BIOGRAPHICAL MEMOIRS OF FELLOWS OF THE ROYAL SOCIETY

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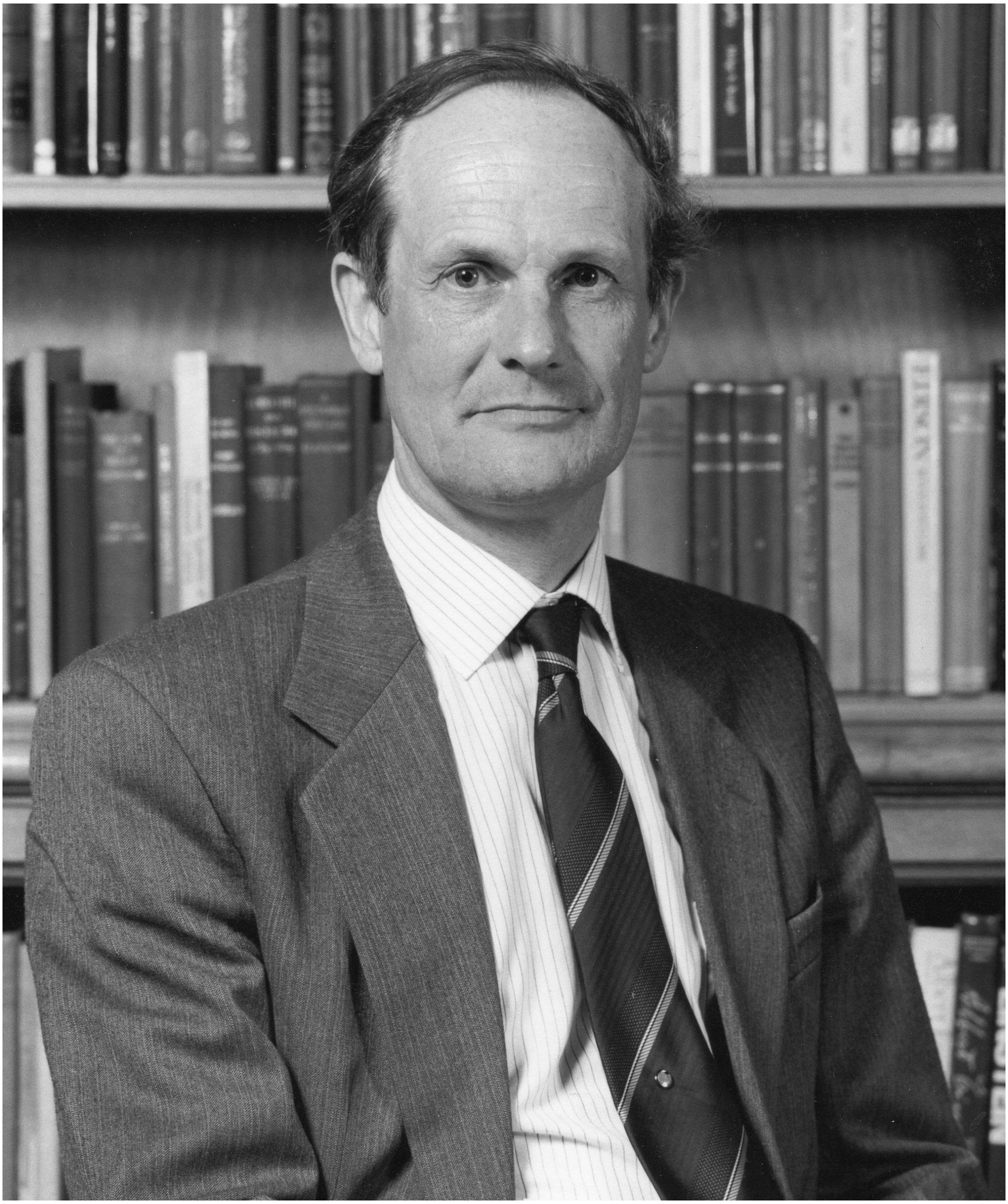

D. C. Robinson

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Elected FRS 1994

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Derek Robinson was a leading UK plasma physicist of his generation. After an early success in measuring the electron temperature in the ZETA plasma through the Thomson scattering of laser light, he became a key member of the team from Culham Laboratory sent to Moscow in 1968 to verify the high temperatures claimed by the Russians for their T3 tokamak. On returning to Culham his research activities continued to broaden and he became an acknowledged expert on a range of fusion devices. His management responsibilities grew in parallel and eventually he became Director of Culham. With his strong support, Culham explored the novel spherical tokamak devices START and MAST, and he promoted this concept as an alternative route to the conventional tokamak for developing fusion power. His energetic leadership and his mastery of theory, experiment and fusion politics brought fusion power nearer to reality. His vision of the 'way forward' for the international fusion programme remains with us after his life was so sadly cut short by the unexpected development of lung cancer in a non-smoker.

THE EARLY YEARS

Derek Charles Robinson was born on the Isle of Man in 1941, the eldest child of Alexander and Grace (*née* Kitchen) Robinson; this location was the result of his father's posting there by the Royal Air Force (RAF). Two sisters, Pamela, the elder, and Patricia were to follow. The real family home was in Cowan Bridge near Kirkby Lonsdale in a small row of cottages owned by Derek's grandmother, mother and aunt. A stone plaque on the end wall records the fact that the cottages were once part of a boarding school for daughters of the clergy, attended during 1824–25 by some of the Brontë sisters: Maria, Eliza, Charlotte and Emily (conditions were abysmal and it is believed that 'Lowood' in *Jane Eyre* was based on the school). Later, Derek was to spend some time researching the Brontë connection.

Derek's mother was a keen gardener, and her family had farmed for several generations. On his father's side, the three previous generations had worked as mechanics or engineers in charge of the engine powering a silk mill on the nearby River Wenning; one of these had taken out a patent for a pressure-reducing valve. This background undoubtedly helped shape Derek's interests and abilities. Derek's father had joined the RAF before World War II, hoping to qualify as a pilot, but problems with eyesight prevented this and he took up a number of more administrative roles. A succession of different postings with the RAF meant that the family moved frequently, so they did not remain on the Isle of Man for long. However, Derek did recall being fascinated by the Ramsay to Douglas electric train, suggesting an early interest in technology. Other memories are sparse, although the wartime shortages of food impressed themselves on his memory.

As his father's postings took place typically at intervals of 18 months, Derek had a somewhat disrupted schooling. The next assignment of his father was in India and resulted in Derek's attending a primary school in Kirkby Lonsdale, the family home, in 1946, where he recalled being taught, coincidentally, by a Mrs Robinson. His father returned from India with movie pictures taken at the transition to independence, and these stimulated another lifelong interest for Derek, namely in photography, beginning with a box camera acquired at that time. The next move, in 1947 to the south, placed him in a school in Hornchurch, where he sensed being regarded by fellow pupils as a 'raw northerner from the countryside'. The evidence of the recent war that was to be seen around London, destruction and bomb damage about St Paul's and the presence of surplus weapons on an airfield, made an impression. He also recalled being fascinated by a visit to the Science Museum. His sojourn at this school was not a success and he was transferred to the Manor House School in Upminster for the years 1948–49. Here his school reports showed little obvious promise, but handiwork and art left some positive memories.

The family then moved to Menston on Ilkley Moor where, during 1950–51, Derek attended his final primary school. It was then that he began to show his academic abilities, passing the '11-plus' examinations and going on to Prince Henry's Grammar School in Otley, where he stayed for more than three years, between 1952 and 1956. Here he was in the top class, although never quite in the top three—he did well in mathematics and science but languages held him back. He developed a serious interest in chemistry, experimenting out of hours—sometimes, he recalled, with devastating results as when his 'best friend blew up his desk and injured himself'. For a while he ran the Science Club at school, being responsible for inviting speakers. Another activity that emerged at this time was music; he joined the local church choir and trained at the Royal School of Church Music at Rossall, singing in many churches. This led to a lifelong enjoyment of church music, particularly the organ. However, he was affected by two tragic incidents that occurred: the loss of his best friend in an accident while on his bicycle, and the serious stabbing of a fellow choirboy friend.

Yet another move took him to the Queen Elizabeth School, back in Kirkby Lonsdale, just before O-levels, and he stayed there for the period 1956–59. Because his parents were then in Berlin, he was placed in the boarding house at the school. He recalled two stimulating teachers who really triggered his interest in science: the headmaster, Mr Defoe, who also taught chemistry, and Mr Ryder, the physics teacher. Mathematics, however, was taught by an old-fashioned master, and Derek felt that the onus fell on himself to make real progress, later reflecting that this was possibly a good training for university! In the event, O-level results were mixed: good results on the science side, balanced by having to retake French.

These encouraging science results fortunately led him to stay on for A-levels, when he began to flower, finding mathematics AS-level 'a pushover', and even A- and S-levels seeming easier compared with O-level, no doubt as a result of good teachers and the focus on subjects he was really interested in. In particular he enjoyed practical work, with the continuing interest in private experimentation in chemistry persisting, sometimes going too far, as evidenced by one explosion in the school boiler house and on another occasion by a large hole in the tennis courts.

The experience of boarding-house life also had an important influence, leading to responsibilities such as looking after the dormitory, being a prefect, and involvement in sport, for example cross-country running. The surrounding countryside and the proximity of the Lake District encouraged other outdoor pursuits: cycling, bird nesting, fell walking and fishing. Furthermore, his interest in music and the church continued and, encouraged by his local vicar, led him to attend a course on science and religion at a theological college in the Wirral, which he found uncomfortable in that it challenged his beliefs. The opportunity to visit the adjacent large industrial chemical plants was perhaps a welcome relief. Indeed, he realized that he was far happier with the 'hands-on' experimental approach to science than struggling with the philosophy of science and its relation to religion, although he enjoyed coming to grips with Einstein's theory of relativity and nuclear physics, both fission and fusion, while at school. He well remembered being told by his headmaster about the ZETA (Zero Energy Thermonuclear Assembly) fusion device at Harwell, never expecting it to play such a role in his subsequent career. His physics master had indeed stimulated a passionate interest in physics even though, academically, chemistry was his most successful subject.

Manchester University

Having obtained good A- and S-level grades and a state scholarship in 1959 he was accepted, and took up a place, at Manchester University. In fact Manchester was the home of some top physics researchers at the time, such as Sir (later Lord) Brian Flowers (FRS 1961) and Sam (later Sir Samuel) Edwards (FRS 1966), both professors of theoretical physics who influenced him during his graduate and postgraduate years. The Manchester University environment triggered interests in solid state physics, fluid mechanics, turbulence and plasma physics, the latter two subjects in particular helping to define Derek's later career. However, Brian Flowers's interest in nuclear physics and Sam Edwards's interest in polymers and turbulence were influential in determining Derek's later line of research and also in gaining support from the UK Atomic Energy Authority (UKAEA) for his thesis work at Harwell and Manchester.

Vacation employment at Windscale nuclear power station gave him a real feel for the practicalities and issues regarding nuclear power, having the opportunity to work with the Calder Hall reactors and to study the plutonium reprocessing system. Despite being encouraged to work there with attractive job opportunities, he was not sufficiently impressed by the science or by the grade structure environment. However, he could see the benefits and challenge of developing nuclear fusion power.

Derek graduated from Manchester in 1962 with first-class honours in physics as the best student in the class, receiving the Samuel Bright Scholarship in Physical Sciences. In the following year he obtained a Diploma in Advanced Studies in Science with Distinction while working for his PhD.

The Harwell years working on ZETA

His PhD thesis research, which he conducted during 1962–65, was under the auspices of Manchester University. The topic concerned theoretical and experimental studies of turbulent plasmas, partly performed on the ZETA device at the Atomic Energy Research Establishment, Harwell. This had been made possible with the help of Brian Flowers's contacts with the UKAEA and the support of R. S. ('Bas') Pease (FRS 1977) of the Culham Laboratory (the UKAEA's centre for plasma physics and fusion research), later to be its Director. Sam Edwards was his supervisor, but he also received guidance from Dr (later Professor) Mike Rusbridge, who collaborated with him on some of the experimental studies (4, 5)*. ZETA was a toroidal magnetic confinement device carrying a large (certainly for that time) plasma current of about a megampère (MA), known as a toroidal pinch; large-scale plasma instabilities were stabilized by a relatively weak toroidal field. It had been believed that neutrons being detected on the device were thermonuclear in origin, but it was soon realized that this was not so and that the plasma did not achieve the necessary temperatures because of 'anomalous' energy loss due to instabilities and plasma turbulence. The observed neutrons were also the result of instabilities that had accelerated plasma ions to high energies. Nevertheless, studies of the device continued and E. P. (Ted) Butt and others found it could enter a 'quiescent phase' when the toroidal field spontaneously reversed at the plasma edge and the fluctuations were reduced (Butt *et al*. 1966). Thus a study of plasma turbulence in ZETA was a very topical subject for his PhD.

The resulting thesis (1) was a considerable achievement: the application to magnetized plasma of the generalized random-phase approach to turbulence modelling pioneered by Sam Edwards (Edwards 1964), followed by experimental studies of fluctuations on ZETA and comparisons of these measurements with the theoretical model. The presence of a magnetic field tends to make the turbulence two-dimensional, varying little along the field, and Derek investigated this situation, exploring the effect of various extensions to a simple magnetohydrodynamic (MHD) plasma model (2). This involved some heroic analytic calculations, aimed at predicting the magnitudes and correlations of the fluctuations, in particular the partition of fluctuation energy between plasma velocity and magnetic field fluctuations (4), followed by more detailed numerical calculations of turbulent correlation functions and the transfer of fluctuation energy between scales, based on Edwards's formulation. The experimental studies (5) involved measurements of fluctuations in magnetic field, plasma velocity, density and temperature, and their variation with plasma conditions, one aim being to identify which particular plasma mechanism controlled the dissipative Taylor micro-scale for the turbulence. Although the comparisons of experiment with the MHD model predictions had only mixed success (kinetic and boundary effects needed to be included), the experience of working at the forefront of research on plasma theory, diagnostic measurements and a major fusion device was invaluable and persuaded Derek to make the pursuit of fusion his life's work.

He clearly made an impact on UKAEA colleagues and after the award of his PhD a staff appointment was soon on offer. Derek joined the Culham Laboratory in 1965 as a Scientific Officer, but continued to work on ZETA at Harwell, living in the 'Officers' Mess' at Ridgeway House. Harwell had been an RAF station in the war, and some traditions persisted; indeed a colleague, Alan Sykes, recalls when he was lodged there temporarily on joining Culham in 1965, Derek was able to advise him which chairs in the refectory and lounge he could sit

* Numbers in this form refer to the bibliography at the end of the text.

on without offending the long-term residents! It was during this period that Derek first met Marion Quarmby, later to become his wife. Marion was from County Durham, working as an analytical chemist at Harwell.

During this period Derek, working with B. C. Boland, R. E. King and R. S. Pease (3, 6), conducted critical experiments on ZETA that established the origin of the turbulence, how the magnetic fields could be shaped to suppress it and that this could arise naturally during the quiescent phase of ZETA. This configuration involved a reversal of the direction of the toroidal magnetic field at the outer edge of the plasma, which was predicted to be more stable to MHD. Unfortunately this process required the presence of plasma turbulence, which necessarily led to plasma loss and limited the plasma temperature. (This self-organizing phenomenon was later given a theoretical basis by J. B. Taylor FRS: the 'relaxation theory' (Taylor 1974).) Derek also performed stability calculations of these configurations, in particular calculating the maximum plasma pressure that was stable against MHD perturbations. His work established the 'diffuse pinch' or reversed-field pinch (RFP), as it came to be known, as a viable confinement device that could sustain high β (that is, $\beta \approx 30\%$), where β is the ratio of plasma pressure to magnetic field pressure, an important measure of the economic efficiency of a fusion device (12).

A key contribution, given what came next, was the first implementation of the technique of Thomson scattering with a laser, developed at Culham Laboratory, to measure the plasma temperature and density in a toroidal confinement device. This temperature measurement is based on the Doppler broadening of the laser light scattered by the plasma. Working with B. C. Boland and R. E. King (3), Derek found that ZETA had an electron temperature of some 2×10^6 K (or 172 electronvolts (eV)), confirming earlier measurements with microwaves by D. J. Wort (Butt *et al*. 1966). Furthermore, the electron temperature was found to increase during the quiescent period of improved stability

A year in Moscow

Temperature is a key variable in any fusion machine, and the ZETA work showed that it could be measured by Thomson scattering of laser light from the plasma. But the plasma density is very low, so the scattered light is very faint and a very high-power laser light source is essential. The ability to make such measurements that had been shown by Culham led to a most important collaboration with the fusion programme in the Soviet Union.

While the UK had been pursuing the toroidal pinch line, epitomized by ZETA, and the USA had followed the stellarator concept at Princeton Plasma Physics Laboratory (PPPL) under Professor L. Spitzer (ForMemRS 1990) (the confining magnetic field in a stellarator is produced entirely by external coils, rather than partly by the current in the plasma), work in the Soviet Union, under Academician L. (Lev) Artsimovich at the I. V. Kurchatov Institute in Moscow, had been quietly proceeding on the tokamak line from the 1950s. The tokamak (a Russian acronym for *toroidalnaya kamera magnitnaya*; that is, 'toroidal chamber-magnetic') device differs from the pinch in having an additional strong toroidal field provided by external coils, to produce greater MHD stability. An exchange agreement between Culham and the Kurchatov Institute was in place and it was proposed that Derek Robinson should spend 13 months there during 1968–69. Fortunately, by then, Marion and he had married in March 1968, satisfying the UKAEA security requirement that he be 'accompanied by a reliable

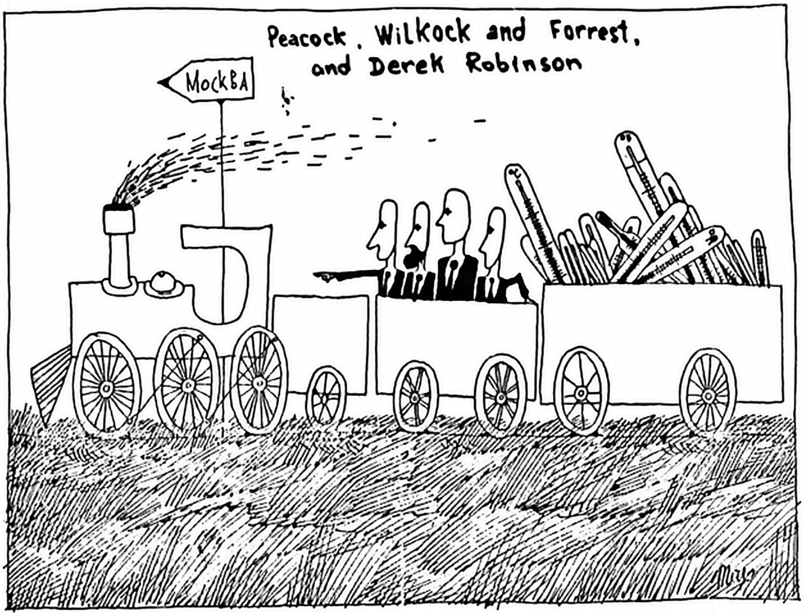

Figure 1. Academician Boris Kadomtsev, later to be Director of the Kurchatov Institute, drew this cartoon of the arrival of the team. (Published at http://www.iter.org/newsline/102/1401.)

person', and they had both taken a crash course in Russian, although their teacher seems to have been unhappy with the time that Derek was prepared to allocate to it in competition with his fusion work. In the event, the Robinsons arrived in Moscow in October 1968, barely six weeks after the Soviet invasion of Czechoslovakia, so diplomatic relations were extremely difficult.

The Soviets had claimed much higher plasma temperatures (about 10^7 °C) for their T3 tokamak device (the Soviets labelled their successive tokamaks numerically: T1, T2, and so on) than had been obtained elsewhere, but there was some scepticism about these measurements in the West. In 1967 Lev Artsimovich had made a remarkable proposition to Bas Pease—coming as it did at the height of the Cold War—namely that, given their acknowledged expertise in Thomson scattering measurements of plasma temperature, Culham should send a team to the Kurchatov to confirm the Soviet measurements. When the T3 results were presented at the 3rd IAEA Conference on Plasma Physics and Controlled Nuclear Fusion at Novosibirsk in 1968 (Artsimovich *et al*. 1969), a meeting was held at which it was agreed to follow up this invitation; plans were soon made to send a team led by Dr N. J. (Nicol) Peacock including P. D. (Peter) Wilcock and M. J. (Mike) Forrest in 1969, and to be assisted by Derek, who was already there (figure 1).

Meanwhile Derek and Marion had been housed in a flat near the Kurchatov Institute. While Derek began working hard at the institute, performing theoretical investigations of the stability of toroidal confinement devices in the evenings and working with the tokamak experiments during the day, Marion recalls how she was left rather isolated, kept busy with the problems of existence in a difficult and alien environment, for instance joining the inevitable queues for food, although visits to the foreign currency Beriozka store provided some relief. However, they were often entertained by Derek's scientific colleagues; there were visits to the Bolshoi

Figure 2. Derek in the Moscow snow in 1969. (Photo provided by Marion Robinson.)

ballet and opera, cross-country skiing in the winter (figure 2), walking in the forests and being entertained at the Artsimovich's dacha in the summer (figure 3), as well as playing football with friends.

Life was somewhat restricted because they were not allowed to travel beyond a 50 km radius of Moscow without appropriate permission or visas. The authorities seemed unwilling to grant even the slightest concessions to facilitate their existence; even requests from Artsimovich were refused. Only when Peacock, Forrest and Wilcock arrived were they deemed to constitute a delegation so that different rules applied. Because no official allowance for leave had been provided for in the exchange agreement, their Soviet hosts organized scientific visits to other institutes for them, so that they could at least manage a few days' sightseeing around these. In this way they were able to visit Leningrad (now St Petersburg), Kharkov in the Ukraine, Novosibirsk in Siberia and Sukhumi in Abhazia.

Unfortunately Derek's health began to suffer. Marion recalls how they were both invited to join the Kurchatov sports club, hoping to play badminton. Apparently health certificates were necessary, but after undergoing medicals both were refused them. Derek had begun to experience digestive problems and after further tests it was concluded that he probably had a stomach ulcer. Under Soviet law he would have been obliged to go to a sanatorium (probably by the Black Sea) to recuperate and have a suitable diet. However, the authorities had no powers to enforce this in Derek's case. The advice from the British Embassy doctor was that he should return to the UK. Characteristically, Derek refused to contemplate either option—it would have jeopardized the whole project.

Figure 3. Nicol Peacock, the Artsimovich's maid and chauffeur, Nellie Artsimovich, Marion and Derek Robinson in the Artsimovich dacha outside Moscow in the summer of 1969. (Photograph taken by Academician Lev Artsimovich, provided by Marion Robinson.) (Online version in colour.)

The Culham team, working with their Soviet colleague Dr Volodya Sannikov, started setting up their equipment in the spring of 1969, eventually getting their ruby laser to operate successfully in its planned relaxation mode (a 30 ms pulse with energy 30 J, producing many photons) in the T3 tokamak environment, although in the absence of plasma. However, on introducing plasma into T3 no scattered signal was observed; this was due to too much light being emitted, unexpectedly, by impurities in the plasma during this long pulse. Disaster loomed! Fortunately there was emergency provision for a back-up mode of operation using a Q-switch to allow much more intense 3 J, 20–30 ns pulses, and the necessary modifications were made. Although the laser energy was reduced by an order of magnitude, the integration time was reduced by a factor 10^5 and the signal-to-noise ratio increased to about 10. The other members of the team had briefly returned to the UK so that it was up to Derek to install the fast optical switch in the laser. Now the intense laser beam led to new problems caused by multiphoton effects in the quartz prism that directed the beam into the plasma, the resulting bubbles stopping the beam from reaching the plasma. Happily this was resolved, and Derek and his Soviet colleagues were able to observe a scattered signal in early July.

Nicol Peacock returned immediately, and by 6 August some 88 scattering results had been obtained, unambiguously indicating plasma temperatures over 1 keV (more than 10^7 °C) and densities 50% higher than the Soviet microwave technique had suggested (figure 4). Radial scans across the plasma were performed, the results fully supporting the Soviet claims. Derek had the honour of presenting these results at the International Symposium on Closed Confinement Systems, Dubna, USSR, in September (7) (figures 5 and 6). (In addition he presented his own separate theoretical calculations of plasma stability (8, 9).) The news of the confirmation of the T3 results spread rapidly around the world, producing marked changes in fusion programmes as

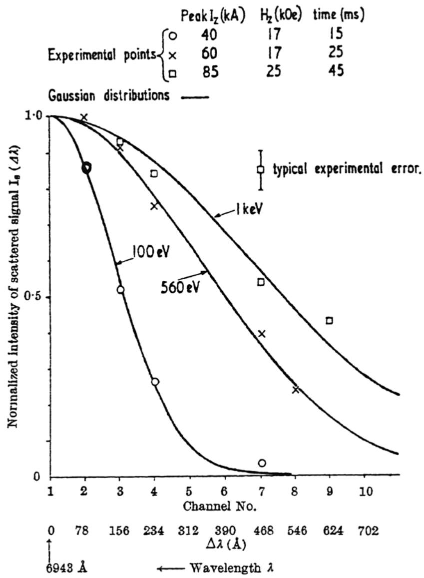

Figure 4. Doppler broadening results from the *Nature* paper published in November 1969 (10). The wavelength changes caused by the motion of the plasma electrons can be fitted by a Gaussian distribution dependent on the plasma temperature. (Reprinted by permission from Macmillan Publishers Ltd: *Nature*, 'Measurement of the electron temperature by Thomson scattering in tokamak T3', N. J. Peacock, D. C. Robinson, M. J. Forrest *et al*. Copyright 1969.)

Figure 5. Derek Robinson with Volodya Sannikov, the Russian member of the collaborative team and co-author of the *Nature* paper, at the meeting in Dubna in September 1969, when the T3 tokamak temperature results were first presented (7). (Photograph courtesy of Culham Centre for Fusion Energy.)

Figure 6. Derek Robinson (left) with Academician Lev Artsimovitch (right) and colleague Volodya Sannikov (centre) at the Dubna conference. (Photograph courtesy of Culham Centre for Fusion Energy.)

these leapt onto the tokamak 'bandwagon'. In particular, the Joint European Torus (JET), built at Culham in the 1970s, was eventually designed on the tokamak principle.

The results were 'fast-tracked' as a scientific breakthrough to meet the publication date for the November centenary edition of *Nature* in November (10), and Nicol Peacock was able to present an eagerly awaited invited paper at the American Physical Society Plasma Physics Division meeting in Los Angeles later in November (11). The last experimental run on T3 was in December, when temperatures of 1.5 keV were recorded, but by then Derek and Marion had returned to the UK in November, exhausted after their 13-month secondment. A further accolade for the Culham team was the invitation by the Royal Society to mount a display at the Annual Soirée in Carlton House Terrace attended by the Queen Mother. Mike Forrest (Forrest 2011) recalls a visit to the display by Sir George Thomson FRS, a pioneer of fusion research, who remarked that his father, after whom the Thomson scattering technique is named, would have been very impressed by what the Culham team had achieved.

Experiments and theory at Culham, 1970–90

After his return to the UK, Derek was promoted to Senior Scientific Officer in 1970, his work now being centred on Culham rather than Harwell. He and Marion lived in a bungalow in Harwell village, but on the birth of their daughter Judith Nicola (known as Nicky), they decided that a somewhat larger house was needed. In 1972 they bought the home they remained in for the rest of Derek's life, the 'Thatched Cottage' in the small village of Appleford, a charming, if challenging, old property with a garden that was to be an important part of their lives.

Derek now had considerable experience in both tokamak and reversed-field pinch physics, and for the next 20 years he contributed strongly to the development of both lines, with a combination of 'hands-on' experiment and theory.

Reversed-field pinches

The High Beta Toroidal Experiment (HBTX) at Culham, under the leadership of Dr H. A. B. (Hugh) Bodin, was a successor to ZETA. Derek led a group exploring the RFP configuration on this fast (microsecond) programmed experiment, spending long hours developing the fast explosive switches needed to produce magnetic field configurations close to the theoretically predicted optimum ones (12). Such discharges achieved higher β, higher temperatures and longer durations than those in ZETA (13). After this, with A. J. L. Verhage and A. S. Furzer (17), he investigated experimentally and theoretically the mechanism by which the nonlinear evolution of MHD instabilities could lead to the stable RFP configuration. In particular he demonstrated agreement between his theoretical prediction for the spatial structure of the magnetic perturbations and that which was observed experimentally. He also predicted theoretically that resistively stable configurations could exist (16), as found experimentally (14, 15). Working with his student T. C. (Tim) Hender (23), he went on to develop a nonlinear theory of pressure-gradient-driven resistive modes and the impact of the resulting stochastic magnetic fields on plasma confinement. In a later contribution with Dr Tim Hender and Dr C. G. (Chris) Gimblett (33), he examined the effect of a resistive wall on MHD instabilities in the RFP.

TOSCA (Tokamak Shaping and Current Assembly), 1974–86

The TOSCA device (figure 7) was entirely Derek's conception, a small, low-cost, flexible tokamak on which to test novel ideas quickly but reasonably rigorously, fully suiting his hands-on approach. It was excellent for training students and spawned an impressive list of PhDs who went on to prominent roles in fusion around the globe, including Culham's present Chief Scientist, Dr A. W. (William) Morris. Practically all aspects of tokamak physics were explored by Derek and a succession of students during its lifetime, 1974–86. One of the first topics addressed was the effect of shaping of the plasma cross-section on confinement and stability, made possible by the flexible coil-set controlling the poloidal magnetic fields for exploring vertical elongation and triangular shaping. Using optimum, D-shaped, conditions he and two students, Kevin McGuire and Alan Wootton, showed that $\beta \geq 2\%$ could be achieved (18). Although this is much smaller than the values possible in the reversed-field pinch, it is a significant achievement for a tokamak.

Another key area for tokamak performance is the onset of plasma disruptions with increased plasma current. Derek studied these with Kevin McGuire (21, 22), using a combination of theory and experiment to elucidate their origin in the nonlinear coupling of resistive tearing modes, leading to the creation of overlapping magnetic islands and stochastic magnetic fields, a topic in which he had an ongoing interest. This mechanism was demonstrated directly by using external magnetic coils, indicating a means for disruption control. They also went on to examine sawtooth oscillations, a periodic disruption of the plasma core, investigating what plasma physics controlled their period (20). With Alan Howling he returned to an early

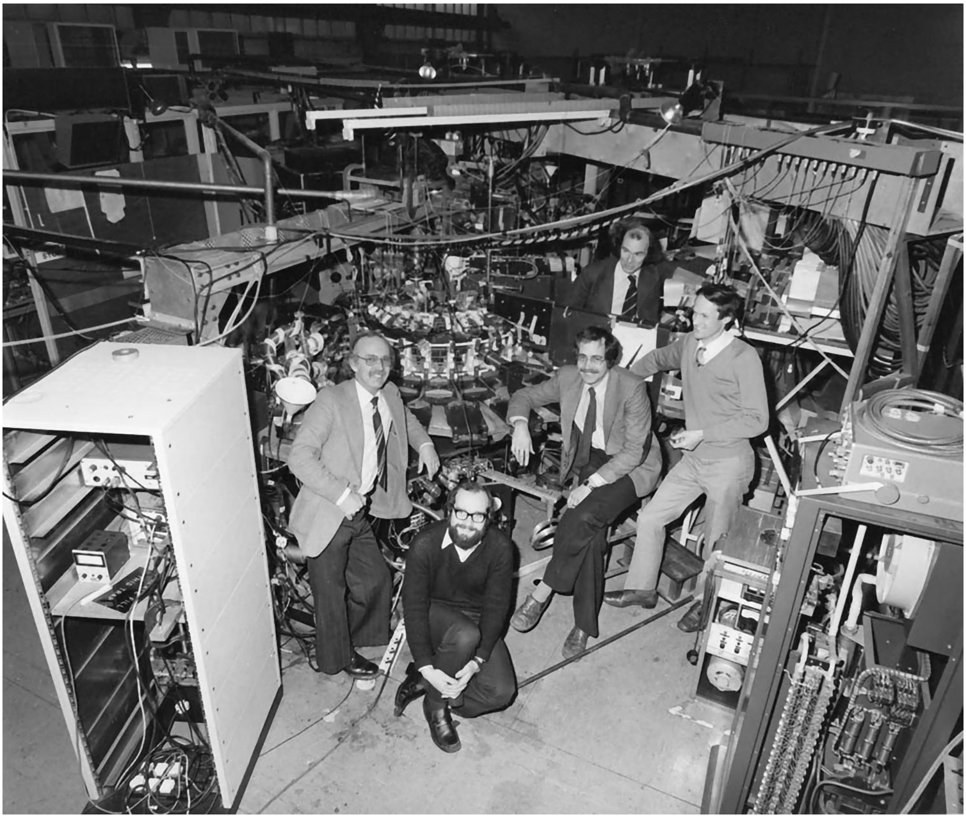

Figure 7. The TOSCA team in 1979. Left to right: Ray Peacock, Kevin McGuire, Chris Gowers, Pete Jones from Aldermaston, and Derek. (Photograph courtesy of Culham Centre for Fusion Energy.)

interest, the role of fluctuations in plasma confinement, showing that losses in the plasma edge were consistent with electrostatic fluctuation measurements (29, 31).

Derek was greatly attracted by the use of electron cyclotron radiofrequency heating (ECRH) to explore tokamak phenomena, seeing it as an elegant tool, easily applied and involving tractable physics. He arranged to have a gyrotron installed, capable of delivering a very high power density to the plasma. Working with Mike Alcock, Trevor Edlington, Brian Lloyd, William Morris and others, he exploited this to achieve high β, comparable with the theoretical MHD stability limit, and to generate a population of magnetically trapped electrons by using ECRH (24, 25, 27). After its closure in 1986, the TOSCA device found a home in the Science Museum at Kensington.

CLEO (Closed Line Electron Orbit), 1974–87

Previously, CLEO had been a tokamak and then a stellarator, but when Derek gained control of it he and T. N. (Tom) Todd modified it to operate in a range of configurations, allowing comparisons of their relative confinement performances. This novel exploration covered the tokamak, the RFP, the OHTE (Ohmically Heated Toroidal Experiment) concept (an idea of Dr T. Ohkawa of General Atomics in San Diego, California, which sought to use helical windings to provide field reversal without the deleterious effects of turbulence (Ohkawa *et al*. 1980)), the HALQT (Helically Assisted Low q Tokamak) configuration (using external fields to raise the tokamak current limit) and the stellarator. It was found that the stellarator had the best confinement time, τ_E, but the tokamak achieved the best 'performance product', $\beta\tau_E$ (26).

In experiments led by Dr Brian Lloyd with Dr A. C. (Tony) Riviere and others, the device was also used to demonstrate non-inductive current drive by electron cyclotron current drive (ECCD) (32). To model such ECRH experiments, Derek encouraged Martin O'Brien to develop a Fokker–Planck code, BANDIT-3D (O'Brien *et al*. 1986), which has been used widely since. For example, it was used to study the transport of non-thermal electrons (39).

Again Derek's ongoing interest in fluctuation-driven transport was to the fore, being involved in experiments to characterize the origins of turbulent losses on CLEO and another Culham tokamak, DITE (Divertor Injection Tokamak Experiment). As well as making fluctuation measurements to correlate with transport (34), these studies included analysing 'thermal wave' experiments using modulated ECRH (38), working with Martin Cox, Dr Jan Hugill and the students Nick Deliyanakis and George Vayakis.

COMPASS (COMPAct ASSembly), 1989–2001

This £10 million (in late-1980s prices) device, which started in 1989, emerged from an initiative of Derek's. Originally he had in mind an upgrade of TOSCA, as a COMbined Pinch And Stellarator System (COMPASS), but by 1982 this had become a low-magnetic-field, shaped-plasma cross-section tokamak, while still retaining the same acronym, now meaning 'COMPact ASSembly'! However, the Culham management decided that this should become a prestige project for the laboratory over many years and that its construction should be placed under the control of professional engineers. European Union (EU) approval was secured and its mission was widened to meet the needs of the EU Fusion Programme. The result was a very flexible, well-built device that initially had a circular vacuum vessel. It also had the largest ECRH facility in Europe, 2 MW at 60 GHz. Tom Todd oversaw the commissioning of the device, but the experimental programme was led by William Morris. As had always been planned by Derek, the vacuum vessel was changed in the 1990s to one that allowed D-shaped plasmas so as to achieve high β and provide physics input to the design of ITER (the International Thermonuclear Experimental Reactor, then under design and now under construction in France).

Derek continued to take a keen interest in the results from COMPASS because of their relevance to ITER. In particular he was involved with Dr Richard Fitzpatrick, Dr Tim Hender and Dr William Morris in studies of the effect of resonant magnetic perturbations in inducing 'mode locking' and disruptions (36). This work showed that plasma rotation could 'screen out' resonant error fields up to a critical amplitude. This explained the resilience of small tokamaks to such error fields but indicated that much care was needed with regard to these in designing ITER, where the plasma rotation is quite slow. Some years after COMPASS completed its mission at Culham it was shipped to a new home in the Institute of Plasma Physics in Prague, where the Czech hosts continue to exploit it with enthusiasm.

The Joint European Torus (JET), 1983–present

Derek was a member of the initial JET Scientific Council, 1974–75, becoming a member of the more formally constituted one in 1983 and being appointed its secretary during 1985–90. Figure 8 shows the Council in 1985. In 1990 he was appointed a UK member of the JET

Figure 8. Members of the JET Scientific Council and others in 1985, when Derek was appointed its secretary. Front, left to right: D. C. Robinson (Honorary Secretary), M. L. Watkins (Staff Secretary), G. Briffod, S. Segre, F. Engelmann, C. M. Braams, F. Waelbroeck, A. Schlüter, G. Wolf, H.-O. Wüster (JET Director), P.-H. Rebut (JET Deputy Director), A. Samain; on stairs, lowest level: V. Jensen, H. Wilhelmsson, P. Valckx; on stairs, middle level: M. Keilhacker, D. R. Sweetman, R. Saison (European Commission); on stairs, top level: F. S. Troyon (Chairman), R. J. Bickerton (JET Scientific Director). (Photograph courtesy of EFDA-JET.) (Online version in colour.)

Executive Committee. In 1996, on becoming Director of Culham, he joined the JET Council. Dr Jean Jacquinot, the last Director of the JET Joint Undertaking, recalls how Derek was renowned for the quality and quantity of his remarks and suggestions on these committees, studying all issues in great depth. He gives as an example how Derek worked with Dr Maurizio Gasparotto, a fellow member of the Scientific Council, to make a recommendation concerning a plan to operate JET at 4 teslas, well above the 3.4 teslas design value (45), recalling: ‘the analysis, which took several months, was quite penetrating and complemented very well the analysis of the JET Project. At the end JET did operate at 3.8 teslas, even during the full deuterium–tritium phase, allowing record fusion parameters to be achieved.’ (In fact, 16 MW of fusion power was produced.)

The end of the 1990s was a difficult period for JET because a dispute over the salaries of the UKAEA staff on JET threatened to bring the project to a premature end. Derek was now the UK member of the JET Council, but as Director of Culham he had to tread cautiously. Eventually a plan acceptable to the interested parties, the EU and the UK, for its successful transition from the status of a Joint Undertaking to ‘EFDA-JET’ (EFDA is the European Fusion Development Agreement) was formulated, in which Culham’s Operations Director, Dr Frank Briscoe, had a key role. This entailed the UKAEA operating the device and a scientific programme being planned and performed under European control. The resulting change took place on 1 January 2000.

However, Derek was also involved in experiments on MHD instabilities on JET. Working with William Morris and Paul Haynes, he investigated the nature of the instabilities associated with plasma disruptions and sawteeth in JET, comparing them with what he had learnt from his experience with smaller tokamaks (28, 30). An important result was the observation of stationary helical modes that resulted from the interaction of a rotating mode with a resistive wall. He was able to provide a detailed comparison of the instabilities observed with the predictions of two-dimensional resistive MHD theory. He also obtained funding from JET for a disruption control experiment on the DITE device (35), led by William Morris, which resulted in the installation of 'saddle coils' on JET, later used for a variety of purposes.

International contacts

The visit to Moscow had indicated Derek's enthusiasm for building links with fusion colleagues in other countries. As Derek's international reputation grew during these years, he was always keen to collaborate and interact with fusion scientists around the globe, passing on his knowledge. Links with European laboratories were built and regular visits to the USA took place. But he went further afield with a four-month tour in 1978–79: accompanied by Marion and seven-year-old Nicky he visited various fusion institutes in Japan (particularly Nihon University, Tokyo, and the Institute of Plasma Physics at Nagoya), lecturing and advising them on their future programmes, with an emphasis on non-circular tokamaks and RFPs. Reporting on his impressions of Japan, he mentioned how he had found the people individually most helpful and that the hospitality shown by the scientific community was magnificent, but that it was difficult to find traces of the traditional Japan, except possibly in Kyoto. After this he visited China under an agreement between the Royal Society and the Academia Sinica, where he lectured on fundamentals of fusion research and discussed their fusion programme. His tour then took them to Australia, where he worked on the 'rotamak' device (this experiment used rotating magnetic fields) at the University of Flinders and extended the theory of resistive modes to include plasma viscosity (19). This tour had lasting consequences, promoting fusion research in China and Japan, countries that later became enthusiastic participants in ITER. Throughout his career he supported fusion studies in the developing world. He also continued to interact with Russian colleagues through collaborative agreements with Moscow State University and the Ioffe Institute, St Petersburg, during the 1990s.

Wider management roles, 1986–2002

Derek's career progressed rapidly: he was appointed Head of Tokamak Division in 1986, Research Director in 1992, Director of the UKAEA's Fusion Division in 1996 and Director of Culham Science Centre in 1998. This appointment, a fulfilment of his life's ambition, was a position he held until his death. Such management roles allowed his strategic vision and tactical abilities to flourish, as shown in his interactions with the UK government and the EU.

He also appreciated the value of active engagement with UK industry, informing businesses about potential opportunities that might arise from ITER. He saw the importance of public support for fusion, encouraging activities that ranged from informing influential individuals and EU elected representatives of the arguments for fusion power, to visits by Culham staff to local schools.

Spherical tokamaks

The economics of fusion power would be improved if fusion were possible with a smaller, simpler device. Theoretical studies of MHD stability had shown that the important β parameter could be improved by going to a low aspect ratio, with the plasma shaped like a cored apple rather than the ring doughnut of a conventional tokamak. A Working Party led by Alan Sykes in 1987 identified the tight aspect ratio, or 'spherical' tokamak (ST) concept, which was being advocated by Dr Martin Peng of the Oak Ridge National Laboratory (ORNL) in the USA (Peng & Strickler 1986), as a new venture for Culham. Derek and Tom Todd created an ingenious concept for a low-cost device based on the imaginative use of available equipment and funds, because an ST was not then part of the fusion programme funded by the Department of Energy. A Working Group was set up by Derek, and a detailed design emerged within a year. The device, which was given the acronym START (Small Tight Aspect Ratio Tokamak), was constructed. The project benefited greatly from collaboration with ORNL, which sent several scientists and, later, a neutral beam injector for heating the plasma.

Alan Sykes was asked to lead the research programme on START, which began in 1990, but Derek took a very close interest in overseeing it. Alan recalls how, at 6.30 p.m. at the end of each busy day, Derek would visit the experiment (he left Culham by 7.00 p.m. to catch the train for the short journey to Appleford) to discuss the day's results. The flexibility of this small device no doubt reminded Derek of his TOSCA days. Indeed, Alan found these visits could be hard going, with Derek saying: 'but we did all this on TOSCA ten years ago!'; and 'No, no, NO, why don't you LISTEN!', but his incisive comments were highly valued. START was found to have exceptionally favourable values for the parameter β—indeed, it achieved world record values for a tokamak of $\beta \approx 40\%$ (figure 9), about three times higher than that achieved in conventional tokamaks and approaching those in RFPs (42). The results were reported at the Royal Society Science Exhibition in 1998 (44).

These exciting results made a huge impact internationally. Indeed, after START's success, ST research began to blossom with new devices in the USA (including the National Spherical Tokamak Experiment (NSTX) at PPPL), Russia, Brazil, Japan and Italy. Derek recognized that they showed that this variant of the tokamak had great potential as a fusion reactor, and he made plans for a larger successor device capable of carrying 1 MA of plasma current, to see whether such performance could be safely extrapolated. William Morris led the initial physics studies to define its parameters, and Martin Cox was appointed the project manager for the device: the Mega Amp Spherical Tokamak (MAST). Experimental results from MAST were published in one of Derek's last papers (46). As ever, looking further forward, he encouraged work on designs for an ST power plant and an ST-based, deuterium–tritium 'volume neutron source', or component test facility (37, 40, 43, 47), by Dr Tim Hender, Dr Howard Wilson and Dr Garry Voss.

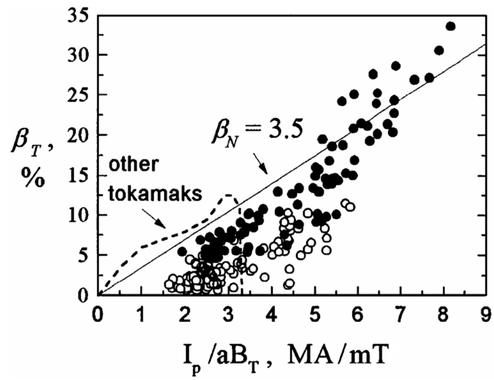

Figure 9. The record results from START as shown at the Royal Society in 1998 and published in *Physical Review Letters* (42). Each point indicates a single plasma shot, with solid circles representing exceptional performance. The broken line shows the operational limits for other tokamaks for comparison. (Reprinted with permission: M. Gryaznevich, R. Akers, P. G. Carolan *et al*. 'Achievement of record β in the START spherical tokamak. *Phys. Rev. Lett*. **80**, 3972. Copyright (1998) by the American Physical Society.)

ITER

Derek was a key leader in the European fusion community, and he recognized early on that the timely construction of ITER, possibly in Europe, was essential for the international fusion programme. The original design for ITER was essentially a scaled-up version of JET, but with superconducting toroidal magnetic field coils, intended to produce 1.5 GW of fusion power. With his wide, perhaps unique, experience of tokamak fusion research, it was no surprise that Derek was appointed a European Member of the Technical Advisory Committee (TAC) to ITER in 1991. The TAC, chaired by Dr P. H. (Paul) Rutherford of Princeton, had the role of conducting technical assessments of the ITER design. Dr Robert Aymar, then a European colleague on the TAC (later to lead the ITER activity and after that to be Director General of CERN), recalls:

> it was not an easy job at that time [the beginning of the ITER EDA (Engineering Design Activity)], because the Project Design was too ambitious, too large, using immature technologies. Everybody was afraid and somewhat discouraged to comment on the details, except Derek, whose behaviour was exactly the same as in any other meeting, scientific or not: to be serious, read all the documentation in detail, weigh every argument as much quantitatively as possible and provide his conclusions in writing for the benefit of all his colleagues, who were largely relying on him. But being always very nice, his negative comments were written in a diplomatic language and balanced against positive remarks; his colleagues, not having English as mother's tongue, were surprised not to find the strong negative (at that time) conclusions they had all agreed upon, and Derek was asked to change his wording; which he did generously, and with amusement, but with a certain disappointment!

Later, in 1998, the project was cast into some disarray when one of the international partners, the USA, withdrew as a result of internal US politics, combined with questions about ITER's scientific basis. Frantic activity ensued to produce a lower-cost but sound design for a reduced version capable of generating 500 MW fusion power. Derek had a key role in this process, working hard to weigh the respective advantages of possible variants for the device, commissioning calculations, making 'back-of-the-envelope' estimates himself and seeking input on particular physics issues from his colleagues at Culham, eventually reaching a consensus with colleagues on the TAC for a new design. This involved numerous assessments of the engineering and scientific capabilities of the design, some of which he chaired. At Culham he ensured that the theoretical and experimental programmes, particularly on COMPASS, addressed key issues for ITER (41). He worked tirelessly to convince the UK government and the EU that the correct step for fusion was to bring ITER to fruition, although final agreement to construct ITER at Cadarache, in France, did not occur until after his death.

The 'fast track'

Fusion research has always suffered from the common perception that the actual delivery of fusion power is '40 years away'. Derek recognized the need to allay this idea and formulated in outline a 'fast track' to fusion power, involving in parallel ITER and a facility for testing fusion materials, possibly based on the ST, followed by a demonstration power plant, DEMO. This strategy gained the support of the Government's Chief Scientist, Sir David King FRS (King 2001), who was convinced of the perils of climate change and saw fusion as a way of lessening the reliance on fossil fuels. This concept was enthusiastically taken up and promoted by Derek's successor as Director of Culham, Sir Christopher Llewellyn Smith FRS, and became part of the European fusion planning (Cook *et al*. 2006).

Committees

Derek served on many boards, councils and committees, as shown on the 'timeline' of Derek's life and career in figure 10. He was a fine committee man who had always read the papers and done his homework. Dr Jean Jacquinot recalled in his 2003 Robinson Memorial lecture:

> With Derek, we had to be particularly careful. For instance, if we were stretching the laws of physics or did not realize a promised experiment, we could be sure that Derek would raise his hand and ask a very polite but well targeted question. He would always work to establish a consensus and be a gentleman with every one. … He was always 'volunteered' by the chairman to write conclusions. He did so in a very subtle way, which would always preserve the 'way forward'. I put inverted commas because he used this expression quite often and would throw his hands forward as he would say it. Clearly his main concern was the 'way forward' for fusion.

His Institute of Physics activities included IOP Publishing, becoming Chairman in 2001; he was a Member of the Institute's Council and Vice President from 2001. Other roles within the UK included being Chairman of the High Power Laser Panel 1988–90 and Chairman of the Nuclear Research Advisory Council, which advises the Chief Scientific Advisor to the Secretary for Defence.

He was also deeply involved in European fusion activities. Professor Karl Lackner recalled, at the Memorial Seminar for Derek in 2003, how the Max-Planck-Institut für Plasmaphysik at Garching in Germany had benefited from Derek's membership of the Fachbeirat (their Scientific Advisory Board), a position he held for 14 years (1987–2000), serving as Chairman from 1997 to 2000. He was also a member of the Conseil Scientifique for Cadarache, the

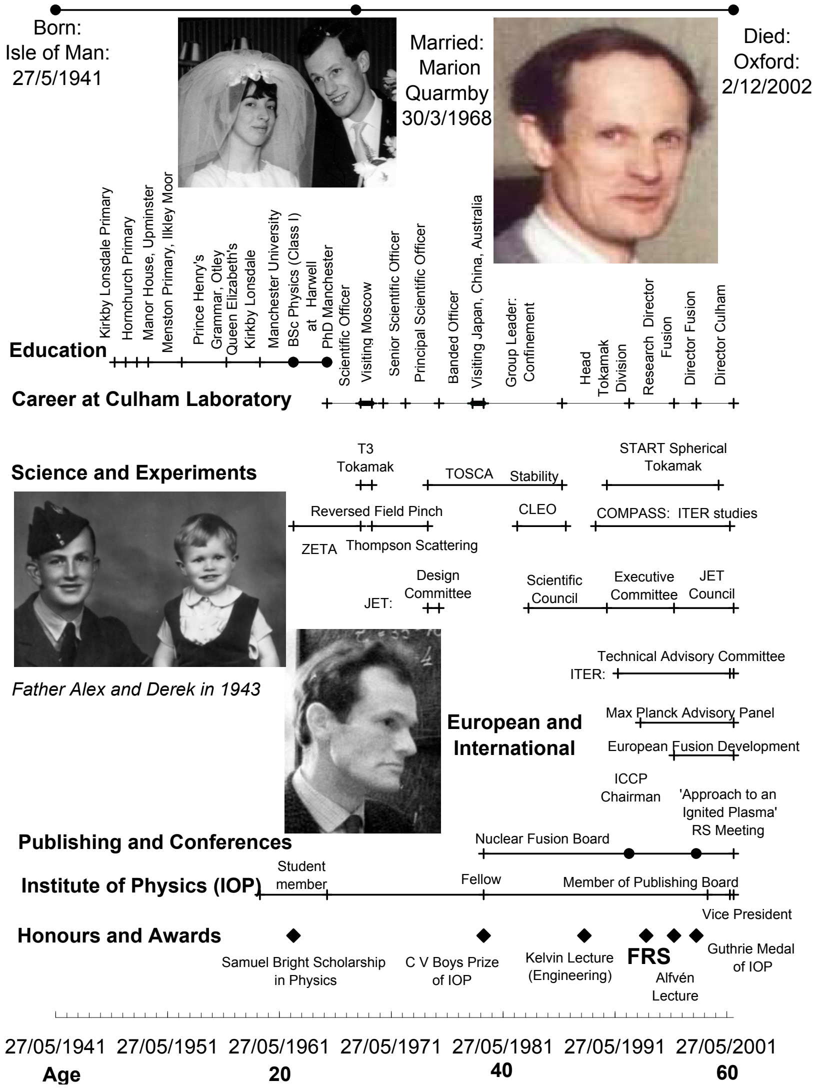

Figure 10. A timeline for Derek's life and his many achievements, committees and honours. (Online version in colour.)

CEA establishment in France, from 1993 to 1997. The UK Fusion Programme had been part of the European Fusion Programme through a Contract of Association with EURATOM since 1973. Throughout the 1990s Derek served on several of its committees. In particular, on becoming Director of Culham, he sat as the UK member of the top committee, the CCFP (the Consultative Committee for the Fusion Programme), chairing its programme subcommittee towards the end of the decade.

On 15 and 16 July 1998 Derek was the lead organizer for a Royal Society Discussion Meeting entitled 'The approach to ignited plasma' (published in *Phil. Trans. R. Soc. Lond.* A **357**, 373–640 (1999)). He attracted speakers from all over the world to present the state of the progress of fusion to what all look forward to—an ignited plasma that would sustain the fusion reaction. He himself talked about alternative approaches, mentioning the then-recent START results (44). The meeting was a fitting climax to his life's work.

Personality, pastimes and family

Derek was a complex person, perhaps a consequence of a disrupted childhood involving a succession of moves and different schools. Many who knew him attested to his intelligence, quickness of mind, stimulating conversation, wide interests and particularly his helpfulness. Allied to these were a very special physical intuition, very high standards, strong scientific leadership and a clear vision. He could be exceptionally supportive of his own staff, opening up their careers in directions they had never even thought of themselves. The 'hands-on' training he gave to others (they thought at the time that they were helping him!) taught them how to operate and get things done, skills that remained useful throughout their lives. He pushed all his staff to perform as well as they were able and towards their full potential, but some do recall occasions when they felt he made excessive demands on them.

Early in his career he could seem an ambitious, brash young scientist to some, but this was based on real abilities and the experience gained from his hands-on approach to science. Later on, his growing programme management role took him away from close contact with experiment. In this period, despite his established reputation as one of the leading fusion scientists in the world, he still seemed to feel the need to maintain his image by emphasizing his own scientific contributions and to be seen to be leading a successful programme at Culham. In character he was extremely cautious, being most careful to be correct in technical matters and to avoid leaving himself open to attack. He could also give the impression of being rather secretive, indicating that he was party to knowledge that he could not fully divulge.

However, the most obvious characteristic was his dedication to his work—he was a true workaholic, committed to fusion science and fusion politics; a vision of the future of fusion, whether in the UK, the EU or the world, apparently never disappeared from his mind, even briefly. In part this might explain the demands he in turn placed on people, circulating papers for urgent comment (even if written in Russian on one occasion!), expecting staff to be available at all times, no matter how inconvenient for them: during holidays, evening visitations, late-night faxes and phone calls. Responding to Derek's copious comments in red ink on one's own reports and other writings was not helped by his often indecipherable handwriting—it was frequently necessary to seek the help of the one individual who seemed capable of doing so, his secretary.

As an example of Derek's own commitment to work as well as his display of initiative, Tom Todd recalls an occasion in 1982, when Derek was working late on a record cold evening (−24 °C); on reaching his car in the car park he found it would not move—the tyres were frozen to the ground! Nothing daunted, he realized what equipment was needed to release it, got the Patrol Service to unlock the site stores to get a hammer and chisel and managed to chip the car free and make his way home. On other occasions he walked to work, taking a short cut along the railway line from Appleford during train strikes. Even though he had suffered from digestive health problems ever since his days in Moscow, he never let these deter him from his work. However, on one occasion he was the victim of another unfortunate incident.

Figure 11. Marion and Derek Robinson in their garden they loved, filled with the unusual plants that Derek liked to collect. (Photograph provided by Marion Robinson.) (Online version in colour.)

Professor Bruno Coppi from Massachusetts Institute of Technology recalls how, after a free morning at an international conference overseas, Derek returned to the hotel in a terrible state: he had been mugged by thieves, his camera and wallet had been taken and he had suffered a broken rib.

Despite this commitment to work, he still managed to find time for other activities, several of which could be traced back to his time at school; for instance he continued his interest in photography, hill walking and collecting plants. Alan Sykes recalls an occasion during free time at a conference in Innsbruck when he and Derek went on a walk in the mountains. Derek being rather fitter, Alan took every opportunity to slow him down by pointing to some rare plant. In time Marion and Derek established a fine garden at the 'Thatched Cottage' (figure 11), on occasion opened to the public and selling a range of unusual plants for charity. Indeed, they were very much part of the community in Appleford: for instance the whole family joined in the building of a new village hall (figure 12). When there were plans to increase activity at the local power station, Derek applied his expertise to fighting these. He continued to take pleasure in church music, and both he and Marion enjoyed visiting historic churches.

His daughter Nicky also followed Derek and Marion in pursuing a scientific career. She graduated in natural sciences from Cambridge in 1993, spending some time on a student placement working on START at Culham, where she was soon considered a member of the team rather than the 'Boss's daughter'. She went on to study for an MSc in hydrogeology from University College London (UCL), leading to a career as a hydrogeologist, including a Research Fellowship at UCL from 1997 to 2000.

Figure 12. The ‘hands-on’ approach. The team that built the village hall in the Robinsons’ village of Appleford. Derek holds the plank and Marion the paintbrush; daughter Nicola is in the front. (From the *Wallingford Herald* on 30 October 1980, provided by Marion Robinson; reproduced with permission from Newsquest Oxfordshire.)

The final months

Derek’s last illness came suddenly and without serious warning, although colleagues noticed that he had had a cough for a long time, about a year, which had been getting slowly worse. One day in late July 2002, while Derek was awaiting his annual medical at Culham, he began to experience severe chest pains. Leaving his office, he went across to see the Occupational Health Section, where the doctor ascertained there was no heart problem but realized that there might be something serious amiss. The doctor sent him straight off to the hospital at Oxford, where he was diagnosed as having lung cancer—which came as a dreadful shock because he was a non-smoker. He never came back to his office, and indeed his keys were still there and had to be returned to his house.

Derek was due to begin his annual leave the following week, and he and Marion spent a prearranged holiday on the Isle of Man, the first time he had visited there since he had left as a small boy. Chemotherapy treatment began in late August. Marion described how he liked to sit in the sunshine in the conservatory he had built in the garden. There he would read papers and keep in touch, but he never returned to Culham. After a second cycle of chemotherapy the side effects began to create more problems. Little more could be done and the end came unexpectedly and quickly. He died in Sobell House, a hospice in Oxford, on 2 December 2002, aged 61 years.

The large number of letters of condolence, recalling fond memories of Derek, that were soon received from all around the world, attested to the great esteem in which he was held. In June 2003 a Derek Robinson Memorial Seminar was held at Culham in which many colleagues and friends from around the world recalled his achievements and reminisced about his life. Some of the talks are presented at http://www.ccfe.ac.uk/DCR-Memorial/.

Honours and awards

1962 Samuel Bright Scholarship in Physical Sciences (Manchester University)
1979 Fellow of the Institute of Physics (IOP) and Chartered Physicist
1979 C. V. Boys Prize from the Institute of Physics
1988 Kelvin Lecturer to the Institute of Electrical Engineers
1994 Fellow of the Royal Society
1996 Alfvén Lecturer for the Swedish Academy of Sciences
1998 Guthrie Medal and Prize of the IOP

Acknowledgements

We are grateful to the following for providing information and their recollections, on Derek's life, personality and career. First, of course, his wife Marion, but also several colleagues: Dr Robert Aymar, Brian Boland, Chris Carpenter, Professor Bruno Coppi, Dr Mike Forrest, Dr Tim Hender, Dr Jean Jacquinot, Dr William Morris, Martin O'Brien, Alan Sykes and Tom Todd.

The frontispiece photograph was taken in 1994 by Prudence Cuming Associates Ltd and is reproduced with permission.

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