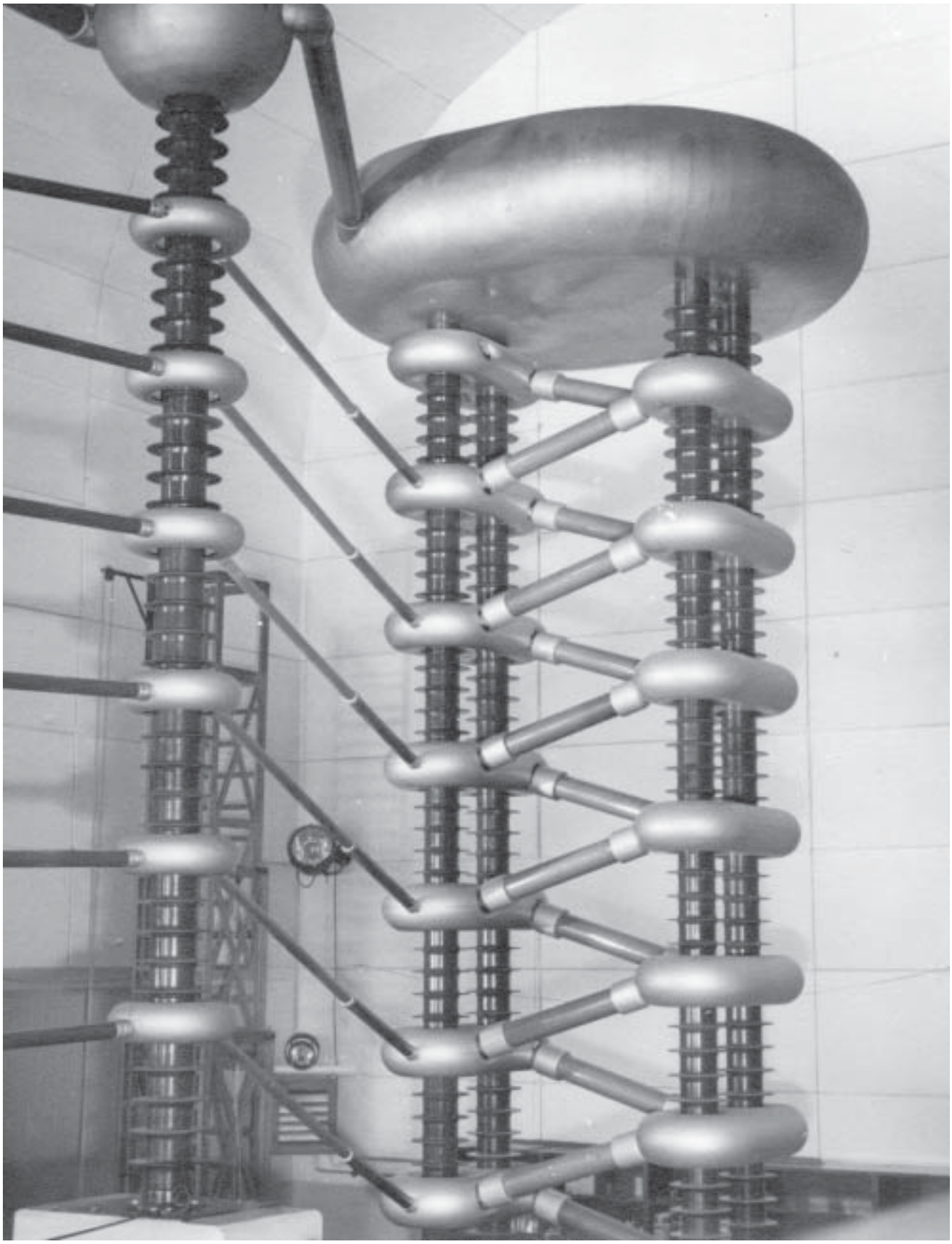
Chapter 7

The Accelerators of Nuclear Physics



The Cockcroft-Waltons 1951-1967

Two Cockcroft-Walton accelerators manufactured by Philips in Eindoven were assembled at the ANU. The first of these, known as HT1, operated between February 1952 and January 1967. It was sold to the University of New South Wales where it was used by Jak Kelly for some years to pursue solid state research. Rated at 1.25 MV, the machine was capable of operation close to this voltage on dry days if it had been cleaned thoroughly to remove all dust. Much of its research use was confined to the production of intense fluxes of high energy gamma rays for photodisintegration studies, requiring operation at only about 500 kV to initiate one particularly prolific resonance reaction. Equipped with a Thoneman-type ion source, proton and deuteron beam currents of ~1 mA were possible. Few experiments could use more than 100-200 μa of protons because of limitations in the cooling of targets or because of count rate limitations of either detectors or their associated electronics. Deuteron beams were restricted to much lower intensities because of the associated neutron fluxes.

Once the original mercury rectifiers of the voltage-doubling circuits were replaced with selenium rectifiers in 1956, HT1 was remarkably reliable, downtime arose mainly from vacuum problems as often as not stemming from power interruptions or as a consequence of the poor water quality.

A second, smaller Cockcroft-Walton HT2 was assembled by Ken Inall, using spare parts that had been acquired with HT1 augmented with purchased components. With a rated voltage of 600 kV, it was used predominantly to provide 14 MeV neutrons, for studies of neutron reactions. HT2 was closed down after suffering fire damage in July 1960.

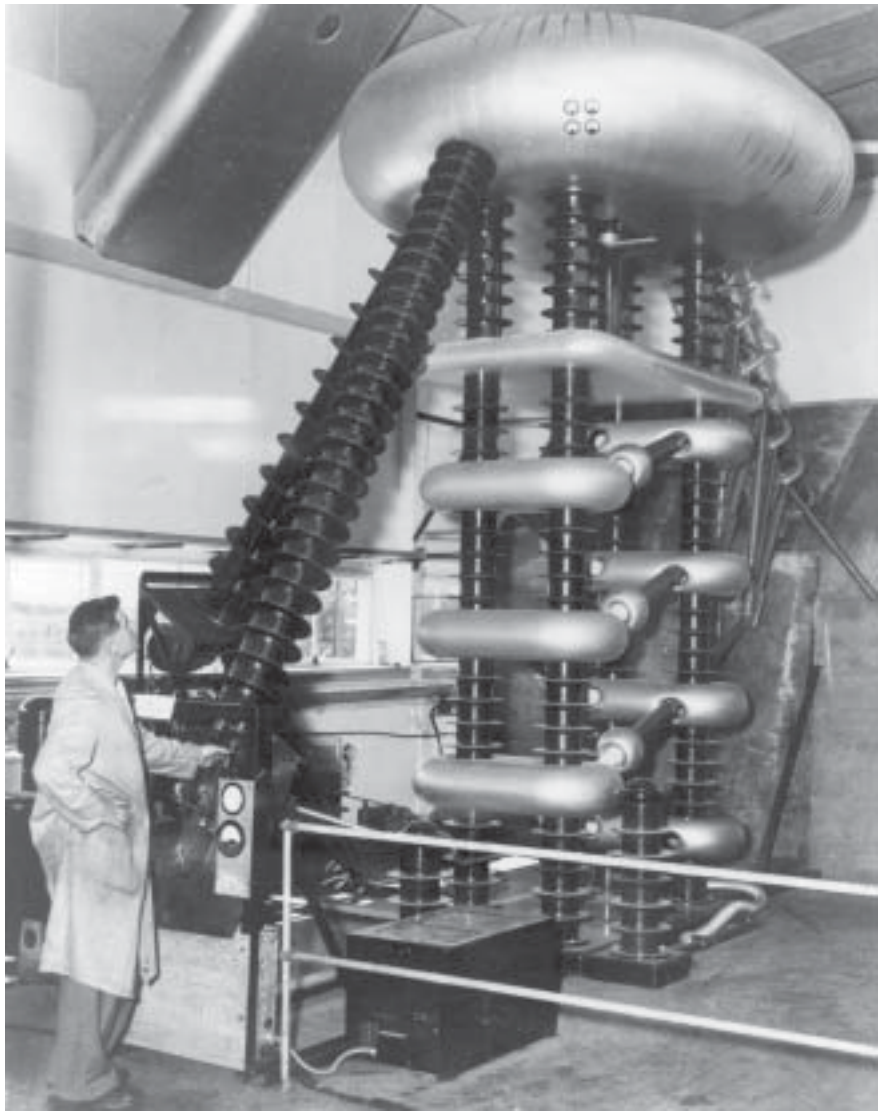
Cockcroft-Walton accelerators had a majestic grandeur that fitted well with the public perception of what an accelerator should look like - perhaps as a result of conditioning by Frankenstein movies. All that charm was lost when Van de Graaff devices within pressurised tanks replaced them. Because of their ability to produce intense beam currents reliably, a number of Cockcroft-Walton type accelerators were built during the fifties and sixties as injectors for high energy accelerators.

Evidently, Cockcroft-Walton accelerators provided a suitable environment for the development of future School directors. John Carver's research initiation, both in Cambridge and Canberra, involved their use as did that of Erich Weigold with HT2.

The Electron Synchrotron 1955-1962

A 33 MeV electron synchrotron was obtained as a gift from the UK Government in 1955. The transfer had been proposed by Titterton and arranged by Cockcroft at Harwell. The synchrotron had been built at Malvern by staff of the TRE radar establishment before many of them were transferred to Harwell. Titterton and Brinkley had used it to irradiate emulsions during 1950 and early 1951 when both were still at Harwell. Installed in an underground room adjacent to the tunnel between the Cockcroft and Chifley Buildings, its presence could rarely be forgotten. Excavation of the vault had caused a collapse of a section of road between the buildings. Thereafter, there was the irritating pervading hum of the magnet during operation, and often sections of the Chifley foyer had to be roped off when radiation levels were sufficiently high to warrant the precaution. Electron synchrotrons of relatively modest energies were the fore-runners of the now-familiar "light-sources". Both are sources of bremsstrahlung, a continuous spectrum of electromagnetic radiation. Rather than by continuous emission during acceleration as occurs in light sources, the synchrotron produced bremsstrahlung

◅ *The 1.2 MV Cockcroft-Walton accelerator (HT1). The high voltage generator is at the left. A uniform gradient was applied to the acceleration tube via the central condenser smoothing stack. The ion source was located within the right hand 'bun'.*

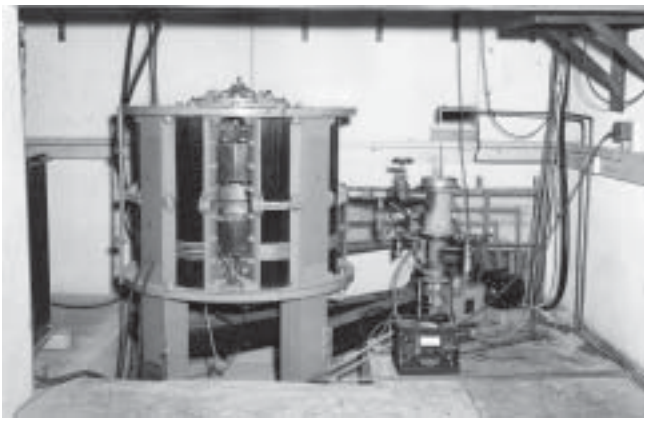


▻ *The smaller 600 kV Cockcroft-Walton accelerator (HT2). The acceleration tube at the far right directed beam into the target area behind the shielded wall (circa 1954).*

▽ *The 33 MeV electron synchrotron (January 11 1955).*

by bombarding a thick tungsten stopping target. The energy of the electrons reaching the target was varied to change the end point energy of the distribution.

Carver and others undertook a program of photodisintegration measurements with it between 1955 and November 1961, when a short-circuit occurred in a magnet winding. Since the research program envisaged was close to completion, repairs were not undertaken. Thies from the University of Western Australia finally persuaded the ANU to give him the machine, despite Canberra's misgivings that the transfer would prove to be a troublesome liability, rather than a research opportunity. In fact, the synchrotron was installed successfully and was operated in Perth for about another twenty years.



The EN Tandem Accelerator 1960-1980

Events leading up to installation of the EN tandem have been described already. The tandem was delivered in October 1960 and installation began immediately. Acceptance tests were completed by May, just prior to the opening by Prime Minister Menzies on May 11, 1961.

The EN tandem heralded a remarkable expansion of low energy nuclear physics during the period between about 1960 and 1980. Successful implementation of two-stage acceleration[1] by High Voltage Engineering Corporation at Burlington, Massachusetts led to the manufacture by that company alone of 26 EN tandems between 1958 and 1971. The Canberra tandem was the fifth one ordered and

delivered. Titterton had monitored progress of the first machine at Burlington and sensing correctly that a "tandem rush" would ensue, moved quickly to secure the necessary funds when the first successful operation made it prudent to do so.

It became a time of intense competition as HVEC met customer demands for accelerators with higher terminal voltages in rapid succession from the model EN (with a rated terminal voltage of 5 MV) to the FN (7.5 MV) in 1963 and the MP (10 MV) in 1965. Again, between 1963 and 1971, 17 "king-sized" FN tandems and 10 "emperor" MP tandems were supplied by HVEC[2].

During almost all of its lifetime of more than 90,000 hours of operation as the prime research tool between 1961 and 1976 - corresponding to an average of 16 hours/day throughout, the EN was capable of matching or exceeding the rated specifications of 5 MV and analysed proton beam currents of 0.5 μa. The highest terminal voltage at which data were recorded was 7 MV. Analysed proton beam currents of more than 5 μa could be obtained, though experiments rarely required more than 1μa.

As will become apparent later, much of the tandem operation was devoted to the provision of helium beams, both ^{3}He and ^{4}He. Some work was done with heavier beams, including ^{7}Li, ^{12}C, ^{13}C and ^{16}O. The EN was a pioneer in the almost exclusive use of foil stripping from 1969 onwards. Even so, the terminal voltage was too low to achieve the energies needed to undertake systematic heavy ion

The EN tandem assembly "crew" (November 1960).
Back row L to R: Gil Lea, Ray Storey, Harry Owen, Tony Bull, Tony Bastin, John Gower, Frank Reeves, George Power and Paddy Lalor.
Front row L to R: John Harrison, Trevor Ophel, Peter Treacy, Tom Fraser (HVEC), Ernest Titterton, Frank Orina (HVEC), John Carver, Norman Bowkett and Mick Cornick.

◅ *Far Left. Arrival of the EN tandem pressure vessel (October 26 1960).*

◅ *Only a few hours after arrival, the pressure vessel had been manoeuvred into position within the Tandem Building. Paddy Lalor can be seen on the left in a typical working pose. Harry Owen, a machinist in Nuclear Physics, is on the right (October 26 1960).*

△ *The actual opening of the Tandem Building by Prime Minister Menzies. (May 11 1961) L to R:"Nuggett" Coombs, Ernest Titterton, Mark Oliphant, Dennis Robinson (President of HVEC) and Prime Minister Menzies.*
The face at the window is John Jenkin.

▻ *An interesting group at the Opening of the EN Tandem (May 11 1961).*

L to R:"Nuggett" Coombs, Gough Whitlam, Prime Minister Menzies and Ernest Titterton.
Gough Whitlam was presumably representing the Leader of the Opposition at the ceremony,

studies. It was here that laboratories with the higher voltage FN and MP tandems began to shape the changing direction of mainstream research.

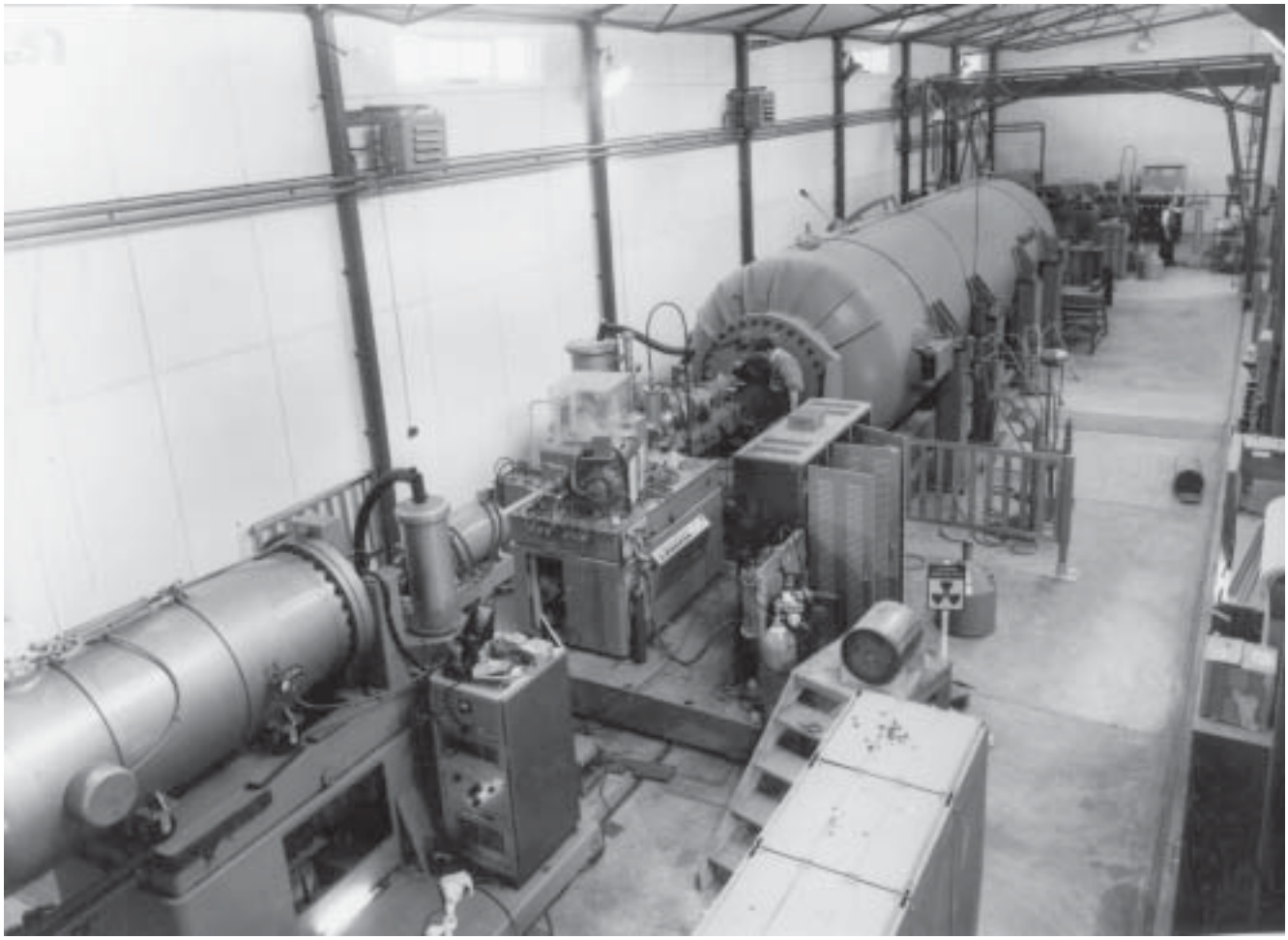
A variety of injectors was added to the EN tandem. Several of these are addressed separately in sections that follow. The remaining one, a polarised ion source, proved unsuccessful, an outcome unfortunately typical of events at a number of other laboratories also. A source was purchased in 1970. Despite intensive effort, proton beams, about 45% polarised, never exceeded the level of a few nanoamperes on target. The source project was stopped in 1975.

Use of the EN tandem began to fall rapidly once the 14UD became available in 1975/6 and projects undertaken before that event completed. Henry Polach of the ANU Radiocarbon Laboratory tried unsuccessfully in 1979 to have the accelerator instrumented for the only recently demonstrated accelerator mass spectrometry of carbon-14[3], either at Nuclear Physics or at an alternative site on campus. In the meantime, there had been discussions about a sale of it with several Australian groups, including AAEC, CSIRO and Macquarie University, and the DSIR, New Zealand. Finally it was sold to DSIR in the latter half of 1979 and moved there early in 1980.

The EN continues to operate in Wellington, New Zealand as an internationally-recognised radiocarbon AMS facility. Like old soldiers, old accelerators never die.

The 2MV AK Van de Graaff (1962-present) and the Helium Ion Source

In 1961, a 2 MV AK Van de Graaff was ordered from HVEC to serve as both a helium injector for the EN tandem[4] and as a stand-alone machine to replace the fire-damaged HT2. Alignment proved to be critical for neutral helium injection, preventing the AK machine from being used as a separate facility for other beams in the period between 1962 when it was installed and 1967. During 1965 and 1966,



almost all of the research program relied upon ^{3}He or ^{4}He beams.

With the sale of the Cockcroft-Walton in 1967, the 2 MV AK was moved to the HT1 laboratory, and a small 1 MV JN Van de Graaff used instead for helium acceleration. Titterton was very sensitive to possible university criticism of "yet another accelerator". The JN machine appeared on the quote and the purchase order as "a helium ion source" and it was politically correct to maintain that terminology for some time afterwards. Over the next few years, several ion sources were built at ANU to exploit developments elsewhere that had succeeded in producing relatively intense beams of negative helium ions. The use of negative helium ions made it possible to achieve higher energies (three times the terminal voltage rather than just over twice that voltage using neutral injection), but had previously been thwarted by very low intensities achievable. A breakthrough came in 1966/7 when it was found that alkali metal vapours, first caesium and potassium and later, lithium provided high exchange yields of negative helium ions[5] when bombarded with positive ion helium beams. By the end of 1972, the use of neutral injection with the EN had been supplanted almost entirely by a lithium exchange source. In 1973, the JN was sold to the Queensland Institute of Technology, again for solid state research.

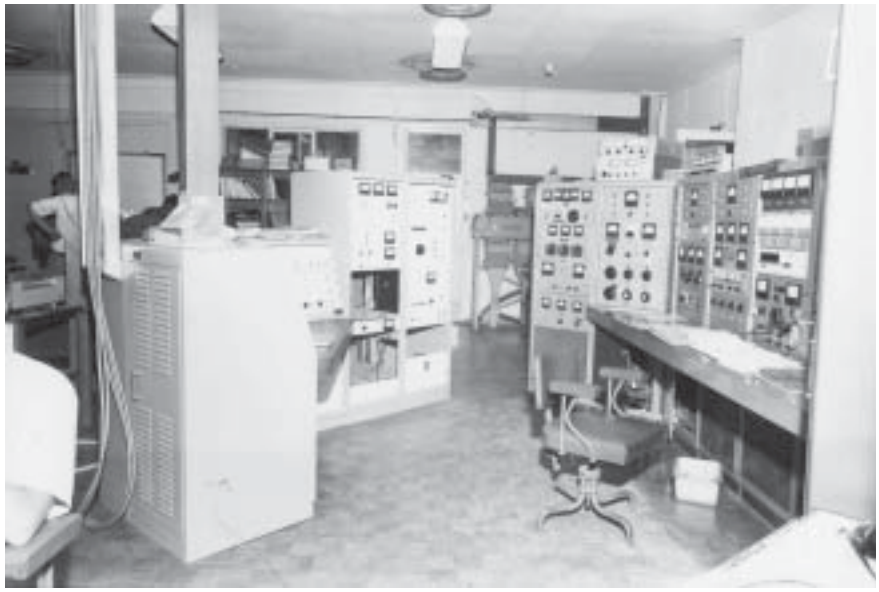
Use of the 2 MV machine for nuclear measurements was gradually replaced by programs using various beams for atomic and solid state physics research. First there was beam foil spectroscopy, initiated by Hal Hay. Subsequently he was joined by Peter Treacy and studies of more general ion-solid interactions evolved, including radiation damage, X-ray production and the formation of Rydberg states. Also, in collaboration with CSIRO, PIXE (proton-induced X-ray emission) analysis techniques were developed for studies of air-borne pollution and applied to mineral analysis. The work led to the installation in 1983 of a 2.8 MV tandem at Mineral Physics, CSIRO (North Ryde) devoted to mineral analysis.

The 2MV machine was handed over to the new Department of Electronic Materials Engineering soon after it was established in 1988. Hay had set the machine up to run for long periods unattended. This mode has proven ideal for sequential characterisation of implanted samples by Rutherford backscattering of helium.

Thus well into the fourth decade of its life, the AK

◅ *The EN tandem accelerator. The 2 MV helium injector is at the lower left (between 1963 and 1966).*

▻ *The control consoles of the EN tandem accelerator. The tandem was operated from the right hand console that also included the controls for the helium injector. The cyclotron injector was controlled from the console at the left (circa 1972).*



has returned to its original reason to be, and continues to produce helium beams for several thousand hours per year. Operation records are incomplete, but it is estimated that the total operating lifetime exceeds 100,000 hours.

The 26 MeV Cyclotron Injector 1972-1980

The cyclotron injector was ordered in 1970 from The Cyclotron Corp in Berkeley, California, as part of the upgrade of facilities made possible by the Tertiary Education Commission's grant of $2.2 M. It was very much a pet project of Titterton's, going back many years to the time of early tandem development when "Wibs" Smith and he had been quite possibly the first to propose coupling a negative ion cyclotron to a tandem. The decision to buy the cyclotron was made unilaterally by Titterton, whereas the more important and more difficult choice of an electrostatic accelerator to replace the EN tandem was done openly and, in appearance at least, democratically. The cyclotron was later justified in terms of the complementarity of the "cyclo-graaff" combination that provided proton beam energies between 26 and 38 MeV and 14UD operation with energies up to 28 MeV.

The cyclotron arrived in January 1972 and was accepted in May. The system worked well and was used productively with proton and deuteron beams until 1976/7 when it became clear that reduced staffing levels prevented operation of both the 14UD and the EN.

As elsewhere, nuclear medicine had expanded rapidly in Australia during the early seventies. Reactor-produced radio-isotopes were available from AAEC, but those from cyclotron facilities had to be imported. Obviously there were severe restraints on the use of the short-lived isotopes. The AAEC, with the backing of several hospital groups, sought funding for a production cyclotron. A concerted effort was made to keep the cyclotron in Australia for isotope production[6]. Objections that the energy of 26 MeV was too low to produce ^{201}Tl, a key isotope for heart scans, were shown to be unfounded. Adequate yields, remarkably free of contaminant activity, were demonstrated at Canberra and used for test scans of laboratory animals[7]. Nonetheless, the AAEC preferred the option of a more modern and higher energy machine. In the event, the ANU cyclotron was sold in 1980 to Nihon Mediphysics in Japan. Australia imported ^{201}Tl from Nihon until a 30 MeV cyclotron at Sydney was finally operating almost thirteen years later. It is believed that the cyclotron is still producing radio-isotopes in Japan.

The 14UD Pelletron Accelerator

The 14UD was born out of discussions between Ray Herb and Titterton at the National Electrostatics Corporation in Madison, Wisconsin where the fledgling company was building the first substantial NEC machine, an 8UD with a 4 MV single-ended injector, for Sao Paulo. By Titterton's account, Herb was very reluctant to attempt an accelerator with a rated voltage above 10MV, but was finally persuaded to quote for a 14MV machine. The ANU considered offers by three manufacturers, choosing that of NEC, largely on the basis of the as yet largely unproven titanium and alumina tube modules developed by Herb's group.

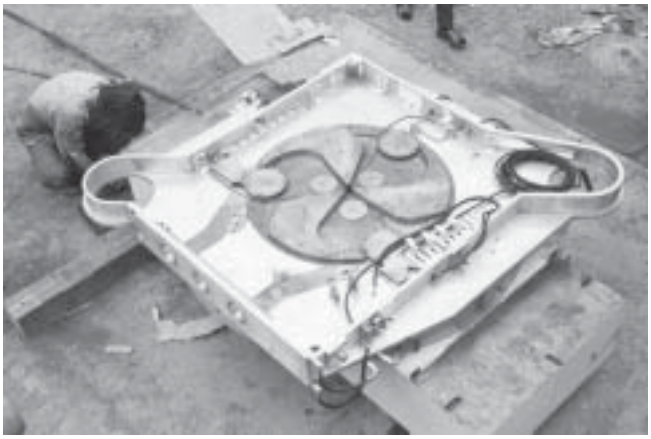
It was a courageous decision by both parties. Construction of the pressure vessel and the gas handling system were undertaken on site by ANU, so that NEC could only test the tube and column in air at Madison. ANU also was responsible for beam handling elements and the target area. Thus the project was a major departure from the custom of acceptance tests at the site of the manufacturer, prior to shipment. Nonetheless, the 14UD was completed successfully and remarkably expeditiously compared to later installations elsewhere.

In many respects, the 14UD was a third generation accelerator. Pelletron charging chains, comprised of metal pellets insulated from each other by nylon links, replaced the rubberised-cotton belts of earlier Van de Graaff machines. The belts were the source of much particulate matter which undoubtedly affected high voltage performance. The combination of near ultra high vacuum, made possible by the tube construction and the titanium sublimer pumps, and geometrical baffles overcame most of the problems due to electron loading that had also plagued earlier machines. In one respect, perhaps it was not. Herb had not recognised the advances made in resistor design and application to establish a constant gradient along the column and tube structure. Instead, point to plane corona discharge assemblies were used in the 14UD. Correctly assembled (there were 1440 of them!) and in good condition, the corona points functioned well until the inevitable erosion from extended use occurred. Moreover, the continuous corona discharge in the 30 tonnes of insulating gas, sulphur hexafluoride, produced low though significant levels of the so-called breakdown products that were both toxic and extremely corrosive in the presence of even traces of water vapour.

Otherwise, it was designed for heavy ion operation. Terminal focussing with an electrostatic triplet lens and augmented foil stripping were implemented following ANU initiatives.

During the span that the machine has operated, a series of modifications and upgradings has resulted in an exceptionally stable and reliable accelerator, capable of sustained operation at terminal voltages of 15.5 MV or more. Indeed, the outstanding performance is freely recognised internationally, a tribute to the efforts of Accelerator Manager, David Weisser and the technical group.

The main changes include modified terminal



The cyclotron being "jockeyed" into position. John Harrison is at second left and Fred Ramsey, an engineer from the Cyclotron Corporation, is at the far right (January 1972).

The interior of the 14UD accelerator. The lower spinning of the central terminal had been lowered for access to terminal instrumentation (circa 1975).

◅ *The bottom section of the 26 MeV negative ion injector cyclotron. The spiral configuration of the poles that provided the strong focussing, essential for isochronous acceleration, is clearly evident (January 1972).*

▻ *Prime Minister Whitlam and Margaret Whitlam with Ernest Titterton at the opening of the 14UD accelerator. Tez Esat is in the foreground, demonstrating Van de Graaff operation with a model (September 1 1974).*

◹ *Bottom Right. Ernest Titterton and Ray Herb, President of National Electrostatics Corporation, in front of the 14UD console (September 1974).*

▽ *The tower housing the 14UD accelerator. The photograph was one of a series taken by Ted Richards in August 1974. Another of that series was used for the official brochure at the opening ceremony.*

spinnings, a compressed geometry tube, ANU designed and manufactured resistor assemblies to replace the corona points and improved injection.

Some twenty years on, given the outcomes of the 14UD performance and the research programs sustained by it, the Department's umbrage over the Street Review report has been replaced by smug amusement.

Nuclear Physics proposes $5.5m upgrading scheme

Power boost planned for accelerator

The Nuclear Physics Department in the Research School of Physical Sciences is proposing to upgrade its existing 14 million volt two-stage accelerator — the 14UD — to operate at twice its present power.

Up to 1982 the 14UD was the world's most powerful electrostatic accelerator. However, it has now been surpassed by new machines operating in Britain, the United States and Japan.

In order to remain competitive it has been proposed that the 14UD be upgraded to include the addition of about 40 superconducting resonators, each of which would give the high-energy beam from the accelerator a "kick" corresponding to an accelerating voltage of around 0.5 million volts per resonator.

Dr Trevor Ophel, a Professorial Fellow in the Department, says that upgrading the 14UD in this way would cost an estimated $3.5 million, whereas a new electrostatic accelerator of equivalent size would cost in the vicinity of $30 to $40 million. Upgrading the existing facility would therefore be a very cost-effective means of achieving the high energies required for modern research and would help maintain Australia's position in the forefront of nuclear physics for the next 10 to 15 years.

The proposal is that the 14UD be used as a 'pre-accelerator' to inject heavy-ion beams into a booster 'post-accelerator' comprising an assembly of superconducting resonators. This additional equipment would greatly enhance experimental studies which contribute to a better understanding of the basic mechanisms of heavy ion reactions and nuclear structure.

A major part of the proposed upgrading would be carried out using facilities in the Department. All design work has been done by staff.

Accelerator Manager Dr David Weisser, in the Department of Nuclear Physics, supervising the withdrawal of the superconducting resonator cavity device from the cryostat — a vacuum chamber to maintain low temperature (that of liquid helium) for superconduction.

A smaller project to upgrade the capabilities of the 14UD has recently been completed and its success provides a basis for a major upgrading.

A superconducting device was installed to compress the normally continuous beam available from the accelerator into separate intense pulses, with a time duration of less than 30 picoseconds (1 picosecond equals 1 millionth millionth of a second). This pulse beam project has recorded the best results of this kind anywhere in the world.

In simple terms it means that beam particles in each pulse arrive at a target within a distance of 1.5mm, with a spacing of about 800mm between each pulse. It is necessary to have such a beam if resonators are to be used to increase the energy.

With a pulse beam it becomes possible to observe the nature of very short-lived nuclear phenomena during the intervals between pulses without the intense backgrounds a continuous beam would produce. In particular, the properties of rapidly spinning nuclei can be studied.

As a whole the 14UD has proved flexible and highly adaptable, according to Dr Ophel.

Its uses include research into stellar evolution, ferromagnetism and crystal structure. Studies using the 14UD have also been used to chart the properties of exotic nuclei and to define the limits of their stability. It is also used for studies of radiation damage in solid crystal structures, heavy ion reaction processes, nuclear decay and nuclear spin.

Of considerable significance has been the study of nuclei under extreme stress, induced by colliding heavy nuclei to produce nuclei rotating so fast that they split under the extreme centrifugal force. Dr Ophel says the vast range of phenomena which can occur in nuclei is matched by the range of studies profoundly affected by nuclear physics. These range from particle physics to condensed matter and even astrophysics, with considerable impact on such fields as geophysics, archaeology, medical science and energy production.

ANU Reporter June 8 1984

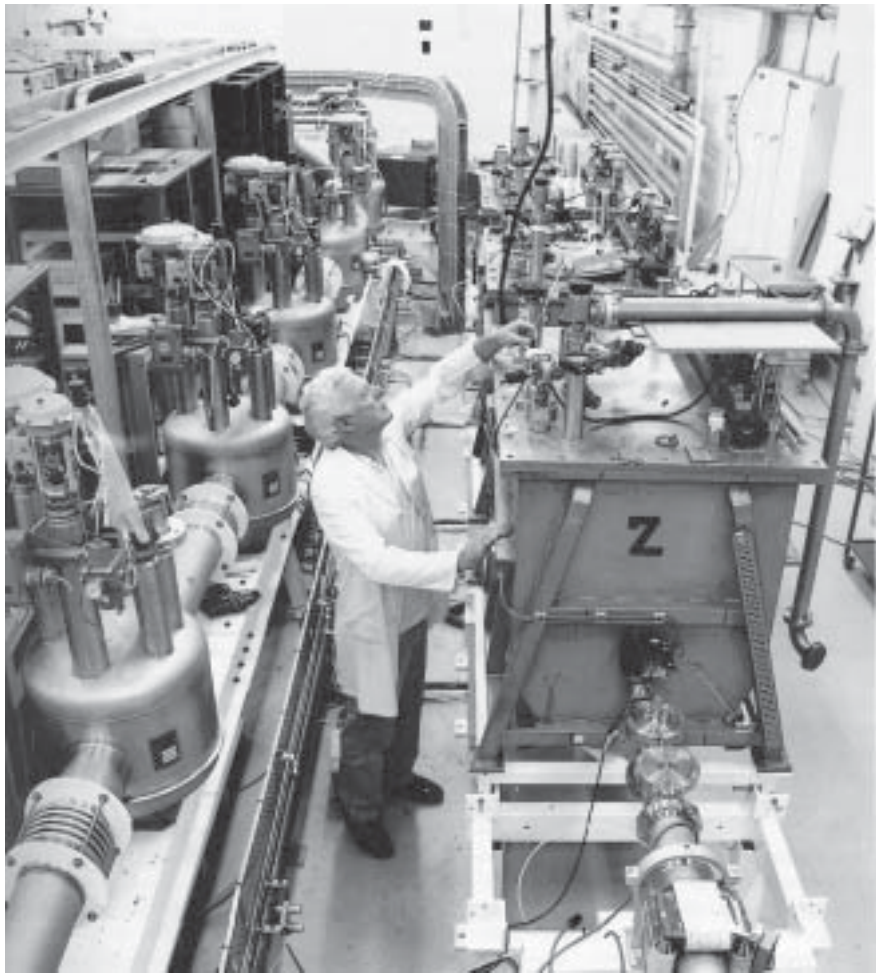
The Linac - A Super-conducting Booster

The concept of a linac made up of a readily-expandable number of individually phased high frequency resonators, preferably superconducting, to boost the energies of beams obtained from electrostatic accelerators arose in the early seventies. Such accelerators are ideal as a source of highly-charged ions since their final output energies are sufficient for almost complete, post-acceleration stripping. Highly-charged ions, for example nickel ions with a charge of 28+, can then be increased significantly in energy by the high instantaneous, surface fields (5-10 MV/m) attainable with resonators[8]. Many laboratories, including that at the ANU, either participated in development or monitored progress, with an eye to the future.

The saga of the linac or booster at Canberra proved to be a tragic comedy of strategic planning before it had been invented, and a cautionary tale for the ingenuous few who now espouse it in the context of inter-organisation co-ordination.

Titterton, as always, was alert to the possibilities. The likelihood of a booster proposal was fore-shadowed in several triennial submissions during the seventies. In 1976, he stated in the annual report of Nuclear Physics: "In planning the 14UD installation, it was anticipated that the most likely major

◅ *David Weisser removing a resonator assembly from the cryostat that houses it. The present booster linac cryostats each contain three such resonator assemblies, whereas the cryostat shown was used to provide picosecond bunching of the beam (1984).*



▻ *The acceleration cryostats of the ANU Linac are at the right of the photograph. The liquid helium distribution system is on the left. The standard man is Bob Ball, a technician in Nuclear Physics (1994).*

◿ *Lower left. A split-loop resonator. Acceleration is obtained from the high-level surface electric fields that obtain on the central doughnut electrodes.*

▽ *The centre electrode of a quarter-wave resonator. Resonators of this alternative configuration have been manufactured by Nuclear Physics.*

future development would be to add a post-accelerator to the machine to enable heavy ions of much higher energy to be produced. The design of the building relative to the EN tandem hall was arranged to conform to this possibility". He also made the initial proposal in 1981, basing it on use of the proceeds of the sales of the EN tandem and the cyclotron (plus interest!) with Government supplementation of $1.8M, to establish a booster over a period of six years. The Department felt that a more complete proposal, supported by a carefully delineated, research program and demonstrated technical preparation and competence to tackle the project, was more appropriate. An essential pre-requisite for a booster, nanosecond and picosecond beam bunching and pulsing, was implemented successfully with the 14UD, using a superconducting resonator purchased from Applied Superconductivity Inc. at Pasadena, California. A project was begun to fabricate resonators and to develop the techniques necessary to coat their surfaces with either lead or niobium. Finally in 1984, a detailed proposal was put forward with full ANU support, including endorsement by Council. The proposed linac with 40 resonators would provide a performance approximately equivalent to that of an accelerator with a terminal voltage of 28 MV, that is energies avail-

able from the 14UD alone would be essentially doubled. Staged funding of ~$5.5M was sought.

Thereafter, the many changes in science bureaucracy and the funding of university research seemed inevitably to exclude any avenue of access for the proposal, or later a updated version in 1988, to be considered properly, let alone funded. A number of agencies or organisations became involved, including the Tertiary Education Commission and the Department of Science before they were both abolished, ASTEC, AAEC, ANSTO (the former AAEC with a new charter) and the newly-created Australian Research Council. The treatment of the proposal brought credit to none of them. Suffice it to state that the proposals were not funded, nor was there any evidence that they had even been read.

Regrettably, the misfortunes of another heavy ion research laboratory were to provide salvation. In 1991, it was announced that the highly successful Daresbury accelerator, located near Manchester, would be closed at the end of 1992. The SERC had to trim its budget by about £10M if the CERN subscription were to be met. The annual grant to the accelerator laboratory was just that amount, so that closure was a neat, book-keeping solution. Despite world-wide protest and "questions in The House", the decision was upheld, though the closing date was extended to March 31, 1993.

A linac had been established at Daresbury using nine resonators obtained from the laboratory at Oxford, that had closed some years before. The linac was offered to the Department of Nuclear Physics in exchange for access rights to the Canberra facilities by UK researchers. Some concerns were raised, perhaps not entirely humorously, that "the curse of Tutankhamen" might strike a third time. Nonetheless, an agreement between the ANU and SERC was negotiated and signed in September 1992 by Sir Mark Richmond and John Carver.

Two shipments of the components of the booster, and additional magnets on loan from Daresbury, arrived in April and November 1993. Even though much of the first shipment suffered severe condensation damage due to inadequate packing, first beam tests of the loop ("the October revolution") took place only one year later. Injected beam from the 14UD was transported through much of the system, with the resonators passive, to check computer control of beam line elements and to confirm beam optics calculations.

Beam tests were made with active resonators in December 1995 and February 1996. During the latter, synchronous operation of some of the resonators, provided the first demonstration of the acceleration of an injected beam. On June 5, the energy of 120 MeV oxygen ions was increased to 130.4 MeV with seven of the resonators and a series of research measurements completed with the "boosted" beam.

Routine operation at full capability (the measurement of June 5 achieved only ~30% of the maximum energy boost ideally possible) is anticipated by the end of 1996. With the exception of the December tests that were delayed by industrial action on campus, the project has thus far maintained the original schedule outlined at the time of the agreement with the SERC - though some eight years behind that set out in the original proposal of 1984 and with a decidedly more modest device. It is planned to add additional resonators in 1997 and onwards.

1 Two stage acceleration involves the injection of negative ions (ie normal atomic species with an additional electron attached) into an accelerator with a central terminal at a positive voltage. Once accelerated by attraction to the terminal, the ions are stripped of two or more electrons to become positive and thus accelerated again by repulsion away from the terminal. With protons, an energy (MeV) of twice that of the terminal voltage (MV) is obtained. For carbon, an energy seven times that of the terminal voltage would obtain for complete stripping.

In early tandems, gas admitted to the terminal region provided the means of electron stripping. Later, thin carbon foils were used. The number of electrons stripped is a function of the ion velocity and the stripper medium. Foils provide a higher mean number of stripped electrons.

At the EN tandem voltages, complete stripping of carbon and heavier ions is highly improbable. The most intense charge state observed for carbon is 3+, and for oxygen 4+, using gas. With foils, the most intense charge state moves upwards by about one charge unit.

2 Bromley, D.A., Nucl. Inst. & Meth 122 (1974) 1.

The reference is an excellent review of the history of electrostatic accelerators. Useful companion reading is "A History of Accelerators in Australia" by T.R. Ophel (ANU P/1207) which is to be published in Nuclear Instruments and Methods.

3 In original application, accelerator mass spectrometry was the direct measurement of minute amounts of naturally-occurring carbon-14 (half life 5730 years) in samples using an accelerator and heavy ion detectors to achieve sensitivities some billion times greater than alternative methods. Measurements that otherwise would take some days by detection of the decay could be done in minutes. Moreover, much smaller sample sizes were feasible.

Extended to longer-lived cosmogenic species such as chlorine-36 (half life 308,000 years), AMS can measure within 30 minutes amounts that would result in about one decay event per year.

An AMS program was established using the 14UD in 1985 as a collaborative venture with CSIRO and AAEC.

4 Neutral helium injection was developed when early attempts to produce negative helium ions with adequate intensity proved unsuccessful. A helium injector, operating at about 500 kV, provided an intense beam (~200 μa) of He^+ ions that was passed through a gas exchange canal. The neutral fraction of the emerging ions drifted to the terminal to be charge-exchanged again by the stripper gas to doubly-charged (He^{++}) ions. Thus the energy obtained was twice that of the terminal voltage plus the injection energy. Beam intensities of ~1 μa were achieved.

5 Donnally, B.L. and Thoening, G., Phys. Rev. 159 (1967) 87.

6 A proposal for the production of ^{201}Tl - a Radiopharmaceutical for the Diagnosis of Coronary Artery Disease (December 1977) (unpublished).

7 Hanna, R.W., Leigh, J.R. and Burch, W.M., Australasian Radiology XXI (1977) 387.

8 A superconducting linac is comprised of a number of high frequency resonators whose surface is a superconducting material such as niobium or lead. Low power excitation of the resonators at liquid helium temperature produces extremely large surface electric fields which can be used to accelerate charged particles.

The particles gain maximum energy if they have a velocity matched to the characteristics of the resonator and enter the field of the resonator with a precise phase relationship to the sinusoidal voltage variations of the resonator. Thus the particles to be accelerated must be bunched in time, so that they all enter each resonator within a short time interval and are then all accelerated by the same amount.

Ideally, all ions in a beam bunch should arrive at each resonator within a span of ~50 picoseconds (50×10^{-12} seconds). Preparation of such a beam is done in two stages. First, the continuous beam from the ion source of the 14UD is bunched with an efficiency of ~50% into discrete beam pulses about 1 nanosecond (10^{-9} seconds) wide. A resonator, serving as a so-called super-buncher, can then compress the nanosecond wide pulses into 50 picosecond pulses, provided that they enter the resonator at a precisely determined phase.