappys
1721 Church St.
322-9932
18. Hog Heaven
115 27th Ave. N.
329-1284
19. Cdoba Mexican
2019 West End Avenue
340-9039
20. Sitar Indian Cuisine
116 21st Avenue North
321-8889
21. Blackstone Brewery & Restaurant
1918 West End Avenue
327-9999
22. Fiesta Azteca
2212 Elliston Place
340-0767
23. Goten Japanese
1718 West End Ave.
321-4537
24. Wild Boar Restaurant
2014 Broadway
329-1313
25. Jackson's Bar and Bistro
1900 21st Ave.
385-9998
26. Maggianos
3106 West End Ave.
514-0270
27. Ruth's Chris Steak House
2100 West End Avenue
320-0163
28. Mellow Mushroom
212 21st Ave. S.
342-0044
29. Las Palmas Mexican Restaurant
1905 Hayes Street
322-9566
30. Café CoCo (Open 24 Hours)
210 Louise Avenue
321-2626
31. Bosco's
1805 21st Ave. S.
385-0050
32. San Antonio Taco Co.
416 21st Avenue South
327-4322
33. Pancake Pantry
1796 21st Avenue South
383-9333
34. Elliston Place Soda Shop
2111 Elliston Place
327-1090
35. Sam's Sports Bar and Grill
1808 21st Ave. S.
383-8601
36. Sunset Grill
2001 Belcourt Ave.
386-3663
37. Samurai Japanese Sushi Bar
2208 Elliston Place
320-5436
38. Logan's Roadhouse
2400 Elliston Place
320-1161
39. Rotiers
2413 West End Avenue
327-9892
40. Schlotzsky's Deli
244 West End Ave.
320-9777
41. Kobe Japanese
210 25th Avenue North
327-9081
42. Jimmy Kelly's
217 Louise Avenue
329-4349
43. Atlanta Bread Company
1720 West End Avenue
329-9100
44. Fleming's Prime Steakhouse
2525 West End Avenue
342-0131
45. Ted's Montana Grill
2817 West End Ave.
329-3415
46. Panera Bread
406 21st Ave. S.
320-1500
47. Starbucks
402 21st Avenue South
340-9665
48. Calypso Cafe
2424 Elliston Place
321-8878
49. Zola's
3001 West End Avenue
320-7778
50. Rumba
3009 West End Avenue
321-1350
51. Tin Angel
3201 West End Avenue
298-3444
52. Outback Steakhouse
3212 West End Avenue
385-3440
53. Michaelangelo's Pizza
205 22nd Ave. N.
329-2979
54. The Trace
2000 Belcourt Ave.
385-2000
55. OMBI
2214 Elliston Place
320-5350