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HEAVY-ION FUSION

U.S. ACCELERATOR RESEARCH PROGRAM FOR HEAVY-ION FUSION

Walter M. Polansky

Walter M. Polansky (BS, physics, Rensselaer Polytechnic Institute, 1970; MS, 1972, and PhD, 1975, physics, University of Cincinnati) is the program manager for heavy-ion fusion accelerator research at the U.S. Department of Energy.

U.S. HEAVY-ION FUSION SYSTEMS ASSESSMENT PROJECT OVERVIEW

Donald J. Dudziak
William W. Saylor
William B. Herrmannsfeldt

Donald J. Dudziak (top) (BS, marine engineering; MS, radiological physics; PhD, mathematics) is presently High Technology Systems Studies Section leader at Los Alamos National Laboratory (LANL), where his responsibilities include inertial confinement fusion (ICF), antiproton propulsion/power, space-debris clearing and laser isotope separation systems studies; magnetic confinement fusion nucleonics; and analyses for a nuclear directed-energy system. Also, he served as project leader for the multi-institutional Heavy-Ion Fusion Systems Assessment (HIFSA) covered in this special issue. Recently, he assumed collateral duties as deputy leader of the energy system analysis group, with line responsibility for cryogenic engineering and high-temperature superconductivity assessments. He has been an active researcher in the fields of transport and reactor theory, radiation shielding, nuclear cross-section technology, and naval and advanced fission reactor design. His academic experience has included the following appointments instructor in the Bettis (naval) graduate reactor engineering school; adjunct professor of mathematics at the University of New Mexico; and sabbaticals at the Swiss Federal Institute for Reactor Research, and as visiting professor of nuclear engineering at the University of Virginia. **William W. Saylor** (bottom) (BS, U.S. Military Academy, 1972; MS, Massachusetts Institute of Technology, 1977) served in the Army for 9 years and worked at Gilbert-Commonwealth for 3 years prior to joining LANL in 1983. At LANL he has worked on inertial fusion systems, and in particular was instrumental in initiating the HIFSA study. He is currently working on systems engineering

and conceptual design issues associated with Strategic Defense and Advanced Conventional Munitions Initiatives. **William B. Herrmannsfeldt** (right) (PhD, nuclear physics, University of Illinois, 1958; AB, physics, Miami University, 1953) is a member of the accelerator department, Stanford Linear Accelerator Center (SLAC). He heads a group doing numerical simulation of accelerator components, especially for the generation and transport of high-intensity charged-particle beams. He has been associated with the heavy-ion fusion (HIF) program since its inception in 1976 and was a visiting staff member of the High Energy Physics Program Office (U.S. Atomic Energy Commission, Energy Research and Development Administration) from 1974 to 1976 when the first discussions of HIF began. He has been a consultant to Lawrence Berkeley Laboratory, Lawrence Livermore National Laboratory, and LANL on HIF projects since returning to SLAC and has also consulted for the Electric Power Research Institute on ICF. His interest in the economic aspects of ICF, and especially of HIF, stems from the need for the HIF research and development program to study the key issues that need to be resolved to determine if heavy-ion accelerators can become viable candidates as drivers for commercial electric power from an ICF system.

AN INDUCTION LINAC DRIVEN HEAVY-ION FUSION SYSTEMS MODEL

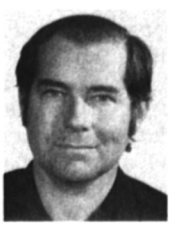
David S. Zuckerman
Daniel E. Driemeyer
Lester M. Waganer
Donald J. Dudziak

David S. Zuckerman (top) (MS, mechanical engineering, Washington University, 1982) has been working in systems integration at McDonnell Douglas Astronautics Company (MDAC) since 1977. His primary work has been in the areas of fusion power plant modeling and technology forecasting. He has been responsible for the creation of a number of commercial fusion power plant computer simulations involving the integration of physics, engineering, and cost algorithms. He has also had a primary role in the development of methods for forecasting future performance of fusion components and other new technologies. **Daniel E. Driemeyer** (center) (PhD, nuclear engineering, University of Illinois, 1980) is a design specialist with the nuclear technology group at MDAC. His primary work has been in the areas of plasma/wall interactions, radiation effects/activation analysis, and systems engineering and integration. He was responsible for radiation shield design on the Elmo Bumpy Torus (EBT) proof-of-principle project and later developed a pumped limiter design for the MDAC/Los Alamos National Laboratory (LANL) EBT reactor and power plant conceptual design study. He subsequently performed activation analyses and developed a plasma erosion/surface heating model for the MDAC/Princeton Plasma Physics Laboratory Tokamak Fusion Test Reactor lower hybrid heating system design study. His current responsibilities include systems engineering and radiation effects analysis on the Neutral Particle Beam Integrated Experiment Program. **Lester M. Waganer** (bottom) (MS, mechanical engineering, University of Missouri, 1963) has been with MDAC since 1970. He is currently project manager on the Heavy-Ion Fusion Systems Assessment (HIFSA) Project and the LANL Inertial Fusion Systems Studies Project and systems integration manager for the LANL Bear I neutral particle beam experiment. He was the project leader on an Electric Power Research Institute project to assess the technical risks of developing a deuterium-tritium fuel system for a commercial fusion power plant. Previously, he was the project engineer on the EBT reactor and power plant conceptual design study for LANL and was in charge of project engineering and systems analysis activities for the STARFIRE reactor design

study. **Donald J. Dudziak** (right) (BS, marine engineering; MS, radiological physics; PhD, mathematics) is presently High Technology Systems Studies Section leader at LANL, where his responsibilities include inertial confinement fusion, antiproton propulsion/power, space-debris clearing and laser isotope separation systems studies; magnetic confinement fusion nucleonics; and analyses for a nuclear directed-energy system. Also, he served as project leader for the multi-institutional HIFSA covered in this special issue. Recently, he assumed collateral duties as deputy leader of the energy system analysis group, with line responsibility for cryogenic engineering and high-temperature superconductivity assessments. He has been an active researcher in the fields of transport and reactor theory, radiation shielding, nuclear cross-section technology, and naval and advanced fission reactor design. His academic experience has included the following appointment instructor in the Bettis (naval) graduate reactor engineering school; adjunct professor of mathematics at the University of New Mexico; and sabbaticals at the Swiss Federal Institute for Reactor Research, and as visiting professor of nuclear engineering at the University of Virginia.

HEAVY-ION LINEAR INDUCTION ACCELERATORS AS DRIVERS FOR INERTIAL FUSION POWER PLANTS

Jack Hovingh
Victor O. Brady
Andris Faltens
Denis Keefe
Edward P. Lee



Jack Hovingh (top right) (BSE, mechanical engineering and mathematics, University of Michigan, 1958; MS, engineering science, University of California, Berkeley, 1973) is a research engineer at Lawrence Livermore National Laboratory (LLNL). He has been involved in the conceptual design of fusion reactors since 1972. His current technical interests include the mathematical modeling of physical phenomena in inertial confinement fusion (ICF) reactors. **Victor O. Brady** (top left) (BS, mathematics, University of California, Berkeley, 1949) joined the Lawrence Berkeley Laboratory (LBL) in 1952. Since 1960 he has been involved in computational support for accelerator design at LBL. **Andris Faltens** (center right) (BSEE, Massachusetts Institute of Technology, 1962; MSEE, University of California, Berkeley, 1964) is a staff senior scientist/engineer at LBL, where he has worked on various accelerators since 1964. He has been involved in all phases of heavy-ion induction Linac design and experimentation since 1975. **Denis Keefe** (bottom left) (BSc and MSc, The National University of Ireland; PhD, Bristol University, United Kingdom, 1955) was a lecturer in physics at University College, Dublin, Ireland, until 1960. Following early work on cosmic-ray physics, he first devoted his research activities to elementary particle physics with balloon-flown nuclear emulsions. Later, he joined the staff of LBL and developed new kinds of Cerenkov counters and spark chambers studying the strong and weak interactions of K mesons and hyperons at the Bevatron. He was in charge of the design of the experimental areas for the multi-hundred-GeV accelerator proposed in the 1960s, which was later built at Fermilab. His interest continued in high energy accelerators when he led a group (1968–1974) in developing the electron ring accelerator using an induction Linac he built at LBL. He first proposed the use of an induction Linac for heavy ions to drive ICF targets and leads an accelerator research group studying this topic. **Edward P. Lee** (bottom right) (BS, physics, California Institute of Technology, 1964; MS and PhD, physics, University of Chicago, 1968) is a staff physicist at LBL working in the area of accelerator theory. For the last 4 years, his efforts have concentrated on the beam dynamics of a heavy-ion fusion driver system. Prior to coming to LBL, he did research in astrophysics and magnetic confinement fusion at the University

of Chicago and the Institute for Advanced Study. From 1970 to 1982, he developed the theory of atmospheric propagation of electron beams at LLNL, and was group leader for this effort from 1976 to 1982.

ANALYSIS OF CAVITY GAS CONDITIONS IN HEAVY-ION BEAM FUSION REACTORS

Robert R. Peterson

Robert R. Peterson (BS, engineering physics, University of California, Berkeley, 1971; PhD, physics, University of Illinois, 1978) is a senior scientist in the Department of Nuclear Engineering and Engineering Physics and in the Fusion Technology Institute at the University of Wisconsin–Madison. He has been a consultant with Fusion Power Associates, Lawrence Livermore National Laboratory, and Los Alamos National Laboratory. His research interests include inertial confinement fusion technology and radiation hydrodynamics.

HEAVY-ION FUSION SYSTEMS ASSESSMENT IMPLICATIONS FOR REACTORS

John H. Pendergrass

John H. Pendergrass (BA, 1962, and BS, 1963, chemical engineering, Rice University; PhD, chemical engineering, Cornell University, 1975) is a senior staff member at Los Alamos National Laboratory. He has worked on many aspects of inertial confinement fusion, including systems and applications studies; experimental and commercial driver, reactor, and power plant conceptual designs; cost and economic studies; research and development program planning; and alternative applications studies. Other activities included advanced isotope separation, synthetic fuels, and defense systems studies.

SENSITIVITY OF ELECTRICITY COST TO HEAVY-ION FUSION TARGET CHARACTERISTICS

Douglas C. Wilson
Donald J. Dudziak
Glenn R. Magelssen
David S. Zuckerman
Daniel E. Driemeyer

Douglas C. Wilson (top) (BS, physics, Massachusetts Institute of Technology, 1968; PhD, astrophysics, University of Colorado, 1976) is currently leader of the inertial fusion and plasma theory group (X-1) at Los Alamos National Laboratory (LANL). He joined LANL in 1979 after completing a thesis on the solar corona and working 3 years at EG&G, Los Alamos on atmospheric spectroscopy. While working on the Heavy-Ion Fusion Systems Assessment (HIFSA), he was the program manager for heavy-ion fusion and for inertial confinement fusion (ICF) theory. His work at LANL has centered on ICF target design for future reactors and current experiments driven by light-ion accelerators and KrF and CO_2 lasers. **Donald J. Dudziak** (bottom) (BS, marine engineering; MS, radiological physics; PhD, mathematics) is presently High Technology Systems Studies Section leader at LANL, where his responsibilities include ICF, antiproton propulsion/power, space-debris clearing and laser isotope separation systems studies; magnetic confinement fusion nucleonics; and analyses for a nuclear directed-energy system. Also, he served as project leader for the multi-institutional HIFSA covered in this special issue. Recently, he assumed collateral duties as deputy leader of the energy system analysis group, with line responsibility for cryogenic engineering and high-temperature superconductivity assessments. He has been an active researcher in the fields of transport and reactor theory, radiation shielding,

nuclear cross-section technology, and naval and advanced fission reactor design. His academic experience has included the following appointments: instructor in the Bettis (naval) graduate reactor engineering school; adjunct professor of mathematics at the University of New Mexico; and sabbaticals at the Swiss Federal Institute for Reactor Research, and as visiting professor of nuclear engineering at the University of Virginia. **Glenn R. Magelssen** (top) (PhD, astrogeophysics, University of Colorado, 1976) is a staff member in the ICF and plasma theory group of the Theoretical Design Division of LANL. At the University of Wisconsin he worked on the Solase laser fusion reactor design and was involved in the heavy-ion fusion program at Argonne National Laboratory. His ICF research interests include target design, ion beam/plasma interactions, radiation and thermonuclear physics, reactor technology, and heavy-ion fusion. **David S. Zuckerman** (center) (MS, mechanical engineering, Washington University, 1982) has been working in systems integration at McDonnell Douglas Astronautics Company (MDAC) since 1977. His primary work has been in the area of fusion power plant modeling and technology forecasting. He has been responsible for the creation of a number of commercial fusion power plant computer simulations involving the integration of physics, engineering, and cost algorithms. He has also had a primary role in the development of methods for forecasting future performance of fusion components and other new technologies. **Daniel E. Driemeyer** (bottom) (PhD, nuclear engineering, University of Illinois, 1980) is a design specialist with the nuclear technology group at MDAC. His primary work has been in the areas of plasma/wall interactions, radiation effects/activation analysis, and systems engineering and integration. He was responsible for radiation shield design on the Elmo Bumpy Torus (EBT) proof-of-principle project and later developed a pumped limiter design for the MDAC/LANL EBT reactor and power plant conceptual design study. He subsequently performed activation analyses and developed a plasma erosion/surface heating model for the MDAC/Princeton Plasma Physics Laboratory Tokamak Fusion Test Reactor lower hybrid heating system design study. His current responsibilities include systems engineering and radiation effects analysis on the Neutral Particle Beam Integrated Experiment Program.

GAIN SCALING RELATIONS – HEAVY-ION TARGETS

Glenn R. Magelssen

Glenn R. Magelssen (PhD, astrogeophysics, University of Colorado, 1976) is a staff member in the inertial confinement fusion (ICF) and plasma theory group of the Theoretical Design Division of Los Alamos National Laboratory. At the University of Wisconsin he worked on the Solase laser fusion reactor design and was involved in the heavy-ion fusion program at Argonne National Laboratory. His ICF research interests include target design, ion beam/plasma interactions, radiation and thermonuclear physics, reactor technology and heavy-ion fusion.

TARGETS FOR HEAVY-ION FUSION

Roger O. Bangerter

Roger O. Bangerter (BA, physics, University of Utah, 1963; PhD, physics, University of California, Berkeley, 1969) is presently deputy division leader for inertial confinement fusion (ICF) theory and group leader of the inertial fusion application group at Lawrence Livermore National Laboratory (LLNL). Before joining the inertial fusion program at LLNL in 1974, he worked

in elementary particle physics at the University of California, Berkeley. In 1981, he joined the ICF program at Los Alamos National Laboratory where he served as program manager for target theory and heavy-ion fusion. He returned to LLNL in 1984.

RESOLVING KEY HEAVY-ION FUSION TARGET ISSUES WITH RELATIVISTIC HEAVY-ION RESEARCH ACCELERATORS

Richard C. Arnold

Richard C. Arnold (PhD, elementary particle physics, University of Chicago, 1962) was a research assistant and lecturer at the University of California, Los Angeles from 1962 through 1965. He then joined the High Energy Physics Division of Argonne National Laboratory (ANL) where he was leader of the Theoretical Particle Physics Group from 1970 through 1975. After a sabbatical year at the Rutherford Laboratory in 1976–1977, he returned to ANL to continue his work in the development of heavy-ion-induced inertial confinement fusion. In 1982, he joined the Max-Planck Institut für Quantenoptik, working on dense plasma calculations for heavy-ion fusion research. In 1987, he became a staff member of the Institute for Applied Physics at the Technische Hochschule Darmstadt.

HEAVY-ION/HOT TARGET INTERACTIONS OF INERTIAL CONFINEMENT FUSION INTEREST

Claude Deutsch
Patrice Fromy
Xavier Garbet
Gilles Maynard

Claude Deutsch (top right) (Dr. Sc., Université de Paris, France, 1969) is leader of the theory group at the Université de Paris XI Plasma Physics Laboratory, where he is the coordinator of the experimental beam/plasma interaction project. His interests include plasma spectroscopy, statistical mechanics of simple Coulomb systems and strongly coupled plasmas, and the stopping of ions in hot and dense matter. **Patrice Fromy** (top left) (Université de Paris XI, France) is a software engineer at Paris-Sud-Informatique, where he is currently working on analytic modeling of equations of states in compressed matter and on numerical simulation of heavy-ion-driven inertial confinement fusion targets. **Xavier Garbet** (bottom right) (Ecole Normale Supérieure, France, 1985) wrote his MS thesis on stopping of heavy-ion beams by excited bound orbitals in compressed matter. He is currently working at Centre d'Etudes Nucléaires de Cadarache on theoretical problems relevant to the Tore-Supra Tokamak. **Gilles Maynard** (bottom left) (Ecole Normale Supérieure, France, 1982) wrote his MS thesis on stopping of heavy ions by partially degenerate electron fluid. Since then, he has made many significant contributions to studies of effective charge of partially ionized projectiles in plasma, radiative transfer in particle-driven targets, and secondary ionic emission.

HEAVY-ION FUSION TARGET COST MODEL

John H. Pendergrass
David B. Harris
Donald J. Dudziak

John H. Pendergrass (right) (BA, 1962, and BS, 1963, chemical engineering, Rice University; PhD, chemical engineering, Cornell University, 1975) is a senior staff member at Los Alamos National Laboratory (LANL). He has worked on many aspects of inertial confinement fusion (ICF), including systems and applications studies; experimental and commercial driver, reactor, and power plant conceptual designs; cost and economic

studies; research and development program planning; and alternative applications studies. Other activities included advanced isotope separation, synthetic fuels, and defense systems studies. **David B. Harris** (top) (BS, 1978; MS, 1982; and PhD, 1984, nuclear engineering, University of Illinois) has worked at LANL since 1984 as a staff member in the energy systems analysis group in the Analysis and Assessment Division. His current work involves systems studies for KrF laser fusion drivers, inertial fusion targets, and ICF reactors and target chambers. He also serves as project leader for the Heavy-Ion Fusion Cost Reduction Study. **Donald J. Dudziak** (bottom) (BS, marine engineering; MS, radiological physics; PhD, mathematics) is presently High Technology Systems Studies Section leader at LANL, where his responsibilities include ICF, antiproton propulsion/power, space-debris clearing and laser isotope separation systems studies; magnetic confinement fusion nucleonics; and analyses for a nuclear directed-energy system. Also, he served as project leader for the multi-institutional Heavy-Ion Fusion Systems Assessment covered in this special issue. Recently, he assumed collateral duties as deputy leader of the energy system analysis group, with line responsibility for cryogenic engineering and high-temperature superconductivity assessments. He has been an active researcher in the fields of transport and reactor theory, radiation shielding, nuclear cross-section technology, and naval and advanced fission reactor design. His academic experience has included the following appointments: instructor in the Bettis (naval) graduate reactor engineering school; adjunct professor of mathematics at the University of New Mexico; and sabbaticals at the Swiss Federal Institute for Reactor Research, and as visiting professor of nuclear engineering at the University of Virginia.