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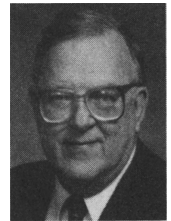
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AUTHORS — JANUARY 1988

ADVANCED LIGHT WATER REACTORS

PREFACE: ON HIGH CONVERSION RATIO LIGHT WATER REACTORS

Milton C. Edlund



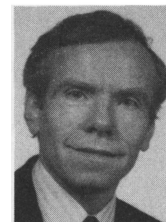
Milton C. Edlund (BS, 1948; MS, physics, 1948; and PhD, nuclear science, University of Michigan, 1966) invented the spectral shift concept of reactor control, which is now being used by the General Electric Company and is the basis for the new Westinghouse advanced pressurized water reactor. He developed the course in reactor physics at the Oak Ridge School of Reactor Technology and in collaboration with Samuel Glasstone wrote the first relatively complete book on reactor theory. He worked in various management positions at the Atomic Energy Division of Babcock & Wilcox Company, helped found the Nuclear Assurance Corporation, and has been a professor of nuclear and mechanical engineering at Virginia Polytechnic Institute and State University. His current interests are primarily in the improvement of nuclear fuel utilization.

DEVELOPMENT TRENDS FOR FUTURE FRENCH PRESSURIZED WATER REACTORS

*Bertrand Barré
Gérard Gambier
Claude Golinelli*



Bertrand Barré (top) (Ing. Civil de la Métallurgie et des Mines, Nancy, France, 1965) joined the Commissariat à l'Energie (CEA) in 1967. He has been technical advisor to the chairman of the CEA (1978) and nuclear attaché at the French Embassy in Washington, D.C. (1980). He is now head of light water reactor (LWR) research and development (R&D) of the CEA. **Gérard Gambier** (center) (MS, physics, University of Paris, France, 1964; engineering degree, Ecole Supérieure d'Electricité, France, 1966; PhD, nuclear engineering, University of Paris, France, 1974) is deputy head of the Reactor Physics Section at Electricité de France. He has worked in R&D of high-temperature reactors and is currently working in conventional and advanced water reactors, together with fast breeders. His main interests and activities are in neutronics, fuel cycle, thermohydraulics, and reactor operation. **Claude Golinelli** (bottom) (Ecole Supérieure d'Electricité, Paris, France, 1961; reactor physics D., 1964) has worked in experimental neutronics for fast breeder reactors and LWRs. In recent



years he has devoted research to nuclear electricity strategy (plutonium recycling, advanced pressurized water reactor). He is currently deputy head of Thermal Hydraulics Laboratories at Grenoble (CEA).

FEASIBILITY STUDIES ON HIGH CONVERSION PRESSURIZED WATER REACTORS WITH SEMITIGHT CORE CONFIGURATIONS

Etsuro Saji (top right) (BS and MS, nuclear engineering, Osaka University, Japan, 1981) is an engineer at Mitsubishi Atomic Power Industries, Inc. (MAPI), where he has been engaged in pressurized water reactor (PWR) nuclear design. **Yoshiei Akiyama** (top left) (BS, physics, Kyoto University, Japan, 1972) is an assistant manager of the Thermal-Hydraulic Engineering Team at MAPI and has been engaged in thermal-hydraulic design of advanced PWR plants. **Norio Kono** (second from top right) (BS and MS, mechanical engineering, Tokyo University, Japan, 1971) is manager of the Water Reactor Fuel Engineering Team II at MAPI and has been engaged in structural and mechanical design of PWR fuel assemblies. **Kiyoshi Nambu** (center left) (BS, nuclear engineering, Tokyo University, Japan, 1969) is manager of the Reactor Equipment Engineering Team at MAPI and has been engaged in reactor equipment design and analysis. **Keiichi Hori** (third from top right) (BS, MS, and Dr. Eng., mechanical engineering, Kyushu University, Japan, 1977) is a senior research engineer at Mitsubishi Heavy Industries, Ltd., and has been engaged in research work on the thermal hydraulics of reactor cores and steam generators. **Toshihiro Umeoka** (bottom left) (BS, electrical engineering, Fukui University, Japan, 1967) is a special assignment manager in the nuclear projects department at Kansai Electric Power Company, Inc., and has been engaged in the fields of high conversion pressurized water reactor (HCPWR) and fast breeder reactor (FBR) research. **Tsuyoshi Kono** (bottom right) (BS and MS, chemical engineering, Osaka Prefectural University, Japan, 1975) is a senior research engineer in the research and development department at Kansai Electric Power Company, Inc., and has been engaged in the fields of HCPWR and FBR research.

*Etsuro Saji
Yoshiei Akiyama
Norio Kono
Kiyoshi Nambu
Keiichi Hori
Toshihiro Umeoka
Tsuyoshi Kono*



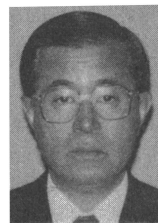
CURRENT STATUS OF HIGH CONVERSION PRESSURIZED WATER REACTOR DESIGN STUDIES

Toshihiro Umeoka (top right) (BS, electrical engineering, Fukui University, Japan, 1967) is a special assignment manager in the nuclear projects department at Kansai Electric Power Company, Inc., and has been engaged in the fields of high conversion pressurized water reactors (HCPWRs) and fast breeder reactors (FBRs). **Tsuyoshi Kono** (top left) (BS and MS, chemical engineering, Osaka Prefectural University, Japan, 1975) is a senior research engineer in the research and development department at Kansai Electric Power Company, Inc., and has been engaged in the fields of HCPWRs and FBRs. **Yukio Toyoda** (bottom right) (BS, physics, Kyoto University, Japan, 1957) is deputy general manager of the nuclear systems engineering department at Mitsubishi Heavy Industries, Ltd., and has been engaged in the development of pressurized water reactors (PWRs). **Masao Ogino** (bottom left) (BS, physics, Tohoku University, Japan, 1961) is a senior engineer at Mitsubishi Atomic Power Industries, Inc.

*Toshihiro Umeoka
Tsuyoshi Kono
Yukio Toyoda
Masao Ogino
Shozo Iwai
Hisashi Hishida*



(MAPI), and has been engaged in PWR safeguards system analysis. **Shozo Iwai** (right) (BS, mechanical engineering, Nagoya University, Japan, 1959) is manager of the nuclear development coordination department at MAPI and has been engaged in the development of PWRs. **Hisashi Hishida** (left) (BA, University of California, Los Angeles; MS and Dr. Eng., nuclear engineering, Osaka University, Japan, 1963) is an assistant manager in the nuclear development coordination department at MAPI and is a visiting lecturer in the Postgraduate Division of Osaka University. He has been engaged in feasibility studies of HCPWRs.



LIGHT WATER REACTOR (LWR) INNOVATION NEEDS IN THE UNITED STATES: THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY LWR INNOVATION PROJECT

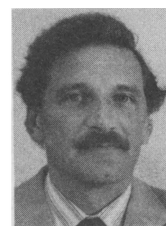
Michael W. Golay

Michael W. Golay (photo not available) (BE, mechanical engineering, University of Florida, 1964; PhD, nuclear engineering, Cornell University, 1969) is the director of the Massachusetts Institute of Technology (MIT) Light Water Reactor Innovation Project and is a professor of nuclear engineering at MIT. His interests focus on the strategies and methods for perfecting nuclear power technology.

RESEARCH AND DEVELOPMENT EFFORTS FOR THE LIGHT WATER HIGH CONVERSION REACTOR

*Rudolf H. Brogli
Claus A. Goetzmann
Bernhard J. Kuczera*

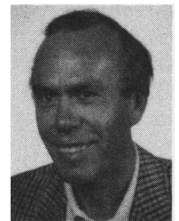
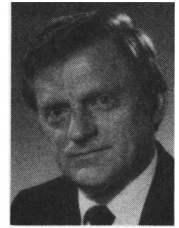
Rudolf H. Brogli (top) (Diploma, physics, Swiss Federal Institute of Technology; PhD, nuclear engineering, University of Berne, Switzerland, 1963) is a department manager at the Swiss Institute for Reactor Research (EIR). He has worked on heavy water reactor designs at EIR and high-temperature gas-cooled reactor fuels at GA Technologies, Inc. Presently, he is responsible for the development efforts at EIR for the advanced light water reactor, high-temperature reactor, and the small district heating reactor. **Claus A. Goetzmann** (center) [Dipl.-Ing., electrical engineering, Technische Hochschule Aachen, Federal Republic of Germany (FRG), 1960] participated in safety analyses for D₂O and CO₂ reactors at Siemens Reactor Division from 1960 to 1964. He then joined General Atomic Company to do research and development work for gas-cooled thermal and fast reactors. In 1969, he returned to the FRG to manage Siemens/Kraftwerk Union AG's gas-cooled fast reactor program until its termination in 1979. He is currently subdivision manager of advanced reactor concepts, responsible for the development of large, tight-lattice, high conversion pressurized water reactors and dedicated small reactors for supplying district heat. His special professional interest concerns the relationship between size and costs of various reactor types. **Bernhard J. Kuczera** (bottom) (PhD, reactor engineering, University of Karlsruhe, FRG, 1974) is a scientific member of the Kernforschungszentrum Karlsruhe. He was assistant to a member of the executive board responsible for the Reactor Development and Reactor Safety Division. During this period, he also coordinated the research and development work for high conversion light water reactor (LWR) systems. Since January 1986 he has been the head of the Nuclear Safety Project, recently reorganized into the LWR Safety Project Group.



KWU's HIGH CONVERSION REACTOR CONCEPT — AN ECONOMICAL EVOLUTION OF MODERN PRESSURIZED WATER REACTOR TECHNOLOGY TOWARD IMPROVED URANIUM ORE UTILIZATION

Hans Märkl (top) [Dipl.-Math., physics and mathematics, and PhD, physics, Munich University, Federal Republic of Germany (FRG), 1957] is vice president and main division executive of systems engineering, instrumentation, and control at Kraftwerk Union AG (KWU). He has worked with Siemens/KWU in the field of nuclear energy since 1958. His present responsibility comprises nuclear and thermohydraulic core design, safety analysis, radiation protection, systems engineering, instrumentation, and control. **Claus A. Goetzmann** (center) (Dipl.-Ing., electrical engineering, Technische Hochschule Aachen, FRG, 1960) participated in safety analyses for D₂O and CO₂ reactors at Siemens Reactor Division from 1960 to 1964. He then joined General Atomic Company to do research and development work for gas-cooled thermal and fast reactors. In 1969, he returned to the FRG to manage Siemens/KWU's gas-cooled fast reactor program until its termination in 1979. He is currently subdivision manager of advanced reactor concepts, responsible for the development of large, tight-lattice, high conversion pressurized water reactors (PWRs) and dedicated small reactors for supplying district heat. His special professional interest concerns the relationship between size and costs of various reactor types. **Helmut Moldaschl** (bottom) (PhD, physics, University of Vienna, Austria, 1968) is project manager for high-converter development at KWU. He joined the company in 1969 and dealt with program development for light and heavy water reactors, as well as with core design and analysis of the inherent safety of PWRs. His responsibilities also included KWU's Convoy core design and long-term reload strategies.

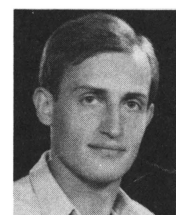
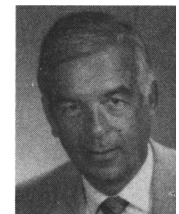
*Hans Märkl
Claus A. Goetzmann
Helmut Moldaschl*



THE FRENCH THERMAL-HYDRAULIC PROGRAM ADDRESSING THE REQUIREMENTS OF FUTURE PRESSURIZED WATER REACTORS

Michel Courtaud (top) (engineering degrees from Ecole Nationale Supérieure d'Electrotechnique de Grenoble, 1959, and Institut National des Sciences et Techniques Nucléaires, France, 1960) joined the Nuclear Research Center, Grenoble, France, in 1961. There he has been involved in heat transfer for organic liquid-cooled reactors and in two-phase flow research for research reactors and light water reactors. He is presently head of the Service d'Etudes Thermohydrauliques of the light water department of the Nuclear Research Center, Grenoble. He is in charge of research and development programs on thermal hydraulics for normal and accidental pressurized water reactor (PWR) conditions (experiments and computer code development and qualification). **Roger Deruaz** (center) (physical sciences degree, University of Grenoble, France, 1967) works at the Nuclear Research Center, Grenoble, where he has been involved in two-phase flow and chemical engineering problems concerning liquid-liquid and liquid-gas contactors. Since 1973, he has worked in the field of reflooding for PWR safety and is presently head of the Laboratoire d'Etudes Systèmes of the Services d'Etudes Thermohydrauliques at the Nuclear Research Center, Grenoble. He is in charge of operating the system loop BETHSY for study of small-break loss-of-coolant accidents and special transients for PWRs. **Luc Gros D'Aillon** (bottom) (engineering degree, Ecole Nationale Supérieure d'Hydraulique de Grenoble, France, 1973) worked in the Marviken critical flow international project as a representative

*Michel Courtaud
Roger Deruaz
Luc Gros D'Aillon*

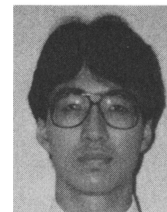


from France and joined the Nuclear Research Center, Grenoble, where he worked on critical steam water flows. He is presently head of the Laboratoire d'Etudes Thermo-hydrauliques des Assemblages Combustibles of the Service d'Etudes Thermo-hydrauliques at the Nuclear Research Center, Grenoble. He is in charge of the thermal-hydraulic qualification of PWR fuel, covering the problems of mixing, pressure drops, and critical heat fluxes.

NUMERICAL SIMULATION OF REFLOODING BEHAVIOR IN TIGHT-LATTICE ROD BUNDLES

Yoshio Murao (top) (BE, ME, and PhD, nuclear engineering, Tokyo Institute of Technology, Japan, 1983) is chief of the Reactor Safety Laboratory II at the Japan Atomic Energy Research Institute (JAERI). Since 1966, he has worked on design and research and development of the fast breeder reactor and thermal-hydraulic research for light water reactor safety at JAERI. He is interested in the modeling of two-phase flow behaviors. **Tsuneyuki Hojo** (BE and ME, nuclear engineering, Tohoku University, Japan, 1987) is an engineer in the Nuclear Engineering Division of Mitsubishi Atomic Power Industries, Inc. He is currently involved in the safety analysis of pressurized water reactors.

*Yoshio Murao
Tsuneyuki Hojo*



NEPTUN-III REFLOODING AND BOILOFF EXPERIMENTS WITH AN LWHCR FUEL BUNDLE SIMULATOR: EXPERIMENTAL RESULTS AND INITIAL CODE ASSESSMENT EFFORTS

Jörg Dreier (top) (Dipl. Phys., Swiss Federal Institute of Technology, Zürich, Switzerland, 1975) joined the Swiss Federal Institute for Reactor Research (EIR) in 1982. He has been working on thermal-hydraulic problems related to reactor safety. Since 1986, he has been responsible for the experimental facility NEPTUN, and his interests focus on reflooding phenomena, especially for light water high conversion reactors (LWHCRs). **Gerassimos Analytis** (center) (BSc-RCS, physics, 1973; MSc, mathematics, 1974; PhD, nuclear engineering, University of London, United Kingdom, 1979) has been employed in the safety department at EIR since 1981. He is engaged in two-phase flow research with particular interest in the modeling of interfacial relations and wall heat transfer in thermal-hydraulic codes during reflooding. **Rakesh Chawla** (bottom) (PhD, Imperial College, University of London, United Kingdom, 1970) is manager of the LWHCR project at EIR. His current research interests mainly concern the generation and application of an experimental data base for evaluating LWHCR physics and thermal-hydraulic design.

*Jörg Dreier
Gerassimos Analytis
Rakesh Chawla*



THERMOHYDRAULIC OPTIMIZATION OF HOMOGENEOUS AND HETEROGENEOUS ADVANCED PRESSURIZED WATER REACTORS

Marco Cigarini (top) [MS, nuclear engineering, Bologna University, Italy, 1982; PhD, Karlsruhe University, Federal Republic of Germany (FRG), 1987] has worked at Kernforschungszentrum Karlsruhe (KfK) since 1983. He is currently engaged in development and verification of thermohydraulic computer programs applied for safety analysis of light water reactors. **Mario Dalle Donne** (PhD, engineering science, Bologna University, Italy, 1956) worked from 1956 to 1959 at Agip Nucleare, Italy, and

*Marco Cigarini
Mario Dalle Donne*



from 1959 to 1963 at the Dragon Project, United Kingdom. Since 1963 he has worked at the KfK Institut für Neutronenphysik und Reaktortechnik, FRG. Since 1976 he has been a professor at Karlsruhe University. He has worked in the field of gas-cooled, water-cooled, and liquid-metal-cooled fission reactors and of blankets for fusion reactors. His main technical interests are thermohydraulics, safety, and reactor assessment.

LOSS-OF-COOLANT-ACCIDENT AND ANTICIPATED TRANSIENT WITHOUT SCRAM CALCULATIONS FOR HOMOGENEOUS AND HETEROGENEOUS ADVANCED PRESSURIZED WATER REACTORS

Mario Dalle Donne (top) (PhD, engineering science, Bologna University, Italy, 1956) worked from 1956 to 1959 at Agip Nucleare, Italy, and from 1959 to 1963 at the Dragon Project, United Kingdom. Since 1963, he has worked at the Kernforschungszentrum Karlsruhe (KfK) Institut für Neutronenphysik und Reaktortechnik (INR), Federal Republic of Germany. Since 1976, he has been professor at Karlsruhe University. He has worked in the fields of gas-cooled, water-cooled, and liquid-metal-cooled fission reactors and blankets for fusion reactors. His main technical interests are thermohydraulics, safety, and reactor assessment. **Claudio Ferrero** (bottom) (MS, nuclear engineering, Technical University of Turin, Italy, 1982) joined the INR at KfK in 1982. In 1983, he was awarded a grant from the European community, to perform PhD work on the safety analysis of advanced pressurized water reactor (APWR) designs within the framework of the German-Swiss joint APWR development project.

*Mario Dalle Donne
Claudio Ferrero*



EXPERIMENTAL INVESTIGATIONS ON THE REFLOODING AND DEFORMATION BEHAVIOR OF AN ADVANCED PRESSURIZED WATER REACTOR TIGHT-LATTICE FUEL ROD BUNDLE IN A LOSS-OF-COOLANT ACCIDENT

Franz J. Erbacher (top) [Dipl.-Ing., mechanical engineering, Technical University of Karlsruhe, Federal Republic of Germany (FRG), 1958] joined the Karlsruhe Nuclear Research Center (KfK) in 1959. As a department leader, he has worked since 1972 in light water reactor (LWR) safety research especially in thermal hydraulics and fuel behavior in loss-of-coolant accidents. He is currently working on the development of a high conversion advanced pressurized water reactor (APWR). **Klaus Wiehr** (bottom) (Dipl.-Ing., chemical engineering, Technical University of Karlsruhe, FRG, 1961) was employed in the petroleum industry in France for 1 year before joining KfK in 1962. Since 1973, he has worked as a project leader in LWR safety research especially in the field of thermodynamics and hydraulics related to fuel behavior in loss-of-coolant accidents for pressurized water reactors and currently for APWRs.

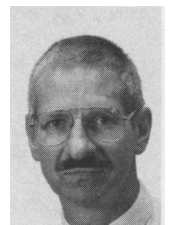
*Franz J. Erbacher
Klaus Wiehr*



HIGH-TEMPERATURE BEHAVIOR OF CrNi-STEEL DIN MATERIAL NO. 1.4970 CLADDING MATERIAL WITH RESPECT TO ADVANCED PRESSURIZED WATER REACTOR SAFETY CONSIDERATIONS

Claus Petersen (right) [Dipl.-Ing., material science, Technische Universität, Clausthal, Federal Republic of Germany (FRG), 1972] is a scientific member and group leader in the Department

*Claus Petersen
Gerhard Schanz
Siegfried Leistikow*



of Mechanical Properties at the Institut für Material- und Festkörperforschung II (IMF-II) of Kernforschungszentrum Karlsruhe (KfK). Since 1973 he has been engaged in research on the mechanical behavior of Zircaloy-4 at high temperatures. His current research interests include high-temperature, inelastic behavior of cladding and structural materials for advanced reactors, as well as of first-wall materials for the Next European Torus fusion reactor. **Gerhard Schanz** (top) (Dipl.-Phys., physics, University of Stuttgart and Max-Planck Institut für Metallforschung, Stuttgart, FRG, 1969) has been engaged in the investigation or the development of metallic materials, with respect to the interrelationship between microstructure and mechanical properties or corrosion behavior since 1970. He has been a scientific member of the Department of Corrosion at the IMF-II, KfK, since 1975. **Siegfried Leistikow** (bottom) (Prof. Dr. rer. nat., physical chemistry, University of Karlsruhe, FRG; Swiss Federal Institute of Technology, Zürich, Switzerland, and University of Paris, France, 1962) is a scientific member and head of the corrosion department at the IMF-II, KfK, and honorary professor at the Technical University of Munich for nuclear materials. Since 1962 he has been engaged in research on high-temperature corrosion of nuclear fuel cladding materials like Zircaloy, CrNi-stainless steels, and nickel-base alloys as well as material research for reprocessing and final storage of nuclear waste.

