



*Professor George Dracoulis
- Head of Nuclear Physics*

The Department operates the premier laboratory in Australia for accelerator-based research in nuclear physics, providing and developing facilities for local staff and national and international outside users. The facilities are used for postgraduate and postdoctoral training over a wide range of research, from basic to applied.

<http://www.rphysse.anu.edu.au/nuclear>

The Department of Nuclear Physics carries out a broad range of research, ranging from fundamental studies of the nucleus to the development and application of techniques for environmental science and the characterisation of new materials. Many of these exploit the unique capabilities of the Heavy Ion Accelerator Facility and its associated instrumentation.

The research program currently includes:

- Fusion and Fission Dynamics with Heavy Ions
- Nuclear Spectroscopy
- Nuclear Moments and Hyperfine Fields
- Perturbed Angular Correlations and Hyperfine Interactions applied to Materials
- Heavy Ion Elastic Recoil Detection Analysis (ERDA)
- Accelerator Mass Spectrometry (AMS)

Much of the research is collaborative involving other departments, research schools, universities and institutions. This year, extensive use of the facilities was again made by outside users including UK scientists who have formal access through the ANU-EPSRC agreement. Collaborations with outside groups and experiments at overseas facilities are also used by the various research groups to complement the local program.

The general research capabilities of the Department have been enhanced with the completion of a flexible data acquisition system capable of handling larger multiple-element high-resolution detector arrays and high count rates. In the fission-fusion area, development of the fusion product separator *SOLITAIRE* has continued with first experiments scheduled for early 2003. In spectroscopy, augmentation of the γ -ray array *CAESAR* is nearing completion following supplementary funding from the University's Major Equipment Committee, and new instrumentation for nuclear moments and hyperfine field measurements is being assembled, supported by an ARC RIEF grant. Support for a number of the Department's activities including the fission/fusion studies, the spectroscopy of metastable states and applications of Accelerator Mass Spectrometry have been won through applications to the ARC Discovery program, with funding beginning in 2003.

Maintenance and development of the accelerator facility itself is a continuing process and an integral part of the Department's research, with a demand from users for a broad range of energetic beams with precise energy and timing characteristics. Re-plating of LINAC resonators with the aim of increasing the high-field limits has continued, with a parallel investigation of plating techniques resulting in the successful development of a superior procedure for the plating of Pb-Sn superconducting surfaces. A new three-stub resonator has also been designed and a model tested that demonstrates large separation between accelerating and non-accelerating modes. A feature of the design is the significant reduction of demountable joint losses. Exploitation of multi-stub resonators could provide a convenient means of extending the mass range of beams accelerated by the LINAC to mass-100, a prospect to be pursued through applications to the ARC.

Following funding from the Institute Planning Committee the activities of the Accelerator Mass Spectrometry Group have been expanded and more closely aligned with environmental studies. Restructuring of the accelerator building to meet the increasing demands for AMS sample preparation, funded through the University's Capital Management Plan was also completed. The most recent staff change in this area was the appointment of a joint RSPHysSE/RSES Fellow (Dr M.T. Esat). Other staff changes in the Department include the departure of Dr R.A. Bark who is joining the iThemba Laboratories (formerly the National Accelerator Centre) in South Africa and the appointment of Dr M. Dasgupta to a standard position, commencing in June 2003.

Dr G.J. Lane will take up an ARC Fellowship in January 2003, based in this Department. Dr I.I. Gontchar has completed his term as a visitor /research fellow with the Fission/Fusion Group while two visitors to the Spectroscopy Group, Professor C-B. Moon (Hoseo University) and Professor C. Günther (University of Bonn) have also returned to their home institutions. Professor M.N. Rao from Sao Paolo spent most of the year with the PAC experimental group and Dr A. Mukerjee and Dr L. Wacker completed their postdoctoral fellowships with the Fission-Fusion and AMS Groups.

Research Summary

A number of long-term research projects in the area of **Fission and Fusion Dynamics with Heavy Ions** have been brought to fruition this year. In the process, three research strands, namely the experimental studies of fusion barrier distributions, fission and quasi-fission, and the break-up of weakly-bound nuclei, have been linked with the demonstration that the understanding of their inter-relationship can be exploited for the understanding of nuclear collisions as a whole.

The new approach developed by the Group to study the competition between nuclear fusion and quasi-fission (Nature 2001), and demonstrated for the case of ^{216}Ra , has been applied to a heavier nucleus, ^{220}Th . Measurements from other laboratories with projectiles ranging from ^{40}Ar to ^{124}Sn exist for this case hence measurements for the fusion of ^{16}O with ^{204}Pb have been made to complement the set. Comparison of the cross-sections shows that fusion with the heavier projectiles is suppressed by quasi-fission, typically by a factor of 10, even at energies well above the respective fusion barriers. This result (published in Physical Review Letters) completely overturns previous assumptions, and throws into doubt the "extra-push" model framework commonly used to interpret quasi-fission. Another series of reactions, forming ^{202}Po , have commenced and preliminary results suggest that conventional expectations will be proven again to be incorrect.

In other detailed measurements the Group has shown that the deformation-aligned nuclear ground-state spin has a large effect on fission angular distributions. The data are well reproduced by newly developed computer codes which can also be used to predict the effects on quasi-fission. A comparison with recent precision measurements of quasi-fission promises to test the understanding of the competition between quasi-fission and fusion in reactions involving statically-deformed nuclei.

Several different studies of the break-up of weakly-bound nuclei have contributed to the development of a consistent understanding of the effect of projectile break-up on fusion. One showed that break-up suppresses complete fusion substantially for ^6Li - and ^7Li -induced reactions on ^{209}Bi , and demonstrated quantitatively the importance of modelling post break-up fragment trajectories (a collaborative study with Dr K. Hagino, Kyoto). Another confirmed experimentally that there is, in contrast, no significant effect of break-up for ^7Li incident on the light nucleus, ^{12}C . A third has led to a new approach allowing a link to be made between sub-barrier break-up probabilities and fusion suppression at above-barrier energies. This work (published in Physical Review Letters) shows that break-up principally occurs close to the nuclear surface and

that a difference in fusion suppression for light and heavy target nuclei is expected, giving a quantitative explanation for the apparently contradictory results described above.

Dr Gontchar's theoretical study, aimed at a more complete understanding of fusion barrier energies and barrier distributions, was able to elucidate subtle geometrical effects in the fusion of deformed nuclei. A double-folding model capable of describing the fusion of both spherical and deformed nuclei was also developed.

In **Nuclear Spectroscopy** there have been significant advances in a number of areas. In collaboration with Professor C-B. Moon the Group has continued studies on soft nuclei with a comprehensive set of measurements on the odd-odd iodine isotopes, ^{118}I , ^{120}I , ^{122}I , and ^{124}I , resulting in extensive new information on the competing effects of shape changes and the coupling of proton and neutron orbitals.

Other studies of odd-odd nuclei have focused on the isotopes of tantalum, in particular ^{180}Ta and ^{176}Ta in a range of light-ion-induced studies intended to complement our extensive studies with heavy ions. Heavy ions favour the population of high-spin states, while fusion reactions induced by light ions, protons and deuterons, offer the hope of exposing the intermediate and low-spin structures. Both low and high-spin structures are needed to characterise such odd-odd nuclei, but an additional interest in ^{180}Ta is our claim that specific low- K rotational bands provide the pathway for the destruction of $^{180\text{m}}\text{Ta}$ in hot stellar environments, through resonant photon scattering and subsequent decay to the short-lived ground state.

Another major area of interest is shape co-existence, particularly in the region of the very neutron-deficient lead isotopes. Analysis of measurements carried out using Gammasphere at the Lawrence Berkeley National Laboratory and aimed at characterising the isomeric states identified in ^{188}Pb in our earlier work, have been completed and have provided comprehensive information on the subtle effects of triple shape co-existence in that nucleus. These results have also provided the basis for studies of the odd-odd and odd-A Tl isotopes whose spectroscopy should show the effects of uncoupled protons and neutrons on the underlying potential.

Related studies have focused on anomalies in the strengths of E3 branches from the 11^- yrast states. Following resolution of those problems in ^{192}Pb and ^{190}Pb , we have extended the measurements to ^{194}Pb , for which the published data were also anomalous, and finally to ^{196}Pb , where no branches were known. This has provided results from a range of lead isotopes that match neutron-deficient polonium cases and should allow a direct test of our contention that the large E3 strengths all have the same origin, specifically hybridisation of the 8^+ final state induced by oblate deformation.

A more dramatic example of shape co-existence in heavy nuclei is the phenomenon of Superdeformation. Despite the identification of over 150 examples, only a handful have been definitely linked into the spectrum of excited states, leaving their fundamental quantum characteristics uncertain. By bringing together the isomer techniques developed locally with the efficiency of Gammasphere at the Lawrence Berkeley National Laboratory, we have successfully identified direct decays from the Superdeformed band in ^{192}Pb , thus establishing

its excitation energy and providing a test of mean-field models. Further experiments in this direction are planned.

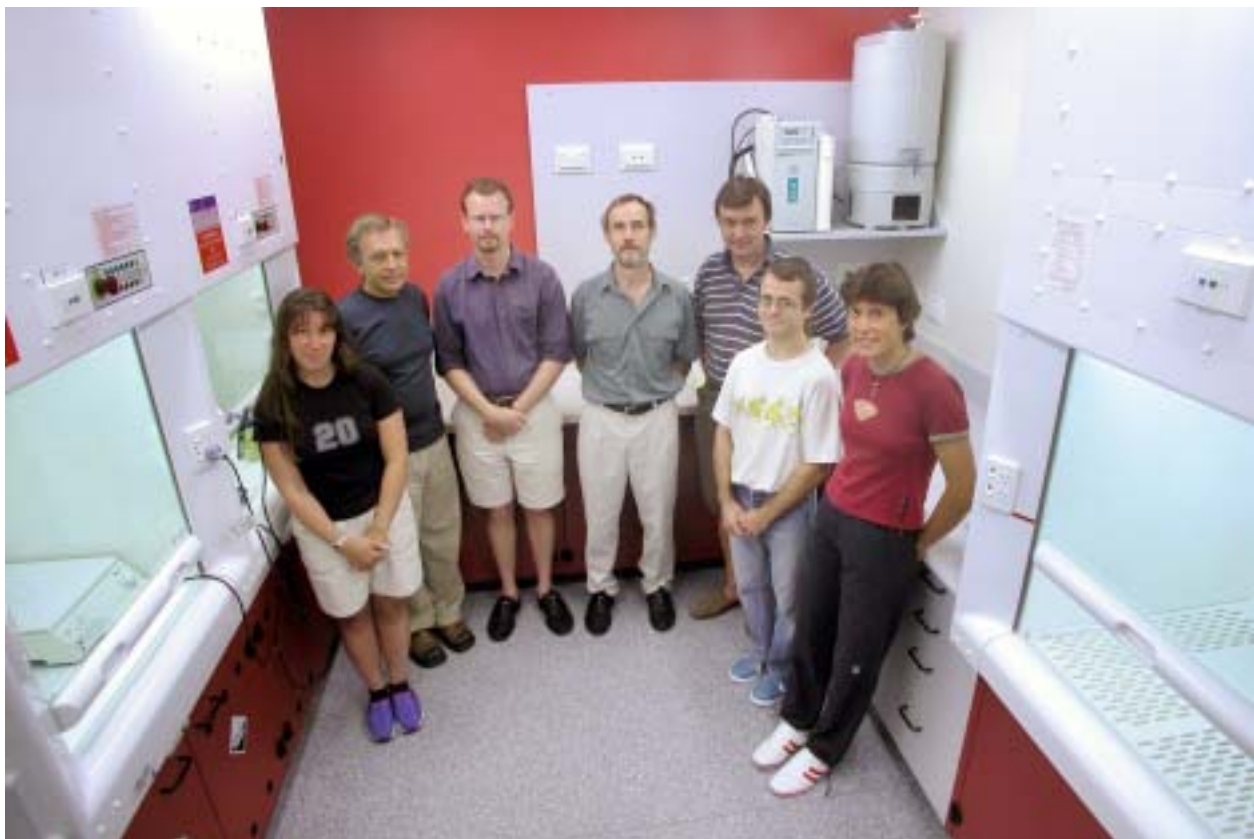
Professor Dracoulis, Dr Lane and Dr Byrne also participated in the first spectroscopy measurement with re-accelerated radioactive ion beams at the new SPIRAL facility at GANIL. The proposal was built on our interest in neutron-rich heavy nuclei such as ^{212}Po and ^{213}At , and aimed to use the $(^8\text{He},4n)$ reaction with the EXOGAM array, in its commissioning phase. In conjunction with such measurements we have continued to use the 14UD for incomplete fusion reactions to complement the information emerging from our experiments with deep-inelastic reactions, carried out locally and at Argonne National Laboratory. The main focus of these studies is the identification of configurations which involve the valence particles outside the $N=126$ and $Z=82$ cores, part of a collaboration with the Cracow, Berkeley and Argonne groups. A further development has been the instigation of a collaboration with the theory group of Covello (Naples) who are using the shell-model with realistic interactions to calculate the primary valence configurations in this region.

The new perturbed gamma-gamma correlation techniques for measuring excited state moments in radioactive nuclei (Robinson, PhD thesis) have led to elucidation of the role of quasiproton excitations in the high-spin continuum of neutron-deficient platinum nuclei. The formalism developed has also allowed the extraction of the spectroscopic quadrupole moments of the first excited states of the even-even isotopes $^{180-184}\text{Pt}$, the first measurements of quadrupole moments on such short-lived excited states in unstable nuclei.

While the studies described above are aimed at an understanding of basic nuclear processes and properties, other research activities have concentrated on the development and application of nuclear techniques to a broad range of scientific activities.

For example the implantation of long-lived nuclear species with known nuclear moments into special materials allows one to probe the properties of the materials by interpreting the perturbations of the nuclear ensemble caused by the local electric and magnetic fields. Such studies of Perturbed Angular Correlations and Hyperfine Interactions in Materials have been applied to semiconductor materials using both ^{111}In and ^{100}Pd radioactive probes. The ^{100}Pd work has focused on gettering by cavities in silicon as part of characterisation that includes EXAS, RBS and XTEM measurements. Distinct differences in PAC spectra have been observed, however it is not yet clear whether these are attributable to the migration of the ^{100}Pd probe into the cavities, or to a modification of the environment within the bulk material. The ^{100}Pd probe has also been used to investigate sapphire material, the initial result being that the anomalous behaviour observed as a function of temperature when ^{111}In was used as the probe, is not present.

To date, these radioisotopes have been introduced into the samples by a direct production/implantation technique using beams from the 14UD accelerator but this year has also seen considerable progress on the development of the ANU/ADFA 150 keV ion implanter located in the School of Physics at the Australian Defence Force Academy, UNSW. Beams of stable indium have been developed and the first implantations of radioactive ions, such as ^{111}In , is expected in 2003. Low energy implantation of radioactive ions will complement the high



The AMS Group, Laura Gladkis, Tez Esat, Tim Barrows, Keith Fifield, Vlad Levchenko, Steve Tims and Susi Olivier (visiting from Berne, Switzerland) in the sparkling new sample preparation laboratories



Students from University of Wollongong and ADFA who participated in the 2002 Workshop on Nuclear Techniques hosted by the Department of Nuclear Physics

energy recoil implantation of probe nuclei and open up new research possibilities in the areas of materials characterisation with Perturbed Angular Correlations (PAC) and Nuclear Magnetic Resonance of Oriented Nuclei (NMRO).

Work has also commenced on the study of amorphisation and annealing effects caused by electronic stopping of very heavy ions with energies around 100 MeV in compound semiconductors

Other activities in the area of materials characterisation with heavy-ion beams include the techniques of Heavy Ion Elastic Recoil Detection Analysis (HERDA). These have concentrated on the stoichiometric analysis of III-V semiconductor films such as GaN, InN and GaAsN, involving researchers from the Department of Electronic Materials Engineering, Macquarie University, and the School of Physics at the Australian Defence Force Academy, UNSW. A particular challenge is nitrogen depletion during analysis, which is most severe for InN. A model has been developed, which describes the depletion as a function of projectile fluence, so that the original nitrogen content of the samples can reliably be extrapolated. The HERDA results have contributed to an improved understanding of film growth conditions and structural and electronic properties of the films.

In related instrumentation development, research into the magnitude and origin of the pulse-height-deficit effect in gas ionisation detectors, as employed for ion beam analysis and accelerator mass spectrometry, continued with experiments probing the dependence of this effect on gas pressure. It was found that for propane gas, even for the heaviest ions the magnitude of the effect changes little over the range of practical gas pressures.

Another major application is Accelerator Mass Spectrometry (AMS) which uses the combination of a high efficiency (small sample) ion source, tandem acceleration, and heavy-ion

detection and identification techniques, to make highly-sensitive measurements of low abundance isotopes.

AMS projects in 2002 were spread across a broad spectrum of isotopes, from ^{10}Be to plutonium with new developments in the use of ^{129}I and ^{99}Tc , both of which required substantial refinements to chemical preparation and detection systems. It was also shown that radium isotopes can be measured with a sensitivity comparable with the best available from other techniques, but with considerable reduction in sample preparation and measurement time.

Commissioning of new chemistry and sample preparation laboratories has resulted in the enhancement of the in-house capabilities, allowing routine preparation of ^{10}Be , ^{14}C , ^{26}Al , ^{36}Cl and plutonium samples, in addition to the ^{129}I and ^{99}Tc noted above. Techniques for radium are also being refined. In the case of ^{10}Be , rapid progress in achieving consistently good samples of BeO was made possible by the use of ^7Be , produced with the ^{14}UD and the (p,n) reaction, to trace beryllium through the various steps of the procedure. Similar reactions have been used to produce $^{95}\text{Tc}^m$ and ^{96}Tc for use as chemical-yield tracers during preparation of ^{99}Tc samples.

Considerable effort continues to go into ^{10}Be for a number of projects on landscape denudation and sediment storage, including studies of catchment area evolution (Sierra Nevada Mountains of southern Spain, San Bernadino Mountains of California), landslide dating (Hong Kong) and sediment tracking (Yangtze River system in China and various Australian sites). Collaborations with groups in Glasgow, Edinburgh, Hong Kong and RSES are ongoing and the Department has hosted several overseas students and visitors for these projects.

An attempt is also being made to constrain the dates of the disappearance of glaciers from the Snowy Mountains by ^{14}C

dating of scarce charcoal fragments from basal sediments in Blue Lake. In another collaboration with the Department of Geology, a radiocarbon chronology has been established for a marine core from the southern end of the Great Barrier Reef with the aim of interpreting climatic signals in the core, and the evolution of coral reef formation on Heron Island is also being determined via radiocarbon ages of ancient corals retrieved from drill cores.

The focus this year of the groundwater collaboration with the Bureau of Rural Sciences (BRS) was on a joint collaboration with a group in Japan to study possible nuclear waste storage sites.

Technetium-99 is finding application as an oceanographic tracer and as a biological tracer in humans. Controlled releases of this isotope and of ^{129}I from the nuclear reprocessing plants at Sellafield and La Hague are well documented, and hence the $^{99}\text{Tc}/^{129}\text{I}$ ratio has considerable potential as an oceanographic tracer in the north Atlantic Ocean, a region which plays a key role in the Earth's climate. In collaboration with a group in

Paris, who perform the ^{129}I measurements, ^{99}Tc in samples of seawater from the Norwegian coast have been measured in order to validate earlier β -decay studies on seaweed. In the longer term, the intention is to measure the isotope in deep-water regions where seaweed is not available.

There is also a public health aspect as ^{99}Tc is concentrated along food chains to humans. In order to study potential radiological consequences of human consumption of seafood, we have shown that concentrations of ^{99}Tc in various bodily fluids can be readily determined by AMS, allowing reliable measurements of uptake and excretion. This work is in collaboration with Professor D. Oughton of the Agricultural University of Norway. Also in collaboration with Professor Oughton, plutonium isotopes in water and sediment from the estuaries of rivers in northern Siberia whose catchments are located near Nuclear-weapon production plants of the former Soviet Union have been measured.

Staff

Professor and Head of Department

George Dracoulis, BSc PhD Melb, FAIP, FAPS, Hon. FRSNZ, FAA

Senior Fellows

Tezer Esat, MSc Queens, PhD (joint appointment with Research School of Earth Sciences) (from July)

Keith Fifield, MSc Auck, PhD Penn, FAIP

David Hinde, BSc Manc, PhD, FAIP

Andrew Stuchbery, BSc PhD Melb, FAIP

Reader

Aidan Byrne, MSc Auck, PhD, FAIP

(joint appointment with Department of Physics, The Faculties)

Fellow

Tibor Kibédi, PhD Debrecen

Senior Research Fellow

Robert Bark, BSc Melb, PhD (until September)

ARC QEII Fellow

Mahananda Dasgupta, BSc MSc Rajasthan, PhD Bombay

Research Fellows

Igor Gontchar, Dip Omsk, PhD Tomsk, DSc Dubna (until August)

Greg Lane, BSc PhD

Clyde Morton, BSc Sydney, PhD (ARC Fellowship)

Stephen Tims, BSc, PhD Melb

Anna Wilson, BSc Bristol, PhD Liverpool

Post Doctoral Fellows

Timothy Barrows, BSc PhD

Lukas Wacker Lic, Phil-Nat PhD Bern (until December)

Anjali Mukherjee, BSc MSc PhD Calcutta (until September)

Visiting Fellows

Allan Baxter, BSc MSc PhD Melb (until January)

Richard Cresswell, BSc MSc Wrekin (until January)

Bertrand Giraud, BEng École Polytechnique, PhD Paris II (jointly with TP) (March – April)

Christian Günther, DipPhys Hamburg, PhD Bonn (February – August)

Chang-Bum Moon, MSc PhD Seoul (until August)

John Newton, MA PhD Camb, DSc Manc, FAA (Emeritus Professor)

Susanne Olivier, BSc Berne, Switzerland (from October)

Narayana Rao, MA Madras, PhD Cambridge (until April)

Ray Spear, PhD DSc Melb, FAPS, FAIP (Emeritus Professor)

Heiko Timmers, Dipl Phys Munich, PhD (jointly with EME)

Accelerator Research and Operations Manager

David Weisser, MSc PhD Minn, FAIP

Engineer

Nikolai Lobanov, BSc Moscow, PhD St Petersburg

Research Officers

Paul Davidson, BSc, MSc Auckland, PhD

Gordon Foote, BSc Lond, PhD

Vladimir Levchenko, MSc PhD St Petersburg

Technical Officers

John Bockwinkel, AssocDipMechEng

Alan Cooper, AssocDipMechEng

Alan Harding

Justin Heighway, AssocDipAppSci

John Kennedy

Lorenzo Lariosa

Alistair Muirhead

Bob Turkentine

Howard Wallace

Departmental Administrator

Marj O'Neill