# Chapter 4. The Widening Circle

With the war's end, Joe Moyal was poised to enter another life. His reputation at De Havilland's had continued to rise and he was offered the job of developing a guidance system for the 'Black Knight' missile which would combine a mixture of the electronic and electrical engineering which, as he put it, he had 'exploited during the war'. But he had had enough of the technology of warfare. 'I was sick of war and research on war', he reflected later, and he was anxious to make revisions and headway on his quantum paper and extend his research in mathematics, physics and statistics.

His intellectual circle, moreover, was widening and moving him into congenial fields. His wartime contacts included his supportive Cambridge contacts, Maurice Bartlett and Dr. Harold Jeffries and, via Professor Fowler, other members of the Department of Mathematics.

**Figure 4.1. Maurice Bartlett, statistician – a valuable ally and colleague of Joe's**

J. Gani Private collection.

Maurice Bartlett was destined to become one of Britain's major statisticians. A scholarship boy at Queen's College, Cambridge, he had taken his first degree in mathematics, soaked up courses on statistical

mechanics with Ralph Fowler and statistical sources with Colin Clark, studied quantum mechanics with Paul Dirac, and launched into early research in mathematical statistics in his fourth year, publishing his first papers as a student. Graduating in 1933, he became an assistant lecturer in the new Statistics Department at University College, London, where he worked (among others) with the new Galton Professor, R.A. Fisher. Eager, however, to come to grips with the practice and application of statistics, he moved the following year to become a statistician at Imperial Chemical Industries Agricultural Research Station at Jealotts Hill, Berkshire. In 1938 he transferred to a lectureship at Cambridge and, as the 'phoney war' ended in 1940, he was allocated to a Ministry of Supply establishment devoted to rocket research first in Kent and later London.

Joe met him sometime during 1940-1. Born the same year in 1910, their meeting struck sparks; Joe the lively, mathematically talented engineer and Maurice, the shy, clever offspring of humble parents, whose interest in probabilistic physics had taken early root. In his autobiographical essay, 'Chance and Change', Bartlett recalls:

'It was during the war years I first met J. E. Moyal, through our mutual interests rather than by chance encounter. I had as part of my general interest in the role of probabilistic ideas in statistical physics, always been puzzled by the anomalous way in which probability had slipped into the new wave mechanics, not fundamentally but as an interpretation of the positive measure $\psi\ \psi^*$, where $\psi$ is the wave function. I heard, I think through J. O. Irwin (who was in Cambridge at the time), that Moyal, who had previously been in France, had been working on this problem; and this was to be the start of a long association between us.'[1]

Bartlett was immediately struck by Joe's knowledge of European work. Progress with 'the wave or quantum-mechanical problem', he acknowledged, was slow and limited in Britain where 'English statisticians for a long time had tended to believe that a traditional empiricism exonerated them from overmuch study of abstract continental mathematics'. He found Joe well acquainted with A.N. Kolmogorov's fundamental work published in German in 1933 and Khinchine's writings,

and, as he put it, 'Moyal's more general knowledge of European work in the theory of stochastic processes was a considerable stimulus to me'.

During 1943-4 the two corresponded extensively and it was Bartlett's interest and advice, as noted in Chapter 3, that encouraged Joe to discuss his evolving ideas on statistics and quantum mechanics with Fowler and Jeffreys, and hence to renew his original overture to Dirac. Clearly, Bartlett's role proved highly sustaining to Joe in his prolonged struggle with the high priest of physics and steered him to further contact with Fowler as his paper grew.

'I do not think I told you about my meeting with Fowler', Joe wrote Bartlett on 27 June 1944. 'What he finally suggested was that the parts of my paper not dealing with quantum theory should appear in the form of a book. Professor Hardy[2] and the Cambridge Press have now accepted it for publication as a monograph of 200 pages.'[3] Since Joe saw that this required an additional overview of all the relevant work already done on stochastic processes, he suggested a collaboration with Bartlett, a project which they mutually agreed to in 1946. Significantly then, while Dirac demurred over Joe's originality in his statistical research, the distinguished Professors Hardy and Fowler were urging it into major print.

A second valuable contact Joe made from De Havilland was with Sidney Goldstein who was destined to become an important academic colleague and friend. During the thirties, Goldstein was a Fellow of St. John's College, Cambridge, and lecturer in Mathematics. A man of diverse parts, he was also the acclaimed editor of the collective work, *Modern Developments in Fluid Dynamics* (1938), and a brilliant researcher and writer on aerodynamics, turbulence and the intricacies of the mechanics of fluids. At war's outbreak, he was seconded from Cambridge to build up a key group concerned with advanced research in aerodynamics and its applications, and it was in this role that he was in touch with Joe at De Havilland to discuss questions of Joe's work on turbulence.

Hence in the course of the war years, Joe Moyal had managed to penetrate the academic community and he knew for certain what he wanted to do. Yet his passage to an active participation in science-based research was

irregular and followed an independent route. Coming as he did from a secondary education in a country remote from science's established tracks, he had made his own way through advanced statistical, mathematical and physics training, but he lacked the personal and institutional mentoring that, traditionally, guides and supports the gifted researcher in an academic career.

His chance, however, came late in 1946 with an opening in the Department of Mathematical Physics at The Queen's University, Belfast. By then he had amassed a mixed but original collection of published scientific papers and some distinguished referees, and was appointed as Assistant Lecturer in Mathematics.

His departmental head was P.P. Ewald, the Professor of Physics. Ewald himself was a man of considerable distinction. German-born, a pioneer of the study of crystals by X-Ray diffraction, he had taught for sixteen years at Stuttgart University where he was a colleague and friend of Schrödinger. During 1937 - one of the many who fled the great centres of German physics - he left Stuttgart with his Jewish wife, declining to endorse 'German physics' and its rejection of 'Jewish relativity', and accepted a lectureship in physics at The Queen's University where he was appointed Professor in 1945. Recognizing Joe's ability, he promoted him rapidly to a lectureship.

This period at Queen's proved a vital academic launch-pad for Joe, introducing him to undergraduate teaching and course development and offering a congenial friendship with Ewald, whose interests embraced the interplay between mathematical formalism and physical phenomena. During his two years there he took the opportunity to visit the famous Dublin Institute of Advanced Studies in Merriot Square, Dublin, which Ireland's Prime Minister, Eamon de Valera (himself a former Professor of Mathematics) had established early in the war as a research centre for Mathematical Physics and Celtic Studies and to provide a safe harbour for Erwin Schrödinger and other eminent scientific refugees from Europe. If Joe met the famous Schrödinger on this visit, he left no formal account of it.

The Queen's University gave Joe a timely foot in the academic door and it was from there that he completed and submitted his paper on 'Quantum Mechanics as a Statistical Theory' for publication. Late in 1948, however, his star ascending, he moved to a lectureship in Mathematical Statistics in the Department of Mathematics at Manchester University where Maurice Bartlett had been appointed to the founding Chair of Mathematical Statistics and director of the new Statistical Laboratory the previous year. For Joe this marked a move to the heart of leading edge statistics and applied mathematics in Britain.

Manchester University enjoyed a particularly high reputation in science. Its professoriate contained a remarkable coterie of men who had played outstanding roles in national scientific projects in World War II. Its senior Professor of Physics, P.M. Blackett FRS (later Lord Blackett), belonged to the glittering cluster of young graduates at Cambridge in the physical sciences in the early 1920s which brought together such luminaries as Chadwick, Kapitza and Fowler, and rose to fame in 1933 when he confirmed the existence of the positron. He had filled the W.L. Bragg Chair of Physics at Manchester from 1937 and throughout the war had served on Britain's Air Defence Committee where he was a key player in developing the technique of operational research. In 1948 he won the Nobel Prize for Physics for his work on particle disintegration and cosmic rays. In Mathematics there was Max Newman and Sidney Goldstein, both Fellows of the Royal Society, recruited from Cambridge at the war's end and appointed respectively as Professor of Mathematics and Head of the Department of Mathematics, and Professor of Applied Mathematics. Together these two colleagues were bent on building a new internationally renowned and dynamic Department of Mathematics which integrated pure and applied mathematics and extended their applications.

Newman and Goldstein's scientific wartime experience (like Blackett's) gave a particular width of vision to this generation of men. Newman, a former university lecturer at Cambridge, teaching mathematics and conducting pioneer work on modern topology, had worked at Britain's secret code-breaking centre, Bletchley Park. There he turned statistics

to practical use by means of specially designed high-speed machines which both contributed to British success in deciphering German messages and ushered in an early development in electronic computing. At Manchester he fostered Britain's first two computers and added the famous wartime code-breaker, A.M. Turing (and his 'Turing machines') to his staff. Newman was known as a shrewd judge of mathematicians and his administrative style shaped a hard-working and harmonious department.[4]

Sidney Goldstein, for his part, was a luminous scholar with the gift for fostering talent and, in his aeronautical work at the Royal Aircraft Establishment, he had gathered a notable group of brilliant young researchers, one of whom, James Lighthill, he would bring to Manchester to succeed him late in 1950. Installed in the Department of Mathematics, Goldstein built a Fluid Motion Laboratory (the Barton Laboratory, later renamed the Goldstein Aeronautical Engineering Research Laboratory in his honour) on the outskirts of the city where experiments with supersonic wind tunnels and other facilities brought great benefit to theoretical discussion and developments at the university.[5]

Joe's transfer to this stimulating environment brought him enormous gain. Here his 'Quantum mechanics as a statistical theory' moved into early circulation and the terms 'Wigner-Moyal formalism', 'Moyal bracket' and the 'Moyal product' began to pass into the language of quantum physics. The Bartlett/Moyal paper, 'The exact transition probability of quantum mechanical oscillators calculated by the phase-space method', was also published during 1949. In the same period he worked up other substantial material from his original quantum document to participate with Bartlett and David Kendall in a ground-breaking Symposium of the Royal Statistical Society on Stochastic Processes. His 'Stochastic processes and statistical physics' was published in the Society's Journal that year. As Joe Gani summed up the papers from this pioneering Symposium, 'To many students and researchers, these three important symposium papers opened up new and important vistas of research.'[6]

During this productive year, Joe also brought into print two other diverse papers, a lucid, generalist paper, 'Causality, Determinism, and Probability', and 'The distribution of wars in time' which commanded some attention in the *Journal of the Royal Statistical Society*. The first was 'just a pot boiler', he said. 'The work I'd done on stochastic processes got me interested in the general problem of the relation between causation and probability theory and this was just a set of remarks on the subject - a philosophical disquisition which I sent to the journal *Philosophy*. I was amazed that it was promptly published!'[7]

In this lively interdisciplinary arena, he was promoted in 1950 to Senior Lecturer. Goldstein sought him out to give a series of seminar lectures on the statistical theory of turbulence then attracting attention from the work of Russian mathematicians. For this Joe examined the new literature including that of Batchelor and Taylor in England. 'I tried', he said,[8] 'to generalize the existing theory because like the rest of hydrodynamics or aerodynamics in those days the theory was developed on the assumption that fluids were incompressible which was an unrealistic assumption. So I introduced the turbulence terms, the pressure terms, and worked out the consequences where it wasn't difficult to see that the terms involving pressure were comparatively small but they were certainly not zero. I advanced a hypothesis that the noise which is produced by turbulence flow of jet engines (then becoming important as people wanted to abate noise produced by big jet engines) was due to these neglected terms which coupled the shear waves of turbulence to the compression waves in the fluid'. His paper, 'The spectra of turbulence in a compressible fluid: eddy turbulence and random noise', appeared in 1952.

In the vital field of stochastic processes, Bartlett and Moyal cherished their larger collaborative plan. Despite advances in the study and use of statistical methods and their application in biology and other sciences, begun in the nineteenth century by Francis Galton and Karl Pearson and culminating at Cambridge in the twentieth century in the work of R. A. Fisher, theoretical work in stochastic processes was limited to a few specialized monographs, and there was no general work on which

students and researchers could build. From 1946, the two prepared to produce a general book presenting the general theory of stochastic processes with special reference to its uses and applications in physics and statistics.

Their decision to split the work into two parts — Joe building on the original manuscript Professor Hardy and the Cambridge University Press had accepted for publication on the basic mathematical theory, while Bartlett dealt with an introductory discussion of mathematical methods and statistical techniques — held fire. While Joe achieved `near completion' of his part, Bartlett was eager for print and it was agreed that he should publish his section based on some earlier lectures, as *An Introduction to Stochastic Processes With special reference to its Methods and Applications*, which appeared in 1955. Bartlett's pioneering volume made frequent reference to Joe's work on mathematical theory as 'M'. But while Joe drew material from it for his ongoing papers (always keener on new ideas than writing them up), he left his book on one side and this early foundation composition remained in manuscript form.[9] Hence `M' disappeared from the many subsequent editions of Bartlett's successful book and his hope that Joe would author a third volume on a systematic discussion of stochastic processes in physics remained a pipe dream.

Joe's lapse over the collaborative project would earn him the reputation of being a perfectionist, 'one of those researchers who are very reluctant to publish anything until they have done everything,'[10] a view confirmed by the fact that, while his output of published papers was by no means huge, all were substantial and characteristically thorough and complete.

With the book in abeyance, Joe's research at Manchester turned to the application of the theory of stochastic processes to physical problems such as neutron diffusion and multiplication and cascades. During 1950 he published a lengthy study, 'The momentum and sign of fast cosmic ray particles', and, among others, prepared 'Statistical Problems in Nuclear and Cosmic Ray Physics' as an invited paper for the Proceedings of the 29th Session of the International Statistical Institute, Rio de Janeiro,

in 1955. His 'Theory of ionization fluctuations' and 'Theory of the ionization cascade' appeared within a further year.

Postgraduate students from overseas flocked to Manchester's Department of Mathematics. Alladi Ramakrishnan, having studied cosmic ray showers with Professor Bhabha at the Tata Institute of Fundamental Research in Bombay, came to work on the theory of point processes and was supervised by Joe and Bartlett. Another Indian student, Uma Prabhu, whom he was supervising, was passed on happily (as Joe departed on a visit overseas) to a surprised newly-arrived `postdoc', Dr. Joe Gani (whom Joe had encouraged to come to Manchester from The Australian National University), with the buoyant words, `You'll be alright, Joe. You can do it!'[11] Prabhu flourished and later became Professor in Operations Research and Industrial Engineering at Cornell University.

Among the undergraduate students drawn from Manchester and its surrounding region, often from families with scant acquaintance with university careers, Joe taught several young women who showed great promise in mathematics only to find, to his chagrin, that they subjugated their research promise to marry mathematicians of lesser skill. Characteristically, throughout his career, he sought to help and encourage women in his fields.

In addition to its scientific abundance, Manchester University offered a rich social milieu. Many of the science professors were Jewish: Goldstein, Newman, Bernhard Neumann, a refugee in the thirties from Germany now engaged (after challenging times) on group theory at Manchester,[12] and Harold Ruben, a fellow Senior Lecturer in mathematics and statistics. In addition, crossing cultures, there was the renowned political, diplomatic and parliamentary historian, Lewis Namier, who had held the Chair of Modern History at Manchester since 1931.

Namier had been Political Secretary of the Jewish Agency for Palestine for two years before his appointment to the University. Closely allied with Chaim Weizmann and now within a few years of retirement, the voluble historian enjoyed the company of the mathematical Israeli. He also picked his brains. A one-time businessman in the twenties, Namier frequently sought Joe's advice, as a probabilist and rising expert in a

discipline with its origins in games of chance, on a mathematical system to 'break the Bank at Monte Carlo!'

While the Jewish presence at the university was rich and energizing, anti-Semitism was not unknown in the town. Joe and his family, now added to in wartime by a son, David, made their home in a village outside Manchester where Joe developed warm friendships with the Unitarian clergyman and other neighbours. But hearing one day that his daughter, Orah, had been publicly described in a school class - in those recent post-holocaust days - as 'a dirty Jew', he arrived at the teacher's door with a whip.

His contact with Namier, and his close friendship with Goldstein, a committed British-born Zionist, who had also imbibed his passion for the Jewish State at the feet of Chaim Weizmann and who would take up the joint posts of Professor of Applied Mathematics and Vice-President of the Technion Institute of Technology in Haifa late in 1950, no doubt stimulated Joe's own thoughts about the possibility of returning as an academic to his own country which had become the State of Israel in 1948.

Memories of the land of his youth ran deeply in his psyche. Could he now contribute professionally to its development? He hoped he might and during the university vacation of 1951, he paid a brief visit to Israel. There he renewed links with old friends; but he also made contact with the new Weizmann Institute of Science which, two years earlier, had been founded at the gateway of the desert at Rehovoth for the purpose of conducting fundamental research.

Weizmann, Israel's first President and himself a distinguished scientist with a world reputation in organic chemistry, had long conceived a blueprint for the Institute as a national research centre that would contribute to the building of a new nation. However, it quickly appeared that, in an embattled country struggling to survive, pure research must be viewed in future terms and the early recruitment of scientists turned, not on well-established talent or highly original 'home-grown' researchers, but on practical scientists imported from abroad. The Institute's earliest appointments accordingly included an English infra-red

spectroscopist, a Scottish and an American crystallographer, an Indian dye chemist in protein chemistry, and a well-qualified applied mathematician from the United States. This last recruit soon found that his Department of Applied Mathematics was little more than an 'accommodation address' in which 'muscular mathematicians' were the Institute's choice in a land more needy of gravimetric surveys and seismic cross-sections than the applications of fundamental mathematics.[13]

Joe was deeply disappointed by this outcome. Indeed, his failure to be accepted in his own country as a `sabra' now making fundamental contributions to research in mathematics and physics abroad was a serious personal blow. He would follow Israel's varied fortunes throughout his life; but he never visited his country again.

At Manchester, however, his contribution to physics and probability were bringing him invitations to research centres around the world. During 1954, he accepted one from Professor Harry Messel, Head of the School of Physics at the University of Sydney, and took up a six months Visiting Readership there in Theoretical Physics. Messel was a rising phenomenon in Australian science. The child of immigrant Ukrainian parents in Canada, he had roared through degrees and scholarships, grasped a Fellowship at St Andrews University, Scotland, and moved on to take his doctoral degree at the Dublin Institute of Advanced Studies under Professor Janossy and Erwin Schrödinger, with the latter becoming his close friend. Vivid and flamboyant, Messel had come to Australia to a lectureship at the University of Adelaide, but, alerted to the opportunity of developing a great physics school, had quickly accepted the directorship of a major new School of Physics at the University of Sydney.

There in the early 1950s, catching big brains and bringing in highly qualified Australians and distinguished scientists from Britain, the USA and Europe, he had made fourteen new permanent academic appointments and began to build a dynamic relationship between his School, the community, and industry. Through personal contacts and compelling entrepreneurship, he rolled in major funding for his Science Foundation for Physics which he created to staunch the brain drain of talented young Australian scientists overseas.

**Figure 4.2. Harry Messel, Sydney University's dynamic director of the School of Physics until 1987**

Ann Moyal, *Portraits in Science*, National Library of Australia, 1994, p. 98.

Messel had first met Joe after leaving the Dublin Institute when he called at Manchester University in 1951. Joe's research was of interest to him and they talked of collaborative work. Though some twelve years Joe's junior, Messel felt a deep rapport with him. 'Joe and I were very close', he recalled in interview. `He had an enormously brilliant mind; an absolute genius, magnificent to talk to, so knowledgeable. There was also a softness about him. He was a very quiet, modest man, always polite, and he had that little grin'. Distinctively different in style and character, 'we got on like a house on fire', said Messel, 'We had a great regard for each other'.[14]

Joe arrived in Australia by ship in August 1954 and was at once struck by the egalitarian ambience reminiscent of his own country. The Sydney University janitor who appeared to help him with his trunk cheerfully joined him for a drink, and putting up at Wesley College, the Methodist college in the University grounds, he found to his amused surprise that resident staff members viewed him 'as a font of knowledge!'.

A step away, the shabby old Physics School with its long dark corridors, was alive with a brilliant group of researchers, 'a new-for-Australia theoretical group' working on cosmic rays and cracking the code of the unusual behaviour of many substances at very low temperature. These included Dr Stuart Butler, Dr John Blatt and a Visiting Reader from Zurich who announced at the time a major breakthrough in the theory of superconductivity and superfluidity.[15]

Joe's months in this circle sowed the seeds of a strong professional and personal attachment to Australia and, in one of his subsequent papers, he acknowledged Harry Messel's contribution to his thinking, together with Bartlett and David Kendall, all of whom 'first interested me in point processes'.

His second overseas visit took place in 1956 when he accepted a Visiting Professorship in the Department of Mathematical Statistics at Columbia University. On this occasion he joined Herbert Robbins, the Professor of Mathematics, a major contributor in statistical research and probability theory, and enjoyed his first taste of rigorous contact with American colleagues and the excitement of New York. In the summer of 1957, he was in the United States again, as Visiting Professor at the University of California, Berkeley, in the Department of Mathematical Statistics presided over by the legendary Professor Jerzy Neyman. There since 1949, this much-loved Polish founding father had organized and published the volumes of the *Proceedings of the Berkeley Symposiums on Mathematical Statistics and Probability* as a disciplinary four-yearly event and had, in the words of David Kendall, created a Statistical Laboratory in his Department 'to which all statistical magnets now point'. It was a centre to which Joe, too, would often return.

Between such visits, at home in Manchester Joe's ranging mind ruminated on another fundamental paper, `Discontinuous Markoff processes,' published in *Acta Mathematica* in 1957. Gani later wrote of this paper that it was `concerned with discontinuous Markov processes where the state of the system may change continuously or by sudden chance jumps. Such processes are specified by two functions: the probability of a transition without jumps, and the probability distribution of the first

jump time and the consequent state of the process. The total transition probability depends on both of these functions. Whereas previous work had concentrated mainly on jump processes only, Moyal was able to generalize existing results and derive new ones for the mixed case, which he analysed with his usual thoroughness.'[16]

Joe's capacity for significant overarching generalizations in probability and physics stemmed from a strong mix of creative imagination and a keenly analytical mathematical mind. `He represented to me', Gani asserted in his Inaugural Lecture as Professor of Statistics at Sheffield University in 1966, `the pure mathematician's approach to probability'. In this, Joe differed from his close colleague, Bartlett, who, grounded in classical statistics and deeply focussed in the discipline, was more `intuitive' in the approach he applied to a number.[17]

Certainly during his nine years at Manchester University, Joe grasped the opportunity to reveal the unique range of his scientific ability, gaining reputation as a mathematician in quantum mechanics and a mathematical statistician and probabilist. In all three he had proved the power of mathematics, in Moshe Flato's phrase, to 'be endlessly interactive'.[18] Essentially, he had demonstrated his capacity to innovate and generalize and bring a statistical theory to bear in quantum mechanics that would yield powerful and diverse ideas, while his work on random functions and random processes in a number of physical fields would provide the backdrop for his subsequent groundbreaking research on stochastic population processes.

Together with his diverse research, both at Manchester and Queen's Universities and as a visitor in academia overseas, Joe developed and presented a range of undergraduate courses in mathematical statistics and mathematical physics including mechanics, hydrodynamics, and electromagnetic theory, and offered advanced courses on quantum theory, statistical mechanics, the theory of turbulence, the passage of atomic particles through matter, and the theory of stochastic processes and its applications. Always eager to incorporate new material, he performed best with graduate students where his method of working things out on

the board and basing his lectures on his own research became a stimulating and challenging procedure.

Received widely as a Visiting Professor overseas, it seemed by 1957 that he had begun to set his sights beyond Manchester. His near decade at this premier University had proved invaluable. But now, his choice and decision formed to resign from the Department of Mathematics and accept a senior position in a country which was destined to become his major home base across the next 40 years.

## ENDNOTES

[1] M.S. Bartlett 'Chance and Change' in J. Gani (ed.) *The Making of a Statistician*, Springer-Verlag, New York, 1982, p. 47.

[2] Professor G.H. Hardy, Sadlerian Professor of Mathematics at Cambridge.

[3] Letter from collection of Joe Moyal Letters in the Bartlett Papers, 'Chance and Change', *op. cit.*, pp. 47-8.

[4] Max Newman Obituary, *Biographical Memoirs of Fellows of the Royal Society*, 1985, vol. 31, pp. 435-452.

[5] Sidney Goldstein Obituary, ibid., 1990, vol. 35, pp. 175.

[6] J. Gani, Obituary of Maurice Stevenson Bartlett, *Journal of Applied Probability*, 2002, vol. 39, p. 666.

[7] Oral interview 1979 *op. cit*.

[8] Ibid.

[9] Preface to the first edition of M. S. Bartlett, *Introduction to Stochastic Processes*, Cambridge University Press, 1955, p. xi.

[10] Quoted Gani, Moyal Obituary, *op. cit.*, p. 1013.

[11] Oral interview with Joe Gani by Ann Moyal, 3 February 2003.

[12] Emeritus Professor Bernhard Neumann, Oral History Interview by Ann Moyal, 2001. National Library of Australia TRC 2902.

[13] Richie Calder, *The Hand of Life. The Story of the Weizmann Institute*, Weidenfeld and Nicholson, London, 1959, p. 27.

[14] Professor Messel Interview with Ann Moyal, 9 July 2003.

[15] D.D. Millar (ed), *The Messel Era*, Pergamon, 1987, pp. 26-7.

[16] Moyal Obituary, *op. cit.*, p. 1014.

[17] J. Gani, 'Chance, Design and Statistical Prediction', Inaugural Lecture, 26 January 1966. University of Sheffield, p. 2.

[18] *The Power of Mathematics*, English edition translated from the French by Maurice Robine, 1990, p. 7.