

Supplementary Material

Radiocarbon Dating at the Museum of Applied Science Victoria 1952–70: A Pioneer Venture

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The Supplementary Material has three sections: the proceedings of the 1960 conference on radioactive dating; the memorandum from the Director at the time of closure of the laboratory in 1970; and a brief account of the establishment and operation of three other radiocarbon dating laboratories in Australia.

1. Dating Conference 1960

Australian Institute of Nuclear Science & Engineering

CONFERENCE ON RADIO ACTIVE DATING 1ST & 2ND April, 1960

The conference was held at the Australian Atomic Energy Commission (AAEC) Research Establishment at Lucas Heights, with Dr. C.M. Focken, Director of the Museum of Applied Science of Victoria, in the chair. Twenty eight people attended, including Anne Bermingham (Victoria), T.A. Rafter (New Zealand), and representatives of the AAEC, CSIRO, universities and the Bureau of Mineral Resources.

The meeting considered various dating techniques and their applicability to samples of ages: tritium (less than 100 years); carbon-14 (less than 50,000 years); thermoluminescence (less than 500,000 years); potassium-argon (greater than 1 million years); rubidium-strontium (greater than 60 million years); lead-uranium (greater than 100 million years). The main emphasis, however, was on radiocarbon dating.

Rafter spoke about the development of carbon-14, tritium and potassium-argon dating at the New Zealand laboratory, each of which had required about two years for establishment. There were five professional staff and seven technical staff plus workshop and drafting facilities. The laboratory performed about 150 carbon-14 determinations and 50 tritium determinations a year, but it was difficult to retain high grade staff for such routine work. The annual operating cost was about £4700; duplication of the carbon 14 facility would cost up to £5000, while the establishment of a whole dating laboratory, although without a mass spectrometer, approximately £10,000. Determinations on local samples were free, but Commonwealth countries were charged £25 and Americans £100 per specimen. Focken had earlier observed that charges by overseas laboratories varied from zero to £90, but one commercial laboratory in the US was charging \$350.

Birmingham reported that the Melbourne facility was almost ready for operation and would charge £20-30 for a determination. J.H. Green (Chemistry) reported that the facility at the University of New South Wales would be ready by the end of the year but was only expected to handle two specimens a week. A start had been made on a carbon-14 dating facility at the University of Sydney, according Dr C. Phipps (Geology), costing £2500

although a further £2000 and a full-time technician would be needed before it was operational. Other speakers outlined developments in dating of mineral samples. Addressing the demand for carbon-14 dating services, E.D. Gill (Melbourne) said that Australian museums would require carbon-14 and geological determinations but it was impossible to quantify the demand, and some university representatives had similar views. However, the New England (Dr R.L. Stanton, Geology) might require 20 a year, Sydney (Dr T. Langford-Smith, Geography, and Dr C. Phipps, Geology) 50, ANU (Mr J.N. Jennings, Geomorphology) 30, and Adelaide (Dr M.F. Glaessner, Geology) up to 6. Summing up, Focken said that it seemed that the two laboratories soon to be operating would be able to meet the need for carbon-14 dates and that 'the Institute's best approach to this problem would be to take all the steps it could to assist these laboratories to become operative, as soon as possible, and to maintain their service, once established.' If further expansion should be needed it could be accommodated by 'establishment of additional laboratories or increasing the capacities of the first two.'

Attendees

Professor J.M. Somerville, president AINSE, Physics, University of New England.
 Dr C.M. Focken, Conference Chairman, Museum of Applied Science of Victoria.
 Mr T.A. Rafter, Director, Institute of Nuclear Science, New Zealand.
 Miss A. Bermingham, Carbon-14 Laboratory, Museum of Applied Science of Victoria.
 Mr E.D. Gill, Curator of Fossils, National Museum of Victoria.
 Mr J.S. Watt, Isotopes, AAEC Research Establishment.
 Dr L.E. Smythe, Chemistry, AAEC Research Establishment.
 Mr R.M. Fry, Health Physics, AAEC Research Establishment.
 Professor A.F. Wilson, Geology & Mineralogy, University of Queensland.
 Mr R. Grigg, Chemistry, University of Queensland.
 Miss M. Neely, History Department, University of New England.
 Mr R.L. Stanton, Geology Department, University of New England.
 Professor C.J. Milner, Applied Physics, University of New South Wales.
 Dr J.H. Green, Radiochemistry, University of New South Wales.
 Professor A.E. Alexander, Chemistry, University of Sydney.
 Dr T. Langford-Smith, Geography Department, University of Sydney.
 Dr C. Phipps, Geology Department, University of Sydney.
 Professor J.C. Jaeger, Geophysics and Geochemistry, Australian National University.
 Mr J.N. Jennings, Geomorphology, Australian National University.
 Dr J.F. Duncan, radiochemistry, University of Melbourne.
 Associate Professor Tattam, Geology, University of Melbourne.
 Mr A.H. Spry, Geology, University of Tasmania.
 Dr M.F. Glaessner, Geology, University of Adelaide.
 Dr P.M. Jeffery, Physics, University of Western Australia.
 Dr W. Compston, Physics, University of Western Australia.
 Mr B.F. Walpole, Geology, Bureau of Mineral Resources, Geology & Geophysics, Canberra.
 Mr J. Daly, Geophysics, Bureau of Mineral Resources, Geology & Geophysics, Canberra.
 Mr B.E. Butler, Soils Division, CSIRO, Canberra.
 Mr J.D. Brooks, Coal Research, CSIRO, North Ryde.

2. Director's memorandum: history of the project

R.H. Fowler, Director

Institute of Applied Science of Victoria

Memorandum for The Under Secretary

Radiocarbon Dating Laboratory – The History of the Project, 1953-70

This account has been put together on a full chronological basis in order to throw light on the rather slowly evolving complexities in which the Trustees of the Institute found themselves involved. An account which included all relevant details would be extremely long so I have tried to scale it down to the more significant essentials. It covers a period of changing personnel, with only two Trustees out of the original seven (Sir Laurence Hartnett and Mr F.M. Read) still in office, and the replacement of the Director (Dr C.M. Focken) by myself after the former's retirement in December 1961. One could therefore say that the only common factor, expert personnel-wise, over the seventeen years, is Miss Bermingham, the Chemist given charge of the operations. Higher responsibilities were therefore "inherited" by a sequence of people at different times, none ever really happy with what they were faced with but reluctant to throw away the results of much effort that had gone before.

Various items are included in this report as attachments and they will be referred to by code letter. EDITORIAL NOTE: these attachments were not included in the Museum archives.

1953

The decision to set up radiocarbon dating was made in April, the Trustees agreeing to the expenditure of £1000 for the necessary equipment. The first intention was to use the solid carbon process, the first to be invented. Temporary accommodation, and the supervisory assistance of Dr Duncan, were provided after consultation, by the Department of Chemistry, Melbourne University.

1954

The limitations of the solid carbon method were becoming apparent. (See reprint "A"). It was decided that the carbon dioxide method should be used. It was believed to be the most accurate method (a reasonably true prediction) but the associated problems had not then emerged. The permanent site for the new laboratory was chosen at the Institute in Swanston Street. A special grant of £1000 for 1954/55 was made.

1955

The experimental set-up at the University was continued. Professor J.S. Anderson reported that progress was unsatisfactory due in the main to the lack of a qualified electronics assistant. Vote provision for 1955/56 was £1000.

1956

After much delay a Physicist was appointed (W. Dejko) but he resigned after a few weeks. The Trustees recommended that Miss Bermingham embark on a six months study tour, visiting the main radiocarbon dating centres of the world, and this was agreed to by the Government. Vote provision for 1956/57 was £1000.

1957

Soon after Miss Bermingham returned in May 1957 Professor Anderson requested that the laboratory at the University be removed as a matter of urgency because of acute accommodation problems. No suitably qualified Physicist was as yet available for appointment at the salary offered, and reclassification of the position from "C2" to "B" was approved. Vote provision for 1957/58 was £1500.

1958

The main transfer from the University, (strongly opposed by Miss Bermingham), was commenced in March. Miss Bermingham commenced construction of the new equipment on the chemical end, and this was to be on a more effective and comprehensive scale than the University set-up had been. R.,D. Carman was appointed Physicist in April. He was sent to New Zealand to study the electronics equipment at the Lower Hutt Laboratory, where important pioneering work had been carried out. On his return he immediately commenced the construction of new equipment for the electronics end of the system. In July the Trustees pressed for a greater rate of progress, requiring a list of target dates for stages. In October the Director reported that at meetings he arranged with Miss Bermingham and Mr Carman there were "differing views". Pumping down the vacuum lines and out-gassing to high purity standards was proceeding around the end of 1958. It was a protracted proceeding. Vote provision for 1958/59 was £1000.

1959

Delays due to a counter chamber leakage were reported in February, and an accident involving a guard ring occurred in March. This necessitated an extra three weeks of pumping down. In May delays due to spurious electronic pulses were reported, and in June Sir Leslie Martin, Trustee, recommended the construction of a new counter chamber. Creditable progress was reported in July. In October the Chairman (Sir Laurence Hartnett) reported that "recent enquiries had not led him to a hopeful outlook". The Trustees expressed general dissatisfaction with progress. Financial provision for 1959/60 was £1250.

1960

The first trial runs were a qualified success, with an excessively high background count. In April a New Zealand expert (T.A. (Athol) Rafter) visited the laboratory and recommended commencement of sample dating runs. The Australian Institute of Nuclear Science and Engineering gave the sum of P1095 for additional equipment in July. Dr Focken published an article (see Reprint "B") in the Australian Journal of Science in October. It is clear now that this carried an air of mistaken optimism on the future of the laboratory. By November it was evident that the background count was not stable enough for serious dating. There was no separate Vote provision for 1960/61.

1961

Mr Carman, Physicist, designed and incorporated a voltage stabilizing system (still in use today), (See Reprint "C"). Work on test samples was commenced. The Official Opening by the Minister took place on the 9th May. Background and modern standard count rates were still excessively variable in February but appeared to improve as the year progressed, and some client samples were dated and the results issued. Publicity resulted in the submission of many samples. Electronic troubles arose from time to time. New storage and treatment equipment was installed. Dr Focken elected to retire (aged 60) in December. Vote provision for 1961/62 was £1300.

1962

The first really baffling (and never really solved) fault occurred early in 1962 when the "modern" count rate showed a sudden downward jump of about 2 counts per minute. Many months of test runs followed, some of these being held up by additional electronic failures. By September the count rates appeared to be stabilized, and client dating was resumed in November. In December a power supply developed a fault which overloaded the Geiger shield. Forty-two new Geiger tubes had to be ordered from England, causing a delay of months. Mr Carman resigned in December. Vote provision for 1962/63 was £1100.

1963

During March the new Geiger assembly had been set up and tested. Miss Bermingham had been instructed to suspend dating by the chairman (Sir Leslie Martin) pending his efforts to seek external advisory aid. Meanwhile Miss Bermingham carried out a systematic check of electronic units. Replacement of the Physicist was proving difficult. Mr G. Tyson was appointed in October, and dating was resumed. In December Mr Tyson submitted a report on the electronics system. (See Attachment "D"). It was extremely critical of Mr Carman's designs and construction. Miss Bermingham strongly disputed the report. The Chairman arranged for a committee of electronics experts to report on the equipment of the laboratory, and the terms of reference set out by the Director are in Attachment "E". Vote provision for 1963/64 was £950.

1964

Mr Tyson resigned in March, just prior to the furnishing of the committee report. (The committee report is Attachment "F"). Reference to its Recommendations on Page 6 will indicate that the members considered Mr Tyson's report to be over-stated, but that there were certain deficiencies in the laboratory which could be remedied. The most costly remedial action was the provision of air conditioning. Miss Bermingham lodged various objections to the terms of reference of the committee and their findings, and was aggrieved at not being given an adequate hearing by the committee (See Attachment "G"). The Trustees held a special meeting on the subject of the laboratory in April. (Minutes – see Attachment "H"). It was agreed that the laboratory should continue operation as the report in general gave good grounds for expecting success before long. As the year progressed some good counting runs were achieved with fewer than usual stoppages from faults and other causes. Mr D. Turner was appointed Physicist in June. Vote provision for 1964/65 was £950.

1965

The performance pattern continued during this year with good production runs, but never on a scale approaching economic operation. There were stoppages from time to time through minor electrical failures and defects in the chemical line. Vote provision for 1965/66 was \$2900.

1966

The 1966 performance is on the lines of 1965. Early in the year air-conditioning of the laboratory was carried out, financed with Loan Funds. There were necessary holdups for a period because of this work, also through installation of a new electrical sub-station on the premises. A list of 50 dates was published in November, this including all released results achieved since the laboratory was commenced. Vote provision for 1966/67 was \$1900.

1967

Apart from some minor interruptions due to electric supply failures and chemical line faults, the laboratory was fairly free from technical failures during the year. The problem of progressive replacement of units of the equipment was by this time engaging the attention of the Trustees. Many components were up to ten or so years old, and not only was the need for replacement or modernising arising, but there were some hopes held for adding equipment which might increase output. Extra finance was sought in 1966/67 Estimates but it had not been approved. It so happened that this was the year when the Australian Research Grants Committee was for the first time considering grants to museums for suitable research projects. It seemed that this would be a suitable occasion to apply for a grant to investigate a long-standing problem in carbon dating (the Dating of Natural Carbonate in Australia, i.e. mainly mollusc shell, and its implications for meaningful dating). An application was lodged by Miss Bermingham, with Dr D.M. Churchill of Monash University as co-investigator. It included a request for \$4000 to make a start on duplicating the counting equipment, coupled with a request for \$4000 to finance

an overseas tour by Miss Bermingham to survey the latest techniques and appraise commercially produced equipment. The Trustees supported the application on several grounds. It appeared to be a useful line of research, it would establish a link with Monash University with implications of good back-up facilities, and it would go some way to solving the problem of modernizing the counting equipment. The application was only half successful. The sum of \$4000 (for 1968) for the first stage of the duplicate equipment was granted, but no travel funds. It was anticipated that further substantial grants for equipment would be made in subsequent years, and some staffing assistance would also be sought at a later stage. Vote provision for 1967/68 was \$2200.

1968

A request to the State Government for the necessary funds for the overseas tour by Miss Bermingham in 1968 was not successful. This made it necessary to ask the ARGC to hold over the 1968 grant until 1969, and this they agreed to do. A request for travel funds of \$4000 from the State Government in the 1968/69 Estimates was not agreed to, but advice was received that a tour limited to 12 weeks would be approved if a re-submission was made with details of a proposed briefer tour with somewhat reduced scope, and this re-submission was examined and approved by the Trustees at the October meeting. Little dating was carried out in the laboratory in 1968. Planning and negotiating for the overseas tour, visits to conferences and laboratories, and some equipment instability problems all contributed to interruptions. Vote provision for 1968/69 was \$2200.

1969

Sample dating continued early in the year, with some minor hold-ups. Miss Bermingham left for her twelve-week tour in April and returned at the end of July. The Trustees asked for a report in August. The only response to this request to date has been an interim one (See Attachment "I"). They were disappointed to be told of numerous difficulties in procuring new equipment of proved efficiency on an "off the shelf" basis. They asked for a firm program to the end of 1969. The response was of a brief and unsatisfactory nature and Miss Bermingham was called into the November meeting. Lengthy discussion on the prognosis ensued, and it was becoming clear that economic operation was an illusion and the laboratory could only be a research asset requiring typical research subsidy, and, if it were to be both a client service and a research unit, greatly expanded subsidy and staff. A further consideration was the newly-declared attitude of Dr D. Churchill of Monash University (co-investigator named in the ARGC application) that he would withdraw unless Miss Bermingham could devote full time to the research project. A Trustees sub-committee was formed to make recommendations. Vote provision for 1969/70 (exclusive of special tour funds) was \$2500, of which about \$1300 was expended.

1970

The sub-committee report was submitted to the Trustees in February and adopted. (The text is set out in Minute 4006 – Attachment "J"). It incorporates a decision to concentrate on the ARGC work to the exclusion of client dating for the time being and called for three specific answers from Miss Bermingham to clarify plans for action ahead, as instructed in Pars. 2, 2.1, 2.2.2, and 2.2.3 of the Minute. The Trustees reached an understanding (not recorded in the Minute) that Miss Bermingham's response to the instructions would be the basis of decision on whether to continue or to close the laboratory. The response was the document of 26th February (Attachment "K") and I believe it speaks for itself. My comments on it were furnished to the April meeting of Trustees (Attachment "L"). Miss Bermingham, instead of clarifying the situation by brief and clear statements, set down a lengthy series of observations and uncertainties which left the Trustees no good alternative to cutting their losses and closing down on the 31st December, 1970. The prospect of pressing on with new custom-built equipment which could repeat the delays of the early

developmental phase and the problems encountered up to 1964 could simply not be faced and the closure decision was reached. Admittedly, the discontinuance of the ARGC research project, after the original hopeful start, has been quite unfortunate. But the Trustees are convinced that as the project looked like involving expenditure of some \$30,000 in subsequent years, the writing off of a relatively small Commonwealth investment was preferable to facing the risk of running into an unsatisfactory situation of far greater magnitude and cost. The decision was conveyed to the Under Secretary in April and a reply advising acceptance of the decision by the Chief Secretary was received. The Australian Research Grants Committee was then informed, and subsequently additional information has been conveyed to their Victorian representative verbally, including the advice that something more than half of the \$4000 grant would be available for returning (by cancellation of equipment orders). At the time of writing the Trustees still await the receipt of comment from the ARGC.

I wind up this report with some observations on general lines. The radiocarbon dating project was a pioneer venture which achieved a significant quota of positive benefits to science. The results could well have been more voluminous with the freer inflow of funds and increased staffing, persistently requested by Miss Bermingham, but in supporting my Estimates submissions the Trustees took the view that the display and educational needs of the Institute just had to take priority over radiocarbon dating. Unfortunately the laboratory was beset with what may be described as more than its fair share of bad luck. But in addition there was the impossibility of foreseeing the interplay of human factors and their impact on highly sophisticated equipment and processes. Miss Bermingham appeared to become perhaps too dedicated to a project which was necessarily predominantly her own, and to her lasting credit she poured effort and skill into it generously, probably excessively. But her personality is such that there emerged a degree of growing resentment of the decision, and in some cases the supposed lack of action, of individuals who knew less of the technicalities of problems arising but who were required in terms of their mandate to become involved in them. This was undoubtedly a factor contributing to the final decision.

3. Other Radiocarbon Dating Laboratories in Australia

Construction of a radiocarbon dating laboratory at the University of New South Wales began in 1958, led by chemist Dr J.H. Green, Head of the Department of Nuclear and Radiation Chemistry, his MSc student, John Neuhaus, and J. Bell.ⁱ In his 1965 MSc thesisⁱⁱ Neuhaus explored the techniques available sample preparation and counting. At the outset the decision was taken to use proportional counting of gaseous carbon dioxide rather than acetylene, which had a better carbon density but was rejected as counting gas on the grounds of safety. He also commented that in future there would be advantage in using methane. Development of the laboratory proceeded smoothly and dating was underway in the early 1960s. Green gave a general account of the radiocarbon technique and the work of his laboratory,ⁱⁱⁱ citing result obtained with bicarbonate from artesian water on the edge of the Great Artesian Basin that gave ages in the range 20,000-35,000 years. This was in contrast to other ground water results that were included in the laboratories first published set of dates^{iv} that revealed the carbon to be no more than a few years old. That was the only set of dates published by the UNSW laboratory although it continued to be listed in the journal *Radiocarbon* for some years as operational.

At the Australian National University (ANU), the Department of Geophysics and Geochemistry in the Research School of Physical Sciences and the Department of Prehistory in the Research School of Pacific Studies joined in 1965 to set up a radiocarbon dating laboratory. To lead it they employed Czech-born Henry Polach who had been working as a technical officer in the New Zealand IGNS radiocarbon dating laboratory.^v Work began with proportional gas counting of methane but problems with the stability of the counting system caused by nearby electrical apparatus prompted a change to liquid scintillation counting with benzene.^{vi} John Mulvaney,^{vii} who had moved to ANU in 1965, and his colleague Jack Golson, were major clients of the service and Mulvaney provided samples of known date for check analysis. The laboratory produced a steady stream of dating results^{viii} and also trained a number of people who later went on to run other laboratories – Jerry Stipp [ref viii] (PhD student at ANU, later Univ Miami and co-founder of Beta Analytic, Inc), Richard Gillespie (Univ of Sydney), Mike Barbetti (PhD student 1969-1973 at ANU [add ref M Barbetti and H A Polach, ANU Radiocarbon Date List V Radiocarbon 197x], later NWG Macintosh Centre for Quaternary Dating, Univ of Sydney), Alan Hogg in Waikato, New Zealand, Sushil Gupta in India, Zhou Weijan and Zhou Mingfu in China.

The interest in radiocarbon dating at the University of Sydney began with a study by MSc student Stuart Parfitt^{ix} but in 1964, Professor A E Alexander of Physical Chemistry at the University of Sydney appointed Dr Richard Temple, formerly of the Australian Atomic Energy Commission, to establish a radiocarbon dating laboratory. Funding to support the venture, however, was not forthcoming until 1970.^x **[Ian, I have always understood that Prof Alexander was a strong supporter of radiocarbon dating, and I am not sure if your ref x is correct - you might like to add this ref :**

<http://adb.anu.edu.au/biography/alexander-albert-ernest-93271> Richard Gillespie, who had trained with Henry Polach in the ANU dating laboratory, was engaged to establish the system in which carbon was converted via carbon dioxide and acetylene to benzene that was subsequently counted in a scintillation counter (the same technique used at ANU).^{xi} Within a few years Gillespie had been awarded his PhD degree for work on radiocarbon dating of marine shells,^{xii} but most of the measurements reported by the laboratory were for charcoal from New South Wales archaeological sites.^{xiii} At first a

counter in another department was used but in 1970 Chemistry was able to purchase its own equipment, partly due to charges for service to users (\$50 per sample).

When Gillespie resigned as Professional Officer in 1979 (to embark on a new career in Accelerator Mass Spectrometry) he was succeeded by Dr Mike Barbetti (an ARC Research Fellow in Physics, Univ of Adelaide) who had earlier gained experience at ANU. A/Prof Richard Temple retired in 1981, and Mike Barbetti was designated as Professional Officer-in-Charge. The laboratory gradually moved to new premises in 1982/83, without ceasing production, and became part of the NWG Macintosh Centre for Quaternary Dating when it was formally established in 1984, as a subsidiary of the Electron Microscope Unit under EMU Director, A/Prof D J H Cockayne. The Macintosh Centre continued to produce results until the late 1990s, by which time the liquid scintillation method had been largely superseded by the growing use of Accelerator Mass Spectrometry, a sensitive technique for measuring the concentration of carbon-14 atoms that enabled the use of much smaller carbon samples.

Indeed, it was like history repeating itself, with new techniques and a new generation of scientists emerging. When Quan Hua arrived in Sydney in 1993, he worked in the Macintosh Centre. With help and collaboration from John Head at ANU, and ANSTO, a small facility was developed for the preparation of AMS carbon targets, on a commission basis for ANSTO's new ANTARES AMS facility. In due course, Quan was appointed to a permanent position at ANSTO, while continuing postgraduate studies and gaining his PhD from the University of Sydney. He is now a Principal Research Scientist at ANSTO.

In the 1990s, the Macintosh Centre had committed substantial resources into developing a state-of-the-art tree ring dating facility, with the aim of generating precisely-dated wood samples for carbon-14 measurements of historic atmospheric levels of radiocarbon. Hua and Barbetti, and collaborators from Columbia University, expanded this work to encompass tree rings in tropical regions of Southeast Asia as well as Australia.

The University of Sydney closed the Macintosh Centre in 2005 after the retirement of its Director, A/Prof Mike Barbetti and all of the remaining staff. The substantial endowment funds donated by Mrs Ann Macintosh were re-allocated to other areas of the University.

ⁱ J. Bell, J.W.G. Neuhaus and J.H. Green, 'Electronic Instrumentation for radiocarbon Dating', *Proceedings of the Institution of Radio Engineers (IRE) Australia*, VOL (1962), 718-721.

ⁱⁱ J.W.G. Neuhaus, 'Ethnological Dating With Radioactive Carbon', MSc Thesis, University of New South Wales, 1965.

ⁱⁱⁱ J.H. Green, 'Radiocarbon Dating', *Atomic Energy in Australia*, 8(1) (1965), 10-14.

^{iv} J.H. Green, J. Harris, J.W.G. Neuhaus, D.K.B. Sewell and M. Watson, 'University of New South Wales Radiocarbon Dates I', *Radiocarbon*, 7 (1965), 162-165

^v M. Barbetti and J. Head, 'Henry A. Polach, 1925-1996', *Radiocarbon*, 38(3) (1996), v-ix.

^{vi} H.A. Polach, 'Optimisation of Liquid Scintillation Radiocarbon Age Determining and Reporting of Ages', *Atomic Energy in Australia*, 12(3) (1969), 21-28.

^{vii} 'Vale Emeritus Professor John Mulvaney', *ANU News*, 22 September 2016.

www.anu.edu.au/news/all-news/vale-emeritus-professor-john-mulvaney.

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- ^{viii} H.A. Polach, J.J. Stipp, J. Golson and J.F. Lovering, 'ANU Radiocarbon Date List I', *Radiocarbon*, 9 (1967), 15-27. H.A. Polach, J. Golson, J.F. Lovering and J.J. Stipp, 'ANU Radiocarbon Date List II', *Radiocarbon*, 10 (2) (1968), 179-199.
- ^{ix} S.S.G. Parfitt, 'Radiocarbon Dating', MSc Thesis, University of Sydney, 1963.
- ^x K. Ratinac, 'Great Moment 24: The NWG Macintosh Centre for Quaternary Dating', in K.R. Ratinac, ed., *50 Great Moments. Celebrating the Golden Jubilee of the University of Sydney's Electron Microscopy Unit* (Sydney, **YEAR?**), pp. 171-178.
- ^{xi} I.W. Fraser, 'Synthesis of Benzene for Radiocarbon Dating', MSc Thesis, University of Sydney, 1973.
- ^{xii} R. Gillespie, 'The Suitability of Marine Shells for Radiocarbon Dating', PhD Thesis, University of Sydney, 1976.
- ^{xiii} R. Gillespie, H.A. Polach and R.B. Temple, 'Sydney University Natural Radiocarbon Measurements I', *Radiocarbon*, 14 (2) (1972), 413-417. R. Gillespie and R.B. Temple, 'Sydney University Radiocarbon measurements II', *Radiocarbon*, 15(3) (1973), 566-573.