

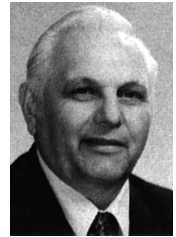
## AUTHORS — AUGUST 1989

### TMI-2: MATERIALS BEHAVIOR

#### PREFACE

**Richard K. McCardell** (BS, 1960, and MS, 1962, physics, Idaho State University) was responsible for the sample acquisition and examination program for the Three Mile Island Unit 2 Accident Evaluation Program. He previously was responsible for experiment specification and analysis for almost all experiments performed in the Idaho National Engineering Laboratory Power Burst Facility. He began his career as a member of the experimental group responsible for the Spert I destructive test program and is presently responsible for safety model and code development for the modular high-temperature gas-cooled reactor version of the New Production Reactor.

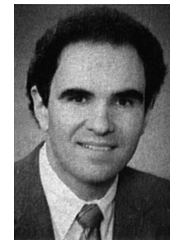
*Richard K. McCardell*



#### SUMMARY—THREE MILE ISLAND UNIT 2: MATERIALS BEHAVIOR

**Dennis E. Owen** (BS, chemistry, California State University, 1969) is president of ENCORE Technical Resources, Inc., an engineering consulting and technical communications firm. He has been a consultant to the nuclear power industry since 1984. Previously, he worked for EG&G Idaho, Inc. at the Idaho National Engineering Laboratory and for the General Electric Company at the Vallecitos Nuclear Center. Most of his career has been spent working on light water reactor fuels and materials, and has included the Three Mile Island core examination, severe accident reactor experiments, postirradiation examination of experimental fuel assemblies, and design modifications to commercial fuel to improve performance. His current interests include nuclear industry technology transfer and innovations in engineering communications.

*Dennis E. Owen*



#### AFTER THREE MILE ISLAND UNIT 2—A DECADE OF CHANGE

**Edwin E. Kintner** [BS, U.S. Naval Academy, 1941; MS, marine engineering, Massachusetts Institute of Technology (MIT), 1944; MS, nuclear physics, MIT, 1946] is executive vice president of GPU Nuclear Corporation. He also is chair of the Electric Power Research Institute's Advanced Light Water Reactor Utility Steering Committee. Previously, he was assistant director for reactor

*Edwin E. Kintner*



engineering and deputy director in the U.S. Atomic Energy Commission's Division of Reactor Development and Technology, and director of the U.S. Magnetic Fusion Program in the U.S. Department of Energy and its predecessor agency. He served in the U.S. Navy for 21 years, 13 of which were in the Naval Reactors Program as project officer for the first nuclear-powered submarine, the *USS Nautilus*; chief of the Advanced Design Group; first nuclear power superintendent at Mare Island Naval Shipyard; and senior naval officer, Bettis Plant.

### THREE MILE ISLAND—THE POLITICAL LEGACY

**Richard T. Kennedy** (BA, economics, University of Rochester; MBA, Harvard University) was appointed by President Reagan as Ambassador-at-Large in 1982. He serves as special adviser to the secretary of state on nonproliferation policy and nuclear energy affairs, and coordinates and directs U.S. nonproliferation efforts. He also serves as the U.S. representative to the International Atomic Energy Agency (IAEA), is a member of the IAEA Board of Governors, and serves as a delegate to the general conference of the IAEA. He is also chair of the Steering Committee of the Organization for Economic Cooperation and Development Nuclear Energy Agency. He served as under secretary of state for management from 1981 to 1982, and as a commissioner of the U.S. Nuclear Regulatory Commission from 1975 to 1980. He also served as deputy assistant to the president for National Security Council Planning from 1965 to 1975, following his service as director, Africa Region, International Security Affairs, Department of Defense.

*Richard T. Kennedy*



### REGULATORY IMPACT OF THE THREE MILE ISLAND UNIT 2 ACCIDENT

**John F. Ahearne** (BS, engineering physics, Cornell University, 1957; MS, Cornell University, 1958; MA, Princeton University, 1963; PhD, physics, Princeton University, 1966) is presently vice president and senior fellow for Resources for the Future. He served as commissioner of the U.S. Nuclear Regulatory Commission from 1978 to 1983, and as deputy assistant secretary of energy for power applications in 1978. He served as assistant to the secretary of energy from 1977 to 1978 and worked on the conservation and nuclear energy portions of the National Energy Plan and the National Energy Bill for the White House Energy Policy and Planning Office. He is also presently serving as chair of the U.S. Department of Energy Advisory Committee on Nuclear Facility Safety and on the Committee on Risk Perception and Communication for the National Research Council. He has participated on the National Research Council's Committee on Nuclear Safety Research and the Steering Committee for the Workshop on High-Temperature and Nuclear Chemical Processes in Severe Reactor Accidents.

*John F. Ahearne*



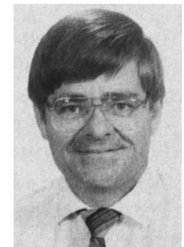
### A SCENARIO OF THE THREE MILE ISLAND UNIT 2 ACCIDENT

**James M. Broughton** (right) (BS and MS, mechanical engineering, Colorado State University) is manager of the Three Mile Island Unit 2 (TMI-2) Accident Evaluation Program at the Idaho National Engineering Laboratory (INEL), where he has been involved in severe accident research for over 15 years. His work has included model development for steady-state and design-basis

*James M. Broughton  
Pui Kuan  
David A. Petti  
E. L. Tolman*



accident analysis; analysis of light water reactor (LWR) primary cooling system response and core behavior under steady-state, design-basis, and severe accident conditions; and participation in all aspects of large-scale separate and integral effects in-pile fuel behavior experiments. His professional specialties are heat transfer, two-phase thermal hydraulics, thermodynamics, steady-state and transient behavior of LWR fuel, and LWR fuel and fission product behavior under design-basis and severe accident conditions. **Pui Kuan** (top) (BS, astronomy, California Institute of Technology, 1970; MA, 1972, and PhD, 1973, astronomy, University of California, Berkeley) is a senior engineering specialist at INEL. He has been involved in the planning and analysis of experiments performed at the Loss-of-Fluid Test (LOFT) Facility and the Power Burst Facility and has contributed to the development of the TMI-2 accident scenario. **David A. Petti** (center) (SB/SM, 1983, and ScD, 1986, nuclear engineering, Massachusetts Institute of Technology) is currently an engineering specialist for EG&G Idaho, Inc. at INEL. His current interests are in the field of LWR severe accident and source term behavior. **E. L. Tolman** (bottom) (BS, physics, and MS, nuclear engineering) has been associated with LWR research conducted at INEL. He most recently managed the technical analysis conducted for the U.S. Department of Energy TMI-2 Accident Evaluation Program, an industrywide program to establish a more complete understanding of the TMI-2 accident. Prior to his work on TMI-2, he was responsible for design and analysis of both severe accident and large-break loss-of-coolant accident experiments conducted in the LOFT Facility, and separate effects fuels damage experiments conducted in the Power Burst Facility. He is currently employed by Advanced Nuclear Fuels.



### THREE MILE ISLAND UNIT 2: PLANT RECOVERY

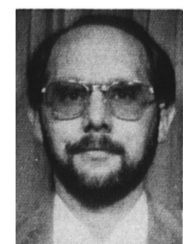
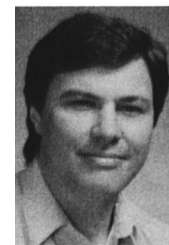
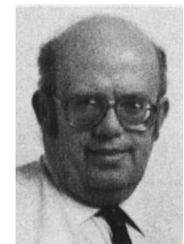
*F. R. Standerfer*

A photograph and a biography for **F. R. Standerfer** were not available at publication time.

### MATERIALS INTERACTIONS AND TEMPERATURES IN THE THREE MILE ISLAND UNIT 2 CORE

*Charles S. Olsen  
Steven M. Jensen  
Eric R. Carlson  
Beverly A. Cook*

**Charles S. Olsen** (top) (PhD, metallurgy, University of Utah, 1967; MBA, business administration, Idaho State University, 1984) is a principal program specialist with the Multimegawatt Project Integration (Technical Integration Support) Office at the Idaho National Engineering Laboratory (INEL) operated by EG&G Idaho, Inc. He worked at INEL for 22 years in developing and implementing nuclear reactor materials testing programs and evaluating materials performance and characterizing materials properties for nuclear safety research. His current research interests are in developing materials and fuels for advanced nuclear space power systems. **Steven M. Jensen** (center) (BS, metallurgical engineering, University of Washington, 1977) is a senior engineer at EG&G Idaho. He is currently the project engineer responsible for the postirradiation examinations of the loss-of-fluid test FP-2 severe fuel damage experiment. **Eric R. Carlson** (bottom) (BS, nuclear engineering, Texas A&M University, 1977; ME, mechanical engineering, University of Idaho, 1985) participated in the metallurgical evaluation of debris samples from Three Mile Island Unit 2 and the Power Burst Facility severe fuel damage tests for EG&G Idaho, Inc. at INEL. He



is currently a mechanical design engineer in the Power Reactor Program. **Beverly A. Cook** (right) (BS, metallurgical engineering, University of Washington, 1975) is manager of the Materials Technology Group of the science and technology department at INEL. Her previous work involved failure analysis of nuclear materials tested under design-basis and severe accident conditions. Her present work includes managing an organization performing research in materials, materials processing, and materials characterization for both nuclear and nonnuclear applications.



**METALLURGICAL REACTIONS INVOLVING Ag-In-Cd CONTROL ROD ASSEMBLIES**

**Yung Y. Liu** (top) (BS, nuclear engineering, National Tsing-Hua University, Taiwan, 1971; MS, 1976, and ScD, 1978, nuclear engineering, Massachusetts Institute of Technology) is a staff engineer in the Irradiation Performance Section, Materials and Components Technology Division, Argonne National Laboratory (ANL). He is principally involved in the postirradiation testing of irradiated metal fuel pins for the Integral Fast Reactor program. He is also involved in the examination of materials from the Three Mile Island Unit 2 reactor and from the U.S. Nuclear Regulatory Commission-sponsored source term experiments conducted by the Oak Ridge and Sandia National Laboratories. **Lawrence A. Neimark** (bottom) (MS, metallurgy, University of Minnesota, 1958) is a senior scientist and the manager of the Irradiation Performance Section at ANL. He has been involved in nuclear fuel development and the postirradiation examination of fuels for the past 30 years. **W. D. Jackson** (photo not available), now retired, was the facility supervisor of the Alpha Gamma Hot Cell Facility at ANL and performed the scanning electron microscopy work for this paper.

*Yung Y. Liu  
Lawrence A. Neimark  
W. D. Jackson*



**EXAMINATION OF THREE MILE ISLAND UNIT 2 CORE MATERIALS AT COMMISSARIAT À L'ENERGIE ATOMIQUE**

**Jacques Duco** (top) (Ecole Centrale de Paris, France, 1962) is a senior engineer of the Institut de Protection et de Sûreté Nucléaire of the Commissariat à l'Energie Atomique (CEA). He currently is the deputy head of the service in charge of siting and severe accident assessment. One of his major interests lies in fuel degradation and fission product behavior in the course of severe accidents in pressurized water reactors (PWRs). **Maria Trotabas** (Cracow Academy of Mining and Metallurgy, Poland, 1965) is a senior engineer of the Institut de Recherche et de Développement Industriel of CEA. She is currently the deputy head of the hot-cell facilities of the Département de Technologie at Saclay. Her main interest is the study of the behavior of various irradiated PWR-type fuels.

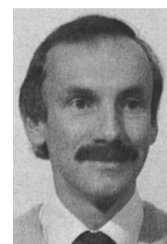
*Jacques Duco  
Maria Trotabas*



**METALLURGICAL EXAMINATION OF BORE SAMPLES FROM THE THREE MILE ISLAND UNIT 2 REACTOR CORE**

**Paul David Bottomley** (right) [PhD, corrosion, University of Manchester, Institute of Science and Technology (UMIST), United Kingdom, 1981] is a scientific officer currently working on the analysis and microstructure of irradiated fuels and materials in the hot-cell facility at the European Institute for Transuranium Elements, Karlsruhe, Federal Republic of Germany. His

*Paul David Bottomley  
Michel Coquerelle*



previous experience lies in the field of ferrous materials performance under high-temperature corrosion, as well as broader based materials and corrosion consultancy at UMIST's corrosion advisory services. **Michel Coquerelle** (right) (PhD, solid-state chemistry, University of Brussels, Belgium, 1960) is in charge of postirradiation examinations at the European Institute for Transuranium Elements. He gained his initial experience in this field while working for the French nuclear research center at Saclay (1960 to 1964). His current interests include both thermal reactor and fast breeder reactor fuels, as well as high-level waste materials.



### ANALYSIS OF CRYSTALLINE PHASES IN CORE BORE MATERIALS FROM THREE MILE ISLAND UNIT 2

**Allan Brown** (top) (PhD, chemistry, Uppsala University, Sweden, 1962) has been in charge of powder diffraction at Studsvik AB since 1966 while engaging in studies of solid-state reactions in powder compacts. He was elected to the Board of Directors, Joint Committee for Powder Diffraction Standards, in 1988 and was made professor of materials characterization by powder diffraction at Uppsala University in 1989. **Garry J. McIntyre** (center) (BSc, 1973, and PhD, 1978, physics, University of Melbourne, Australia) was a research engineer at Studsvik Nuclear AB in 1987-1988. His research interests are diffraction physics and novel application of X-ray and neutron diffraction. He is currently a staff scientist at the Institut Laue-Langevin, Grenoble, France. **Christian Gräslund** (bottom) (Dr. Tech., reactor physics, Royal Institute of Technology, Stockholm, Sweden, 1971) is head of radiation applications at Studsvik Nuclear AB. He was previously employed by the Swedish Nuclear Power Inspectorate, where he was responsible first for safety research, then for licensing and safety assessment. His main interest lies in the utilization of research reactors.

*Allan Brown  
Garry J. McIntyre  
Christian Gräslund*



### REACTOR CORE MATERIALS INTERACTIONS AT VERY HIGH TEMPERATURES

**Peter Hofmann** (top) [BS, mechanical engineering, 1964; MS, nuclear engineering, 1968; and PhD, materials science, 1974, University of Karlsruhe, Federal Republic of Germany (FRG)] is a senior scientist and group leader at the Institute of Materials and Solid State Research (IMF) at Kernforschungszentrum Karlsruhe (KfK). Since 1968, he has been engaged in research on the behavior of light water reactor (LWR) fuel elements under accident conditions, Zircaloy stress corrosion cracking phenomena, physical chemistry of irradiated fuel rods, and compatibility behavior of fuel rod components. Current research interests include LWR fuel rod behavior under severe fuel damage conditions, core melt phenomena, and all related in-vessel material behavior processes. **Siegfried J. L. Hagen** (center) (Diplomphysicist, PhD, inelastic neutron scattering, University of Karlsruhe, FRG, 1970) is group leader at the Hauptabteilung Ingenieur-technik at KfK. He has worked in the field of severe core damage since 1974 and has been responsible for the out-of-pile LWR bundle meltdown tests in the NIELS and CORA facilities. **Gerhard Schanz** (bottom) (Dipl.-Phys., physics, University of Stuttgart and Max-Planck Institut für Metallforschung, FRG, 1969) has been engaged in the investigation and development of metallic materials with respect to the interrelationship between microstructure and mechanical properties and

*Peter Hofmann  
Siegfried J. L. Hagen  
Gerhard Schanz  
Alfred Skokan*



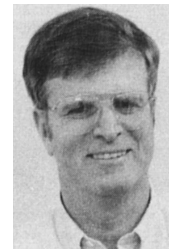
corrosion behavior since 1970. He has been a scientific member of the Department of Corrosion at the IMF, KfK, since 1975, where he has been mainly engaged in reactor safety-related material investigations. **Alfred Skokan** (right) (Dr. rer. nat., University of Bonn, FRG, 1972) is a scientific staff member of the IMF at KfK. His interests include phase relations and reactions of nuclear materials, as well as the structure of solids. He is currently involved in materials research concerning LWR core melt accidents and fusion-related ceramic material development.



### FUEL RELOCATION MECHANISMS BASED ON MICROSTRUCTURES OF DEBRIS

**Robert V. Strain** (top) (BS, metallurgical engineering, Colorado School of Mines, 1965; MS, metallurgy, Iowa State University, 1966) is currently an engineer in the Experimental Breeder Reactor Division at Argonne National Laboratory (ANL). His current interests are in the performance of mixed-oxide and metal fuel systems for liquid-metal reactors. **Lawrence A. Neimark** (center) (MS, metallurgy, University of Minnesota, 1958) is the manager of the Irradiated Performance Section in the Materials and Components Technology Division at ANL. His section performs in- and out-of-reactor fuel development experiments for different reactor types and also operates the Alpha-Gamma Hot-Cell Facility (AGHCF). **John E. Sanecki** (bottom) is the supervisor of the AGHCF's Electron Beam Laboratory and performed the scanning electron microscopic, Auger, and electron microprobe analyses for this work.

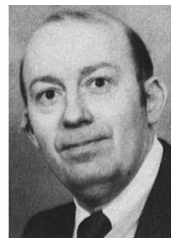
*Robert V. Strain  
Lawrence A. Neimark  
John E. Sanecki*



### THREE MILE ISLAND UNIT 2 B-LOOP STEAM GENERATOR TUBESHEET LOOSE DEBRIS EXAMINATION AND ANALYSIS

**George O. Hayner** (top) [BS, metallurgical engineering, Michigan State University (MSU), 1967; MNS, metallurgy, University of Idaho, 1973] is supervisor of failure analysis at the Babcock & Wilcox Company (B&W). Previously, he was a metallurgical engineer at Argonne National Laboratory-West and has been involved with the development of breeder reactor fuel. He is currently involved with metallurgical and failure analysis of samples and components removed from nuclear power plants. **Todd L. Hardt** (BS, chemistry, MSU, 1968; PhD, nuclear chemistry, Texas A&M University, 1975) is manager of EcoTek Laboratory Services, Inc. Previously, he was principal radiochemist at B&W, where he was involved with the radiochemical analysis of samples from the nuclear industry. He is currently involved in the development and start-up of a new environmental and low-level radiochemistry laboratory for EcoTek, Inc.

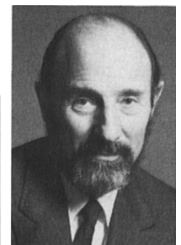
*George O. Hayner  
Todd L. Hardt*



### FISSION PRODUCT RELEASE PATHWAYS IN THREE MILE ISLAND UNIT 2

**Sidney Langer** (top) (PhD, physical chemistry, Illinois Institute of Technology) worked on the Three Mile Island Unit 2 (TMI-2) Accident Evaluation Program at the Idaho National Engineering Laboratory (EG&G Idaho, Inc.). He was previously employed at General Atomics, working on the high-temperature gas-cooled reactor, the gas-cooled fast breeder reactor, and a number of other programs. A photograph and a biography for **M. L. Russell** were not available at publication time. **Douglas W. Akers** (bottom) (BA, chemistry, Idaho State University) is

*Sidney Langer  
M. L. Russell  
Douglas W. Akers*

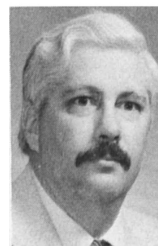


currently the technical leader of the Radiological Physics Section at EG&G Idaho, Inc. He has been involved in the examination and analysis of results from TMI-2 since shortly after the accident. He is currently involved in the examinations of the lower head of the TMI-2 reactor vessel and in the development of nuclear materials measurement methods.

### THREE MILE ISLAND UNIT 2 FISSION PRODUCT INVENTORY ESTIMATES

**Douglas W. Akers** (top right) (BA, chemistry, Idaho State University) is currently the technical leader of the Radiological Physics Section at EG&G Idaho, Inc. He has been involved in the examination and analysis of results from Three Mile Island Unit 2 (TMI-2) since shortly after the accident. He is currently involved in the examinations of the lower head of the TMI-2 reactor vessel and in the development of nuclear materials measurement methods. **E. L. Tolman** (top left) (BS, physics, and MS, nuclear engineering) has been associated with light water reactor research conducted at the Idaho National Engineering Laboratory (INEL). He most recently managed the technical analysis conducted for the U.S. Department of Energy TMI-2 Accident Evaluation Program, an industrywide program to establish a more complete understanding of the TMI-2 accident. Prior to his work on TMI-2, he was responsible for the design and analysis of both severe accident and large-break loss-of-coolant accident experiments conducted in the Loss-of-Fluid Test (LOFT) Facility, and separate effects fuels damage experiments conducted in the Power Burst Facility. He is currently employed by Advanced Nuclear Fuels. **Pui Kuan** (center right) (BS, astronomy, California Institute of Technology, 1970; MA, 1972, and PhD, 1973, astronomy, University of California, Berkeley) is a senior engineering specialist at INEL. He has been involved in the planning and analysis of experiments performed at the LOFT Facility and the Power Burst Facility and has contributed to the development of the TMI-2 accident scenario. **Daniel W. Golden** (bottom left) [BS, engineering, California State University; SM (NA and ME) and ocean engineer, Massachusetts Institute of Technology, 1975] is a research engineer with INEL. For the past 9 years, his work has been related to reactor thermal hydraulics and fuel behavior during severe accident conditions. His current interests are accident management issues and their resolution. **Masahide Nishio** (bottom right) (MS, nuclear engineering, Kyoto University, Japan, 1972) is a manager in the Nuclear Safety Design Section, Nuclear Energy Division of Toshiba Corporation and is responsible for the nuclear safety design of boiling water reactors. For the last 2 years, he has worked in the TMI-2 research project.

*Douglas W. Akers  
E. L. Tolman  
Pui Kuan  
Daniel W. Golden  
Masahide Nishio*



### CORE MATERIALS INVENTORY AND BEHAVIOR

**Douglas W. Akers** (top) (BA, chemistry, Idaho State University) is currently the technical leader of the Radiological Physics Section at EG&G Idaho, Inc. He has been involved in the examination and analysis of results from Three Mile Island Unit 2 (TMI-2) since shortly after the accident. He is currently involved in the examinations of the lower head of the TMI-2 reactor vessel and in the development of nuclear materials measurement methods. **Richard K. McCardell** (BS, 1960, and MS, 1962, physics, Idaho State University) was responsible for the sample

*Douglas W. Akers  
Richard K. McCardell*

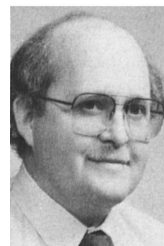
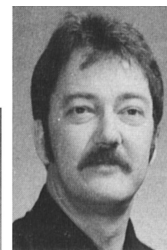


acquisition and examination program for the TMI-2 Accident Evaluation Program. He previously was responsible for experiment specification and analysis for almost all experiments performed in the Idaho National Engineering Laboratory Power Burst Facility. He began his career as a member of the experimental group responsible for the Spert I destructive test program and is presently responsible for safety model and code development for the modular high-temperature gas-cooled reactor version of the New Production Reactor.

#### FISSION PRODUCT AND CORE MATERIALS DISTRIBUTION OUTSIDE THE THREE MILE ISLAND UNIT 2 REACTOR VESSEL

**Charles V. McIsaac** (top right) (BS, earth and planetary sciences, Massachusetts Institute of Technology, 1971) is a research staff member of the physics and mathematics group at Idaho National Engineering Laboratory. His current research interest is in the area of low-level radioactive waste. **Richard S. Denning** (top left) (PhD, nuclear engineering, University of Florida, 1967) is senior research leader for nuclear safety analysis at Battelle. He has been involved in the development of methods for analyzing severe accident behavior and their application to probabilistic risk analysis for the past 15 years. He provided technical support to the U.S. Nuclear Regulatory Commission's Three Mile Island Unit 2 (TMI-2) special inquiry group. **Rajiv Kohli** (bottom right) (PhD, School of Mines, Leoben, Austria, 1980) is involved in nuclear technology and space commercialization at Battelle. His research interests include fuel/cladding interactions, decontamination and decommissioning, spent-fuel storage, chemical thermodynamics, high-temperature materials chemistry, and space materials processing. **Douglas W. Akers** (bottom left) (BA, chemistry, Idaho State University) is currently the technical leader of the Radiological Physics Section at EG&G Idaho, Inc. He has been involved in the examination and analysis of results from TMI-2 since shortly after the accident. He is currently involved in the examinations of the lower head of the TMI-2 reactor vessel and in the development of nuclear materials measurement methods.

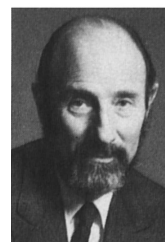
*Charles V. McIsaac  
Richard S. Denning  
Rajiv Kohli  
Douglas W. Akers*



#### CONSIDERATION OF CESIUM AND IODINE CHEMISTRY AND TRANSPORT BEHAVIOR DURING THE THREE MILE ISLAND UNIT 2 ACCIDENT

**August W. Cronenberg** (top) (PhD, engineering science, Northwestern University, 1971) is presently an independent consultant working on various aspects of reactor safety and fuel behavior. He worked at Argonne National Laboratory from 1971 to 1974, was professor of chemical and nuclear engineering at the University of New Mexico from 1974 to 1977, and was a senior scientist at EG&G Idaho, Inc. from 1977 to 1979. His main interests are in the areas of thermal and material science and reactor safety. **Sidney Langer** (PhD, physical chemistry, Illinois Institute of Technology) worked on the Three Mile Island Unit 2 Accident Evaluation Program at the Idaho National Engineering Laboratory (EG&G Idaho, Inc.). He was previously employed at General Atomics, working on the high-temperature gas-cooled reactor, the gas-cooled fast breeder reactor, and a number of other programs.

*August W. Cronenberg  
Sidney Langer*

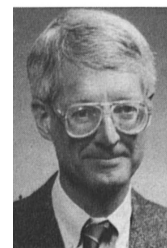
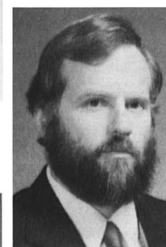




## ANALYSIS OF FISSION PRODUCT RELEASE BEHAVIOR FROM THE THREE MILE ISLAND UNIT 2 CORE

**David A. Petti** (top right) (SB/SM, 1983, and ScD, 1986, nuclear engineering, Massachusetts Institute of Technology) is currently an engineering specialist for EG&G Idaho, Inc. at the Idaho National Engineering Laboratory (INEL). His current interests are in the field of light water reactor severe accident and source term behavior. **James P. Adams** (top left) (BS, physics, Brigham Young University, 1968; PhD, physics, Iowa State University, 1972) has been at the INEL (EG&G Idaho, Inc., prime contractor) since 1979, working in reactor safety research. His interests include integral pressurized water reactor response as well as fission product release and transport during design-basis and severe core damage accidents. He is currently a senior scientist in the Nuclear Engineering Research and Development Group. **James L. Anderson** (bottom right) (MS, mechanical engineering, Oregon State University, 1974) is a senior engineering specialist in the Energy and Systems Technology Division at the INEL. His research interests include multiphase thermal hydraulics, scaled experimental systems analysis, and development of measurement systems. **Richard R. Hobbins** (bottom left) (AB, physical chemistry, Princeton University, 1960; PhD, physical metallurgy, University of Delaware, 1969) is a principal scientist in the Fuels and Materials Unit of EG&G Idaho, Inc., at the INEL. He has been at the INEL for 20 years working in the areas of fuel behavior and reactor safety, especially under severe accident conditions.

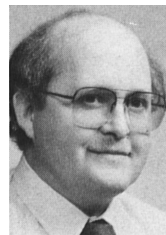
*David A. Petti  
James P. Adams  
James L. Anderson  
Richard R. Hobbins*



## FISSION PRODUCT PARTITIONING IN CORE MATERIALS

**Douglas W. Akers** (top) (BA, chemistry, Idaho State University) is currently the technical leader of the Radiological Physics Section at EG&G Idaho, Inc. He has been involved in the examination and analysis of results from Three Mile Island Unit 2 (TMI-2) since shortly after the accident. He is currently involved in the examinations of the lower head of the TMI-2 reactor vessel and in the development of nuclear materials measurement methods. **Richard K. McCardell** (BS, 1960, and MS, 1962, physics, Idaho State University) was responsible for the sample acquisition and examination program for the TMI-2 Accident Evaluation Program. He previously was responsible for experiment specification and analysis for almost all experiments performed in the Idaho National Engineering Laboratory Power Burst Facility. He began his career as a member of the experimental group responsible for the Spert I destructive test program and is presently responsible for safety model and code development for the modular high-temperature gas-cooled reactor version of the New Production Reactor.

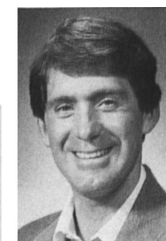
*Douglas W. Akers  
Richard K. McCardell*



## THERMAL INTERACTION OF CORE MELT DEBRIS WITH THREE MILE ISLAND UNIT 2 VESSEL COMPONENTS

**August W. Cronenberg** (top) (PhD, engineering science, Northwestern University, 1971) is an independent consultant working on various aspects of reactor safety and fuel behavior. He worked at Argonne National Laboratory from 1971 to 1974, was professor of chemical and nuclear engineering at the University of New Mexico from 1974 to 1977, and was a senior scientist at EG&G Idaho, Inc. from 1977 to 1979. His main interests are in the areas of thermal and material science and reactor safety. **E. L. Tolman** (BS, physics, and MS, nuclear engineering) has been

*August W. Cronenberg  
E. L. Tolman*



associated with light water reactor research conducted at Idaho National Engineering Laboratory. He most recently managed the technical analysis conducted for the U.S. Department of Energy Three Mile Island Unit 2 (TMI-2) Accident Evaluation Program, an industrywide program to establish a more complete understanding of the TMI-2 accident. Prior to his work on TMI-2, he was responsible for design and analysis of both severe accident and large-break loss-of-coolant accident experiments conducted in the Loss-of-Fluid Test Facility, and separate effects fuels damage experiments conducted in the Power Burst Facility. He is currently employed by Advanced Nuclear Fuels.

### **THERMAL BEHAVIOR OF MOLTEN CORIUM DURING THE THREE MILE ISLAND UNIT 2 CORE RELOCATION EVENT**

**James L. Anderson** (top) (MS, mechanical engineering, Oregon State University, 1974) is a senior engineering specialist in the Energy and Systems Technology Division at the Idaho National Engineering Laboratory. His research interests include multi-phase thermal hydraulics, scaled experimental systems analysis, and development of measurement systems. **James J. Sienicki** (PhD, physics, University of Illinois, 1975) is a member of the Experiment Modeling Section within the Reactor Analysis and Safety Division at the Argonne National Laboratory. His research currently involves analysis of severe accident phenomena and experiment modeling for light and heavy water reactors.

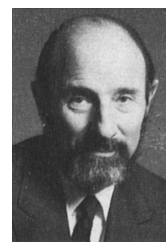
*James L. Anderson  
James J. Sienicki*



### **JUST HOW MUCH WATER IS REQUIRED TO COOL A MOL-TEN CORE?**

**Sidney Langer** (PhD, physical chemistry, Illinois Institute of Technology) worked on the Three Mile Island Unit 2 Accident Evaluation Program at the Idaho National Engineering Laboratory (EG&G Idaho, Inc.). He was previously employed at General Atomics, working on the high-temperature gas-cooled reactor, the gas-cooled fast breeder reactor, and a number of other programs.

*Sidney Langer*



### **THE THREE MILE ISLAND ANALYSIS EXERCISE**

**Daniel F. Giessing** (BS, physics and mathematics, Valparaiso University, 1961; MS, physics, Oklahoma State University, 1963) is the director of the U.S. Department of Energy's Office of Light Water Reactor Safety and Technology, which has been sponsoring research and development (R&D) work involving Three Mile Island Unit 2 (TMI-2) fuel debris. The work on the TMI Analysis Exercise is one of the activities in the overall TMI-2 R&D program.

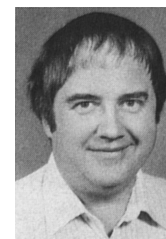
*Daniel F. Giessing*



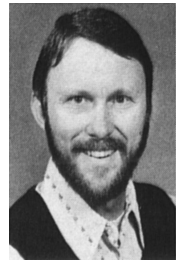
### **MODELING OF THE THREE MILE ISLAND UNIT 2 ACCIDENT WITH MELPROG/TRAC AND CALCULATION RESULTS FOR PHASES 1 AND 2**

**Frank E. Motley** (right) (BS, mechanical engineering, 1965; MS, nuclear engineering, University of Kansas, 1967) is a staff member at Los Alamos National Laboratory (LANL), where he has been analyzing international reactor safety experiments and contributing to the development of advanced reactor safety analysis

*Frank E. Motley  
Richard P. Jenks*



codes. Analysis of actual plant transients and resolution of reactor safety issues for the U.S. Nuclear Regulatory Commission (NRC) have also been completed. He was previously a fellow engineer at Westinghouse Electric Corporation, where he conducted experiments and developed correlations for the thermal-hydraulic design of reactor cores. **Richard P. Jenks** (right) (BS, nuclear engineering, 1974; MS, nuclear engineering, Oregon State University, 1981) is a nuclear energy systems engineer. He serves as liaison to the NRC and is currently leader of the NRC Reactor Application Section at LANL. He is the principal investigator for TRAC-related programs and is engaged in thermal-hydraulic code development and systems analysis. His previous background includes boiling water reactor fuel engineering work at Westinghouse on in-core/out-of-core fuel management and on-line core monitoring software. He has worked in radioisotope applications to mineral detection, neutron radiography, extended burnup fuel experiments, and power plant economics research, as well as telecommunications, computer programming, graphics, statistics, and data base management.



**MARCH CALCULATIONS PERFORMED FOR THE THREE MILE ISLAND UNIT 2 ANALYSIS EXERCISE**

**Roger O. Wooton** (BSE, engineering mechanics, 1958, and MSE, nuclear engineering, 1959, University of Michigan) has been with the nuclear systems group at Battelle Columbus Division for nearly 30 years. He is the principal author of the MARCH code. His technical interests in the thermal-hydraulic aspects of light water reactor meltdown accidents precede the Reactor Safety Study. His current interests include accident management issues.

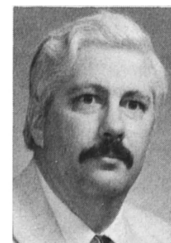
*Roger O. Wooton*



**SUMMARY OF THE THREE MILE ISLAND UNIT 2 ANALYSIS EXERCISE**

**Daniel W. Golden** (top right) [BS, engineering, California State University; SM (NA and ME) and ocean engineer, Massachusetts Institute of Technology, 1975] is a research engineer with the Idaho National Engineering Laboratory. For the past 9 years, his work has been related to reactor thermal hydraulics and fuel behavior during severe accident conditions. His current interests are accident management issues and their resolution. **Kikuo Akagane** (top left) (MS, chemistry, Osaka University, Japan, 1970) is a principal engineer at the Japan Institute of Nuclear Safety (JINS) Nuclear Engineering Test Center. His previous experience has been on fast breeder reactor research and development (R&D) at Hitachi Ltd. and the Power Reactor and Nuclear Fuels Development Corporation (PNC) and on light water reactor (LWR) safety analyses. **Maurizio Colagrossi** (bottom right) (PhD, nuclear engineering, University of Rome, Italy, 1973) is a safety analyst for the Directorate for Nuclear Safety and Health Protection of ENEA, Italy. He has been involved in the development and application of thermal-hydraulic and severe accident computer codes in nuclear power plant analysis. He is a member of the Organization for Economic Cooperation and Development PWG2 on primary coolant system behavior. He is currently the coordinator of the nuclear departments of Pisa and Roma universities and is involved with the Three Mile Island Unit 2 (TMI-2) international exercise. **Patrick Dumaz** (bottom left) (Eng. ENSAM, mechanical engineering, 1983; Dr. Eng., solid mechanics, Université de Grenoble, France, 1985) is a research engineer at the Nuclear Safety Institute of the Commissariat

*Daniel W. Golden  
Kikuo Akagane  
Maurizio Colagrossi  
Patrick Dumaz  
Tohru Haga  
Kazuichiro Hashimoto  
John N. Lillington  
Risto Sairanen  
Ariel Sharon  
Roger O. Wooton  
Theo Van Der Kaa*



à l'Énergie Atomique. His areas of interest include constitutive equations of visco-plastic materials. His recent work has involved thermal-hydraulic calculations with the CATHARE code and the interpretation of aerosol experiments. **Tohru Haga** (top right) (MS, nuclear engineering, Tokyo Institute of Technology, Japan, 1961; PhD, engineering physics, Cornell University, 1967) is head of the Boiling Water Reactor Safety Analysis Division at JINS Nuclear Engineering Test Center. His previous experience has been on R&D of the plutonium-fueled FUGEN heavy water reactor at Hitachi Ltd. and PNC and on LWR safety analyses at JINS. **Kazuichiro Hashimoto** (top left) (BS, electrical engineering, Keio University, Japan, 1976) is a research engineer at Japan Atomic Energy Research Institute. He is presently engaged in severe fuel damage research for LWRs. His current interest is pool scrubbing effects for aerosols under severe accident conditions for LWRs. He has previously been engaged in the solvent fire test program for reprocessing plants. **John N. Lillington** (second from top right) (BSc, mathematics, 1971, and PhD, mathematics, 1974, London University, England) is a research scientist with the United Kingdom Atomic Energy Authority, Winfrith. His interests include the numerical modeling of fluids, multiphase flows, and heat transfer. For 15 years, his technical interests have been in the field of reactor safety for both liquid-metal fast breeder reactors and pressurized water reactors. **Risto Sairanen** (center left) (MSc, nuclear engineering, Helsinki University of Technology, Finland, 1977) is a senior research scientist at the Nuclear Engineering Laboratory at the Technical Research Center of Finland (VTT). His current research activities involve modeling of fuel and fission product behavior in severe accidents. **Ariel Sharon** (third from top right) (BSc, 1970, and MSc, 1976, chemical engineering, Technion, Israel; PhD, chemical engineering, Northwestern University, 1979) joined the faculty of nuclear engineering at Ben Gurion University, Israel, in 1980, where he conducted research on various LWR thermal-hydraulic topics including simulation of various steam generator transients. In 1982 he joined Fauske & Associates, Inc., where he serves as a project manager on a large variety of simulation projects and benchmarking including the TMI-2 and the Chernobyl accidents as well as many experimental programs. He has also conducted numerous safety analyses of nuclear power plants in the United States and abroad. Currently, he is working on introducing severe accident phenomena to full-scope simulators for the purpose of operator training and accident management evaluations. **Roger O. Wooton** (bottom left) (BSE, engineering mechanics, 1958, and MSE, nuclear engineering, 1959, University of Michigan) has been with the nuclear systems group at Battelle Columbus Division for nearly 30 years. He is the principal author of the MARCH code. His technical interests in the thermal-hydraulic aspects of LWR meltdown accidents precede the Reactor Safety Study. His current interests include accident management issues. **Theo Van Der Kaa** (bottom right) (MS, mechanical engineering, Amsterdam University, The Netherlands, 1968) has been working in nuclear safety analysis at the Netherlands Energy Research Foundation (ECN) since 1982. He was previously in irradiation engineering at the High Flux Reactor at Petten. Since 1984 he has been a member of the Reactor Safety Committee and currently serves as chairman.

