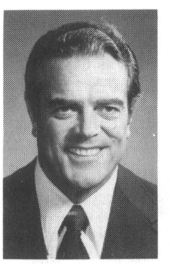
nuclear technology®

AUTHORS — MARCH 1976

REACTORS

PREFACE: NUCLEAR STEAM GENERATORS

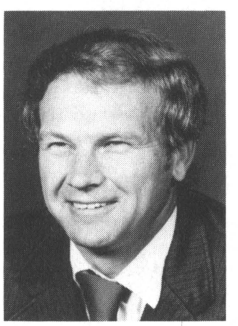
P. Patriarca
W. R. Martin



P. Patriarca (top) (MS, metallurgical engineering, Rensselaer Polytechnic Institute, 1950) joined the Oak Ridge National Laboratory (ORNL) staff in 1950 and organized the welding and brazing laboratory in the Metals and Ceramics Division. He is presently manager of the LMFBR Fuels and Materials Programs at ORNL. William R. Martin (BS, University of Cincinnati, 1957) is manager of the Engineering Materials Section within the matrix organization of the Metals and Ceramics Division of ORNL, responsible for work on programs ranging from fossil and geothermal to fusion and fission.

MATERIALS DEVELOPMENT FOR ADVANCED REACTORS

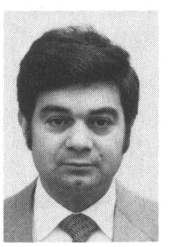
G. W. Cunningham



George W. Cunningham (PhD, metallurgical engineering, Ohio State University, 1960) is Acting Deputy Director for Development and Technology, Division of Reactor Research and Development, U.S. Energy Research and Development Administration.

DESIGN OF THE CLINCH RIVER BREEDER REACTOR PLANT STEAM GENERATORS

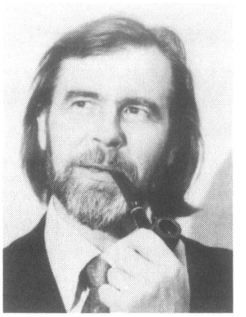
J. C. Whipple
C. N. Spalaris



J. C. Whipple (top) (BS, University of California, 1951) is manager of test projects with the General Electric Company, working on LMFBR systems and components. Previously, he was responsible for Clinch River Breeder Reactor Plant steam generator design, development, and manufacturing. C. N. Spalaris (BS, University of Pittsburgh, 1949; MS, University of Oregon, 1950; PhD, Oregon State University, 1956) is manager of plant materials engineering with General Electric Company's Fast Breeder Reactor Department. He has done work in commercial power reactors, boiling water reactor programs, and since 1966 has been associated with the breeder programs.

HIGH-TEMPERATURE GAS-COOLED REACTOR STEAM GENERATOR DESIGN

W. G. Schuetzenduebel



W. G. Schuetzenduebel (MS, mechanical engineering; MS, power engineering, Technical University Berlin, Germany) is presently manager, Technical Services, Steam Generator Program, General Atomic Company.

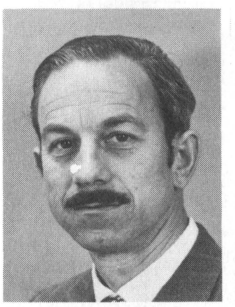
MATERIALS IN CANDU STEAM GENERATORS FROM THE DESIGNER'S POINT OF VIEW

S. Vandeth
R. L. Hemmings

S. H. Vandeth (top) (ME, mechanical engineering, University of Toronto, 1972) is currently section head of the Nuclear Heat Transfer Equipment Engineering Section of Atomic Energy of Canada Limited (AECL), which deals with the procurement of nuclear steam generators and heat exchangers. He has formerly worked on the design of various moderator and heat transport systems associated with the CANDI PHW NSSS. R. L. Hemmings (PhD, chemical engineering, Imperial College of Science and Technology, University of London, England, 1965) has worked in chemistry and materials research and development and is currently superintendent of the Process Engineering Branch, AECL/Power Projects, Montreal, Quebec.

DESIGN AND MANUFACTURING EXPERIENCE FOR THE GERMAN THORIUM HIGH-TEMPERATURE REACTOR 300-MW(e) STEAM GENERATOR

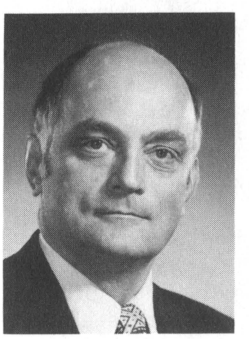
Hans W. Fricker



Hans W. Fricker (mechanical engineer, Burgdorf, Switzerland, 1956) did research on gas turbine components at Escher Wyss, Zurich, from 1956 to 1959, and on friction in high-temperature reactor atmospheres at the O.E.C.D. Dragon Project, Winfrith, England, from 1959 to 1964. He is presently in charge of design of steam generators for nuclear plants in Sulzer, Winterthur.

MATERIALS PERFORMANCE IN OPERATING PRESSURIZED WATER REACTOR STEAM GENERATORS

John R. Weeks



John R. Weeks (MetE, metallurgical engineering, Colorado School of Mines, 1949; PhD, metallurgy, University of Utah, 1953) joined the Brookhaven National Laboratory staff in 1953 as an associate metallurgist, except for 2 years (1972-1974) as a corrosion specialist with the former U.S. Atomic Energy Commission's Directorate of Licensing. Currently head of the Materials Safety Group, his research prior to 1972 was primarily in liquid-metal corrosion. Presently he is technical advisor to the U.S. Nuclear Regulatory Commission in the area of corrosion and coolant chemistry in light-water and liquid-metal-cooled reactors.

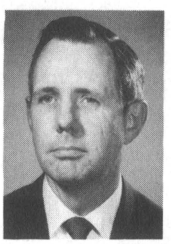
OPERATING EXPERIENCE WITH WESTINGHOUSE STEAM GENERATORS

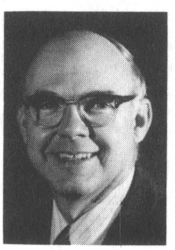
W. D. Fletcher
D. D. Malinowski

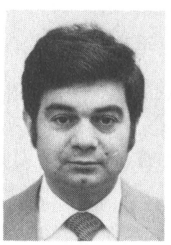
Wilson D. Fletcher (left) (BS, chemistry, Hardin-Simmons University, 1950; MS, chemistry, Fordham University, 1960) is a consultant, Systems Technology, Westinghouse Nuclear Energy Systems, and has been engaged in development and plant operational programs pertaining to nuclear, chemical, and radiation systems since 1957. He is currently engaged in the management of development programs pertaining to all aspects of steam generator technology, and has been involved in the particulars of steam generator operating experiences since 1971. His interests are in chemistry, corrosion, and radiochemical aspects of nuclear systems. D. D. Malinowski (BS, Duquesne University, 1959; MS, Massachusetts Institute of Technology, 1963; JD, Duquesne University, 1976) is employed as a senior engineer in the Pressurized Water Reactor Systems Division of Westinghouse Nuclear Energy Systems. He has been involved with nuclear reactor technology since 1963, commencing with radiochemical studies at the Bettis Atomic Power Laboratory; radiochemical service work at Tracerlab; and, since 1968, with general chemistry and radiochemistry aspects of pressurized water reactors. His present area of activity concentrates on steam generator related programs, including in-plant studies and laboratory investigations.

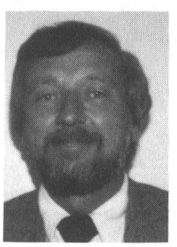
FABRICATION AND INSPECTION DEVELOPMENT FOR CLINCH RIVER BREEDER REACTOR PLANT STEAM GENERATORS

R. W. McClung
G. M. Slaughter
C. N. Spalaris
A. F. Lillie





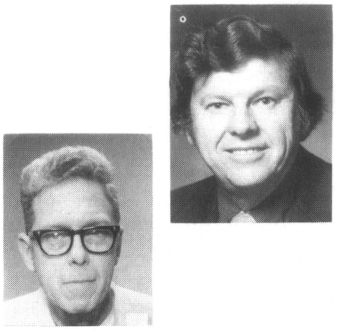




Robert W. McClung (top left) (BS, chemical engineering, University of Tennessee, 1950) is employed by Oak Ridge National Laboratory (ORNL) as supervisor of the Nondestructive Test Development Group of the Metals and Ceramics Division. McClung has worked extensively in all phases of nondestructive testing. Gerald M. Slaughter (top right) (MS, metallurgical engineering, Rensselaer Polytechnic Institute, 1951), supervisor, Welding and Brazing Laboratory of the Metals and Ceramics Division, ORNL, is studying the welding behavior of a wide range of structural alloys and is developing procedures for joining these materials. He has worked extensively in the development and testing of improved welding and brazing filler metals. C. N. Spalaris (bottom left) (BS, University of Pittsburgh, 1949; MS, University of Oregon, 1950; PhD, Oregon State University, 1956) is manager of plant materials engineering with General Electric Company's Fast Breeder Reactor Department. He has done work in commercial power reactors, boiling water reactor programs, and since 1966 has been associated with the breeder programs. A. F. Lillie (bottom right) (MS, engineering, University of California, Los Angeles, 1966), project manager of the Clinch River Breeder Reactor Plant prototype design and supporting development activities, now completed, has engaged in design and development in support of the Space Nuclear Auxiliary Power Program, and the sodium-cooled reactor programs. He was involved with systems designs optimizations of fast flux test facility core design, fuel handling, heat transfer system design, and reactor containment studies.

N REACTOR STEAM GENERATOR PERFORMANCE

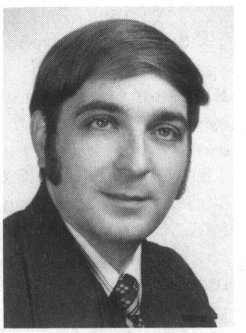
P. A. Carlson
W. K. Kratzer



P. A. Carlson (top) (BS, Iowa State University, 1949) is the manager of Reactor Technology with United Nuclear Industries, Inc. This assignment includes responsibility for research and development and technological support for operation of the Hanford N Reactor. W. K. Kratzer (BS, physical metallurgy, Washington State University) is currently employed as a senior engineer by United Nuclear Industries, Inc., with responsibility for corrosion control, water quality control, and decontamination development programs.

CAUSTIC STRESS CORROSION CRACKING OF INCONEL-600, INCOLOY-800, AND TYPE 304 STAINLESS STEEL

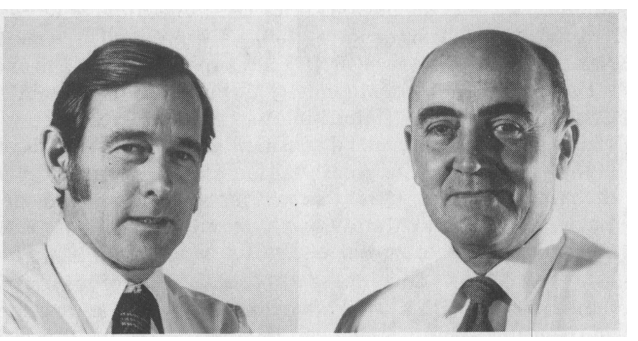
G. J. Theus



George J. Theus (BS, metallurgy, Case Institute of Technology, 1966; PhD, metallurgical engineering, Ohio State University) is supervisor of the Babcock and Wilcox Corrosion Group at the Alliance Research Center in Alliance, Ohio. His current responsibilities are to direct the corrosion research using electrochemical and conventional corrosion techniques for nuclear and non-nuclear divisions. His current research interests include the effect of metallurgical variables and the effect of solution contaminants on the corrosion behavior of metals. His past work has included electrochemical corrosion studies in fused caustic soda.

CLINCH RIVER BREEDER REACTOR ENVIRONMENTAL EFFECTS—GENERAL WATER-SIDE CORROSION

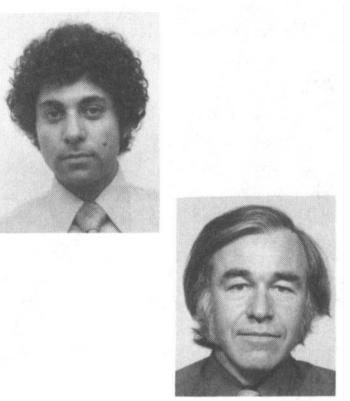
J. H. DeVan
J. C. Griess



J. H. DeVan (left) (MS, metallurgy, University of Tennessee, 1960) is a group leader and J. C. Griess (MA, chemistry, University of Indiana, 1947) is a chemist in the Metals and Ceramics Division of Oak Ridge National Laboratory. Both have been involved in materials compatibility studies for many years.

EFFECTS OF SERVICE ENVIRONMENTS ON THE BEHAVIOR OF HIGH-TEMPERATURE GAS-COOLED REACTOR STEAM GENERATOR STRUCTURAL MATERIALS

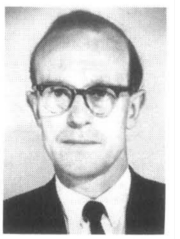
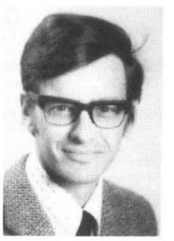
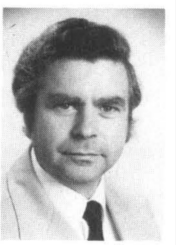
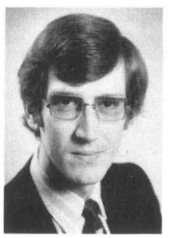
F. N. Mazandarany
P. L. Rittenhouse



Farhad N. Mazandarany (top) (PhD, University of Michigan, 1972) has been with General Atomic Company since 1972. His work involves theoretical and experimental thermodynamics and kinetics of gas-metal reactions at high temperatures. P. L. Rittenhouse (BS, chemical engineering, University of Tennessee, 1956; MS, metallurgical engineering, University of Tennessee, 1961) is technical manager of studies on high-temperature gas reactor structural materials—including creep, cyclic behavior, thermal stability, and steam and helium corrosion—at Oak Ridge National Laboratory.

THE BEHAVIOR OF METALS IN HIGH-TEMPERATURE REACTOR HELIUM FOR STEAM GENERATORS

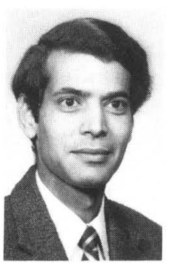
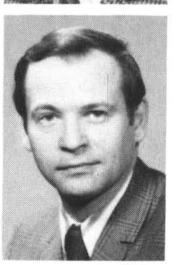
H. G. A. Bates
W. Betteridge
R. H. Cook
L. W. Graham
D. F. Lupton

H. G. A. Bates (top left) (BS, MIM, metallurgy, University of Wales, Cardiff, 1954) is a research metallurgist working on the development of improved materials and welding procedures for use in turbo machinery. His special studies include the optimization of microstructure and composition and creep properties of low alloy and austenitic steels followed by in-corrosion and wear problems. He joined Dragon Project and is currently involved in the development of high-temperature reactor primary circuit materials. Walter Betteridge (top right) (DSc, F Inst P, FIM) is now a scientific consultant after 12 years in the aircraft industry working on materials for aero engines, including gas turbines. Roger H. Cook (center left) (PhD, metallurgy, MIM, University of Sheffield, England, 1964) spent two years on a postdoctoral fellowship at the University of Pennsylvania, Philadelphia. He has worked on mechanical properties of materials at high temperature. Currently his interest is in effects of environment on creep behavior, now on the Dragon Project metals program. Leslie W. Graham (bottom right) (PhD, metallurgy, University of Manchester, 1956) is currently employed by General Atomic International but still works on the Dragon Project, heading the Materials Team, backing the exploitation and development of the high-temperature gas-cooled reactor. David F. Lupton (bottom left) (PhD, metallurgy, University of Sheffield, 1969) has worked on the new alloys development, particularly strengthened low-expansion alloys for service at elevated temperatures. Since 1974, he has worked on the Dragon Project.

COMPATIBILITY OF Fe–$2\frac{1}{4}$ wt% Cr–1 wt% Mo STEEL IN A SODIUM ENVIRONMENT

K. Natesan
O. K. Chopra
T. F. Kassner

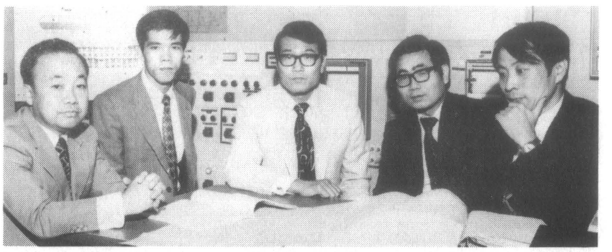
K. Natesan (top) (PhD, metallurgy and materials science, Carnegie-Mellon University, 1969), O. K. Chopra (center) (PhD, materials science, University of Waterloo, 1972), and T. F. Kassner (bottom) (PhD, metallurgical engineering, Purdue University, 1962) are in the Materials Science Division at Argonne National Laboratory. The authors are presently involved in various aspects of the corrosion and mechanical behavior of LMFBR materials in a sodium environment.

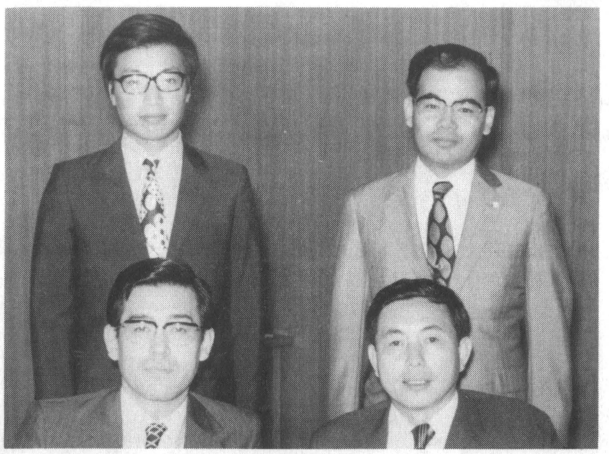
CARBON TRANSFER BEHAVIOR OF MATERIALS FOR LIQUID-METAL FAST BREEDER REACTOR STEAM GENERATORS

Keishi Matsumoto
Yoshio Ohta
Tadayuki Kataoka
Shigeji Yagi
Katsumi Suzuki
Teruo Yukitoshi
Taishi Moroishi
Kunihiko Yoshikawa
Yoshiaki Shida

K. Matsumoto (top left) (Dr. Sci., physics, Gakushuin University) is a senior manager of the Nuclear Power Technology Department, Research Institute, Ishikawajima-Harima Heavy Industries Co., Ltd. His main interests include corrosion and radiation damage of nuclear materials. Y. Ohta (top second from left) (Ms. Eng., metal

engineering, Tokai University), K. Suzuki (top center) (B. Eng., chemistry, Science University of Tokyo), S. Yagi (top second from right) (B. Eng., applied physics, Toyama University), and T. Kataoka (top right) (B. Eng., applied physics, Fukui University) are research members of the Research Institute, Ishikawajima-Harima Heavy Industries Co., Ltd., working in the Materials Research Group of the Nuclear Power Technology Department. T. Yukitoshi (bottom right, seated) (Dr. Eng., Kyoto University, 1968) is a senior research engineer and leader of Nuclear Materials Development Program at Sumitomo Metal Industries. His major technical interest is in the area of steels and alloys for high-temperature use. T. Moroishi (bottom left, seated) (Dr. Eng., Osaka University, 1973) is a senior research engineer and leader of the High Temperature Corrosion Research Group at Sumitomo Metal Industries. His interests include every kind of high-temperature corrosion of steels and alloys in special environments. K. Yoshikawa (bottom right, standing) (B. Eng., Osaka University, 1963) is a research engineer at Sumitomo Metal Industries. His major interest is in the area of steels and alloys for high-temperature use. Y. Shida (bottom left, standing) (Ms. Eng., Tokyo University, 1971) is a staff member at Sumitomo Metal Industries. He is engaged in the study of high-temperature corrosion of nuclear materials.





THE EFFECTS OF TEN YEARS EXPERIMENTAL BREEDER REACTOR II SERVICE ON $2\frac{1}{4}$ Cr–1 Mo STEEL

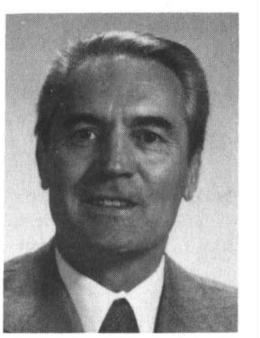
J. A. Shields, Jr.
K. J. Longua

J. A. Shields (top) (BS, 1968; MS, 1971; PhD, 1974, Case Institute of Technology, Case Western Reserve University) is currently associated with Argonne National Laboratory's EBR-II Project, in the Fuels and Materials Department. His current areas of responsibility, in addition to materials properties in the ex-core systems, include the establishment of irradiation exposure limits for in-core components and the introduction of new structural materials into the EBR-II core. Kerry J. Longua (MS, metallurgical engineering, University of Idaho, 1965) is a member of the Fuels and Materials Group at Argonne National Laboratory in Idaho Falls, Idaho. He is presently involved in the material used in the EBR-II plant.

FRENCH STEAM GENERATOR EXPERIENCE—PHENIX AND BEYOND

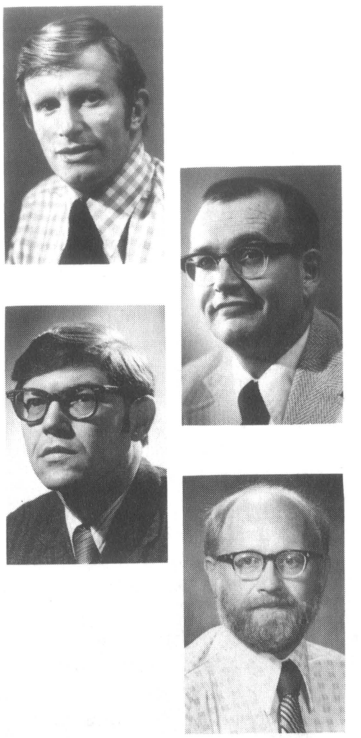
M. G. Robin

M. G. Robin (Licence es Sciences, University of Besancon, 1947; Diploma d'Etudes Superieures de Physique, University of Paris, 1949), head of the Steam Generator Development Section, has been with the Commissariat à l'Energie Atomique (CEA) since 1953. He has been involved in sodium research since its beginning in France. He participated actively in the preliminary design of the heat transfer loops of Rapsodie and Phenix. In 1960 he was assigned to Atomic Power Development Associates, Inc. for a year and worked on the Fermi Project. He is now in change of the development of a sodium-heated steam generator for CEA and is responsible for preliminary studies of the secondary sodium system of Super Phenix and beyond.



MECHANICAL AND PHYSICAL PROPERTIES OF $2\frac{1}{4}$ Cr–1 Mo STEEL IN SUPPORT OF CLINCH RIVER BREEDER REACTOR PLANT STEAM GENERATOR DESIGN

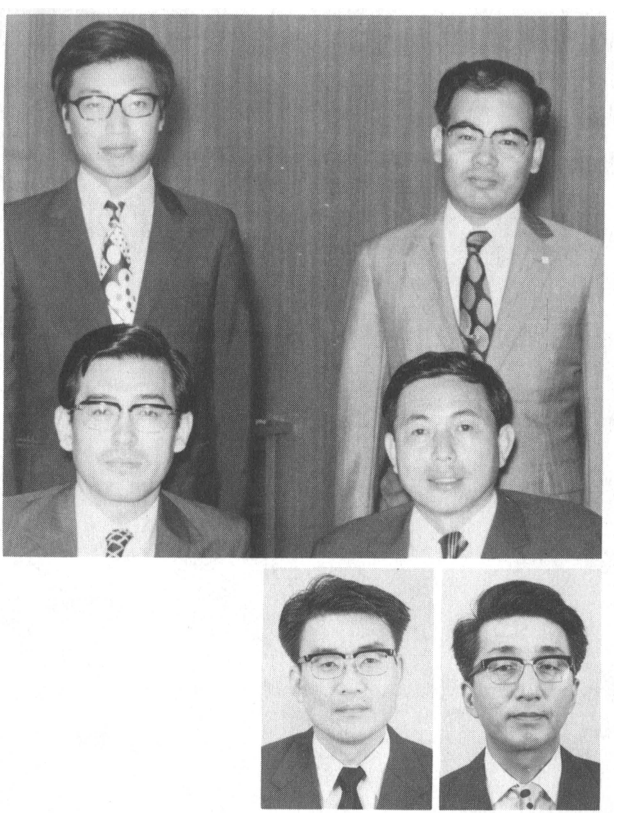
C. R. Brinkman
R. K. Williams
R. L. Klueh
T. L. Hebble



C. R. Brinkman (top left) (PhD, metallurgy, University of Utah, 1966) is group leader of the Mechanical Properties Group, Metals and Ceramics Division, Oak Ridge National Laboratory (ORNL). His previous experience and interests include recovery and recrystallization, hydrogen embrittlement, fracture mechanics, radiation effects, creep and elevated temperature fatigue behavior. R. K. Williams (top right) (PhD, metallurgical engineering, Carnegie-Mellon University, 1965) has been involved in measurements and analysis of thermal conductivity data since 1965. R. L. Klueh (bottom left) (BS, metallurgical engineering, Purdue University, 1961; PhD, metallurgy and materials science, Carnegie-Mellon University, 1966) is a research metallurgist in the Metals and Ceramics Division at ORNL. He is involved in mechanical property studies on LMFBR steam generator materials. Thomas L. Hebble (bottom right) (MS, statistics, Florida State University, 1964) has been a consultant in the Mathematics and Statistics Research Department of Union Carbide's Nuclear Division since 1964. His consulting activities include the application of statistical methodology to experimental programs in the physical sciences.

COMPARISON OF VARIOUS CHROMIUM-MOLYBDENUM LOW-ALLOY STEELS FOR LIQUID-METAL FAST BREEDER REACTOR STEAM GENERATORS

Teruo Yukitoshi
Taishi Moroishi
Isamu Koizumi
Takashi Abe
Kunihiko Yoshikawa
Yoshiaki Shida



T. Yukitoshi (top right, seated) (Dr. Eng., Kyoto University, 1968) is a senior research engineer and leader of the Nuclear Materials Development Program at Sumitomo Metal Industries. His major technical interest is in the area of steels and alloys for high-temperature use. T. Moroishi (top left, seated) (Dr. Eng., Osaka University, 1973) is a senior research engineer and leader of the High Temperature Corrosion Research Group at Sumitomo Metal Industries. His interests include every kind of high-temperature corrosion of steels and alloys in special environments. I. Koizumi (bottom left) (Dr. Eng., Osaka University, 1973) is a senior research engineer and leader of the Welding Section at Sumitomo Metal Industries. He is responsible for the welding of ordinary steel and special alloy pipes. T. Abe (bottom right) (Sumitomo Technical High School, 1951) is an assistant manager of the Engineering Services Section at Sumitomo Metal Industries. He was previously responsible for a study on the weldability of alloy steels. K. Yoshikawa (top right, standing) (B. Eng., Osaka University, 1963) is a research engineer at Sumitomo Metal Industries. His major interest is in the area of steels and alloys for high-temperature use. Y. Shida (top left, standing) (Ms. Eng., Tokyo University, 1971) is a staff member at Sumitomo Metal Industries. He is engaged in a study of the high-temperature corrosion of nuclear materials.

U.S. ADVANCED MATERIALS DEVELOPMENT PROGRAM FOR STEAM GENERATORS

P. Patriarca
S. D. Harkness
J. M. Duke
L. R. Cooper

P. Patriarca (top left) (MS, metallurgical engineering, Rensselaer Polytechnic Institute, 1950) joined the Oak Ridge National Laboratory (ORNL) staff in 1950 and organized the welding and brazing laboratory in the Metals and Ceramics Division. He is presently manager of the LMFBR Fuels and Materials Programs at ORNL. Samuel D. Harkness (top right) (PhD, metallurgical engineering, University of Florida, 1967) is manager of the Materials Technology Section of Combusion Engineering, Inc., and is responsible for the performance of the UO_2 Fuel Fabrication Development Group, the Cladding Development Group, and the Fast Breeder Reactor Materials Group. J. M. Duke (bottom left) (BS, engineering sciences, Illinois Institute of Technology, 1964; MS, engineering mechanics, Case Institute of Technology, 1968) is manager, Analytic Methods Development at Westinghouse Electric Corporation, Tampa Division. His responsibilities include metallurgical engineering and structural analysis of LMFBR steam generators as well as development of computer programs for design and analysis of pressurized water reactor steam generators. Lloyd R. Cooper (bottom right), deceased, was a graduate of Lehigh University. Prior to his retirement in 1972, he was vice president and technical director of Heppenstall Company and served the company for 30 years.