SCHOOL OF ENGINEERING

CRESP

Short Course
Introduction to Nuclear Fuel Cycle Chemistry

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

August 4-6, 2009

Speakers Affiliations

Vanderbilt University
Washington State University
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Acknowledgements

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SPEAKERS:

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Cynthia Atkins-Duffin, Lawrence Livermore National Laboratory
John M. Begovich, Oak Ridge National Laboratory
James H. Clarke, Vanderbilt University
Allen G. Croff, ORNL, ret., and USNRC
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This course is based on work supported by the U. S. Department of Energy, under Cooperative Agreement Number DE-FC01-06EW07053 entitled 'The Consortium for Risk Evaluation with Stakeholder Participation III' awarded to Vanderbilt University. The opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily represent the views of the Department of Energy or Vanderbilt University.

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 Presentations

Course Agenda

Introduction to Nuclear Fuel Cycle Chemistry

August 4-6, 2009

Marriot Crystal City at Reagan National Airport

1999 Jefferson Davis Highway

Arlington, VA 22202

Topics and Speakers:

Tuesday, August 4, 2009 – A Managers Overview

7:30 – 8:00 Registration

1. Welcome and Course Introduction — David S. Kosson, Vanderbilt University
2. 20 Years of Progress in Processing Nuclear Waste — Steven L. Krahn, Department of Energy
3. The Fuel Cycle From Back to Front — Terry A. Todd, Idaho National Laboratory

Break

4. Introduction to Fuel Cycle Separations and Waste Management — Terry A. Todd, Idaho National Laboratory
5. Nuclear Radiation — Robert Sindelar, Savannah River National Laboratory

12:30 – 1:30 Lunch

6. Reactor Fuels — Allen Croff, ORNL, ret., and USNRC
7. Spent Fuel Recycle — Robert M. Wham, Oak Ridge National Laboratory

Break

8. Nuclear Nonproliferation — Cynthia Atkins-Duffin, Lawrence Livermore National Laboratory
9. Mining, Milling, Conversion and Enrichment of Uranium Ores — John M. Begovich, Oak Ridge National Laboratory

5:00 Adjourn

Wednesday, August 5, 2009 – In-Depth Topics

8:00

10. Management of High Level Tank Waste — Neil R. Davis, Savannah River National Laboratory
11. Non-Aqueous Processes — Mike Goff, Idaho National Laboratory

Break

12. Complexation Chemistry and Precipitation/crystallization Processes — Gordon D. Jarvinen, Los Alamos National Laboratory

12:30 – 1:30 Lunch

13. Ion Exchange and Adsorption Processes — David T. Hobbs, Savannah River National Laboratory

14. Separations Equipment — Jack D. Law, Idaho National Laboratory

Break

15. Environmental Performance Assessment — James H. Clarke, Vanderbilt University
16. Role of Modeling and Simulation in Used Fuel Recycling — David DePaoli, Oak Ridge National Laboratory

Open Discussion with Speakers and Get Acquainted Period

5:00 Adjourn

<u>Thursday, August 6, 2009– In-Depth Topics</u>

8:00

17. Quantifying the Risk of Nuclear Fuel Recycling Facilities — David H. Johnson, ABS Consulting
18. Transportation — Mark Abkowitz, Vanderbilt University

Break

19. Waste Forms — John D. Vienna, Pacific Northwest National Laboratory
20. Geologic Repositories — George Hornberger, Vanderbilt University

12:30 – 1:30 Lunch

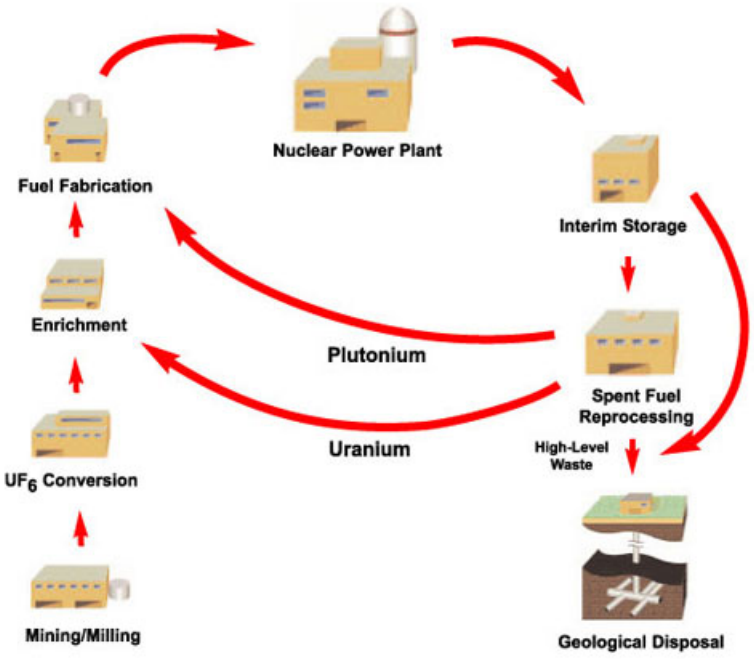
21. Sustainability and Nuclear Energy: Perspectives on Alternative Futures — Kenneth Nash, Washington State University

Summary and Discussion

3:00 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 and Authors Biographies

MARK ABKOWITZ

Mark Abkowitz holds an appointment as Professor of Civil & Environmental Engineering at Vanderbilt University, and serves as Director of the Vanderbilt Center for Environmental Management Studies. He is also the founder and former Chairman of Visual Risk Technologies, a management consulting firm headquartered in Nashville. Dr. Abkowitz received his B.S., M.S. and Ph.D. degrees in Civil Engineering from Massachusetts Institute of Technology.

Dr. Abkowitz specializes in transportation systems analysis and operational risk management. He has authored over one hundred publications on these and related topics, and has appeared on National Public Radio, Fox National News and CNBC to discuss risk issues of national importance. Dr. Abkowitz is currently a member of the Nuclear Waste Technical Review Board, having been appointed to this position by President George W. Bush in 2002. He is the recipient of the 1996 Distinguished Service Award from the National Academy of Sciences for his leadership role with the Transportation Research Board.

Dr. Abkowitz has served as a researcher and consultant to a wide variety of businesses and government agencies. As an accomplished public speaker, Dr. Abkowitz has addressed audiences at many national and international forums. He is also the author of Operational Risk Management – A Case Study Approach to Effective Planning and Response, recently published by John Wiley & Sons.

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.

JOHN M. BEGOVICH

John Begovich is currently Group Leader of the Export Control Implementation Group in the Global Nuclear Security Technology Division at the Oak Ridge National Laboratory (ORNL). He started his nuclear fuel cycle career in the Chemical Technology Division at ORNL in 1974 after receiving his BChE Degree from the University of Dayton. While working fulltime at ORNL, he obtained MS and PhD degrees in chemical engineering from the University of Tennessee in 1978 and 1982, respectively. He became a registered professional engineer in Tennessee in 1979. His initial areas of research included three-phase fluidization, continuous chromatography, urania sol-gel sphere-pac, waste management, and computer simulation. In the late 1980's, John served as Associate Program Leader for Uranium Processing in the Atomic Vapor Laser Isotope Separation Program at Lawrence Livermore National Laboratory. John returned to ORNL in 1989 to head up the Engineering Coordination and Analysis Section, a post he held until 2001. He then moved into the areas of nuclear nonproliferation and international safeguards utilizing his nuclear fuel cycle background. He serves as point of contact for several organizations within DOE/NNSA, including the Nuclear Noncompliance Verification Team in NA-241, and the U-235 Production Detection and Plutonium Production Detection Programs in NA-22. John is a member of the Oak Ridge-Knoxville Section of the American Nuclear Society, the Knoxville-Oak Ridge Section of the American Institute of Chemical Engineers, and the Institute of Nuclear Materials Management. He received the Distinguished Alumni Award from the University of Dayton School of Engineering in 1998 in recognition of his significant professional accomplishments.

JAMES H. CLARKE

Dr. Jim Clarke is Professor of the Practice of Civil and Environmental Engineering at Vanderbilt University and Professor of Earth and Environmental Sciences. He also serves as Director of Graduate Studies for the graduate program in Environmental Engineering. Prior to joining the faculty of Vanderbilt University in the Fall of 2000, he was Chairman, President and CEO of

Eckenfelder, Inc, an environmental engineering and consulting firm focusing on services to the private sector in the areas of hazardous waste management, contaminated site investigation and remediation and wastewater treatment. Jim has expertise and experience in the overall areas of fate and transport of chemicals and radionuclides in the environment, risk assessment for hazardous chemicals and radionuclides, hazardous and radioactive waste management, innovative approaches to the remediation of contaminated sites, environmental forensics and environmental chemistry. His research interests are in the areas of sustainable environmental protection, contaminant containment technology, risk analysis and performance assessment, and the investigation, remediation and long-term management of contaminated sites.

Jim was a member of the Nuclear Regulatory Commission (NRC) former Advisory Committee on Nuclear Waste and Materials and served as an advisor on issues concerning the Yucca Mountain project. risk-informed performance-based approaches to site decommissioning and remediation and the overall nuclear waste regulatory program. He currently serves as a consultant to the NRC Advisory Committee on Reactor Safeguards and a member of its subcommittee on Radiation Protection and Nuclear Materials. Jim also served on the National Academy of Science Committee on Remediation of Buried and Tank Waste. He is a peer reviewer for the Department of Energy, the Nuclear Regulatory Commission, the National Academies, the U.S. Environmental Protection Agency and several journals and book publishers. Professor Clarke has over 30 years of professional experience with approximately 150 publications and presentations. He received a Ph.D. in theoretical physical chemistry from The Johns Hopkins University and a B.A. in chemistry with honors from Rockford College.

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.

NEIL R. DAVIS

Neil joined the Savannah River Site in 1980 and has worked at the site for over 29 years. He is currently the Deputy Program Manager for Waste Removal & Tank Closure. His previous assignment was the Program Manager for Technology Development where he was responsible technology selection and development for many of the innovations that are currently being incorporated into the Savannah River flowsheet. Neil is a former Facility Manager and HLW System Integration Manager.

Neil currently serves as an advisor to the HLW Corporate Board and has served on numerous expert panels in the areas of HLW operations, waste removal, tank closure, waste pretreatment and waste disposition at the Savannah River, Hanford, West Valley and Sellafield sites. Neil received a B.S. in Civil Engineering from Lowell Technological Institute in Lowell, Massachusetts and a MBA from Augusta College in Augusta, Georgia.

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 decision-making 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.

DAVID T. HOBBS

David Hobbs is a Senior Advisory Scientist at the Savannah River National Laboratory (Aiken, SC). He obtained his B.S. in Chemistry from the University of North Carolina at Chapel Hill (1974) and Ph.D. in Inorganic Chemistry at Vanderbilt University (1979). Professional affiliations include the American Chemical Society, the Electrochemical Society, Sigma Xi and Alpha Chi Sigma. David has been employed at the Savannah River Site since 1984.

Dr. Hobbs' research include radiochemical and metal ion separations using inorganic ion exchange materials. He has led the development of the inorganic ion exchange material, monosodium titanate (MST), that is currently used at the Savannah River Site for the separation of Sr-90 and actinides (Pu, Np, Am and U) from high level nuclear waste solutions. He is a co-discoverer of a new class of peroxotitanate materials that exhibits better performance than that of MST for radiochemical separations as well as interesting affinities for a wide range of elements under a variety of environmental conditions. Currently he is exploring medical-based applications of the titanates including their use as metal delivery agents and contrast agents. Dr Hobbs' research interests also include electrochemical separations and currently lead the development of a sulfur dioxide-depolarized electrolyzer as part of the Hybrid Sulfur Thermochemical Process for the large-scale production of hydrogen.

GEORGE HORNBERGER

George M. Hornberger is Distinguished University Professor at Vanderbilt University, where he is the Director of the Vanderbilt Institute for Energy and the Environment. He has a shared appointment as the Craig E. Philip Professor of Engineering and as Professor of Earth and Environmental Sciences there. He previously was a professor at the University of Virginia for many years where he held the Ernest H. Ern Chair of Environmental Sciences. He also has been a visiting scholar at the Australian National University, Lancaster University, Stanford University, the United States Geological Survey (USGS), the University of Colorado, and the University of California at Berkeley. His research is aimed at understanding how hydrological processes affect the transport of dissolved and suspended constituents through catchments and aquifers. He is an ISI "Highly Cited Researcher" in environmental sciences and engineering, a recognition given to the top 250 individual researchers in each of 21 subject categories. Hornberger is a fellow of the American Geophysical Union (AGU), a fellow of the Geological Society of America, and a fellow of the Association for Women in Science. He was President of the Hydrology Section of AGU from 2006-2008. He has been a member of the Nuclear Waste Technical Review Board (a Presidential appointment) since April 2004. He has served on numerous boards and committees of the National Academies, including as chair of the Commission on Geosciences, Environment, and Resources (1996-2000) and chair of the Board on Earth Sciences and Resources (2003-present). Professor Hornberger won the Robert E. Horton Award (Hydrology Section) from the AGU in 1993. In 1995, he received the John Wesley Powell Award from the USGS, and in 1996 was elected to membership in the U.S. National Academy of Engineering. In 1999, he was presented with the Excellence in Geophysical Education Award by the AGU and in 2007 he was selected Virginia Outstanding Scientist. Hornberger received his B.S. and M.S. degrees from Drexel University in 1965 and 1967, respectively. In 1970, he received a Ph.D. in hydrology from Stanford University.

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.

DAVID H. JOHNSON

Dr. Johnson has more than 30 years of experience in risk-based analysis for industry and government applications. His extensive experience and knowledge in all facets of nuclear reactor probabilistic risk assessments (PRA) and expertise include probabilistic modeling and investigation of impacts of industrial endeavors, the development of quantitative risk assessment methods and the practical application of these methods to support risk management.
Dr. Johnson served as project manager and a lead technical contributor to ABS Consulting's contributions to the assessment of California's operating nuclear plants in response to California law AB 1632. Dr. Johnson served as project manager for the High Flux Australian Reactor PSA. Project manager and key technical contributor to the DOE High Flux Isotope Reactor PRA and the Health Physics Research Reactor PRA. Technical lead for the Level 1/Level 2 interface consulting that ABS Consulting (formerly PLG) is providing to Electricité de France.

Dr. Johnson served as project manager for the Defense Threat Reduction Agency's (formerly the Defense Special Weapons Agency) "START III Active Stockpile/Inactive Stockpile" Study. Dr. Johnson served as project manager for the Defense Special Weapons Agency (DSWA) (formerly the Defense Nuclear Agency) B-52 Electrical Study performed to identify and evaluate the hazard scenarios associated with the exposure of the B-52H weapon system to electrical environments that could lead to special nuclear material dispersal. Key technical contributor to the DSWA Fire Resistance Enhance (FRE) study. Principal Investigator for the B-52H Weapons System Safety Assessment.

Dr. Johnson served as key technical contributor to the NRC BETA project to develop the Kalinin PRA (Russia) as well as training and procedures for future PRAs to be conducted in Russia. Co-author of PRA procedures developed for use in former Soviet Union and Eastern European countries. Received training on VVER technology and operations in Russia. International Atomic Energy Agency Technical Expert missions to Bulgaria in support of the Kozloduy PSA. Dr. Johnson performed oversight and review for the analysis of programmatic risks associated with the Viability Assessment of the Yucca Mountain Project.

ROBERT T. JUBIN

Dr. Robert T. Jubin is currently the Project Manager for ORNL's Advanced Fuel Cycle Initiative (AFCI) Advanced Fuel Cycle Science and Technology activities including the Coupled-End-to-End Demonstration. As part of this role, 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 has also co-authored a book chapter on the recovery and retention of radioactive Iodine and NOx 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. He is a member of the American Nuclear Society.

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.

STEVE L. KRAHN

Dr. Krahn is the acting Deputy Assistant Secretary for Operations, Safety and Security (EM-60). Prior to rejoining the government in 2007, Dr. Krahn spent 30 years in technical and project management positions of increasing responsibility in government, private industry and the military, including: the management of the $140 million complex overhaul of a nuclear submarine; technical direction of the research and development program for a major DOE reactor program; providing technical direction and leadership for a federal agency providing safety oversight to the U. S. nuclear weapons complex; directing a $25 million division in an engineering services company; and providing technical consulting services to the U. S. nuclear industry. He holds a BS in Metallurgical Engineering from the University of Wisconsin, a MS in Materials Science from the University of Virginia, a Doctorate in Public Administration from the University of Southern California, and is a graduate of the Bettis Reactor Engineering School (USDOE).

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.

JOHN E. MARRA

John E. Marra is Associate Laboratory Director; Environmental & Chemical process Technology at the Savannah River National Laboratory (SRNL), Aiken, South Carolina.

He received his B.S. in ceramic science and B.A. in chemistry from the New York State College of Ceramics at Alfred University in 1983, and Ph.D. in ceramic engineering from The Ohio State University in 1987. Since 1987, Dr. Marra has held various technical staff and management positions at the Department of Energy's Savannah River Site (SRS). In his 20 years service at SRS and SRNL, Dr. Marra has worked in the management and treatment of high-level radioactive waste, development and application of advanced materials, and advanced chemical process applications. He has coauthored numerous publications on the application of ceramic materials in the nuclear industry.

Dr. Marra is a Past-President of The American Ceramic Society (ACerS). He is an ACerS Fellow and a past Chair and past Trustee/Director of the Nuclear & Environmental Technology Division.

KENNETH NASH

Kenneth L. Nash, Professor of Chemistry, joined the faculty in the Chemistry Department at Washington State University in 2003 after nearly 25 years of conducting and directing basic and applied research on the chemistry of radioactive materials and chemical separations at Argonne National Laboratory, and at the U.S. Geological Survey. He received a B.A. in chemistry from

Lewis University (Illinois), M.S. and Ph.D. in Inorganic Chemistry from Florida State University. He has published extensively and given many lectures on the fundamental solution chemistry of actinides, chemical separations, environmental chemistry, and on the application of fundamental science to real-world problems associated with the use of radioactive materials. He is actively involved in basic and applied research on future directions for the nuclear fuel cycle. He is a co-editor of three books, Co-editor in Chief of the journal Solvent Extraction and Ion Exchange, an Associate Editor of the journal Radiochimica Acta and a member of the Editorial Board of the journal Separation Science and Technology. Dr. Nash was a visiting scholar at the Japan Atomic Energy Research Institute at Tokai-mura in 2000, and is the 2003 recipient of the Glenn T. Seaborg Award for Actinide Separations. His primary focus at present is on bringing some of this extensive experience in actinide solution chemistry and separation science to the task of helping to educate a new generation of nuclear/radiochemists and separation scientists. A key component of his teaching and research is to demonstrate the connection of the central themes of the chemical sciences to the challenges faced in 21st Century society.

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.

TERRY TODD

Terry Todd holds BS and MS degrees in Chemical Engineering from Montana State University and a Ph.D. in Radiochemical Engineering from St. Petersburg, Russia, with over 25 years experience in the field of chemical separations involving spent nuclear fuel and radioactive waste. He is currently a Laboratory Fellow and Director of the Fuel Cycle Science and Technology Division, at the Idaho National Laboratory, and is responsible for directing research and development of advanced technologies for spent nuclear fuel reprocessing and other chemical separation applications. He also serves as the DOE Advanced Fuel Cycle Initiative (AFCI) Separations and Waste Form Program Director. He has published over 150 journal articles, reports and conference proceedings and has been awarded 15 U.S. patents and 6 Russian patents. He has received the Glenn T. Seaborg Actinide Separations Award (2005), Illinois Engineering Council Outstanding Engineering Achievement Award (2005), an R&D 100 award (2006) a Nano50 Award (2006), and a Federal Laboratory Consortium Outstanding Technology Development award (2006). He currently serves on the Actinide Separations Conference Advisory Board and on the Editorial Board for the journal Solvent Extraction and Ion Exchange. He is a senior member of the American Institute of Chemical Engineers and a member of the American Nuclear Society (ANS). He is current Chair of the ANS Fuel Cycle and Waste Management Division and a lifetime member of the Idaho Section of the ANS.

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.

ROBERT M. WHAM

Robert Wham, Ph.D., is heavily involved with radioisotope production and radiochemical separations including recycle of used nuclear fuel. He currently serves as Technology Integration Manager for Fuels, Isotopes, and Nuclear Materials. He is responsible for six groups within the Nuclear Science and Technology Division at the Oak Ridge National Laboratory. The groups cover diverse areas such as radiochemical processing, robotics, stable isotope production, radioisotope production, and design of remotely operated equipment.

Previously he was program manager for several radiochemical processing programs at the Radiochemical Engineering Development Center (REDC). The REDC uses heavily shielded hot cells as well as glove box facilities for many DOE actinide processing programs such as the Advance Fuel Cycle Initiative and the Heavy Element Production Program. The Californium-252 Sales program is also located at the REDC. He has led recent efforts to evaluate options for reestablishing domestic 238Pu production.

He received his bachelor's degree in Chemical Engineering from the University of Illinois as well as completing a Master's degree and a Ph.D. from the University of Tennessee. He has been a previous chairman of the local section of the American Institute of Chemical Engineers (AIChE) and served as the national chairman of the Nuclear Engineering Division of the AIChE.

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