

AUTHORS — JANUARY 1987

DESIGN, CONSTRUCTION, AND FIRST OPERATIONAL EXPERIENCE ON THE JOINT EUROPEAN TORUS (JET)

THE JET EXPERIMENT: EVOLUTION, PRESENT STATUS, AND PROSPECTS

*P. H. Rebut
B. E. Keen*

Paul-Henri Rebut (top) (L'Ecole Polytechnique, Paris, France, 1955; L'Ecole Militaire des Poudres, Paris, France, 1957; Doctorat d'Etat, 1966) joined the Fusion Division, Commissariat à l'Energie Atomique (CEA), France, in 1958 and throughout the 1960s participated in the design, construction, and operation of a number of plasma physics experiments and contributed to the theory of stability and propagation of waves in plasmas. From 1970 to 1973, he contributed to the design, construction, and operation of the TFR tokamak at Fontenay-aux-Roses, France. In 1973, he became head of the design team of JET at Abingdon, U.K., and during the construction phase he was appointed deputy director of JET and head of the construction department with special responsibility for the construction, operation, and development of JET. In 1985, he was appointed director of JET.

Brian E. Keen (MA, physics and mathematics, 1959, and D. Phil., low-temperature physics, 1962, University of Oxford, U.K., C. Phys., F. Inst. P.) served as a research fellow in low-temperature physics at the University of Oxford from 1962 to 1964. From 1964 to 1966 he was a research associate at Yale University in solid-state phase transition phenomena, and a lecturer in the Department of Physical and Mathematical Sciences at the University of Sussex, U.K., in 1966-67. He joined the Culham Laboratory in 1967 to undertake research in various microinstabilities and their suppression or stabilization by feedback and dynamic techniques. In 1975 he became publications and overseas relations officer at the U.K. Atomic Energy Authority (UKAEA), Harwell. He is presently publications officer and technical assistant to the head of the scientific department and the director at JET.



THE JET MACHINE: DESIGN, CONSTRUCTION, AND OPERATION OF THE MAJOR SYSTEMS

*M. Huguet
K. Dietz
J. L. Hemmerich
J. R. Last*

Michel Huguet (right) (engineer, 1964, and Dr.-Ing., 1967, Ecole Supérieure d'Electricité, Paris) moved from the fusion laboratory at CEA, Fontenay-aux-Roses, France, in 1973, to join the JET design team at Culham Laboratory. He is currently head



of the machine and development department at JET. **Karl Jürgen Dietz** (top) [Dipl. Phys., University of Göttingen, Federal Republic of Germany (FRG), 1965; Dr. rer. nat., University of Göttingen, FRG, 1967] worked in the Institute of Plasma-physics of Kernforschungsanlage (KFA), Jülich, FRG, until 1979. Since then he has been a member of the JET team and presently is head of the First-Wall Division. **Johann L. Hemmerich** (center) (Dipl.-Ing., Technische Hochschule, München, FRG, 1964; Dr.-Ing., Technische Hochschule, Aachen, FRG, 1968) moved from KFA, Jülich, FRG, in 1981, to join the JET team at Culham Laboratory. He is presently group leader of the vacuum systems group. **John Last** (bottom) (BSc, engineering, MIEE) has been involved with JET since 1973. His responsibility has been the design and manufacture of the JET poloidal field coil system. He is now group leader of the magnet group, in charge of all development work and operation of the JET magnets and structural components.



THE JET MAGNET POWER SUPPLIES AND PLASMA CONTROL SYSTEMS

Enzo Bertolini (top) (PhD, electrical engineering, 1958; Post Dr., applied nuclear physics, University of Padova, Italy, 1959) worked from 1959 until 1962 at CERN, Switzerland, on high-energy physics experiments. During 1962 to 1973, he was at the Laboratori Gas Ionizzati, Frascati, Italy, where he worked on thermonuclear fusion and magnetohydrodynamic power generator experiments. He spent 1969-70 at the University of California, Davis, teaching a course on advance energy conversion systems, where he still lectures frequently. He joined JET in 1974, with responsibility for the power supplies for the tokamak system and subsequently for neutral beam and radio-frequency generators and for plasma control systems. He is presently deputy head of the machine and development department and head of the Magnet and Power Supplies Division at JET. **Pier Luigi Mondino** (center) (Dr. Ing., electrical engineering, 1964, and full professor, 1981, University of Padova, Italy) started his scientific career with a 1-year fellowship and then as lecturer at the University of Padova. Electrical machinery was his first research field followed by plasma physics, where he collaborated on the design and construction of a theta pinch and later on a reversed-field pinch experiment, particularly on system design and component development. He joined the JET design team in 1976 to design the neutral injection power supplies, and in 1978 to design the ohmic heating circuit. Since 1983, he has been group leader responsible for operation and development of JET power supplies. **Peter Noll** (bottom) [Dipl. Phys., Technical University (TU), Munich, FRG, 1954; Dr. rer. nat., TU, Institut für Kernphysik, FRG, 1960] worked on experimental plasma physics from 1961 at the Institut für Plasmaphysik, KFA, Jülich, FRG (on plasma acceleration, theta pinch, and toroidal pinch). He spent 1 year at the Princeton Plasma Physics Laboratory on plasma neutral beam diagnostics. He was a member of the Joint European Torus Working Group and joined the JET project in 1974. He has been involved in several physics aspects such as plasma buildup, elongated plasma cross sections, divertors, etc. He has been leader of a group to provide basic design of the control and data acquisition system (CODAS), and he has been responsible for the development of the plasma position and current control system. He is now a member of the Magnet & Power Supplies Division, dealing mainly with the further development of plasma control systems in relation to future enhancements of JET operation.

*E. Bertolini
P. L. Mondino
P. Noll*



CODAS: THE JET CONTROL AND DATA ACQUISITION SYSTEM

Henri van der Beken (top right) (Ing., ENSI, IRG-Grenoble, France, 1960; license-es-sciences, Genie Atomique, Grenoble, 1961) established one of the first computer control systems on the 25-GeV proton synchrotron at CERN, Switzerland. He worked on computer control systems at the Los Alamos Meson Physics Facility and at GANIL, Caen. He joined JET in the CODAS Division in 1979 as control group leader. He has been CODAS division head since November 1984. **Clive H. Best** (top left) (BSc, physics, 1974; PhD, Liverpool, U.K., 1977) researched in high-energy physics on experiments at CERN, Switzerland where he developed on-line systems for event reconstruction and display, and monitored data acquisition. He analyzed results of high-energy muon-scattering experiments. In 1982 he joined the scientific department of JET to develop software for the computer interface and analysis of data from JET diagnostics. He is currently section leader in the data processing and analysis group. **Keith Fullard** (center right) (BSc, physics, Kings College, London, 1960; MSc, Electronics University of Southampton, U.K., 1962) developed aircraft instrumentation with the English Electric Aviation Company until 1965 when he joined the UKAEA Culham Laboratory to work on electronics for the fusion program. He took a special interest in CAMAC systems. He joined JET in 1979 as leader of the electronics and instrumentation group, which has since built an extensive system of computer-controlled instrumentation and consoles. **Richard F. Herzog** (center left) (Ing., ESE, 1968, and PhD, EECS, 1972, University of California, Berkeley) worked on several computer control projects in Berkeley, Paris, and Ottawa. He established the computer group of the European Molecular Biology Laboratory, Heidelberg, FRG. He joined the JET CODAS Division, as systems manager, in October 1980. His current areas of work include performance analysis and tools, operating systems, low-level control software, and software tools. **Eric M. Jones** (bottom right) (PhD, plasma physics, Newcastle University, U.K., 1971) worked from 1969 to 1982 at Culham Laboratory (UKAEA) on the Levitron experiment. Since 1982, he has worked on JET, becoming data acquisition group leader in November 1984. He has worked in the fields of cryogenic plant and coil design, magnetic field calculations and particle orbits, data acquisition systems, CAMAC, and computer hardware. His main interests are data acquisition and control systems along with graphical presentation of data. **C. Arthur Steed** (bottom left) (HNC, applied physics, Oxford Polytechnic, U.K., 1963) joined the UKAEA Culham Laboratory in 1961, working on development of diagnostics for the fusion program. He implemented one of the first computer-based systems for on-line data acquisition and analysis of fusion experiments. He played a leading role in implementation of the integrated data acquisition system at Culham Laboratory. He joined JET in 1980 as a member of the CODAS group, became group leader of the newly formed data acquisition group in April 1983, and later leader of the control group in November 1984. He has worked in the fields of plasma diagnostics, data acquisition and control systems, CAMAC, and computer hardware and software.

NEUTRAL BEAM INJECTION AND RADIO-FREQUENCY POWER SUPPLIES

Rene Claesen (right) (Ip, electromechanical engineering, Leuven, Belgium, 1967) worked at Siemens Ltd. from 1967 until 1971, on radio links and teletransmissions in coaxial cables. In 1971, he joined EBFS, a Belgian electricity production and distribution company where he was head of the control section of the Merksem transport center and was responsible for all radio links, data

*H. van der Beken
C. H. Best
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E. M. Jones
C. A. Steed*



*R. Claesen
P. L. Mondino*



transmission from and to the high-voltage substations, and the center's main computer installation. He also became head of the section for protection of all high-voltage transmission lines at the center. He joined the JET project in 1980, where he was first responsible for the 33-kV distribution. In 1983, he became group leader of the additional heating power supply group, responsible for the power supplies for the radio-frequency generators and the neutral injection. **Pier Luigi Mondino** (right) (Dr. Ing., electrical engineering, 1964, and full professor, 1981, University of Padova, Italy) started his scientific career with a 1-year fellowship and then as a lecturer at the University of Padova. Electrical machinery was his first research field followed by plasma physics, where he collaborated on the design and construction of a theta pinch and later on a reversed-field pinch experiment, particularly on system design and component development. He joined the JET design team in 1976 to design the neutral injection power supplies, and in 1978, to design the ohmic heating circuit. Since 1983, he has been group leader responsible for operation and development of JET power supplies.



NEUTRAL BEAM INJECTION SYSTEM

Georg Duesing (top right) (Dipl. Phys. and Dr. rer. nat., Technische Hochschule Aachen, FRG, 1969) worked from 1965 to 1972 at KFA, Jülich, FRG, and the Institut Laue-Langevin, Grenoble, France, in nuclear solid state physics, and from 1973 to 1978 at the Max-Planck-Institut für Plasmaphysik, Garching, FRG, on stellarator engineering and project control. Since 1978, he has been a division head at JET with responsibility for the torus, first-wall, and vacuum systems (during the construction phase to 1983). Since 1983 he has been involved with neutral beam injection development, construction, operation, and scientific exploitation. **Henk Altmann** (top left) (D. Phil., engineering, University of Oxford, U.K., 1970) worked from 1970 to 1974 at the University of Oxford as research assistant on magnetic suspension systems in a low-density wind tunnel, research officer on turbomachining studies, and at Christchurch College as lecturer in fluid mechanics and thermodynamics. In 1974 he joined the Royal Military College of Science, Shrivenham, as a lecturer in fluid mechanics and carried out research work in turbomachinery and wave power development. In 1980 he joined JET where he has been responsible for the neutral beam sources and associated equipment. **Hans-Dieter Falter** (no photo available) (Dipl. Phys. and Dr.-Ing., Technische Hochschule Karlsruhe, FRG, 1972) worked from 1972 to 1979 at the Kernforschungszentrum Karlsruhe on the production, ionization, and electrical acceleration of hydrogen cluster ions. He joined JET in 1980 and was responsible for the design, procurement, and assembly of the JET neutral beam test bed. Since the start of the operation phase, he has been working as a senior physicist at the neutral injection test bed. **Adelbert Goede** (bottom right) (Doctorate, physics and mathematics, University of Amsterdam, The Netherlands, 1975) worked from 1967 to 1975 at the FOM Institute for Atomic and Molecular Physics in Amsterdam as a research assistant on ion beam/plasma interaction and the production of a quiescent target plasma employing the multipole permanent magnet concept for the first time. From 1975 to 1980 he started the development of multipole ion sources as a research associate of the UKAEA Culham Laboratory. He joined JET in early 1980 as a member of the neutral injection group, being responsible for the physics design of the deflection magnet and later its procurement and commissioning. He is presently responsible for the beam line physics of the JET neutral injection system. **Remmelt Haange** (bottom left) (Dr.-Ing., nuclear engineering, Technische Hochschule Aachen, FRG, 1973) worked from 1973 to 1976 on the high-temperature fission reactor Dragon Project, U.K. From 1976 to 1979, he worked on materials development

*G. Duesing
H. Altmann
H. Falter
A. Goede
R. Haange
R. S. Hemsworth
P. Kupschus
D. Stork
E. Thompson*



for high-temperature fission reactors. He joined JET in 1979. He is currently a group leader, responsible for the design, procurement, and assembly of the neutral beam injection systems.

Ronald Hemsworth (top right) (PhD, physics, University of York, U.K., 1970) worked from 1970 to 1973 at York University, Toronto, Canada, on proton transfer reactions and proton affinity measurements. He joined the UKAEA Culham Laboratory in 1973 to work on neutral injection for the DITE tokamak and CLEO stellarator experiments. He joined JET in 1979, and worked on the physics design of the JET injectors until 1983. Since 1983, he has been the group leader for the JET neutral injection test bed. The main activity of the test bed is the testing of the beam sources and the assembled injectors prior to their installation on JET. **Peter Kupschus** (top left) (Dipl. Phys. and Dr. rer. nat., University of Kiel, FRG, 1966) worked on spectroscopy applied to arc plasmas at the University of Kiel from 1964 to 1969. He has also worked on flow-stabilized arcs at the Aerospace Research Labs, and on magnetohydrodynamic energy conversion, fusion technology, and preparation of neutral injection for TEXTOR at KFA, Jülich. He joined JET in 1981 to act as a group leader for neutral injection beamline construction and became the technical assistant to the technical director of JET in 1983. He is presently head of the pellet injector group. **Derek Stork** (bottom right) (PhD, physics, University of Manchester, U.K., 1974) worked from 1974 to 1979 at the CERN Intersecting Storage Rings in Geneva, on high-energy diffractive scattering in proton-proton and proton-deuteron collisions. From 1977 to 1978 he was part of the JADE collaboration studying muon production in high-energy electron-positron collisions at the PETRA facility at DESY, Hamburg. He joined the UKAEA Culham Laboratory in 1978 to work on neutral injection for the DITE tokamak. He joined JET in 1980, and worked from 1980 to 1985 on the control and instrumentation design of the neutral injection system. Since 1985, as a member of the neutral beam operation group, he has been involved in JET plasma heating experiments, with special emphasis on plasma rotation studies. **Ernest Thompson** (bottom left) (PhD, physics, Imperial College, University of London, U.K., 1971) spent 1960 to 1964 as research associate in the Department of Nuclear Engineering, Massachusetts Institute of Technology, where, in conjunction with Fiocco, he made the first experimental observation of Thomson scattering from an electron beam using a ruby laser. He joined the UKAEA Culham Laboratory in 1964 and carried out experimental investigations on magnetic mirror confined plasmas produced by energetic neutral injection. These studies were continued on the Baseball II experiment at Lawrence Livermore National Laboratory. From 1974, he worked on ion optics and the development of high-power neutral beam systems at Culham Laboratory, until joining JET in 1979 as group leader for neutral injection systems design and later on operations. His present interests are focused on exploitation of neutral beam heating on JET.

RADIO-FREQUENCY HEATING SYSTEM

Alan Kaye (top right) (D. Phil, University of Oxford, U.K., 1968) joined JET from UKAEA Culham Laboratory in 1983. He is group leader responsible for the ion cyclotron range of frequency (ICRF) antenna systems. **Jean Jacquinot** (top left) (Dr. de Troisième Cycle, 1963, and Dr. d'Etat, 1972, Université de Paris-Sud, Orsay, France) has been head of the Radio-Frequency (rf) Division since joining JET from CEA, Fontenay-aux-Roses, France in 1982. **Pascal Lallia** (bottom right) (Dr. de Troisième Cycle, Université de Paris, Orsay, France, 1969) joined JET in 1979 and was leader of the rf physics group until 1986 when he transferred to a new position as scientific assistant to the director. **Terry Wade** (bottom left) (MA, mechanical sciences, University of Cambridge, 1963) joined JET in 1981. He is group



*A. Kaye
J. Jacquinot
P. Lallia
T. Wade*

leader responsible for the rf generators and transmission lines for the ICRF system.

ENGINEERING ASPECTS OF JET DIAGNOSTIC SYSTEMS

Peter Millward (top right) (CEng, MIME, MIEE) first worked in the heavy engineering and steel industries. He joined the UKAEA, Harwell, in 1960 and was engaged in the design of experimental equipment for fusion experiments. He moved to the UKAEA Culham Laboratory in 1961 and was employed in various engineering fields related to fusion devices. He transferred to JET in 1980 as a member of the diagnostic engineering group. He was appointed leader of the group in 1982. **Alan Ainsworth** (top left) (BA, University of Oxford, U.K., 1977) served 5 years in the gas turbine industry before moving to the JET project in 1982. He is now responsible for the engineering aspects of microwave, neutron, soft x-ray, and bolometry diagnostic systems. **Christopher J. Caldwell-Nichols** (center right) (MA, 1970, and PhD, 1975, University of Cambridge, U.K.; TD, CEng, MIEE) worked on the development of a 2-mm microwave valve for which he was awarded a PhD in 1975. Subsequently, he was employed at UKAEA, Risley Laboratory, on the development of instrumentation for fast reactors and nuclear chemical plants. He transferred to JET in 1982, where he has been in the diagnostic engineering group and responsible for the vacuum and computer interfaces for JET diagnostics. **Robert Lobel** (bottom left) (MA, University of Oxford, U.K., 1978) worked in the area of new engine designs at Ruston Gas Turbines, U.K., where he had served an apprenticeship. He moved to the JET project in 1981 as a diagnostic design engineer. He has been responsible for a number of different systems but has been employed chiefly on Thomson scattering and spectroscopy diagnostics. **C. John Hancock** (bottom right) [BSc (Tech), University of Manchester Institute of Science and Technology, 1959] entered industry in 1959 as a design and project engineer for instrumentation and computer peripheral equipment. He has been responsible for the engineering aspects of the surface physics diagnostic since he became a member of the JET diagnostic engineering team in 1982.

P. Millward
A. Ainsworth
C. J. Caldwell-Nichols
R. Lobel
C. J. Hancock



JET REMOTE MAINTENANCE DURING ACTIVE OPERATION

John R. Dean (top) (BSc, engineering, University of London, U.K., 1943) worked until 1954 with Joseph Lucas Ltd., U.K., on a wide range of electromechanical research and development projects. He joined the UKAEA, Harwell, in 1957 and, after working on a variety of proposed fission reactor systems, was seconded to the Dragon [high-temperature reactor (HTR)] project in 1959. Initially, he was responsible for the design and construction of the control system studies for the proposed steam generating, direct cycle helium gas turbine, and process heat versions of the HTR plant. After 3 years with the Swiss Federal Institute for Reactor Research, he joined the JET project as technical assistant to the deputy director. In 1982, he was appointed head of the Fusion Technology Division responsible for the development of equipment and techniques for all aspects of maintaining and handling the JET machine in its radioactive operating phase. **Tullio Raimondi** (Dr.-Ing., Ingegneria Industriale, Politecnico di Milano, Italy, 1956) developed servosystems for telemanipulators at ENEA, Rome, Italy, and was responsible for the design of an automatic refueling system for a nuclear reactor. Since 1974, he has been in charge of the remote handling development at JET.

J. R. Dean
T. Raimondi

