BIOGRAPHICAL
MEMOIRS

Lewis Edward John Roberts CBE. 31 January 1922 –– 10 April 2012

Brian Eyre

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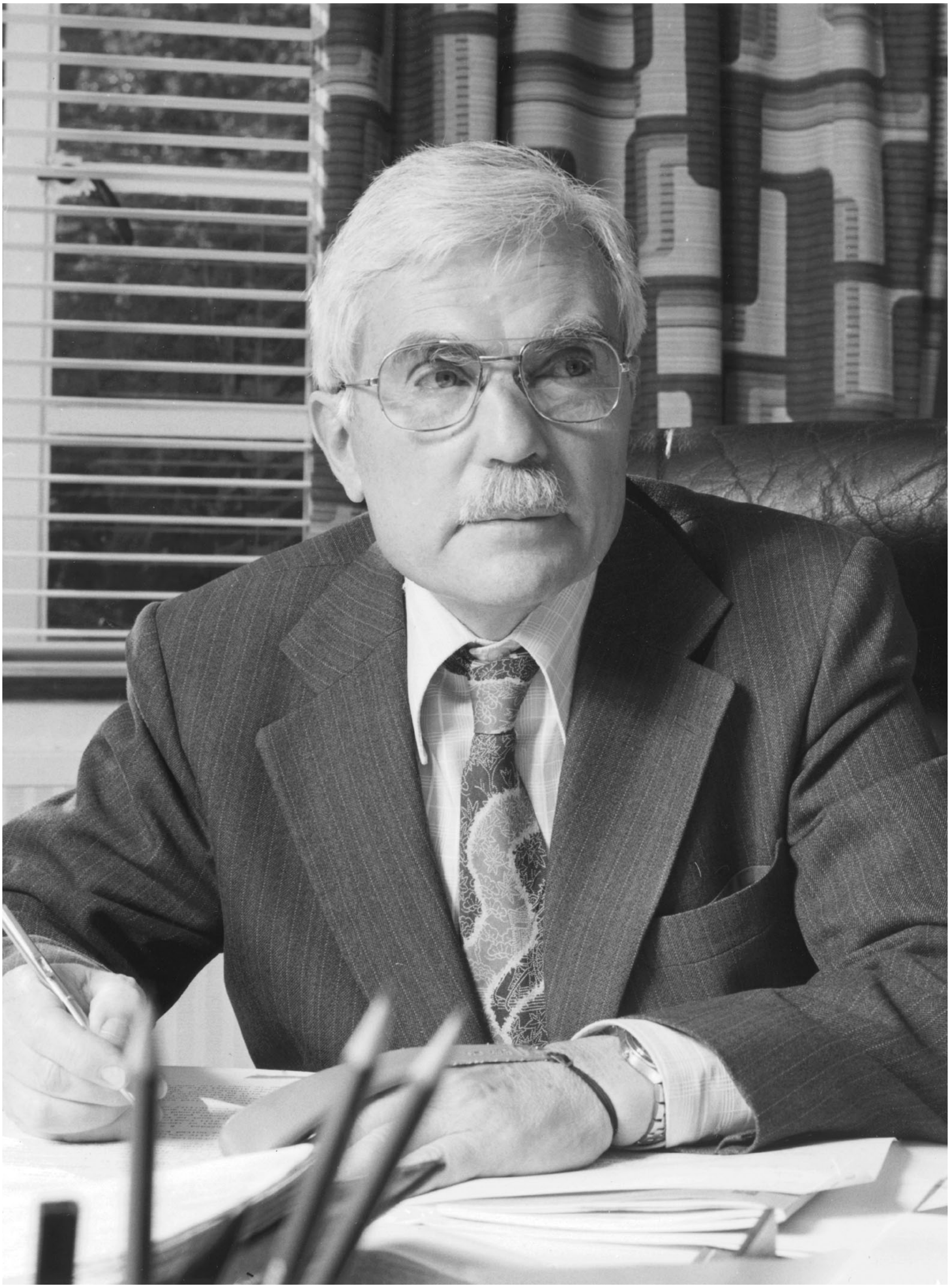

Lewis Roberts

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Elected FRS 1982

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Lewis Roberts was a distinguished nuclear chemist and outstanding leader in the development of science and technology. He read chemistry at Oxford, where he graduated with an honours BA and then conducted research for a DPhil on the separation of actinides. Actinide chemistry formed the central theme of his work for the next 20 years, during which he conducted pioneering research into the thermodynamic properties and structures of actinide oxides. In 1968 he underwent a major career change, moving into senior management at Harwell and eventually becoming Director in 1975. During this period he showed outstanding judgement and leadership first in developing the non-nuclear industrial programme at Harwell and then in leading the laboratory through a time of great change. In addition to his executive responsibilities as Director, Roberts played a major role in influencing the nuclear industry's approach to the difficult issue of nuclear waste management, a particularly important achievement being the setting up of NIREX under his chairmanship. In his mid sixties Roberts made a further major career change in moving to the Chair of Environmental Risk Assessment at the University of East Anglia. This allowed him to widen his interest in risk and environmental issues and to apply this to areas outside the nuclear field.

Roberts was a rather shy and reserved man with a strong sense of public responsibility underpinned by clear principles. He was highly respected and held in great affection by all who worked with him.

INTRODUCTION

Lewis Roberts was one of the pioneers of the UK nuclear programme, starting research into the separation and properties of the actinides in 1943. I first met him in the early 1960s, not long after I had arrived at Harwell as a young research scientist working in the Fuels Group in Metallurgy Division. I had started a project using transmission electron microscopy to determine the microstructure of uranium carbide as a function of thermal treatment. An important aspect was phase stability and its influence on structure; I met with Roberts for advice on the thermodynamics of such reactions. By this time, around 1963, he was already very senior and a leading world authority on actinide chemistry. On this initial encounter, I found Roberts to be rather reserved, but with a warmth and readiness to help with my questions. These initial perceptions were strengthened by my subsequent interactions with Roberts, confirmed by a much more substantial body of recollections and correspondence with many people across the scientific community and beyond. I hope that the memoir will do justice to the essential qualities and many achievements of Lewis Roberts.

Formative years

Early years

Lewis Roberts was born on 31 January 1922 in Cardiff. Both parents were academically inclined; his father, William Edward Roberts, studied theology at the University of Wales and Bangor and was subsequently a successful minister in the Presbyterian Church of Wales. The Reverend William Roberts was also interested in philosophy and was gifted in music; he was an accomplished pianist. Roberts's mother, Lilian Lewis Roberts, also came from an academically inclined family and she, together with her siblings, were schoolteachers, with a focus on the arts and languages. Both parents suffered ill health during Roberts's early years and he recalled that he had had a rather lonely childhood. A particularly traumatic event was the death of his father in 1932 at around the time he was making the transition to secondary school. But the atmosphere at home during these formative years, as well as being supportive and loving, 'was scholarly and bookish'. His father had built up a good library and his aunts who lived nearby had a remarkable collection of nineteenth-century and early-twentieth-century literature. Lewis was therefore widely read at an early age, particularly in classical English literature. As he points out in notes that he deposited with the Royal Society, his subsequent focus on science was an aberration against that family background. In later life he appreciated that this introduction at an early age, particularly to classical English literature, together with inspired teaching in history while at Swansea Grammar School, provided a balancing influence outside science. Most importantly, the foundations for his Christian faith were laid in these early years that underpinned the values—ethics, integrity and a strong sense of duty—that governed his approach to both his professional life and his personal relationships.

Schools

The family moved to Swansea in 1927 and Roberts went to local schools, first to St Hilda's, a private primary school (1927–32), from which he won a scholarship to Swansea Grammar School (1932–39). In spite of the trauma of losing his father and being about a year younger than his classmates, he had a glittering record at the grammar school, achieving distinctions in most subjects every year. Interestingly, he was particularly strong in Latin and French, perhaps reflecting the strong background in languages and literature on his mother's side of the family. His weakest subject was art, although in later life he developed a strong interest in paintings and collected at a modest level. But Swansea Grammar was strong in science under the headmaster, Greg Morgan, who was a mathematician, and this undoubtedly influenced his sixth-form choices. After matriculation in 1936 Roberts focused on mathematics, physics and chemistry and in 1938 he gained his Higher Schools Certificate. He was awarded a State Scholarship to read chemistry at Oxford.

But it was not all work and no play for Roberts at school. He contributed in a major way to the wider school life, including being a prefect (Deputy Head Boy in his final year), a member of the Dramatic Society, Vice President of the Scientific Society and Chairman of Committee of the Debating Society, which provided valuable building bricks for his future career. He was also active in sports, being senior fives champion (in 1938) and captain of the school cricket second eleven.

Oxford University

Roberts went up to Jesus College as a Meyricke Scholar in 1939 to embark on his undergraduate studies in chemistry. However, he was subjected to a further major trauma in September 1940 when he was at the family home in Swansea with his mother. The flat they were living in received a direct hit from a German bomb. Both Roberts and his mother miraculously survived, although the building was totally destroyed. Roberts came very close to being killed when the blast ejected him from the building and left him unconscious on the surrounding rubble. He suffered a severe head injury with a nail that penetrated his left temple and eye socket, and the hospital initially felt he was unlikely to survive. Fortunately the nail did not sever the optic nerve and he made a good recovery; the only physical consequences were slightly impaired sight and a broken nose.

He was able to return to college in October 1940, shaken but more or less recovered from his injuries, to resume his undergraduate studies. Jesus College historically had a strong presence in chemistry, and Roberts formed early professional relationships with fellow chemistry undergraduates, William Hardwick, Bill Armstrong, Peter Shaw and Jimmy Duncan. Unusually, Jesus had its own chemistry laboratory (long since converted into a library and reading room) where they spent many hours. He graduated with an honours BA in chemistry in 1943. Significantly, in the light of his subsequent career, Roberts embarked on his first research project on actinide chemistry during his final year (a requirement at Oxford for a chemistry honours degree).

While at Oxford Roberts met his future wife, Eleanor Mary Luscombe (known to family and friends as Mary), who was reading languages at St Hugh's College. They were married in Bournemouth in 1949 (figure 1), marking the start of a long, happy and successful partnership until Mary's death in August 2010. On graduating, Mary was also directly involved in war-related work in intelligence at Bletchley Park. She subsequently became a schoolteacher and it is interesting that her professional background was close to that of Roberts's family, further counterbalancing his focus on science. In 1954 they had a son, Matthew, who on leaving school trained at art college and subsequently went on to study novel structures. This led to an interest in invention and intellectual property with the continuing support of his father.

Research chemist

Roberts's introduction to research in 1942 was under unusual circumstances. It was at the height of the war and he was directed into a project related to the UK's work on the atomic bomb, codenamed the Tube Alloys project. This was not long after the first discovery of fission and the subsequent famous Peierls–Frisch memorandum pointing to the feasibility of developing a nuclear fission weapon, which led to the setting up of Tube Alloys. Before embarking on the research, which was concerned with actinide chemistry, Roberts had to sign

Figure 1. Lewis with his wife, Mary, at their wedding in Bournemouth in 1949.

the Official Secrets Act and not talk to anyone outside the project about his work, an unusual position for an undergraduate to be in. It must have been a shock for him, particularly given his strong Christian background. Nevertheless, he would also have been aware of the strong sense of threat and fears for national survival facing Britain at the time and the perceived urgency and importance of the work. What must also have been disconcerting for him is that in his organic chemistry lectures Roberts had been told that a 'uranium bomb' was a fantasy.

A secret deal was brokered between his college supervisors and the senior people responsible for the Tube Alloys work in the Clarendon Laboratory, to allow the college laboratory to become part of the nuclear weapon project and enabling related research to be conducted there by Roberts and fellow chemistry undergraduates. One wonders to what extent this was an unprecedented position for the college and whether it involved any transgression from its statutes. Initially a young Jesus College Fellow, Leonard Woodward, supervised Roberts.

After graduation, Lewis Roberts and William Hardwick registered as postgraduate students and their research moved to the Clarendon Laboratory, where they joined a tightly knit team working on a small part of the project on uranium isotope separation by diffusion, supervised first by Professor Francis (later Sir Francis) Simon FRS, and later by Nicholas Kurti (FRS 1956). The aim was to isolate the lighter fissile ^{235}U isotope required for a fission bomb from its much more abundant and non-fissile ^{238}U isotope. At the time the only method considered feasible was multiple filtration of a volatile gaseous compound UF_6 through a porous metal membrane through which the lighter isotope diffused a little faster than the heavier one. A key issue was the high reactivity of UF_6, resulting in corrosion and plugging of the pores in the membranes. Roberts's research was concerned with the microstructure and chemical reactivity of metal and composite membranes, the objective being to identify compositions and pore distributions that limited the effects of corrosion and enabled isotope separation. This work on actinide isotope separation became of increasing importance to the British bomb project, particularly as restrictions were placed on access to the US work in this area after the war. For Roberts this early work marked the start of a distinguished research career in actinide chemistry and also led to an enduring interest in applied science/technology and multidisciplinary research.

After the war, Roberts moved to Chalk River, Ontario, in 1946 to continue his research on the chemistry of isotope separation under the overall direction of John (later Sir John) Cockcroft FRS and supervision by Bob Spence (FRS 1959) (both later to be Directors of Harwell). Here he was introduced to plutonium chemistry and, working with Maurice Lister, achieved the first separation outside the USA of a minute quantity of a pure plutonium compound extracted from a fuel rod irradiated in an experimental pile assembly. A potentially disastrous incident from this period, which must have made a deep impression on Roberts—he related it on various occasions in later life, including in his speech at his retirement dinner at Harwell in 1986—concerned an accidental spill in his laboratory of the solution containing all of the separated plutonium (some 25 mg) that they had obtained so far. With great presence of mind and armed with special equipment—rubber gloves, a sharp knife and a bottle of nitric acid—the young Roberts cut the linoleum containing the spill, dissolved it in the nitric acid and eventually recovered almost all (more than 99%) of the plutonium. What must have been rather more difficult for Roberts to manage, given his reserved nature, was the distraught reaction of the young female assistant who on dropping the flask burst into tears and flung her arms around his neck for comfort.

The Harwell years

Roberts returned to the UK from Chalk River towards the end of 1947 and joined Chemistry Division at the Atomic Energy Research Establishment, Harwell, as a Scientific Officer. Harwell was at a very early stage in its development under its founding Director, John Cockcroft, and Roberts once again worked under Bob Spence, his Group Leader (and subsequently his Division Head). His return to the UK also enabled him to finally submit his DPhil thesis in 1948, following the delay due to his war work and time abroad.

A key factor in Roberts's decision to go to Harwell was the opportunity to work again with Bob Spence, for whom he had an enormous respect, both professionally and personally—he once referred to Spence as one of the finest human beings he had worked with. He also recalled that Harwell was very fortunate in having a founding Director of the calibre of John Cockcroft. Cockcroft's vision of what he believed Harwell should be, together with his leadership and personal qualities, were vital in attracting people of very high calibre and developing the establishment into one of the leading research centres in the world.

When Roberts joined Harwell it was very much in its pioneering days. The site was a sea of mud, with everyone living and working under very makeshift conditions. The total staff was about 1000, including some hundreds of scientists, many of them at an early stage in their research careers and with little experience in nuclear science and technology. Nevertheless, programmes were under way and the main lines of development were clear. It was a period of rapid development for Harwell; for example, the staffing level doubled within two years of Roberts's arrival.

In the early days there was understandably some unease among the local population, amplified in the local press. In response to these concerns the Harwell scientific community actively involved themselves with the local community. Led by Cockcroft, they talked with local people about their research to set their minds at rest about potential hazards, particularly those associated with radioactive materials. Over time the community was reassured and a good relationship was built up that was certainly well established during my time at Harwell from the early 1960s.

Inside Harwell there was a serious and dedicated atmosphere. The relatively inexperienced young scientists, mostly in their twenties, led by a few more senior people and inspired by Cockcroft, were committed to their mission of exploiting the peaceful uses of power from nuclear fission. This was the environment that the young Roberts was introduced into in 1947, and although he had some relevant experience from his wartime work it was a new and exciting venture for him; to the end of his life he remained a strong, although not uncritical, advocate for the benefits from nuclear power.

Although Harwell was not involved directly in the development of nuclear weapons or the engineering development and construction of nuclear power reactors, Cockcroft was clear that the priority for Harwell was to support, through high-quality research, the solving of the major technology challenges facing these projects. This work was held to be extremely important not only by Cockcroft's opposite numbers in the Atomic Weapons and Production groups (Bill (later Lord) Penney FRS and Christopher (later Lord) Hinton (FRS 1954), respectively) but also by government at the highest level. Specifically, Cockcroft was told by Prime Minister Attlee that Harwell's work was of the highest national importance and, as related by Roberts (notes by L.E.J.R.), he and his colleagues were in no doubt on this.

Research at Harwell

One of the early achievements at Harwell was to quickly build and operate two graphite-moderated reactors, the Graphite Low Energy Experimental Pile (GLEEP) in 1947 and the much larger British Experimental Pile 0 (BEPO) in 1948. The UK development programme of power reactors over the next 40 years was based on graphite-moderated reactors—Magnox and the advanced gas-cooled reactor (AGR). This required detailed programmes of study on the structure and properties of graphite particularly, because they would influence its behaviour in reactor cores. A key factor limiting the life of graphite-moderated reactors is the deterioration in moderator integrity under irradiation. Experiments and analysis to understand these aspects and develop predictive models remains a major activity in support of the operational Magnox and AGR power stations. Roberts's first task on joining Chemistry Division was a detailed study of the microstructure and chemical reactivity of graphite (2)*. He examined the pore structure of synthetic graphite and used liquid density measurements to show that a significant fraction of the pores were closed to external liquid and gaseous media. He also found that surface oxidation in the temperature range 430–500 °C (typical reactor operating temperatures) resulted in a density increase that was attributed to the removal of pore blockages. This work is relevant to the in-core behaviour of graphite, and reference was made to the significance of the density results when considered in conjunction with absorption measurements that would be discussed in a future publication. (However, I have been unable to locate this further discussion.)

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

A key development for Roberts in 1951 was to join the group led by J. S. Anderson (FRS 1953), when he was encouraged to study non-stoichiometric actinide oxides, building on the early work by Anderson on the thermodynamics of such compounds. This was the initial inspiration for his research over the next 15 years or so, during which he published seminal papers on the structure and behaviour of the actinide oxides.

Actinide oxides, particularly UO_2 and PuO_2 (and also ThO_2), are of central importance as fuel materials for fission reactors. An understanding of how their structure and thermodynamic properties relate to fuel properties and performance is relevant to the operation of nuclear reactors. Thus to work in this area was consistent with Roberts's underlying interest in the applications of basic science. Of particular importance are the initial structures and defect configurations as a function of composition and stoichiometry and how these are affected by transmutation during irradiation. Roberts's early work with Anderson focused on the reactivity and surface chemistry of the uranium oxides and urania–thoria mixed oxides (1, 3–7). Specifically, X-ray and density measurements were used to study phase relationships and crystal structures as a function of mixed oxide compositions and oxidizing conditions. An important conclusion from this work was to confirm that, for non-stoichiometric compositions, excess oxygen is accommodated as anionic interstitials rather than occupying cation vacant lattice sites. Workers in Roberts's group and elsewhere subsequently found, somewhat surprisingly, that this behaviour with regard to the take-up of excess oxygen did not apply to PuO_{2+x} and NpO_{2+x}.

Before joining Harwell in 1946, Anderson had been a senior lecturer in the Chemistry Department at Melbourne University, and in 1954 he decided to return as Professor and Head of the Chemistry Department. This coincided with Roberts's being awarded a one-year fellowship funded by the Commonwealth Fund. He spent the year at the University of California at Berkeley, where he worked with Professor Leo Brewer on exchange reactions of the uranium oxides and related oxides. Importantly, the fellowship gave him an opportunity to visit other centres for solid state research in the USA, and a key encounter was with Carl Wagner at Harvard, where he was introduced to the use of solid electrolytes to study solid state diffusion and thermodynamics in refractory oxide compounds.

On returning to Harwell in 1955 Roberts was able to broaden his research on the actinide oxides. The main emphasis switched to the determination of the thermodynamic properties and phase diagrams of oxide and mixed oxide systems as a group of non-stoichiometric compounds showing high defect concentrations on the anionic sub-lattice (8, 9, 11, 14). Roberts recognized that it was important to have an easily available and consistent set of thermodynamic data for uranium compounds. A key initiative that he took in 1959 was to arrange for a member of his group (Malcolm Rand) to spend six months working with O. Kubachewski, head of the thermodynamics group at the National Physical Laboratory and a world expert in the field, to learn about the methods being used there. Moreover, stemming from his earlier visit to Wagner, Roberts realized that the use of ThO_2–Y_2O_3 solid electrolytes was an excellent way of making precise oxygen potential measurements on non-stoichiometric oxides, a field that his group was to exploit very successfully in actinide oxide studies (see, for example, (13)). As well as research papers Roberts also published several major reviews on the structure and properties of the actinide oxides in journals and conference proceedings (12, 15, 17, 19, 20, 22). The wider relevance of this work to nuclear power formed the basis of papers presented by Roberts and his Harwell colleagues at UN International Conferences at Geneva on the Peaceful Uses of Atomic Energy (in 1958 and 1964) and at International Atomic Energy Agency (IAEA) conferences (10, 16, 18).

Inevitably, as his scientific reputation grew both within and outside Harwell and as his qualities of leadership were increasingly recognized, Roberts was promoted to more senior positions. While still active in research he became leader of the Solid State Chemistry Group in 1958 and then head of the Radiation and Solid Chemistry Branch in 1961 (about half of Chemistry Division), before briefly becoming Deputy Head of Chemistry Division in 1968.

During this period, and as an early move to diversifying into non-nuclear work (see below), Roberts's interests in solid state electrolytes to measure thermodynamic functions of actinide oxides led to the idea of using the same electrolytes in high-temperature fuel cells (HTFCs) (for a review see Markin *et al*. 1976). It was shown that ZrO_2–Y_2O_3 has reasonable conductivity for oxygen ions at temperatures above 900 °C. These early results led Roberts to establish a joint programme with the Atomic Weapons Establishment at Aldermaston, funded by the Department of Trade and Industry (DTI) to investigate the possibility of building small experimental HTFCs based on this electrolyte. The feasibility of the approach was demonstrated. Parallel work was undertaken in the USA and now the technology has advanced to the point that units of up to 300 kW electric output are commercially available. This interest by Roberts's group in solid state electrolytes for use in power sources led in the 1970s to the programme at Harwell on sodium/sulphur batteries using β alumina as the solid electrolyte conductive to Na^+ ions at about 300 °C (Dell & Bones 1968). Subsequently, the Na/S battery was succeeded on grounds of safety by the $Na/NiCl_2$ battery and has culminated in the commercial manufacture of such batteries for use in electric vehicles and telecommunications applications.

In 1968 Roberts moved into the senior management team as a member of the Harwell Directorate. As outlined in the next section, this was a major change of direction for him and in particular marked an end to his direct involvement in research for the remainder of his time at Harwell (to 1986). It also marked the end of his casual dress—he generally came to work on his bicycle dressed in an old gabardine raincoat over a well-worn sports jacket. His colleagues do not remember seeing Lewis in a suit until his move into the Directorate, and they speculate whether his new senior colleagues had a word with him. More importantly, he continued to take a close interest in the technical projects, particularly those having links to solid state chemistry such as the battery project referred to above. Moreover, his strong research background remained at the core of his approach to the wide range of problems he encountered in his new management role and his later move into academia. To the end of his life he maintained his critical interest in scientific issues and, as friends and colleagues will acknowledge, he could always be relied on for shrewd but not uncritical advice.

Leading the Harwell industrial programme

Walter (later Lord) Marshall (FRS 1971) succeeded Bob Spence as Director of Harwell in 1967, and he immediately recognized the need to address increasing external pressures regarding Harwell's future role and funding. In early 1963 Harold (later Lord) Wilson (FRS 1969), Prime Minister of the Labour government, emphasized the importance of the scientific revolution, stating, 'Britain is going to be forged in the white heat of this revolution.' The Wilson government believed that government had a key role to play; a new ministry, the Ministry of Technology (MinTech), was formed to provide a focus for working with industry to promote the exploitation of science into technological applications. It was perceived that although the UK was internationally in the first rank in basic science it was less successful in its practical application. Thus there was an increasing debate about the balance of resources between those going to research and those going to development, raising the question of whether the UK was funding too much research.

Against this background, questions were raised regarding Harwell's future role. It was perceived (questionably, as it has turned out) that it had largely fulfilled its mission in laying the scientific and technological base underpinning the exploitation of nuclear power. The UK Atomic Energy Authority (AEA) was faced with having to run down its nuclear technology work, and this was set to impact particularly severely on Harwell: the laboratory was faced with the prospect of being run down very substantially unless a major new mission was identified that it might tackle. Marshall responded by identifying the opportunity for employing more widely Harwell's multidisciplinary base and experience in science and technology. Hence the so-called non-nuclear diversification programme was launched with the objective of using the laboratory's skills to support industry more widely. On Roberts's appointment as Assistant Director, Marshall asked him to lead the realization of this objective.

Roberts recognized that this would be a marked career change for him, away from experimental research, which he had very much enjoyed, into scientific administration on a major scale. Nevertheless he accepted the challenge and while Marshall took the lead in initiating the diversification programme, it was Roberts who made it happen against a background of scepticism and even some hostility outside Harwell. Even within the Harwell scientific community there were some initial concerns that the laboratory's culture and reputation for scientific excellence would be adversely affected. But this perception changed as the programme gained momentum, won external support and moved into new areas.

An interesting aspect is the contrast between Marshall's strong and extrovert personality and Roberts's more painstaking and thorough approach. Roberts must have found it an exhilarating, if sometimes hair-raising, experience to work as Assistant Director and subsequently Deputy Director during Marshall's period as Director. But the partnership proved to be very effective and the period 1968–76 was one of major transformation for Harwell.

The major challenge that Roberts had to address was to first establish the legal framework within which the non-nuclear work could be supported. Expansion of the Authority's work beyond the limits set by the original Atomic Energy Act (1954) was granted by the Science and Technology Act of 1965. This enabled the Authority to work in 'such fields of non-nuclear technology as the Secretary of State should require.' Roberts led the work at Harwell to define these Requirements and agree them with the government. The areas had to be based on the Authority's technical strengths while not encroaching on other institutions' technical areas. Each Requirement was quite broad, covering a major area of technology such as high-temperature chemical technology, heat transfer and fluid flow, and materials development, all of which had a clear synergy with the Authority's nuclear mission. Considerable skill was needed in the preparation and subsequent negotiation of the Requirements with the government, but success in this task was vital in laying the foundations to enable the Harwell non-nuclear programme to develop. Roberts's qualities, derived in part from his research background—meticulous attention to detail, scrupulous care in not being diverted from the brief and a natural authority in managing the Harwell team and negotiating with government representatives—were all key factors in achieving success.

The second key challenge was to obtain new funding for the non-nuclear work. In taking the programme forward Roberts adopted three underlying principles: first, to work within the existing technology base of the laboratory, consistent with the requirements of the 1965 Science and Technology Act; second, to establish strong links with Harwell's industrial customers, recognizing that success would be judged in large measure by industry's willingness to collaborate with and fund work by Harwell; and third, to behave in a professional commercial way in establishing a customer–contractor relationship with both government and industrial customers.

All of this involved a substantial cultural shift for Harwell. Major changes in management style and ways of working were required, including proactive marketing of its capabilities and products. It also required new ways of working with government and industry. An important initiative in which Roberts had a major role was the setting up of technical units to support government departments in policy development and implementation, two key examples being the Marine Technology Support Unit (MATSU) and the Energy Technology Support Unit (ETSU). The establishment of ETSU within the Authority raised questions of a possible conflict of interest in view of its historical mission to support the nuclear power programme. But a particular strength of Roberts was his ability to put in place organizational routes to mitigate such risks. A further successful venture was the setting up of 'clubs' where companies paid a subscription to gain access to research and data in specified areas such as heat transfer and fluid flow. These had the merit of establishing longer-term relationships with industrial customers, often leading to additional funding for new projects.

In his various lectures and papers (see, for example, (21, 23)) on the Harwell non-nuclear programme Roberts summarized some of the main measures of success and lessons learnt. One simple measure was that the funding going to the non-nuclear programme increased from less than £1M to about £4M over the first five years to 1975, representing about 50% of the laboratory's total spend. Initially, most of this was from the government with non-financial support from industry. But a second critical achievement was the increasing support and confidence from industry in terms of both funding and the increasing number of customers that returned. A third, more qualitative, measure that Roberts also attached great importance to was the benefits to the Harwell scientists working on the industrial programme in broadening their experience in relating and transferring their technology through to commercial exploitation. Characteristically, Roberts gave credit for this success to the number of excellent scientists at Harwell who responded to the chance of using their expertise in new applications. He also rightly paid tribute to Walter Marshall's drive and optimism in driving the programme forwards (48). But major credit must go to Roberts for his clarity in defining the objectives, laying the legal foundations and translating these into successful implementation. Above all, his personal qualities of integrity and clear principles were vital in winning the confidence of the Harwell staff and its external government and industrial customers.

Harwell Director

In 1975 Walter Marshall was appointed Deputy Chairman of the Authority, and Roberts succeeded him as Director of Harwell (figure 2). Traditionally the Harwell Director was appointed to the AEA Board. Marshall retained this responsibility until 1979, when Roberts succeeded him as a Board member. As the member responsible for research, Roberts took the lead in imaginatively developing the careers of talented scientific staff across the Authority and was chairman of the senior committee that oversaw their career development, a role he took very seriously.

As Harwell Director he retained overall responsibility for the continued development of the non-nuclear programme, but its detailed direction and management passed to others in

Figure 2. A formal occasion marking Lewis Roberts's succession as Director in 1975, with his predecessor, Walter Marshall, and his wife, Ann Marshall.

his directorate team. Harwell still had a major involvement in supporting the AEA's nuclear programme on both applied projects supporting specific reactor designs, most notably the pressurized water reactor and the fast reactor, and on the associated underlying research. He was also responsible for the important commercially oriented 'applied nuclear' work based on exploiting for industry and other external customers the expertise, techniques and facilities derived directly from nuclear research and development, including specialist analytical methods using, for example, the research reactors and accelerators.

Roberts had maintained his strong interest in and support for nuclear power, and his new wider role gave him the opportunity to get more directly involved in the AEA's work supporting the UK's nuclear programme. In particular, on joining the Board in 1979 he adopted the lead responsibility for radioactive waste matters because 'no-one else wanted to do it'. This was a characteristically self-deprecating statement from Roberts; in fact he was the obvious person to take this on given his strong research background in nuclear chemistry.

Harwell had developed a process for the vitrification of high-level waste with a view to subsequent burial in deep-level geological sites. Roberts was directly involved in work with the Institute of Geological Sciences to identify potentially suitable sites and proposals to conduct the necessary research. He was the lead witness in two public enquiries at Ayr in 1979 and Newcastle in 1980. However, although the inspectors at both enquiries found in favour of progressing with exploratory work, they were overturned by the government of the day. This reflected a lack of political will, underpinned by public hostility, to grasp the waste management nettle, a situation that persists to this day, not only in the UK but in all countries with civil nuclear programmes.

An important initiative by Roberts was to propose the formation of Nirex (initially the Nuclear Industry Radioactive Waste Executive; subsequently it became United Kingdom Nirex Limited) as a means of coordinating the waste disposal policies of the different key players in the nuclear industry, most notably the Central Electricity Generating Board (CEGB) and British Nuclear Fuels Limited (BNFL), and to provide a measure of independence. This was accepted by the industry and government, and in 1982 Roberts became the founder Chairman of the Nirex Board. Nirex performed much essential analysis, for example on waste categorization, volumes, radioactive characterization and requirements for disposal. Further proposals by Nirex to investigate four clay sites in 1985 were again rejected by the government, this time without a public enquiry. This, together with the earlier experience, left a deep impression on Roberts. He later recorded that 'we were slow to realize the true meaning of the Government's rejection of the original programmes in 1980 and all of the MPs' opposition to investigate the four clay sites'. He went on to point out that the fundamental issue was a lack of public trust in the strategy rather than a deficiency in the technical data. But in the continuing absence of a clear waste management strategy supported by the public, successive White Papers regarding the future development and deployment of nuclear power were meaningless.

Against this background Roberts felt it essential to make his colleagues on the Authority Board fully aware of the significance for the future of the failure by government to address waste disposal and particularly the selection of sites for exploration. Even though, as he said later, he did not then fully appreciate how the problem would bedevil things in future, he certainly did all he could to bring to the notice of the Board the fears he already had, to assist their strategic thinking on the future role of nuclear power.

More generally, Roberts made a major contribution over the subsequent years, giving many lectures and publishing important papers on both radioactive waste management and more widely on nuclear power (24–32, 35, 39, 40). As a result he gained wider public prominence (a role he probably did not relish), and even took part in a debate at the Cambridge University Union, where he opposed the motion 'that this house would halt the nuclear power programme', in which he was faced by Jonathan Porritt. It is interesting to note that Roberts's side won the argument and the motion was defeated. Roberts was exceptionally good at speaking and writing for non-technical audiences in clear and understandable terms. One of his colleagues commented that the inability to communicate clearly to a wider audience was the nuclear industry's Achilles heel and that Roberts was one of the few distinguished exceptions.

It is also interesting to note that this appreciation of the social dimension of nuclear technology chimed with Roberts's earlier concerns when working on the Tube Alloys project. He maintained a strong interest in this, not only with respect to nuclear technology but also as regards the wider question of how science relates to society; I consider this aspect of Roberts's life in a later section.

Roberts was the second longest serving Director of Harwell (after Cockcroft), a position of major influence, not only in the nuclear industry but also in the wider scientific and political world, including interacting with government ministers (figure 3). He filled this position with great distinction, having to lead the laboratory through a period of considerable change, including the continued reorientation of Harwell's role and major changes in the way it was funded. This change stemmed from a decline in Harwell's mission of laying the science and

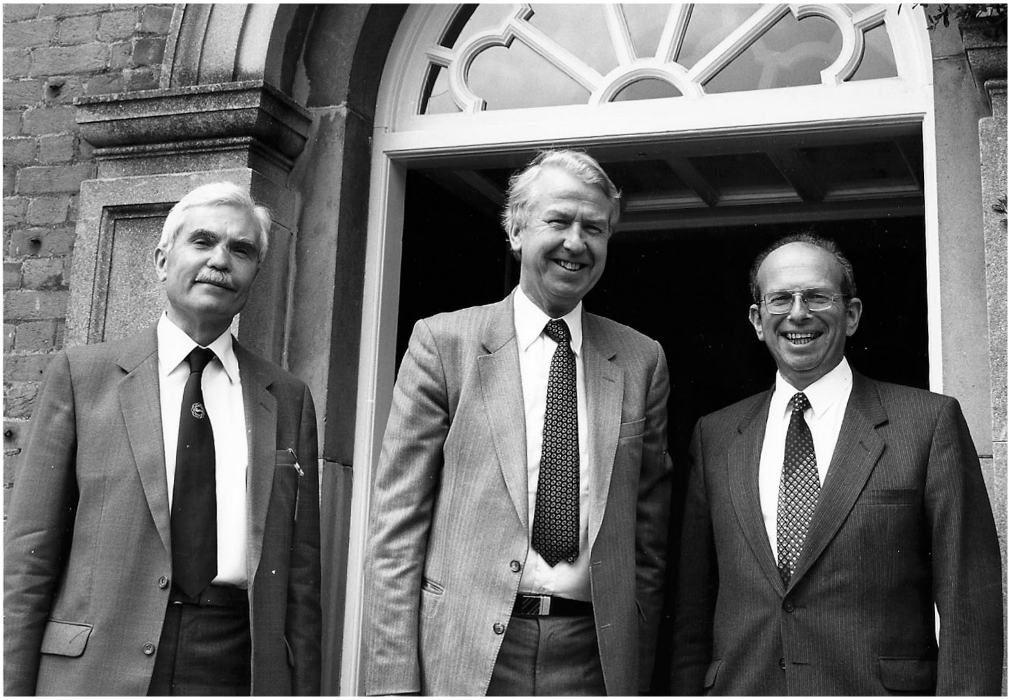

Figure 3. Lewis Roberts and the UK AEA Chairman, Sir Peter Hirsch FRS (right), with the Secretary of State for Energy, Peter Walker, during a visit in the early 1980s.

technology foundations for the Authority's nuclear programmes dating back to the mid 1960s. As already mentioned, the need for change was clearly identified by Roberts's predecessors as Director, particularly Walter Marshall, who provided the initial drive for diversification in both technical programmes and funding. But the pace of change increased under Roberts. Particularly significant was the introduction in the 1980s of a Trading Fund relationship with government, thus placing the basis of all Harwell's programmes on a customer–contractor relationship, with the associated greater commercial discipline that this implied. Although Roberts's earlier role in leading the development of the diversification programme was invaluable in preparing him for these new challenges, he nevertheless had a major task of leading Harwell and the Authority into this more commercial environment. Specifically, he took the lead on the Authority Board in persuading fellow Board members that it was a necessary way forward for the Authority as a whole. This had an important impact on the part-time members, who felt able to support the plan despite knowing that there was not unanimous internal support. Roberts's subsequent activities as Harwell Director in furthering the Trading Fund within Harwell flowed from this. From the laboratory's earliest days Cockcroft had established a culture of encouraging initiative and freedom of expression. The challenge for Roberts was to gain the support of the Harwell community to adapt to the new, more commercial, way of working without losing the enterprising spirit embedded in its cultural tradition that would certainly be essential in the new environment.

Although Roberts's quiet approach contrasted with that of his predecessor, he was equally clear-sighted and determined in leading the laboratory through the more substantial changes it faced in the 1980s. He was fair-minded and patient in settling differences of opinion, without ever compromising on key strategic objectives, and he led a notably harmonious senior management team. These qualities were vital in winning the support of all the Harwell staff, and he was held in great respect and affection. At the time of his departure in 1986, Roberts characteristically gave great credit for the success that the laboratory had achieved during his period as Director to the excellence of all sections of the staff. He commented that the ethos of the Harwell he left was still that of a public service laboratory working within a unitary organization, the UK AEA, to serve both the nuclear sector and the wider industrial sector. In later years he very much regretted the loss of this ethos, while recognizing that the organization could not withstand the multiple blows suffered by the nuclear industry over the years in terms of a loss of confidence in nuclear power and the associated reductions in funding.

University of East Anglia

In 1985 Lord Zuckerman FRS suggested to Roberts that he might apply for the new Wolfson Chair of Environmental Risk Assessment at the University of East Anglia (UEA). Zuckerman had been instrumental in founding the School of Environmental Sciences at UEA as a multidisciplinary centre of excellence covering subjects from geology to sociology. At the time, Roberts was nearing the normal AEA retirement age and it would involve a further major career change. Nevertheless, he decided to apply and, somewhat to his surprise, was appointed. In making this change he was following a long tradition of distinguished Harwell scientists who moved to academic posts, including his former mentors John Cockcroft, Bob Spence and John Anderson. In addition, the then Vice-Chancellor of UEA, Professor Mike (now Sir Michael) Thompson, was an old Harwell colleague, having been in Metallurgy Division in the 1960s before moving to academia as Professor of Physics at Sussex University. Thompson performed pioneering research on the structure of crystalline solids and the effects of radiation damage, a subject that had some synergy with Roberts's earlier research on the structure and defect configurations in the actinide oxides.

Roberts delayed joining UEA until April 1986 to enable him to ensure that the new Trading Fund arrangement was bedded in at Harwell. In taking up his new appointment he found 'the intellectual atmosphere stimulating and joining it was a privilege'. However, as many others have found, making the transition from a major research institution such as Harwell to an academic environment was something of a culture shock and it took some time to adjust to a completely different way of working. But, as Roberts recorded (notes by L.E.J.R.), he never forgot the 'warm welcome extended to this newcomer, with his background in the controversial area of nuclear power, nor the kindly support afforded by Lord Zuckerman when requested.'

During his time at UEA, Roberts maintained a strong interest in issues related to nuclear energy, and he continued to publish papers that made important contributions on radioactive waste management (35, 39, 40). He acted as specialist advisor to the House of Lords Select Committee for their 1988 study 'Radioactive waste management', chaired by the Earl of Cranbrook. His teaching commitments were relatively light—he taught a short course on the statistical record of risks and the technical aspects of risk regulation to third-year students, and some introductory lectures to first-year students. Thus he was also able to develop more widely his interests in environmental issues, particularly regarding their impact on the energy industries. An important initiative by Roberts was to found the Environmental Risk Assessment Unit (ERAU) with the initial aim of assessing and comparing risks in an objective manner and to contribute to the public understanding of relative risks. The Unit started at a modest level with three people and had grown to twelve by the time he retired in 1991. Roberts recorded that the subject did not fit easily into the prevailing mechanism of academic financial support, and he had to cast the net widely to win sufficient support. Core finance was provided by the Wolfson Foundation, supplemented by a portfolio of research contracts from both public (including the European Union) and private sectors. Roberts was able to draw on the wide network of contacts as well as the reputation that he had established during his time at Harwell. Given the interlocking nature, he saw the ERAU as a focus for coordinating interests across the School of Environmental Science and other schools at UEA such as the Climate Change Unit. A further illustration of the coordinating role of the ERAU was that it became a collaborating centre of the World Health Organization with the title 'Environmental Health Risk Assessment and Communication'.

While at UEA and after retirement in 1990 he published and lectured widely on environmental issues and risk with the objective of achieving a wider understanding of risk assessment and safety (33, 34, 36–38, 41–43, 46, 47). A particularly important task was being a member of the panel convened by the Health and Safety Executive that produced the very influential report *The tolerability of risk from nuclear power stations* in 1988 (Rimington *et al*. 1988). He also expanded his work with the ERAU to include a comparative study of the resources allocated to risk reduction in different industries, closely allied to the various factors affecting the perception of risks and to the risks that could follow climate change.

It is also interesting to note that Roberts, in his biographical notes deposited with the Society, made comments retrospectively that relate to the approach he adopted while at UEA. In particular he notes:

> from the 1970's onwards there was an increasing interest in the interaction of science and technology and of technology with politics. The study of technological risks leads inevitably to an interest in the way concepts of risk and safety are embedded in the cultural assumptions of a society. This subject or range of subjects becomes ever more interesting and intellectually challenging as the debate develops of the effects of a large and growing human population on the natural environment. How priorities for action are chosen is a question for a risk-oriented discipline and the mechanisms for making choices both nationally and internationally become very relevant.

Roberts's time at UEA was relatively short (1986–90), but it was a period of great achievement. He had built up the ERAU to become an influential body, and while retaining his interests in nuclear power he was able to consider the core issues such as waste management and safety in a wider context and to address in particular the thorny problem of perception and public trust. He clearly relished the greater freedom of an academic position and he responded very positively to the opportunities it gave him to exchange views with a wider range of people. One example of this is his interaction with Professor Derek Burke, the second Vice-Chancellor he served under, who encountered risk in an acute way in chairing the Advisory Committee on Novel Foods and Processes, which had to deal with the genetically modified (GM) foods issue. As Roberts recorded, 'there are similarities in the public reaction to GM foods and the endemic scares about radiation.' More generally, his period in academia allowed him time to reflect on the wider societal issues associated with science and technology, a subject of abiding interest throughout his professional career that I shall return to in the last section of this memoir. As at the time he left Harwell, Roberts paid generous tribute to the support and kindness shown him by his colleagues at UEA and they clearly held him in high respect and affection. It was a very rewarding time for him.

The 'retirement' years

Roberts continued to be very active professionally after his retirement from UEA, publishing papers, giving public lectures, and advising public bodies. He was heard to observe that on retirement 'they stop your salary, take away your secretary and throw you out of your office, otherwise nothing changes.' In his case he retained a strong professional interaction with his ERAU colleagues, allowing him to complete two studies he had initiated: 'An analysis of electricity generation—a UK perspective', carried out for Nuclear Electric, and 'Reducing global warming through the provision of hydrogen from non-fossil fuels', carried out in collaboration with ETSU at Harwell for the DTI.

Roberts also continued to serve the public interest more widely throughout the 1990s. Particularly notable was his appointment as Special Advisor to the Secretary of State for Wales in relation to a study of contamination with polychlorinated biphenyls and dioxins near a commercial incinerator in south Wales. This enquiry went on for four years from 1991 to 1995 and produced a series of four reports, all of which were published after review by Roberts. He also continued to provide advice on defence-related issues, serving as Specialist Advisor to the House of Commons Defence Committee until 1991, focusing particularly on issues such as the decommissioning of nuclear submarines, radiation protection of the civilian population, and the British nuclear testing programme in the 1950s. In addition he was appointed a member of the Independent Advisory Panel set up by the Ministry of Defence looking at the application of risk assessment methodology to the storage of explosives.

His advisory work went beyond government and Parliament. In particular he was involved in studies by Christian groups of environmental and energy-related matters. Thus from 1988 to 1992 he was a member of the Environmental Issues Panel of the Board of Social Responsibility of the Church of England (chaired by Professor R. J. Berry and later by Professor John (now Sir John) Polkinghorne FRS). He was also a member of the *ad hoc* 'Churches Energy Group' convened by Bishop Stephen Verney and chaired by Sir Frank Layfield (well known to the nuclear industry for his outstanding chairmanship of the Sizewell B public enquiry) and subsequently by Bishop David Bonser. The group published a series of papers in *Christian Action Journal* for the winter of 1993, including two by Roberts on the world energy situation and on the victims of climate change (44, 45) and a further paper in a document related to 'Christ and the Cosmos' Initiative (49).

Roberts continued to publish papers and lecture widely on environmental and risk-related topics. Most notably he delivered the 1992 Royal Society Rutherford Lecture entitled 'Achievements and prospects for nuclear power', first delivered in Delhi and subsequently at the Bhabha Atomic Research Centre Trombay and at Bangalore. He subsequently went on a lecture tour in 1993 to New Zealand, partly sponsored by the Royal Society and the Royal Society of New Zealand, where he spoke on problems of risk assessment and on the challenges and response to changing climate.

In the mid 1990s Roberts was a member of the National Academies Policy Advisory Group on Energy and the Environment in the 21st Century, which reported in July 1995. Subsequently he and I worked together as members of the Royal Society working group on

'The management of civil plutonium in the UK', and a report was published under this title in 1998 (Mason 1988). Roberts wrote two papers for the group on plutonium in the environment and plutonium as a reactor fuel. This issue is of particular importance in the UK because of the UK's practice of reprocessing civil nuclear fuel, partly as a necessity for Magnox fuel but also on the original basis that the separated plutonium would eventually be recycled as fuel in fast reactors. This possibility has receded with the withdrawal of UK support for the fast reactor programme. But the issue of what to do with the separated plutonium remains, and the Royal Society set up a second working group in the late 2000s that came to similar conclusions to the first group regarding both secure storage of the plutonium and the possibility of recycling in thermal reactors (following the practice in France and Japan). This second group published its report in 2008 (Boulton 2008) and although the government of the day apparently took it very seriously, the issue remains unresolved.

Roberts continued to take a close, although less active, interest in energy, environment and safety-related matters beyond 2000. As an example, shortly before his death he was reviewing a paper by a colleague (Derek Pooley) analysing the comparative effectiveness of wind and nuclear power in reducing CO_2 emissions—he was formulating his thoughts during his final days in hospital, but unfortunately there are no written records of these.

Science and society

As we have seen, a core theme running throughout Roberts's life as scientist and leader in his profession was his close interest and appreciation of the societal impacts of science and technology, including the development of policy. This stemmed from his strong sense of humanity, public duty and responsibility. An early example (recorded in a BBC interview in the late 1970s) related to his undergraduate and postgraduate years at Oxford and Chalk River. He recalled that in Oxford he and his colleagues were part of a small isolated team working on isotope separation. 'We knew very little of the general thrust of work in America and Canada or about plutonium or indeed about nuclear reactors.' Nevertheless, Roberts and his colleagues at the Clarendon Laboratory were quite concerned when the American project reached its successful conclusion with the dropping of the bombs on Japan. On his moving to Chalk River not only was the technical distinction fairly sharp but there was quite a change in atmosphere that was somewhat curious to someone fresh from the UK. As Roberts recorded in his BBC interview:

> The people in Canada seemed to me to be taking a much more relaxed and longer view of the development of nuclear power. They were of course a much larger group of people and perhaps not so ingrown. Yet it shocked me that there was so much less political discussion of the consequences of the military use of atomic weapons than we had indulged in during the last days at Oxford. We at the junior levels of the project had known what we were working on, of course, and there was a feeling of satisfaction that the work had been successful in the military sense. But the way in which the bomb was used and the realization of the enormous power of the weapon did cause us great concern. I think we made the imaginative leap to the conclusion that the world had virtually entered a new era, certainly in the military sense, almost overnight, and there were several very anxious discussions as to the consequences of the bomb, the proper attitude that scientists should take and whether there was anything constructive that ought to be done.

On his return to the UK to take up his appointment at Harwell, Roberts joined the British Atomic Scientists Association (BASA), which had been formed in 1946 with Joseph (later Sir

Joseph) Rotblat (FRS 1995) as its first executive Vice President. Full membership was initially restricted to scientists who had worked on the allied atomic bomb project in World War II, although the membership was soon broadened to include people who were outside this select group and who were not necessarily scientists but were interested in the Association's aims. BASA was politically neutral and was concerned with UK public policy regarding the applications and potential dangers of nuclear physics. Many eminent scientists, most of them Fellows of the Royal Society, were members; the Board included (as well as Rotblat), Cockcroft, Rudolf Peierls, Marcus Oliphant, Kathleen Lonsdale, Nevill Mott, Harrie Massey, Mike Thompson, Patrick Blackett and Basil Schonland (who succeeded John Cockcroft as Harwell Director). BASA communicated its views through publications (including *Atomic Scientists News*), reports and public meetings, and a particularly novel venture was the Atomic Energy Exhibition, the so-called Atom Train. This was a mobile museum featuring models placed in two railway carriages, illustrating the peaceful and military uses of atomic energy. The Atom Train toured through the British Isles and even visited Scandinavia and the Middle East. One of Roberts's earliest involvements in the work of BASA was to go with the Atom Train to his home town of Swansea along with Brian (later Lord) Flowers (FRS 1961). He recalled:

> the public interest was quite amazing. Hundreds of people came in and we talked to them all day—all sorts of people from schoolchildren to old age pensioners and we went round Swansea giving lectures in schools. I remember that I talked to the Rotary Club, but we talked to every club that would listen to us.

As a further testament to Roberts's ability to communicate to a lay audience, one attendee commented that he gave the only coherent talk.

Eventually BASA was dissolved in 1959 as a result of a lack of resources; its role was taken over to some extent by Pugwash, an international body also formed on an initiative by Rotblat, but the latter's focus has been more on the military aspects of atomic energy and particularly the nuclear disarmament issue.

It is clear from Roberts's remarks during the BBC interview that involvement in the work of BASA brought with it an early realization of the wide spectrum of views regarding atomic energy and its uses. It also induced a greater tolerance for other views. He recalls that one very distinguished scientist took part in the Association's work largely to press her view that scientists should not work on the military aspects of atomic energy, neither should they ever work under conditions of secrecy. Roberts commented, 'that was a perfectly respectable but rather extreme point of view.'

Another example of Roberts's balance, understanding and compassion relates to the arrest of Klaus Fuchs. When he first heard (during a meeting of BASA), Roberts did not believe it, thinking that some dreadful mistake had been made, for example over some breach of rules that Fuchs was being hounded for. When he was convinced of the story's awful truth he felt, like all of his colleagues, very much betrayed and terribly angry. It was only later that he formed a more balanced judgement and some feeling of compassion returned. Roberts also recalled that some of the statements Fuchs made during his trial went a long way to assuaging the feelings of rage and betrayal his actions had aroused at Harwell. These statements, that he had been worried about the effect of his actions on Harwell because of his loyalty to his colleagues, were in Roberts's view sincere and reflected Fuchs's sorrow that he had betrayed a trust. But there is no doubt that Fuchs's betrayal did great damage to US–UK relations, particularly with regard to the military uses of atomic energy, that took many years to repair.

As reflected in his many publications and lectures, the difficulties faced by nuclear technology in terms of public confidence were a particular concern for Roberts. He addressed many of the key issues underlying these difficulties in his book *Nuclear power and public responsibility* (29). As well as setting out the scientific background, the book addresses such thorny issues as the principles behind the regulation of radiation exposure, the risk of accidents and the cost of safety and radioactive waste management, and its potential impact on our environment. His move to UEA enabled him to develop his thinking on risk assessment more widely (33, 34, 36, 37, 40). A theme that particularly concerned him was the difficulty in communicating complex issues related to the risks and safety aspects of technologies. He saw this as having an impact on public responses that in turn influence government policies, particularly as they relate to the applications of new technologies. Although this has clearly been important with respect to nuclear power, the problem of public understanding and confidence extends to other technology-related issues, for example GM food, radically new medical treatments such as the use of stem cells, and climate change. Again, the lack of trust by the wider community on such issues stems from the inability of 'experts, to communicate the issues in a clear and understandable manner', a weakness that Roberts had worked hard to overcome in the case of the nuclear debate.

In notes he deposited with the Royal Society, Roberts reflected more widely on the science and technology interface with wider society. One aspect is the way in which concepts of risk and safety are embedded in the cultural assumptions of society. How priorities for action are chosen is a question for a risk-oriented discipline, and the mechanisms for making choices both nationally and internationally become extremely important. This leads to the crucial issue of how informed such choices and decisions are and the role of education. Roberts felt that the greater gap in the UK seems to be between the scientifically literate and the rest of the population, a gulf of comprehension that can be truly crippling. This is particularly obvious in questions involving hazard and risk, which tend to be emotive. A badly educated innumerate population is open to manipulation by pressure groups and by headlines that seek to shock (rather than encourage informed debate). The resulting political discussions on safety matters are distorted (and rarely based on evidence) and are far from serving the true cause of public safety. Roberts concluded that the only answer seems to be more and better science teaching in schools, with an early training in very elementary statistical concepts as part of the expected equipment of a 'numerate person'. This is an issue that has been widely debated by educationalists and policy makers in recent decades and is central to the current discussions regarding the school curriculum. Roberts, influenced by his years at Harwell and UEA, also felt that there were questions that needed to be addressed by university education, relating not just to the public understanding of science and technology but also to the proper balance between fundamental and applied research. It is essential that this balance be sought in an atmosphere of true mutual respect. Roberts proposed that there should be more use of taught postgraduate courses in the first year of a doctorate course, to consolidate undergraduate work and broaden minds. Again, these issues are very much at the centre of the current discussions of how universities can best respond to the needs of their students.

In conclusion

Lewis Roberts was distinguished both as an individual scientist and as an outstanding leader of scientists and major scientific endeavours. This is demonstrated by the published evidence, the many tributes from colleagues and the wider community that he interacted with, and his

Figure 4. Lewis Roberts with his wife, Mary, at a Harwell Directors reception for staff.

public recognition in terms of honours and awards. His approach to life was governed by clear principles founded in his Christian faith and a strong sense of public responsibility. The record demonstrates that he did not shy away from confronting difficult issues, nuclear waste management being just one example. But in doing so he always exercised balance and fairness in engaging with and understanding other viewpoints before reaching conclusions. It must have greatly distressed him to have experienced hostile, sometimes virulent ill-informed attacks, particularly during the period when he had a highly visible role in managing public enquiries and other debates on the waste management issue. But he demonstrated his innate leadership qualities in managing such experiences with a calmness, dignity and integrity that won wide respect.

Overall, Roberts had a very full and rewarding life underpinned by a long and loving partnership with his wife, Mary (figure 4), and a close relationship with his son, Matthew. Outwardly he had a rather reserved personality but with an underlying warmth and humanity and a wonderful sense of humour. Outside his very full professional life he was a keen and knowledgeable gardener, an ability that he was able to exercise in the extensive garden at his and Mary's house in Chilton village. He also maintained an interest in history (stemming from the excellent education he received at Swansea Grammar School), music and art, all of which provided a balance to his professional life. Lewis and Mary took part in every aspect of village life and were always generous in praising other people's contributions. It is clear from the many tributes after his death that those who came to know Lewis were rewarded with a friendship that was loyal and rich in understanding. A frequent comment from friends and colleagues is that he was a kind and honourable man and a gentleman in the very best sense of the word.

Honours and distinctions

1978 Commander of the British Empire
1978 Elected Fellow of the Royal Society of Chemistry
1981 R. M. Jones Lecturer, Queen's University, Belfast
1982 Elected Fellow of the Royal Society
1985–87 President, British Nuclear Energy Society
1992 Royal Society Rutherford Memorial Lecture

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