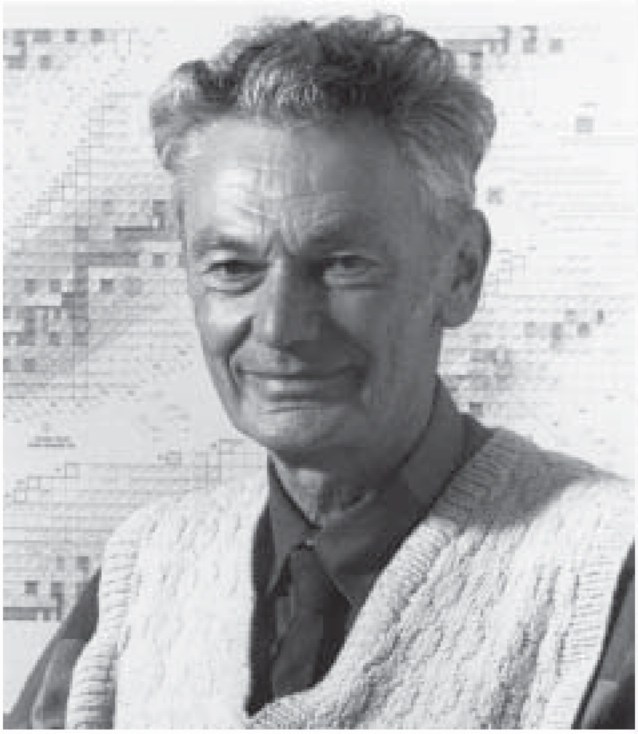
Departments of the Research School

Nuclear Physics

Nuclear Physics was one of the early departments of the School and has a long history of notable achievements. The following highlights are taken from the period 1970 onwards. References to earlier developments are contained in the main body of the text.



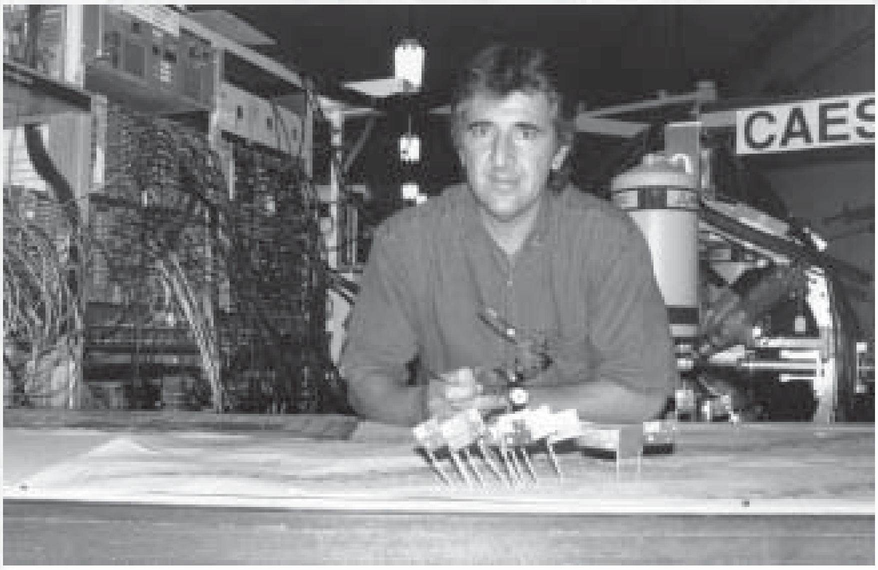
John Newton, head of Nuclear Physics between 1970 and 1988.

The outstanding achievements of the Department have rested in many ways on its ability to develop state-of-the art accelerator and detector facilities with modest resources and staff, and to operate these continuously and reliably. The result has been a record of competitive research in physics for an unbroken period of over 40 years. This is a tribute to the skill, dedication and foresight of technical staff (Tony Brinkley, John Harrison, Cliff Hill and Gerald Clarkson to name a few of the old guard) and academic staff (particularly Trevor Ophel), who have striven to establish and maintain an ethos of excellence to support the research.

When the most visible symbol of the Department, the 14UD accelerator, began producing beams in 1974, the Department had in concurrent operation a 26 MeV cyclotron, a 6MV EN tandem, capable of stand-alone use or injection by the cyclotron, and a 2MV single-ended machine. This suite of accelerators was the legacy of the efforts of Ernest Titterton, who had begun with a Cockcroft-Walton in 1951. By 1974, the 6MV tandem had supported over a decade of research which had established an international profile for the Department, particularly in the study of the level structure of light nuclei and of proton and alpha-particle capture that probed the Giant Resonance region of light and medium-weight nuclei. In the early 1970s it was being used for studies of single-nucleon transfer reactions with heavy ions near the Coulomb barrier, indicative of a world-wide trend towards the use of heavy ions. That interest coincided with a general change in research direction following the appointment of John Newton to the chair and headship of the department.

The successful observation of the 'Yrast and Statistical Cascades in (Heavy Ion, xnγ) Reactions', published in the January 1975 issue of *Physical Review Letters* (Newton, Lisle, Dracoulis, Leigh and Weisser), marked the start of the modern era of continuum γ-ray studies, which have been a major field of research since that time and which have played, in various guises, pivotal roles in understanding the behaviour of nuclei under extreme rotational stress. These 14UD pre-acceptance experiments marked a new presence for the laboratory on the international scene. According to an apocryphal story circulating at the time, the 'yrast' letter caused some consternation the day it was received by a competing group at the Lawrence Berkeley Laboratory. That group saw itself as the leader in the field and reportedly referred to the occasion as *Black Friday!*

Other areas developed in parallel, bringing work with the 14UD to prominence. Research on exotic light nuclei was to presage a growth area in the use of heavy ion reactions as a tool for determining the properties of highly unstable nuclei. An early high point was the difficult measurement of the mass of the very neutron-rich isotope ^{22}O, which was reported in *New Scientist* in 1976 as a significant



George Dracoulis, the present head of Nuclear Physics, in front of the CAESAR detector array.

advance in Nuclear Physics. The techniques developed here also formed the basis of our expertise in gas-filled detector systems, which was a key element in the success of the Enge spectrometer and of a number of the reaction studies that made major impacts then and a decade later. This knowledge was crucial to the establishment of the AMS program mentioned below.

Another group led by Ray Spear pursued nuclear quadrupole moment measurements and established a reputation for reliability in an area littered with irreproducible results. One of their successes, also deemed worthy of a news item in *New Scientist*, was the measurement of the quadrupole moment of the 3^- state of ^{208}Pb, reported in *Physical Review Letters* in February 1977. One of a number of definitive studies, it resolved a perplexing discrepancy between experiment and theory and established the reliability of the technique.

In the γ-ray area, research on continuum studies did not continue in the longer term, but in the next decade the Department developed a reputation for systematic and definitive spectroscopic studies by successfully exploiting the flexibility of the pulsed - beams from the 14UD and the range of instrumentation for γ-ray and electron spectroscopy. The broad expertise that was built up allowed an approach which was unusual compared to many competing laboratories, who often focussed on one particular technique. The reputation of the ANU group can be gleaned from exchanges at an international conference in Pittsburgh in 1990, where theorists suggested that suspicious experimental results should be sent to Australia for certification or correction !

This investment in a breadth of spectroscopic techniques led in the early 1980s to the measurement of both static and dynamic moments in a range of high-spin metastable states in heavy nuclei, particularly by Aidan Byrne and in collaboration with Alan Poletti of Auckland.

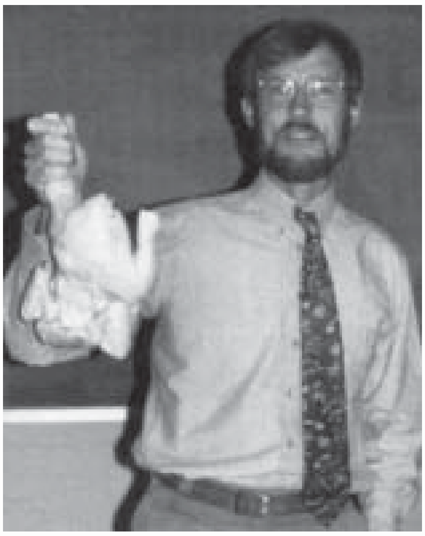
The measurements set records that still stand for the most extreme high-spin metastable states identified. More importantly, when the measurements were coupled with a theoretical approach which sought to treat all the experimental properties on an equal footing, the combined approach overturned accepted and oft-repeated notions of how these states were formed. They were thought to be examples of the stabilisation of a pancake-type distortion of the nucleus caused by a concentration of protons and neutrons orbiting in the equatorial plane. This was shown to be but one factor, the more crucial one being the coupling of the motion of specific orbits to the octupole vibration of the core nucleus. The successful translation of this sort of coupling to the many-particle case provided the basis for explaining the static and dynamic electromagnetic properties of many exotic states, many more of which were subsequently identified. A key breakthrough in the theoretical modelling was due to an MSc student, Stephen Poletti, whose thesis was awarded the 1986 ANU Crawford Prize. A distinguished referee for that award stated ‘The calculations provide for the first time a consistent explanation of a wide range of previously unexplained nuclear properties.

The identification and characterisation of metastable states in deformed nuclei is another area where a major impact has been made recently. By improving the instrumental sensitivity by an order of magnitude, it was possible to expose another layer of detail, thus resolving a long-standing anomaly in forbidden decays (*Physical Review Letters* , April 1991). What had been a mysterious decay in ^{179}W was naturally explained by an intermediate path involving quantum interference effects between close-lying states. Serendipitously, the intermediate states revealed arose from a structure involving rotation in the nuclear system tilted (at 45^0) to the principal axes of deformation, along which previous limits of motion were thought to be concentrated. This tilted motion is claimed to be a general phenomenon but is controversial. The group, in a fruitful collaboration with Phil Walker and co-workers from the University of Surrey, has continued to lead the way with the recent identification in a neighbouring nucleus of the highest-seniority multi-particle state with an associated collective band yet found (*Physical Review Letters*, July 1995), allowing another aspect of collective-particle motion to be probed.

The techniques honed for nuclear physics and the beams offered by accelerators often lead to application in, or stimulation of, other areas in physics and science. By the early 1970s, Peter Treacy and Hal Hay had ventured into a number of areas under the coded banner of ion-solid interactions. This research had sprung in part from pioneering work on beam-foil spectroscopy and from a general interest in atomic effects in solids and particularly in crystals, which used both light and heavy beams from the 2MV and the 14UD accelerators.

The present research program devotes over 20% of the 14UD accelerator time to studies using Accelerator Mass Spectrometry (AMS), established in 1985 by Trevor Ophel and Keith Fifield with considerable encouragement from the then-Director, John Carver. Initially aimed at hydrological studies in Australia using the isotope ^{36}Cl, the program has diversified into other isotopes and other fields as disparate as global climate change and bio-medicine. Successes in this area have relied on the ability of the accelerator to operate stably for long periods at high voltage, making the ANU system the most sensitive in the world for ^{36}Cl. Fifield, in collaboration with a group from the Chemistry Department of the University of Manchester, recently demonstrated the capability for measuring precisely and reproducibly very low concentrations of ^{26}Al, introduced as a tracer for the uptake of aluminium by the body, thereby providing a new tool for the study of the biochemistry of aluminium.

Understanding the dynamics of heavy ion reactions and of nuclear matter impinges on all nuclear physics research. The Pawsey Medal, which recognises excellence in research by young scientists, was awarded to David Hinde in 1992 for innovative work which showed that global studies involving absolute cross-section measurements were imperative for a proper understanding of the fusion-fission process. That work was followed by novel studies on the dynamics of nuclear fission enriching the jargon of the field with the term ‘neutron clock’, but more importantly providing insights into



Keith Fifield asserting that he can measure aluminium in a chicken at Founder’s Day 1994.

The Pawsey medallists, Andrew Stuchbery and David Hinde show off their medals.

A celebration of the signing of the ANU-EPSRC agreement. L to R; Trevor Ophel, Max Neutze, the Director of the Institute, David Weisser and George Dracoulis (September 14 1992).

Mild-mannered Jack Leigh on the attack.

nuclear viscosity. Such successes, fostered in this case by John Newton and Jack Leigh, attract many imitators and illustrate again the worth of systematic and sustained studies exploiting both accelerator capabilities and instruments developed within the School, a style which has become a hallmark of the Department.

Just one year earlier, the 1991 Pawsey medal had been awarded to Andrew Stuchbery, for contributing to elucidation of the origins of the very large and anomalous magnetic fields experienced by ions moving swiftly through matter and for using those fields to measure magnetic moments of very short-lived nuclear states, thus providing critical confrontations for theory. This was a line of research begun at the ANU by Herb Bolotin from Melbourne University, a consistent user of the facilities available at the School.

The willingness to invest in precise and systematic studies again bore fruit with the demonstration in 1991 (*Physical Review Letters*, December 1991) that, if measurements of the cross-sections for heavy ion fusion reactions could be carried out sufficiently accurately to allow reliable extraction of the second differential with respect to the beam energy, then the influence of the structure and excitation modes of the projectile and target would be revealed and insights into a consistent interpretation of sub-barrier tunnelling effects would become accessible.

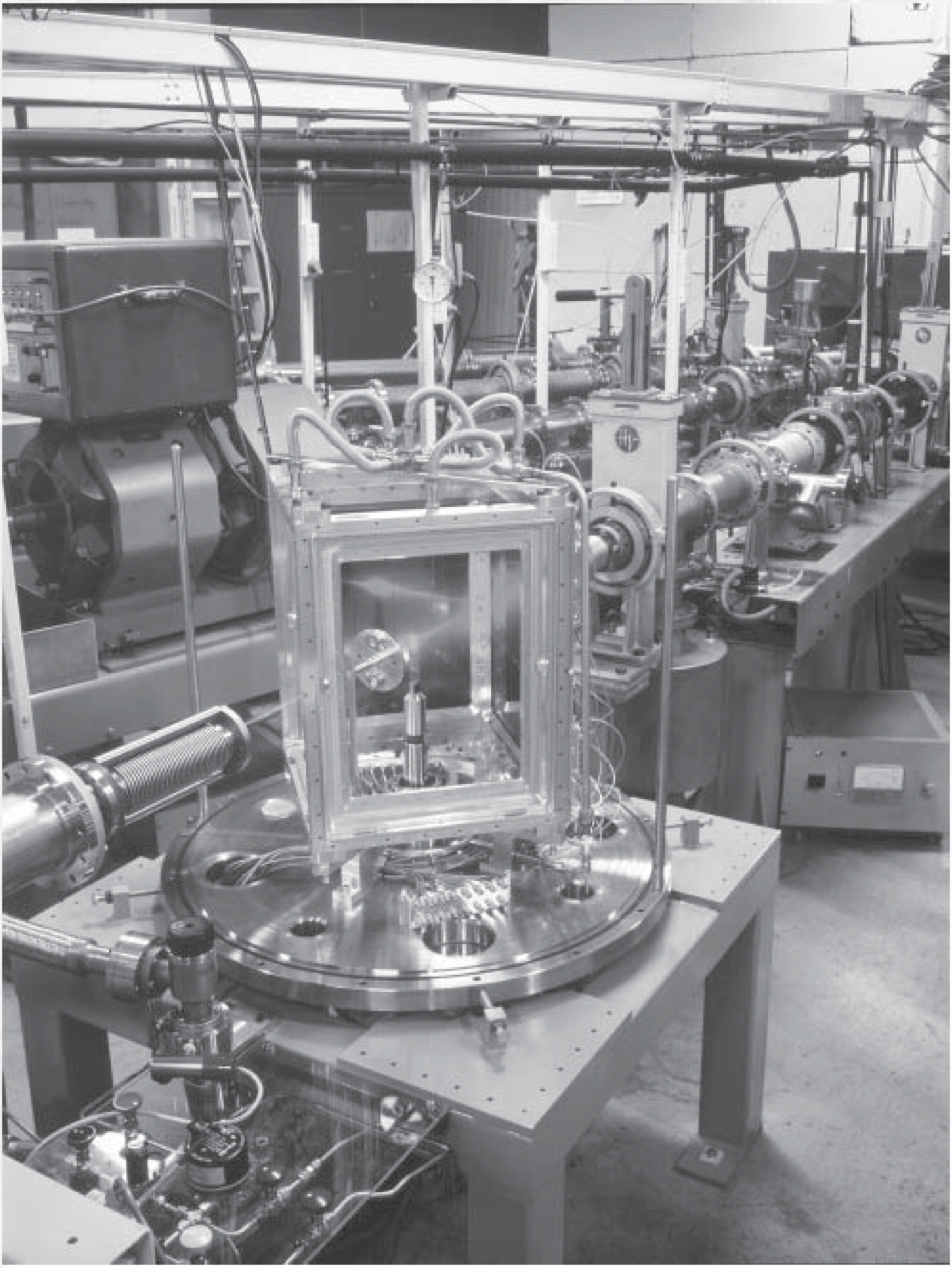
This program, led by Jack Leigh and stimulated by theoretical ideas from Neil Rowley of the Daresbury Laboratory, has been influential in re-directing the thrust of international research in heavy ion fusion. Referring to these advances, the Long-Range Plan for Nuclear Physics in the USA drafted in 1995, stated ‘The mapping of complex barrier distributions in heavy-ion fusion reactions is a breakthrough that will have continuing significance’.

The Department continues to build on the tradition of providing state-of-the-art technology in accelerator facilities and instrumentation. Progress is evolutionary and, while the Department celebrates its history, it looks to the future and its younger staff. Of the ten tenured staff in place at the time of the installation of the 14UD, only one remains. The Department is poised again to build on its successes and pursue new directions with the imminent commissioning of the Linac booster, a major project led by David Weisser. The agreement between the ANU and the EPSRC (the UK Engineering & Physical Sciences Research Council) which led to the transfer of the booster from the UK to Australia has seen, in the period of construction of the booster, extensive use of the 14UD facility by British physicists, working both independently and in close collaboration with ANU staff.

The result has been new research, an invigorating exchange of ideas, an increasing international profile, and the establishment of a balance of internal and external usage, setting the pattern for the next decade.

George Dracoulis

Nuclear Physics (October 31 1968).
Nuclear Physics in a vintage year when Australian graduate students were plentiful and there were no fee complications for overseas students. The countries of origin of the 15 students were Australia (7), UK (2), US (2), Germany (1), Indonesia (1), Sweden (1) and New Zealand (1).
Ten of the technical staff - out of a total of 14 (excluding the microscope scanners) were "imports" from the UK. Only two were Australian. Thereafter, the composition of technical staff began to change rapidly as locally-trained technicians replaced the "old guard".
Back row L to R:
K. Coop, D. Baugh, W. Zuk, H. Cords, H. Owen, W. Caelli, K. Carter, A. Djaloeis, D. Rosalky, C. Osman, G. Carriveau, J. Harrison, C. Shaw, D. Powell, G. Symons.
Third Row L to R:
W. Lambeth, D. Kean, J. Hellstrom, G. Clarkson, R. Watson, S. Tucker, S. Whineray, W. Davidson, P. Dallimore, H. Read, R. Krege, J. Gower, D. Rowe, A. Freeman, W. Daniel, I. Graham.
Centre Row L to R:
N. Chin, V. Tippett, M. Strautmanis, V. Pfluger, Mrs Pound, L. Jokisch, A. Weatherall, J. Piluso, S. Cloud, C. Hill.
Front Row L to R:
N. Bowkett, D. Livesey, J. Black, R. Spear, T. Ophel, E. Titterton, D. Hebbard, H. Hay, J. Nurzynski, G. Din and H. Lefevre.
Absent: P. Treacy, W. Bourke, R. Turkentine and T. Brinkley (the photographer). Livesey and Lefevre were visitors from UBC and Oregon repsectively.



The CUBE fission spectrometer in Nuclear Physics.