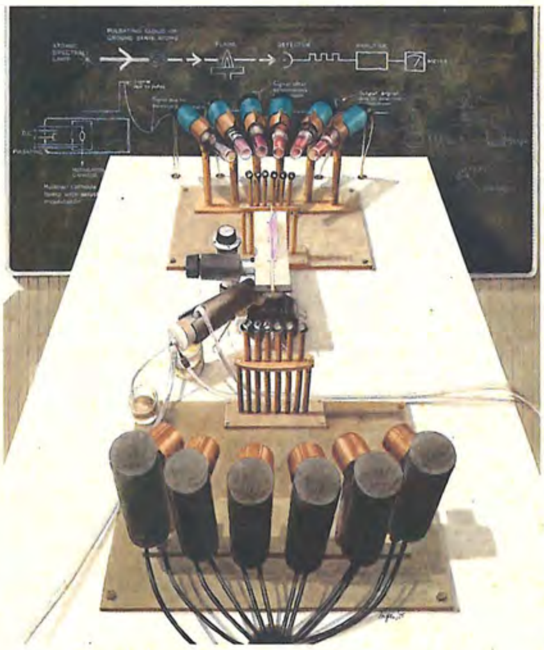
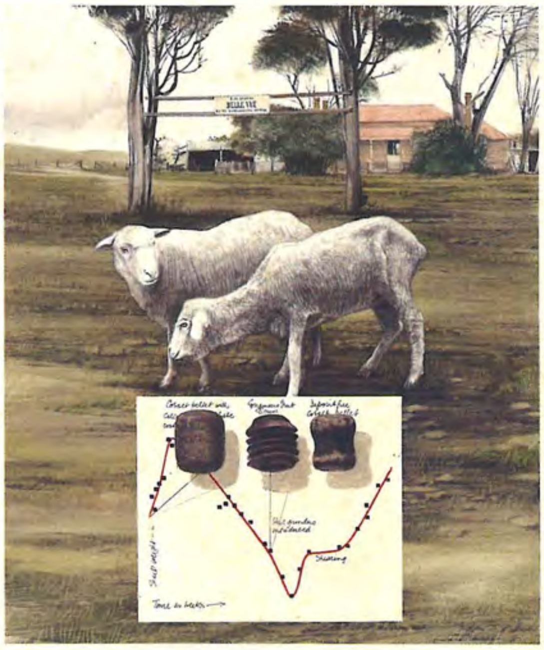
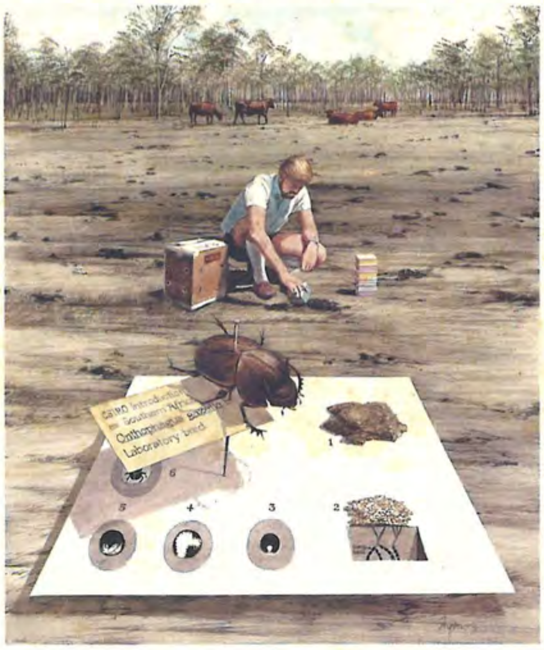
Surprise and Enterprise

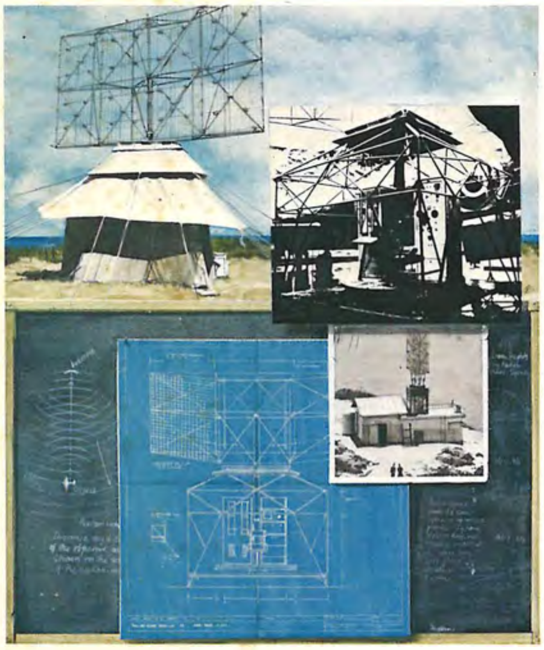
Fifty years of science for Australia

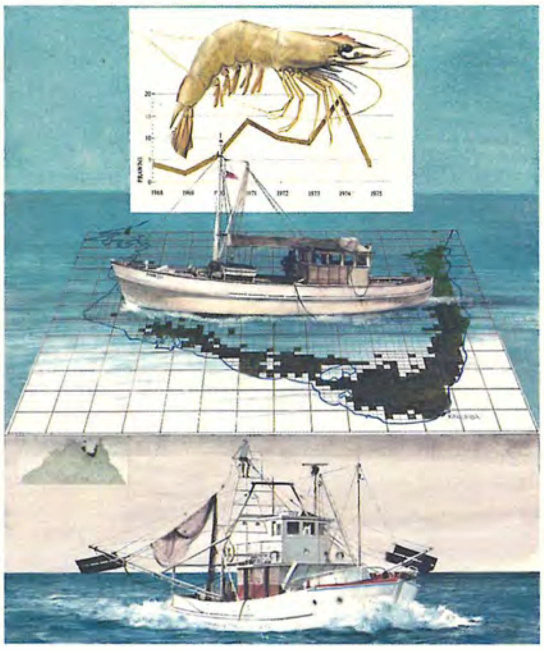
CSIRO

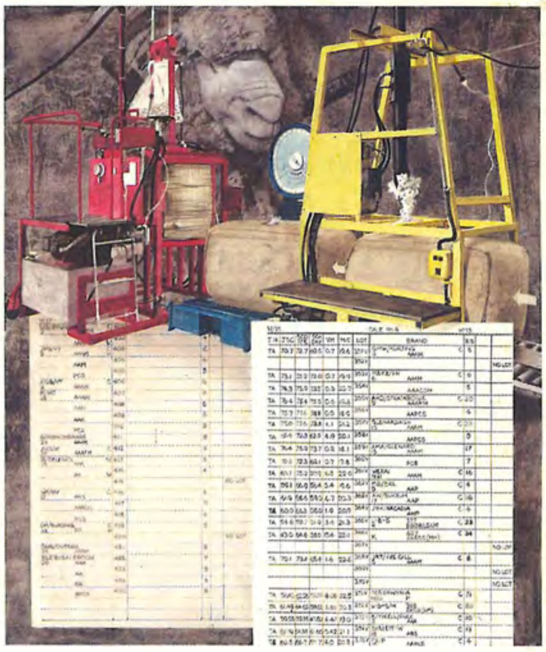












SURPRISE AND ENTERPRISE

FIFTY YEARS OF SCIENCE FOR AUSTRALIA

COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION, AUSTRALIA

Text by Andrew McKay

Illustrations and design by Robert Ingpen

Editors, Frederick White and David Kimpton

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Foreword

To many people, scientific research conjures up images of rather colourless individuals in white lab coats proceeding unemotionally and relentlessly towards the solution of a problem by a series of coldly calculated and impeccably logical steps. Nothing could be further from the truth. Scientific research is an enterprise undertaken by highly individualistic and highly motivated people pursuing knowledge on many fronts simultaneously—searching for new meanings and new relationships.

The process of discovery is painstaking and frustrating. Many of the leads followed arrive at a dead end and the scientist must retrace his steps and tackle the problem from a new angle. Surprise and enterprise are two essential characteristics of this process. Enterprise—the readiness to try something untried—contains within itself the seeds of surprise. In the words of Charles Kettering: 'Keep on going and the chances are you will stumble on something, perhaps when you are least expecting it. I have never heard of anyone stumbling on something sitting down.' In this sense, the element of surprise or chance is not passive; it reflects the imagination of the scientist that enables him to perceive the importance of the seemingly insignificant. As Louis Pasteur said, 'Chance favours only the prepared mind.'

This book has been written to mark the fiftieth anniversary of CSIRO. The stories in it have been chosen both to draw attention to some of the significant achievements of CSIRO in the last fifty years and to illustrate how the research leading to these achievements has been characterized by the elements of surprise and enterprise. In attempting to keep these stories reasonably brief and suitable for a wide audience, it has been necessary to sacrifice a great deal of detail; indeed, behind each of the achievements described is enough material for a substantial book.

Nevertheless I believe that these stories illustrate that research is not an impersonal pursuit by scientists 'living in an ivory tower'. CSIRO people are involved in the affairs of the society in which they live and have a deep concern for the impact of their work. Their human attitudes and their devotion to the search for new knowledge to advance science and serve Australia will be apparent.

While the stories have of necessity concentrated on the scientists concerned, the important role in research of the various technical, administrative, trades and other staff who provide the scientist with support services cannot be overlooked.

One of the reasons CSIRO has succeeded as an enterprise is because its staff at all levels have developed an appreciation and understanding of surprise; have learned how to allow for and capitalize on the unexpected. CSIRO's record of achievement over 50 years is one of which every Australian can be justly proud.

J. R. Price
Chairman of the Executive of CSIRO

The making of CSIRO

In 1926 a few small rented rooms in a technical college in the Melbourne suburb of Brunswick housed the first laboratory of what was to become Australia's largest scientific research organization—CSIRO. The organization's first annual report to Parliament listed some 41 scientists on its staff. Today, 50 years later, CSIRO has more than 2000 scientists and a total staff of almost 7000 located across Australia in more than 100 laboratories and field stations.

CSIRO, or CSIR as it was then called, was set up by Act of Parliament in 1926, but its origins go back 10 years earlier. In 1916 the Prime Minister, Mr W. M. Hughes, called together a number of prominent scientists and industrialists to discuss the formation of a scientific research institution to work on problems affecting primary and secondary industry. A temporary body, the Advisory Council of Science and Industry, was formed to prepare the way for a permanent Institute of Science and Industry. Its aim, said Hughes, 'was to apply to the pastoral, agricultural, mining and manufacturing industries the resources of science in such a way as to more effectively develop our great heritage'.

By 1917 a scheme had been drafted, but at the critical moment political support failed. The Advisory Council struggled on. It had neither laboratories nor research staff of its own; its financial resources were extremely limited. Nevertheless, it appointed a number of expert committees which did much valuable work in coordinating and stimulating research in existing laboratories. Among other things, the Council set in motion the agencies which succeeded in largely eradicating prickly pear from this country and started the investigation that led to the successful utilization of Australian hardwood pulp in paper-making.

It was not until 1920 that the Government passed an Act establishing a permanent Institute. But finance continued to be restricted. Some progress was made, however, particularly in forest products research. It was during this time, also, that research initiated by the Institute saved the banana industry from extinction by the virus disease 'bunchy-top'.

In 1925 the Government convened a conference of scientific and industrial leaders to advise how the Institute might best be organized and its activities extended. At about the same time, the then Prime Minister, Mr S. M. Bruce, invited an eminent British science administrator, Sir Frank Heath, to advise on the organization of national scientific research in Australia. As a result of the conference recommendations and Heath's report, Parliament passed the Science and Industry Research Act in 1926 establishing CSIR, the Council for Scientific and Industrial Research.

The Act vested control of the new organization in a relatively large Council which was composed almost entirely of part-time members representative of a wide range of scientific, agricultural and industrial interests in each State. The Act also provided for an Executive Committee of three to carry out the Council's functions between Council meetings. The first Chairman of the Council and the Executive Committee was Mr G. A. Julius (later Sir George), a leading consulting engineer. The Chief Executive Officer was Professor A. C. D. Rivett (later Sir David) who resigned the Chair of Chemistry at the University of Melbourne to accept the appointment. The third member of the Executive Committee was Professor A. E. V. Richardson, a distinguished agricultural scientist. Julius resigned at the end of 1945 and was succeeded as Chairman by Rivett.

A number of the scientists who had advised the Government on the establishment of CSIR had argued strongly that creative scientific research required a type of environment not usually found in government departments. Because of this, CSIR was set up as a statutory authority and the Council was given considerable freedom in the appointment and management of its staff. The Council, particularly Julius, Richardson and Rivett, and its first Secretary, Mr G. A. Lightfoot, were thus able to develop an organizational structure and style of management which contributed significantly to the success of CSIR and later CSIRO.

Although CSIR was established to undertake research for the benefit of Australia's primary and secondary industries, the Council decided to devote most of its limited resources initially to problems of agriculture and the utilization of forest products. Gradually CSIR built up divisions dealing with animal health and nutrition, soils, plant industry, fisheries, food preservation and transport, entomology and forest products. Only a few of the Council's officers were engaged in activities such as radio research and mineragraphy.

A succession of useful discoveries helped the new organization gain acceptance by the industries it served and by the community generally.

In 1936 the Government decided to extend the activities of CSIR to provide scientific assistance to secondary industry. This proved to be a fortunate decision, for the National Standards Laboratory, the Aeronautical Laboratory and the Division of Industrial Chemistry created in the years 1937-40 played an important part in the rapid wartime development of Australian industry. In 1940 three other laboratories were established to deal with problems raised by the war. They were the Division of Radiophysics, the Dairy Research Section and the Lubricants and Bearings Section (later the Division of Tribophysics).

After the war the Council was able to concentrate once more on problems of primary and secondary industry. New groups were formed as the Council expanded its research on building materials, wool textiles and coal and entered new fields such as atmospheric physics, physical metallurgy and assessment of land resources.

Then in the late 1940s, a political controversy was stirred up over the compatibility between the needs of scientific freedom and national security. This led to the passing of the Science and Industry Research Act of 1949. Under the Act, CSIR relinquished all secret or 'classified' work of a military nature.

The Council was reconstituted as CSIRO, the Commonwealth Scientific and Industrial Research Organization. The management of CSIRO was placed in the hands of a small Executive instead of the previous Council. Sir David Rivett retired in the same year and Dr I. Clunies Ross (later Sir Ian) became the first Chairman of the Executive.

Under the guidance of Sir Ian Clunies Ross and his successors, Sir Frederick White (1959-70) and Dr J. R. Price (1970-), CSIRO has gradually expanded its activities so that, in one way or another, the work of its 37 Divisions and six Units carries over into almost every field of primary and secondary industry and into many other areas affecting the community at large—the environment, human nutrition, conservation, urban planning. In fact the range of CSIRO's activities makes it one of the most comprehensive research organizations in the world.

CSIRO's reputation among scientists both in Australia and overseas rests on the quality of the Organization's research and its contribution to advancing the frontiers of scientific knowledge.

Among the Australian public, however, CSIRO's reputation is based more on the numerous achievements that impinge on the life of every Australian, achievements that are reflected in the clothes he wears, the food he eats, the house he lives in and the quality of his environment generally.

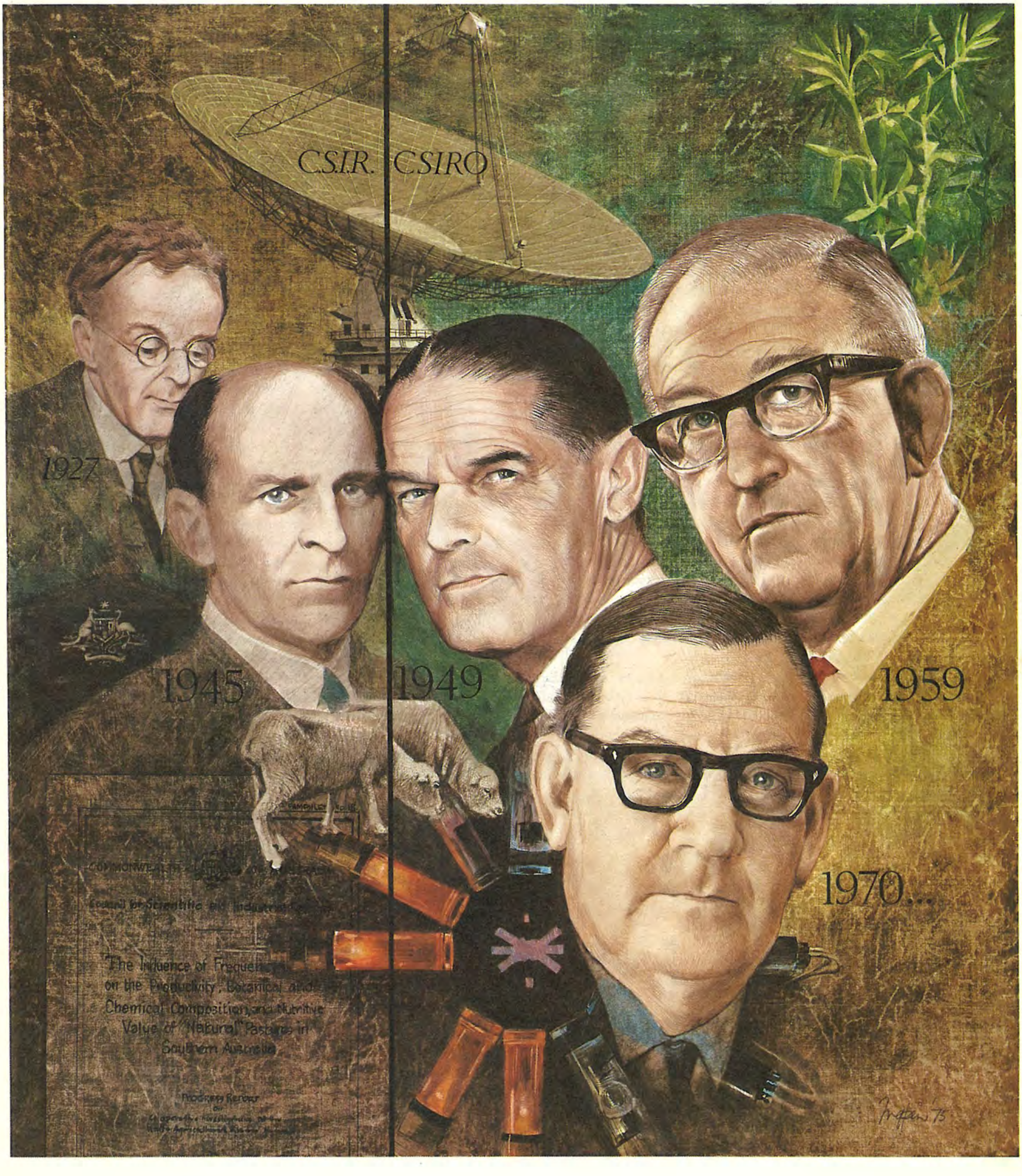
Sir George Julius 1926-45

Sir David Rivett 1946-49

Sir Ian Clunies Ross 1949-59

Sir Frederick White 1959-70

Dr J. R. Price 1970-



The absorbing atom

For years Alan Walsh, a tall and wiry Lancashire-born physicist of oceanic moods, had weathered despair in trying to find an answer to a problem that had defeated other scientists since the last century. It was the problem of how small concentrations of metallic elements could be measured more exactly by spectroscopy. The normal procedure in spectroscopy was to vaporize an element and measure the energy emitted as light by its excited atoms.

On a Sunday morning in March 1952, Walsh was working off his frustration in the garden of his home in the Melbourne bayside suburb of Brighton. Suddenly in one revealing flash of thought, something that he was never able to rationalize later, he had the answer. He hurried inside, dirt still on his shoes, and phoned his working colleague John Shelton. 'Look, John!' he exulted. 'We've been measuring the wrong bloody thing! We should be measuring *absorption*, not emission!' Early on Monday morning he set up a simple experiment, using the element sodium, in his laboratory at the Division of Chemical Physics. By morning-tea time he had a successful result—the basis of what has been called the most significant advance in chemical analysis this century. In purely scientific terms it was a remarkable achievement. In subsequent practical use its value has been beyond measure.

It saved the life of a young boy who went into violent convulsions after being admitted to a Sydney hospital with severe burns. Atomic absorption tests showed the boy had suffered a critical loss of magnesium. Given doses of that element, he recovered. Today his photograph has a special place in Walsh's office. Other atomic absorption tests solved the riddle of the crazed Minamata cats which were diving into the sea off Japan. The discovery that they had eaten mercury-polluted fish saved thousands of people from crippling illness and death. Similar tests recently explained the soaring delinquency rate in Sudbury, Ontario, revealing that a lead-smelting plant was contaminating the town. Atomic absorption has detected tainted baked beans during canning and helped find huge mineral deposits in Western Australia.

And yet Walsh's flash of inspiration was not an end but a beginning, of countless hours at his laboratory bench and then years during which he had periods of deep despondency as his discovery met almost universal indifference. The head of a big American corporation once challenged him, 'If this goddam technique is as useful as you say it is, why isn't it being used right here in the United States?' Walsh sharply retorted that in many ways America was an underdeveloped country. Now the corporation is the world's largest manufacturer of atomic absorption equipment.

The previous method of flame emission spectroscopy detected only seven or eight elements with the light given off by atoms when they were excited in a flame. But even in the hottest laboratory flames only very few atoms reach this excited state. On the other hand, all atoms in their normal state are capable of absorbing light until they reach an excited state and so a measurement of their light-absorbing capacity is generally much more sensitive.

With this in mind Walsh built his device which had a bunsen-type flame to produce atomic vapours from the sample solution. In order to measure the concentration of a particular element in the material, say sodium, he placed a sodium lamp operating from a.c. frequency on one side of the flame. On the other side he placed a filter which picked up only that particular sodium light frequency. It was linked to a highly selective photocell receiver which passed the selected frequency on to an amplifier. This amplified only the a.c. frequency and ignored any direct d.c. sodium light. Put to work, the device measured the amount of a.c. light from the sodium lamp that was absorbed by the sodium atoms in the flame while rejecting the d.c. light they put out directly.

Atomic absorption spectrometers can now detect 67 elements and a single apparatus has made up to 1700 analyses of different samples in a single day. Practically all atomic absorption analyses are made by Walsh's original technique.

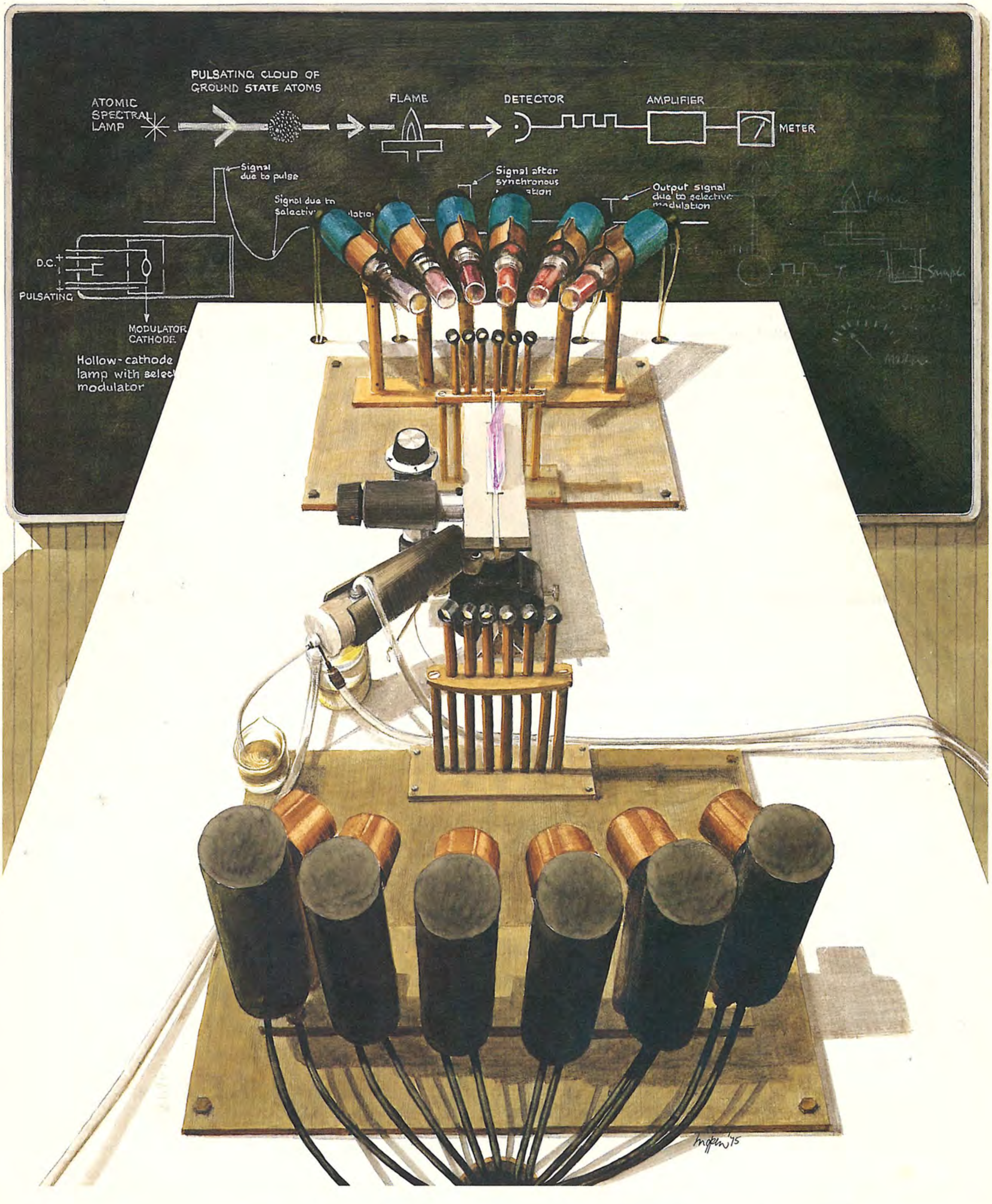
He and his fellow workers have since developed a wide range of improvements in the flames and atomic spectral lamps that are key components in atomic absorption spectrometers. Another refinement is a discharge lamp that can be used as a detector, doing away with the need for a monochromator. The recent invention of a sputtering chamber has done away with the need to dissolve the samples for analysis—solid samples can now be used direct.

Walsh's months of frustration and years of hard work are paying off handsomely. More than 30 000 atomic absorption instruments are now in use in hospitals, factories and laboratories around the world measuring traces of metallic elements in a whole range of substances as diverse as soil, blood, urine, plant leaves, minerals, wine and engine oil. A research outlay of $2 million has already benefited Australia by more than $100 million. By the end of the decade the value is expected to be many times this amount.

The absorbing atom

This experimental apparatus enables a sample of material to be analysed by atomic absorption spectroscopy for six different metallic elements. Blackboard diagram illustrates the principle involved. The sample is first dissolved and vaporized in flame. Each of the six lamps at the rear produces a beam of light at a wavelength characteristic of a particular element. Each beam passes through the flame and a monochromator into a photoelectric detector that measures the amount of light absorbed by the flame. This measurement provides a precise determination of the amount of the particular element in the sample.

Dr A. Walsh



The industrious dung beetle

The cattlemen of Queensland were surprisingly polite in the circumstances. From April 1967, CSIRO teams began knocking on homestead doors saying they had brought boxes of beetles to bury the cow pads on their properties. Not a single cattleman succumbed to derisory comment and only one complained. A studmaster near Ayr said he used cow pads to prop up his irrigation pipes. Now, he supposed, he would have to heft around blocks of wood.

So began a remarkable program to correct a balance of nature that was first disturbed nearly 200 years ago when the first English settlers landed five cows and two bulls on Australian soil. Throughout the Mediterranean area and Africa, nature had developed a refined waste-disposal system operated by a wide variety of dung-burying beetles. These insects, ranging from the fearsome *Heliocopris gigas*, as big as a golf ball, to midgets no bigger than a pea, squeeze nutritious juices from cattle dung for their food and use the residue to form dung balls in which their eggs can hatch.

In Australia about 250 kinds of scarab beetle busy themselves in similar cleaning-up operations on the dung left by native animals. But even the largest kangaroos leave only small, dry and fibrous pellets. The moister and much larger pads of imported cattle are a different problem. Only a few of the native beetles attack them effectively and then only at certain times of the year. So, as the cattle population has grown and spread, its dung fallout has become a serious concern. Cow pads dry on the ground to hard cakes and can remain for many months, even years, until they disintegrate.

The average adult cow drops 12 dung pads every day. If the pads are not disposed of, they may cover up to several per cent of the grazing area. Moreover, an area of rank pasture will grow around the edge of each cow pad. Cattle tend to avoid this unless ravenous. A quick calculation shows that the 30 million cattle in Australia, producing 300 million cow pads a day, could be spoiling more than a million hectares of grazing land each year. In addition, the unburied dung is an important breeding ground for several flies, particularly the pestiferous bush fly that so impairs the quality of outdoor living throughout much of Australia during summer.

In October 1951, while working with the Zoology Department of the University of Western Australia, a Hungarian-born entomologist named George Bornemissza collected beetles at Northam, east of Perth. Bornemissza had been in Australia only nine months and the first thing that struck him out in the field was the quantity of old cow pads and the apparent absence of dung beetles. This was something he had never seen in Europe. The thought stuck like a burr in his mind and he continued making observations after joining CSIRO three years later. In the late 1950s his suggestion that foreign dung beetles could usefully be imported into Australia was taken up by the Division of Entomology in Canberra. Bornemissza went to study in Europe and then to Hawaii and Fiji where he selected the first species of beetles for release in pilot schemes on northern pastures.

The first large-scale release of dung beetles by CSIRO followed in 1967 and over the next three summers 275 000 beetles of four species were let loose, mainly between Broome in Western Australia and Townsville in Queensland. The little *Onthophagus gazella* made extraordinary progress, colonizing an area 400 kilometres by 80 kilometres in just two years. Other African species have since spread through southern Queensland and northern New South Wales, making short work of clearing pad-spoiled pastures in summer when conditions aren't too dry.

George Bornemissza now works from the CSIRO Dung Beetle Research Unit which he set up in Pretoria, South Africa. He has investigated more than 160 species and sent the eggs of 34 species to Australia, under strict quarantine conditions, for breeding and release. In Canberra the Division's entomologists take turns at the least attractive operation in the whole program—hand-rolling dung balls in which the eggs can hatch.

Curiously, this strict quarantine which was designed to prevent importing the minute parasites that live on adult beetles is now being questioned. It is believed that tiny mites which live on dung beetles could be important in another delicate balance of nature and that they might, if allowed to breed here, attack the fly maggots which breed in cow pads. It could mean the end of the great Australian salute—that reflex flick of the hand which begins with the first flies of summer.

The industrious dung beetle

Dung beetles are released in a paddock in Queensland. The beetle's breeding cycle begins on the fresh dung pat (1). Beetles break up the pad and bury the rolled dung balls after laying their eggs in them. The eggs proceed through larval and pupal stages before hatching as young adult beetles. Pinned on a collection tag is an adult of the species *Onthophagus gazella* F., now established in Australia.

Dr G. F. Bornemissza

Mechanizing cheese-making

The secret of cheese-making was discovered possibly 6000 years ago. Certainly the ancient Greeks knew it. Homer composed songs about cheese and the goddess Aphrodite was said to have sent gifts of cheese to the warriors of Troy. The knowledge spread throughout Europe and became shrouded in mysteries and rituals as it was passed from generation to generation.

The early settlers brought their knowledge of cheese-making to Australia and by 1870 the first factories had opened on the rich dairy-farming country of the south coast of New South Wales. Manufacture spread and further cheese factories were built to keep pace with Australia's growing population. During World War II a hungry Britain sent pleas for more food and manufacture expanded still further.

After the war the industry went into a decline, worsened by the trouble that cheese-makers were having with starter cultures of fermentation bacteria which refused to multiply satisfactorily, and a virus infection that was killing the bacteria.

The CSIRO Division of Food Research placed advertisements in British newspapers seeking scientists who might solve the problem. One answer came from Josef Czulak, a former Polish cavalry officer who had survived the heroic charges against Hitler's panzer tank battalions in the battle for Poland. He had later taken part in the Normandy invasion, which qualified him for British repatriation and enabled him to take an Agricultural Science degree and a Postgraduate Diploma in Bacteriology at Reading University. 'I had a farming background and I wanted to do practical science', he once explained. 'Not fighting, but growing food. A rejection of war and a concentration on peace.' The Division asked Czulak to come to Australia and he arrived in 1951 with his Scots wife. Two years later he had beaten both the starter-culture trouble and the infection.

Then the Division turned to the mechanization of cheese-making, at a time when the industry still regarded technology with deep suspicion. A leading British dairy scientist said, 'I fear that we are in very great danger of thinking that the engineer can solve the problem of the mechanization of cheese-making. Despite the assistance of the engineer and the scientist, cheese-making is still an art.'

In fact, mechanical agitators were already in use in the first phase of cheese-making, the conversion of milk to curds and whey and the 'cooking' of the curd. Curds are the coagulated solids in milk which compose most of the protein and fat, and whey is the pale yellowish liquid that is left.

The rest of the cheese-making process can be divided into a further three phases. In the second or 'cheddaring' phase, the free whey is drawn off and the curds are fused into large slabs with a fibrous texture. In phase three the slabs are milled into finger-sized pieces, salt is added, and the salted curd is placed in large drums or in stainless steel hoops. The fourth phase involves compressing the curd and packaging.

By 1957, Czulak and a team of engineers and technologists had built a pilot system combining phases 1, 2 and 3. A film of the plant in operation was shown to the largest meeting of cheese-making experts to gather in Britain and their response was enthusiastic, if still cautious. In Australia, suspicion lingered on. 'Resistance was colossal', Czulak recalls. 'The cheese-maker was supposed to be in command of so many varieties and, next to God, he knew most about cheese-making. But he didn't really know, because there were so many mysteries and these were covered up with "art". In order to make any inroads with technology, we had to demolish this concept of mystery. But it's one thing to demonstrate something on a pilot scale and another to put it into commercial operation.'

Phase 3, the most labour-hungry operation, was tackled first and by 1960 the first commercial machine, developed by the food engineering company Bell Bryant Pty Ltd with CSIRO, went into operation. Now more than 50 Bell–Siro Cheesemaker 3 machines are working in Australia, New Zealand, Britain, Ireland, Holland and the United States. These machines can handle up to 4530 kilograms of curd an hour, the present economical limit.

In 1967 the first phase 2 machine, Bell-Siro Cheesemaker 2, was installed in a New Zealand factory, followed in 1970 with an improved model in a factory at Camperdown, Victoria. The new model gives greater flexibility in the types of cheese made and can be used to produce Cheddar, Cheshire, Cheedam, Colby, stirred-curd and Romano cheese varieties. Between them, Cheesemakers 2 and 3 have cut labour costs in the Australian industry by two-thirds.

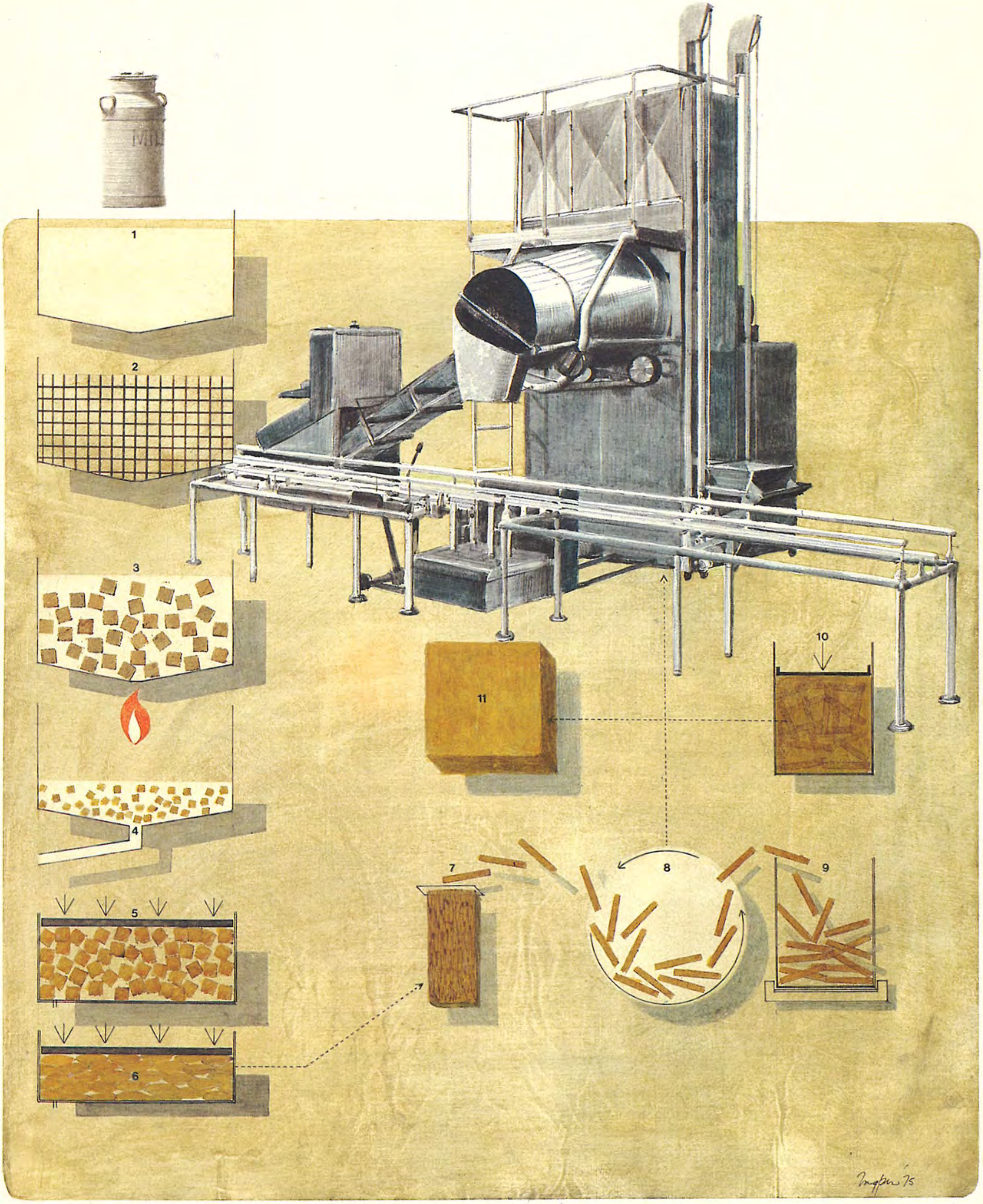
In 1975, Bell–Siro Cheesemaker 4 went to work at Lismore, New South Wales, revolutionizing the final phase with a huge hoop-press, producing 453-kilogram blocks of cheese instead of the traditional 18-kilogram blocks. All the machines are self-cleaning, previously a messy business that used to take up to five hours, and two technicians now do the work of 20 cheese-makers.

The mechanization of cheese-making, together with other economic factors, has led to a vast reorganization of the Australian industry. Sixty factories have been absorbed into 12. And, with mystery replaced by scientific control, cheese quality in all varieties has improved. In 1952 the average Australian ate less than three kilograms of cheese a year. Now he eats twice as much.

Mechanizing cheese-making

A bacterial culture and rennet turn pasteurized milk into jelly-like curd (1) which is cut to separate whey from solids (2). Warming and stirring shrink curds (3) and free whey is drawn off (4). Curds are heaped and pressed (5), fusing or 'cheddaring' into a fibrous mass (6), which is then milled into small pieces (7), salted (8) and measured into moulds or hoops (9). Pressed into blocks (10), the cheddar is wrapped in plastic and left to mature. The Bell-Siro milling and salting machine is illustrated.

Dr J. Czulak



A yarn with a twist

For physicist David Henshaw it was a moment when weeks of thought wove into one complete and perfect pattern. An instant in which he found the way around a problem which had baffled wool spinners for 200 years.

David Henshaw, who works with the CSIRO Division of Textile Industry at Geelong in Victoria, had spent months investigating wool-spinning—an operation unchanged since a fateful day in 1764 when Jenny, the small daughter of an impoverished English spinner James Hargreaves, knocked over his spinning wheel, and Hargreaves, seeing how the spindle continued to turn while upright, had that flash of intuition which produced the spinning jenny. His invention increased a spinner's output eight times and changed spinning from a simple cottage craft to a complex component of the Industrial Revolution, feeding those 'dark satanic mills' of poet William Blake.

Wednesday 8 February 1961 was a day of sudden and unexpected rain which ended 13 days of acute fire danger and put out bushfires across the State. It was the day on which Henshaw, a sandy-bearded, laconic man with a reserved manner, sat down once again in the poky library of the old Textile Division building and surrounded himself with the books and papers he had gathered in his research. He had run into a blank wall with the realization that mechanical improvement to Hargreaves's invention had an absolute limit. It was impossible to turn the spindle which spun wool 'rovings' into yarn faster than 10 000 revolutions a minute. This produced about 15 metres of yarn a minute—and it takes 20 000 metres to make up an average two-piece suit. If a spindle went faster than this, centrifugal forces became too high and the yarn broke. This was the point at which all research had foundered.

So David Henshaw began thinking laterally. If he could not make a better spindle he would find a way of making a different yarn. Conventional yarn was spun with a single-direction twist so he looked at alternate twist and then double-folded alternate twist. But it was not much good. The twist was unstable and easily unravelled, particularly under tension. It seemed to be yet another dead end.

And then, suddenly, he had the answer.

Bundling up his papers, he hurried to the nearby office of his colleague Gordon Walls. There was a blackboard on one wall and with a few quick chalk lines he drew his extraordinary but simple discovery . . . take two lengths of wool rovings pinned at their heads and twist the middle of each independently, in the same direction. Now hold them together—and then release them.

What happens?

The energy stored in the twist makes them wrap around each other to form a new type of yarn with an alternating twist. And, despite the reversal of twist, its strength is still comparable with conventional yarn. Because only a very small section need be rotated to impart the twist, it can be spun at virtually limitless speed. Hargreaves's old twist-imparting spindle and its successors could be thrown out the window.

The discovery was to Walls an instantaneous and perfect solution. He was even more excited than Henshaw who had ploughed through those months of tedious groundwork. For years Walls had worked on cotton and rayon spinning research in England and he immediately saw tremendous implications.

But after the first terrific rush of excitement came the long, frustrating and sometimes disheartening work of inventing a machine that would make the new 'self-twist' yarn a reality on the factory floor.

Secrecy at this time was vital to allow maximum development before patents were taken out. The Chief of the Division of Textile Industry, Dr M. (Pip) Lipson, gave Henshaw a small room tucked away in a remote corner of the crowded red-brick building that then housed the Textile Division. They installed a workbench and then the door was locked. It stayed locked, except for Henshaw's frequent visits to the machine workshop, for the next 15 months. Henshaw, a spare-time handyman, devised a Heath Robinson contraption of spinning tubes and intricate components machined for him by two tool-makers who had been sworn to secrecy.

It worked, but only just.

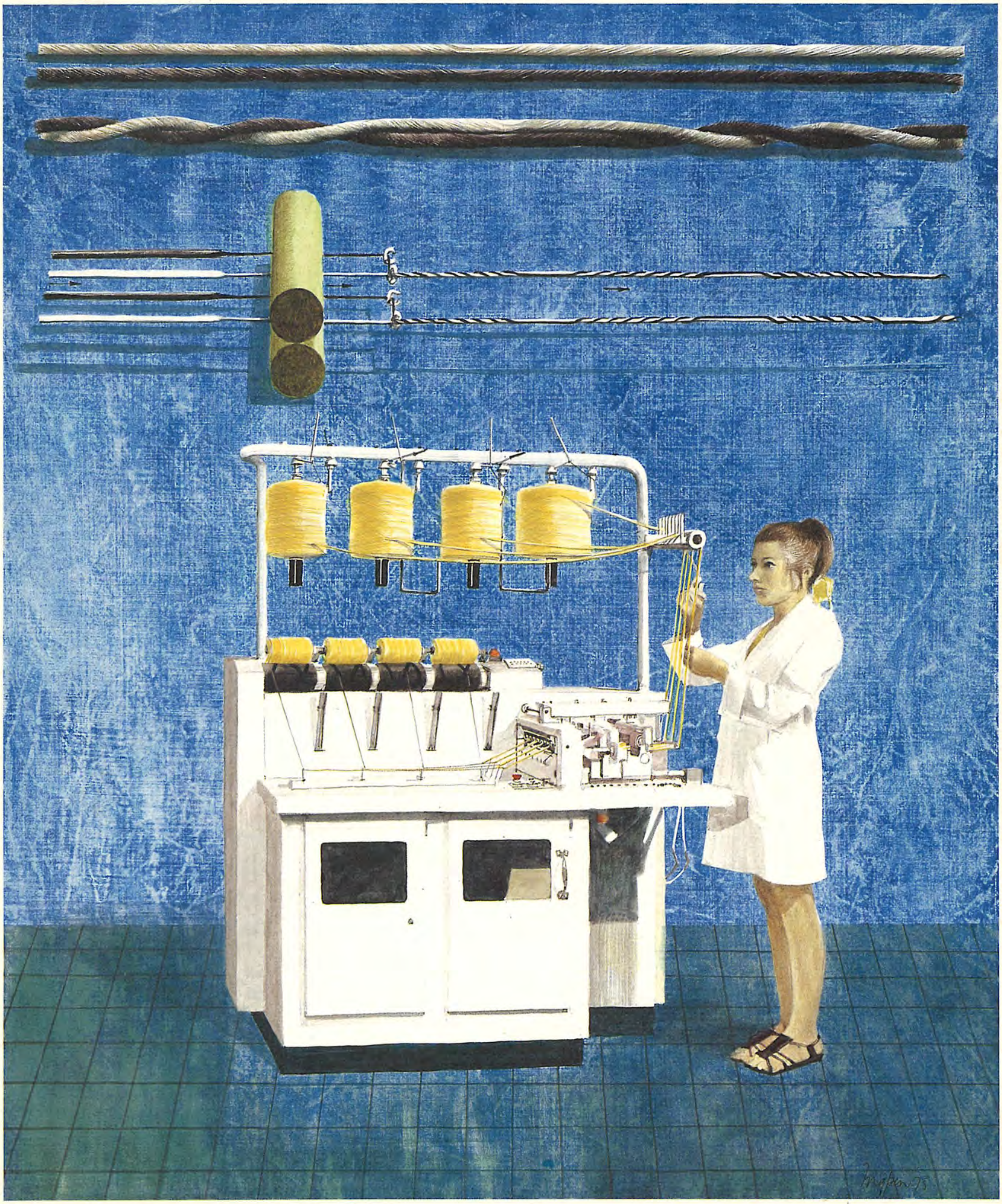
He pressed on, graduating to a more sophisticated machine using rotating discs with arcs of rubber arranged to insert intermittent twist as rovings were pulled between them. This worked well enough to produce self-twist yarns in quantities which could be tested for weaving. Henshaw and Walls had the very first self-twist worsted suits made and gave them everyday wear. None of their textile-conscious colleagues picked the new fabric from conventional cloth.

CSIRO then brought the manufacturing firm of Repco Ltd into the project to build three prototype machines. Repco had an outstanding reputation both in design and in manufacture of working machines for industry. Previous experience had

A yarn with a twist

Winner of the 1970 Prince Philip Prize for industrial design, the Repco spinner produces a new type of yarn by twisting two parallel fibres in the same direction and then bringing them into contact so that, in unwinding, they wrap around each other. Eight fibre strands are spun simultaneously, making four packages of two-ply yarn. Detail shows how the spinner's reciprocating rollers impart alternate-direction twists along the yarn's length.

Dr D. E. Henshaw and Mr G. W. Walls



shown CSIRO the problems of working with distant machinery manufacturers in Europe and America.

But the process was still too slow. The main problem was twisting the yarn—a sideways movement—while moving it forward onto a spindle as fast as possible. These conflicting movements seemed to restrict severely the speed at which a machine could be made to operate.

Then Walls hit on the idea of using rollers instead of discs to impart twist. He found that by reciprocating a pair of rollers (making them move backwards and forwards along their axes) he could get the twist in the wool strands, while continuous rotation of the rollers moved the strands forward.

He selected a pair of standard rubber sleeves from the machine-room stock to use as rollers and by purest chance they worked first time. (He found just how lucky he had been when later tests showed that none of the other 25 types of sleeve in stock would have worked.)

The choice of Repco now proved to be a winner. Their team, under Lionel Stern, created a machine of engineering and design standards that surpassed anything seen in the textile industry. Their first batch of six machines was delivered to CSIRO in early 1969. They were hidden in a back room at Geelong and put to work on 24-hour shifts.

By now patents had been published in many of the 24 countries where CSIRO had sought protection but still no whisper reached any of the hundreds of overseas textile experts visiting the Geelong Division. The Prime Minister, Sir Robert Menzies, was given Clan Menzies tartan curtains for his study made from self-twist yarn, but not even he was told of the new process. Finally, after feeding many thousands of metres of fabric into commercial outlets, CSIRO was satisfied that self-twist was a 'goer' and ready for the outside world.

These first-generation machines increased the output of yarn from 20 metres a minute to 220 metres and decreased the size of the machine by four-fifths. Of the six machines, three were sent to Australian mills and two to Britain for trials and demonstration. The remaining one stayed at Geelong for further testing.

On 10 February 1970 more than 200 wool industry men gathered at Geelong to see the first public demonstration and, at last, self-twist was out in the open. They saw a machine spinning wool 12 times faster than it had ever been spun before. More than that, the machine was quieter and more pleasant to work than any other, and used less power.

But there was a last-minute crisis. A year later one of the machines sent to England developed swollen rollers only weeks before it was to go on display at the International Textile Machinery Exhibition in Paris. The cause of its malaise was diagnosed as a special oil widely used in Europe to lubricate the wool fibres, and an urgent call for help was cabled back to Geelong. Chemists in the Division developed new synthetic rubber and the machine was given new rollers just in time for the exhibition opening.

Then came recognition. In 1971 the Repco Spinner won the Prince Philip Design Prize for industrial design. (Curiously, Prince Philip had been one of the first people to handle self-twist material without knowing it, when he officially opened Clunies Ross House in Melbourne in 1969, and admired the curtains. Several people were tempted to tell him the secret—but nobody did.) Then in 1972 Henshaw and Walls shared the $10 000 Encyclopaedia Britannica Australia Award for Science with Lionel Stern of Repco Ltd.

More than 1600 machines worth $15 million have been exported.

The benefit to the wool industry is enormous. Spinning costs for self-twist wool yarn are 10 cents to 30 cents cheaper per kilo than with conventional methods.

Ten self-twist spinners installed at Macquarie Worsteds in Albury in 1971 soon indicated their potential. The machines, operated in a small air-conditioned room by one girl, had an output of 1200 conventional spindles worked by three girls. Macquarie have since put in another 20 self-twist spinners. But they were only the second generation of machines. At the International Textile Machinery Exhibition in Milan in 1975, Repco unveiled the third generation—the SELFIL spinner.

The SELFIL spinner produces a completely new type of yarn from a mixture of wool and synthetics. The yarn, consisting of 80 per cent or more of wool, is superbly strong and long-wearing and is ideal for knitting into a wide range of garments. It consists of two thin continuous strands of nylon or other synthetic fibre twisted around a central strand of wool, spun at 16 times the speed of conventional machines. The process has opened up a whole new market for wool in the field of commercial knitting—a market which was virtually closed to wool because of costs and breakage of the yarns. The SELFIL spinner is likely to revolutionize wool knitting around the world and put wool back into strong competition with synthetics.

The absolute ohm

In 1875 eighteen countries created an International Bureau of Weights and Measures at Sèvres, near Paris. One of its first tasks was to re-define the metre which was taken to be one ten-millionth of a quadrant of the Earth's meridian, passing through Dunkirk and a point near Barcelona. The conference agreed that the new definition should be the distance between two engraved lines on a bar of platinum - iridium alloy at zero degrees Celsius.

In 1960 the metre was re-defined, as 1 650 763·73 wavelengths in a vacuum of the radiation of the orange line of the krypton-86 isotope. Today there is pressure to re-define it still more precisely in terms of the distance travelled by light in a certain time.

So new technology keeps producing new definitions and new standards against which measurements of all physical quantities can be made. A major contribution to new technology was made at the CSIRO National Measurement Laboratory, in the grounds of the University of Sydney, in the infinitely more complex field of electrical measurements.

In electrical engineering there is a constant need to check the values of the standards used to maintain the basic units of electrical measurements—the volt and the ohm. Millions of dollars' worth of electrical equipment is made in Australia every year. If each manufacturer used even a slightly different value for the volt or the ohm enormous confusion and huge financial losses would follow. The values of such basic building blocks as capacitors and resistors—which go into TV sets, radios and tape recorders—must be known accurately to prevent signals from straying into the wrong channels.

In 1861 the British Association for the Advancement of Science set up a committee on electric units and standards. For the ohm—a measure of resistance to the flow of electric current—they chose the resistance of a column of mercury, one square millimetre in cross-section and 106·3 centimetres long. This mercury ohm has long since been replaced by the so-called absolute ohm which is derived from the units of length and time.

It was later found that the mercury ohm differed from the absolute ohm by up to 1·5 per cent.

The classical method of relating the ohm to the units of length and time involves the construction of a coil of copper wire of a large number of turns wound onto a very precise former usually nowadays of fused silica. By measuring the position and diameter of each turn of wire the inductance of the coil can be calculated. The inductance is a measure of the magnetic energy generated when a current is passed through the coil and depends only on the geometry of the coil. A complex series of electrical measurements is necessary to relate the resistance of a standard resistor to the inductance of the coil. Once the absolute value of one resistor is determined in this way it is a relatively simple matter to obtain the values of other resistors by comparing them with it. But the measurement of a coil's many physical dimensions is a finicky and frustrating business which can take up to six months.

By the early 1950s the CSIRO National Measurement Laboratory had developed methods for the precise measurement of small values of electric capacitance and for the comparison of capacitance and resistance. By 1955 scientist Keith Clothier had a well-developed design for a variable capacitor of two metal-coated flat glass plates isolated in a vacuum. But this required measurements of the plates and their spacing to get an accurate value. Then another scientist, Mel Thompson, was struck by an idea which he was later to describe as 'pure serendipity'. He realized that the drudgery involved in measuring the exact physical dimensions of a capacitor could be avoided with a device of simpler cylindrical geometry. If the cross-section of the cylinder which was divided into two pairs of electrodes was nominally symmetrical then any imperfections in the symmetry could be taken into account by measuring both 'cross-capacitors'. His colleague Doug Lampard calculated the capacitance per unit length of a number of different cross-sections and was able to prove that all cross-sections gave the same answer independent of size and shape. This was an unexpected but tremendously useful result.

Thompson persuaded Clothier to abandon his research and make a new design based on this idea. It resulted in a calculable capacitor of four parallel brass rods which needed only one length measurement to determine its absolute value. This was done with light waves and resulted in an accuracy that surprised even the scientists. 'We thought we would get an accuracy of one part per million', Thompson has said. 'Well, it turned out that we did 10 times better than that—and we could now do 10 times better still.'

From 1964 to 1974, when the Americans confirmed the value with similar equipment based on Thompson's idea, the National Measurement Laboratory gave the world its best value of the absolute ohm, and readings took not six months, but three hours.

Waterfowl and water levels

Harry Frith sat 10 metres up in a redgum tree in a swamp near Griffith. With a razor-sharp tomahawk he chopped at a limb in which a grey teal had made her nest. The limb broke—and it was then that Harry Frith decided it was not the best method of gathering breeding data, anyway. Instead he began examining the testes and ovaries of ducks shot to a regular schedule.

The year was 1953 and Frith was making the first scientific survey in Australia of waterfowl. What he found by looking at the reproductive organs of male grey teal in the Murray–Darling area revealed evidence of remarkable adaptation to its environment and the first understanding of the species' eccentric life cycle. His findings demanded a radical reappraisal of accepted concepts of waterfowl conservation.

A keen amateur naturalist and a qualified agricultural scientist working in CSIRO on horticulture, Frith transferred to the newly formed Wildlife Survey Section in 1950. His first brief was prompted by complaints from rice-growers in the Murrumbidgee Irrigation Area that wild duck were destroying their crops. But his investigation was much wider than that, encompassing the 'ecology and bio-economics of the wild duck'.

The basic areas of information needed were diet, breeding, movement and the factors regulating them. He was able to get approval from the New South Wales authorities to conduct year-round selective shooting. Each month he began taking a variety of waterfowl including 20 black duck and 20 grey teal, Australia's two most important game birds, to provide a steady and unbroken stream of data. He was soon able to show that ducks were not the pest rice-growers supposed them to be and that much of the damage attributed to them was, in fact, caused by other factors.

In 1953 Frith began banding duck, not just the two most common species but whatever he was able to trap. About this time the natural conditions of the Murray–Darling area—which includes their tributaries the Ovens and Goulburn, the Lachlan and Murrumbidgee, the Macquarie and Gwydir, and the Bulloo–Paroo–Warrego systems—began to shape his observations. The flood years of 1951 and 1952 were followed by a near drought in 1954 and Frith began to see how this had a marked effect on duck behaviour and populations.

In 1955 there was a minor flood down the Lachlan and Frith drove east of Booligal where he shot several duck and found their testes were sexually mature. Then in the same day he drove 160 kilometres to get ahead of the floodwaters and shot several more duck. Their testes were sexually inactive. In that moment Frith had dramatic confirmation of what he had begun to suspect: that breeding was controlled by water level. In the following two years he was blessed with good luck; floods in 1956 and then drought in 1957 provided him with further evidence of how duck had adapted to their unpredictable environment to ensure the continuation of their species.

In 1957 Frith was making an investigation of wild geese in the new rice-growing areas near Darwin, when grey teal began arriving in thousands. Frith phoned an urgent request to his colleagues in Canberra to send traps and within a few months he and others had banded 5000 birds. At this time there was already a well-established duck-banding program under way in southern Australia. Over the following years as banded grey teal were shot, the recovered bands revealed an extraordinary pattern of explosive dispersal in times of drought. Driven out of the Murray–Darling breeding area by dry conditions the teal would fly at random until they reached other water. Some might reach New Guinea and New Zealand but it was likely that many more fell into the ocean and died. Others found their haven along the east coast in the natural swamp refuges, many of which are now threatened by land reclamation and real-estate development.

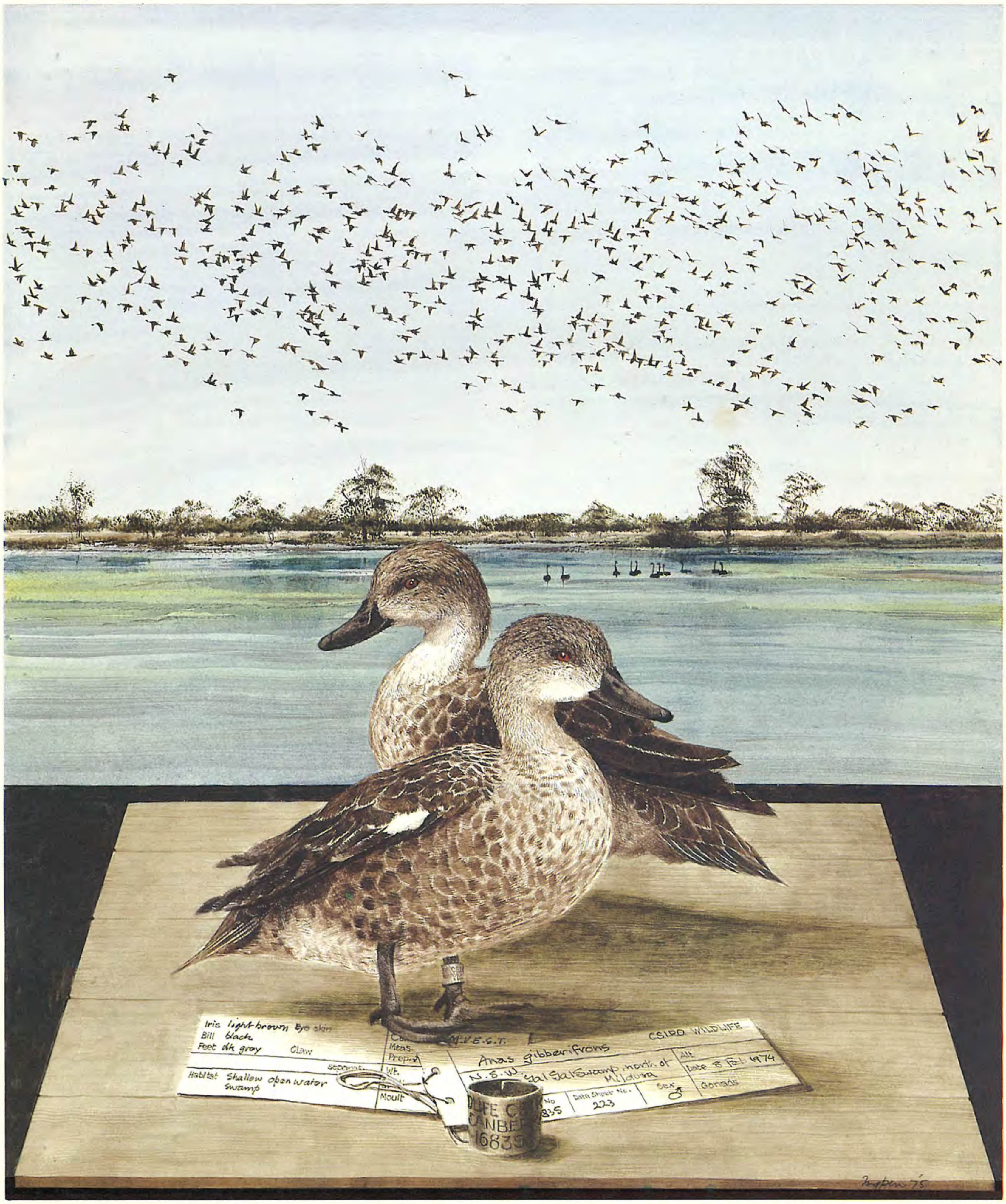
Later work showed that in times of drought grey teal might not breed for several years yet within only 10 days of an increase in water level they could become sexually active and lay eggs.

'When hydroelectric and irrigation schemes finally control all floods, the grey teal and many other waterfowl will have few places left to breed', says Frith. 'To prevent this the replenishment of billabongs along inland rivers must be ensured and the coastal swamp refuges protected. Most importantly the States and the Federal Government must agree on a common resource policy and involve biologists in the planning of water conservation.'

Waterfowl and water levels

Two grey teal stand on a collection table as a flock of grey teal fly above a Riverina swamp. One bird carries a CSIRO band on its leg. Both sides of a taxonomic tag for CSIRO's grey teal skin collection are shown.

Dr H. J. Frith



Cobalt and coast disease

Under a windswept clear blue sky a score of lambs frisked, stiff-legged and tails bobbing, over rolling sand-dune pasture at Robe, on the south-east coast of South Australia. Farmer Bob Dawson tipped back his hat and a grin split his weathered face. 'Pretty good, John', he said. 'Pretty good, John . . . pretty good.'

CSIRO scientist John Lee could not reply. He simply nodded and the two men stood in silence watching the beginning of a miraculous change at Robe. The year was 1937 and for the first time since Bob Dawson's father took up the property in 1877 a spring crop of lambs had not only survived, but thrived. The land that had broken Bob Dawson's heart for 40 years had given up its sour secret and had been beaten. Two years later a flock of Dawson lambs fetched top price at a nearby market.

The land looked promising enough to the first settlers. It had a good reliable rainfall; the rough scrub and native grasses were readily cleared for pasture. But the settlers soon found that sheep grazed on these pastures lost their appetite and their wool became 'steely' and dead-feeling. If the sheep were not moved inland every year they became anaemic, lethargic and wasted away until, often, they died. The settlers called this mysterious ailment coast disease. Similar and equally mysterious wasting diseases occurred in many parts of the world; in the south-west of Western Australia cattle were afflicted with what the locals called Denmark disease.

In 1975 Bob Dawson was still living on his property, Belle Vue. He was an old man of 98, but with undimmed memories of the remarkable bloom of life brought to the country once blighted by coast disease. He could be proud of his MBE awarded for his contribution to agricultural research; in the early days of investigation into coast disease Belle Vue was designated a CSIR experimental farm and he was made a field officer. He held the position until he was 96, the Australian Government's oldest 'employee'.

But many farmers did not have the dour determination that made Bob Dawson hang on to his unrequiting land, even though it meant labouring as a slaughterman, butcher and road-maker to support his family. They quit the south-east coast forever and today their abandoned farm-houses, with blind and broken windows and roofs gaping at the sky, remain as mausoleums of their defeat.

In 1928 visiting South African veterinarian Sir Arnold Theiler suggested that coast disease might be caused by a deficiency of phosphorus. Ted Lines of the CSIR Division of Animal Nutrition in Adelaide dosed 'coasty' sheep on Kangaroo Island with phosphate. The sheep died even more quickly than usual.

But at the same time another member of the Division, Dick Thomas, a chemist with a background in geology, was mapping out the areas affected by coast disease on Kangaroo Island. He recognized that these areas had calcareous soils formed during the last Ice Age when the continental shelf was exposed and prevailing winds blew fragmented shell material inland. He believed that all these soils would be short of traces of heavy metals, some of which were already known to be essential animal nutrients.

This, and the Kangaroo Island experiment, provoked a new line of thought. At that time the Division's senior biological officer was Hedley Marston, a brilliant man with a huge capacity for absorbing knowledge and making olympic jumps to conclusions. Marston later became Chief of the Division and had a major influence on trace-element research in Australia for more than 20 years. Thomas drew Marston's attention to a report by two German scientists who had induced an excess of red blood cells in rats by feeding them with cobalt. As a profound anaemia with a gross lack of red cells was a common feature of coast disease, Thomas reasoned that a deficiency of cobalt in coastal soils might be responsible. The scientific correlation was fragile, to say the least. Neverrtheless, Marston felt it was a lead worth following and he suggested to Lines that he dose sheep on Kangaroo Island with a mixture of trace minerals including cobalt, nickel, molybdenum, copper and zinc. The mixture proved beneficial but the element, or elements, responsible still needed to be identified. Lines was hampered in his field tests by the fluctuating severity of the disease until the Chief of the Division, Sir Charles Martin, suggested that he set up an experiment at the Division's headquarters, at the University of Adelaide, using penned sheep fed on a coasty diet. In 1934 he dosed his now coasty sheep with pure cobalt nitrate—one milligram a day—and achieved for the first time a clear-cut cure.

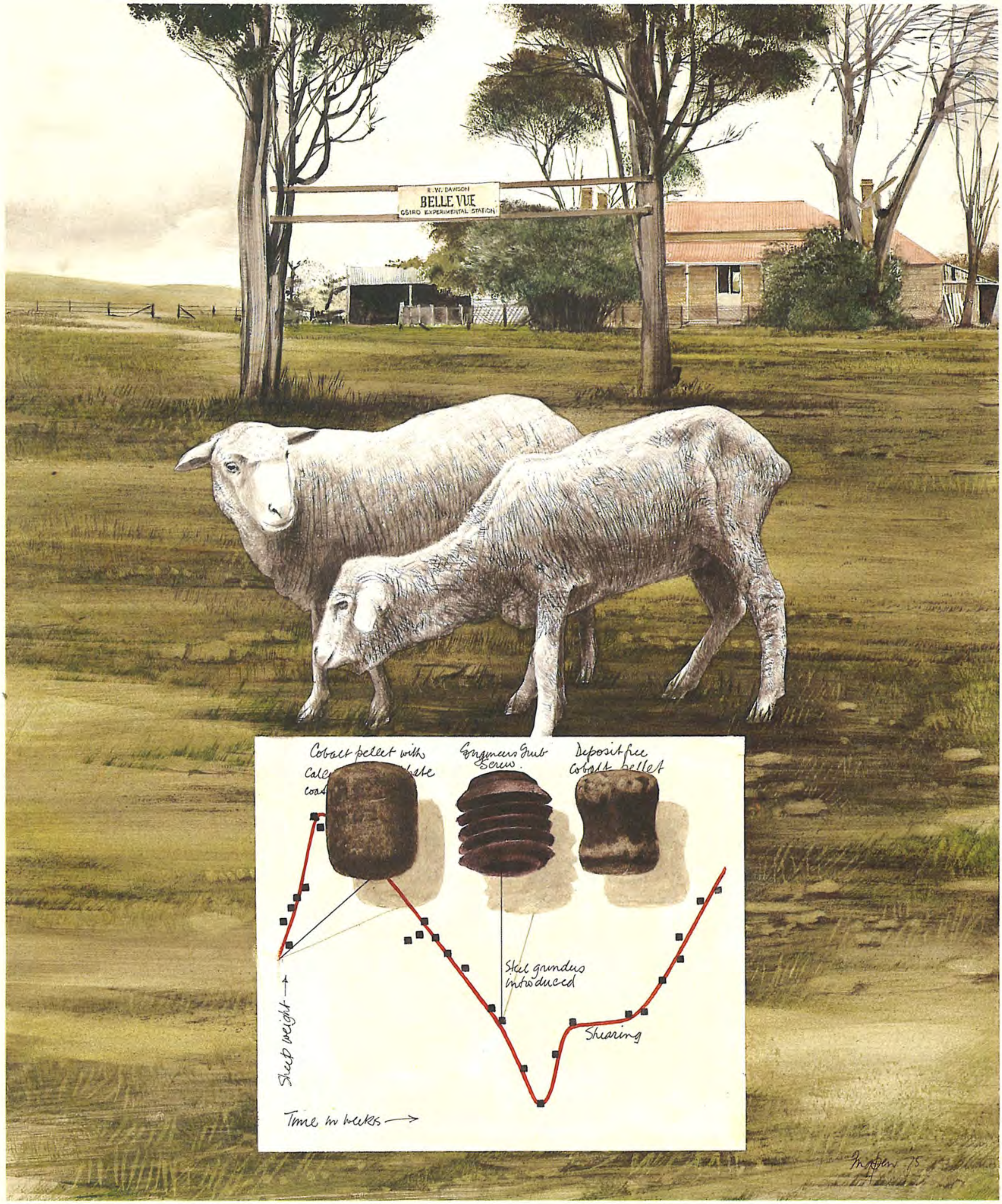
Late in 1934 Eric Underwood, an animal nutrition officer with the Western Australian Department of Agriculture and later a member of the CSIRO Executive, visited the Division and described the work that he and his colleague John Filmer had been doing in Perth on Denmark disease. At that time they suspected the disease was due to a dietary deficiency of traces of either zinc, manganese, nickel or cobalt. Dosing cattle with a nickel compound had proved moderately successful; however, it turned out later that the compound used had been grossly contaminated with cobalt. The Adelaide scientists listened to Underwood's findings and then took him outside to show him the sheep that had been cured with cobalt. Underwood returned to Western Australia to learn that further experiments with a purer nickel salt had been unsuccessful. Zinc, manganese and cobalt were then tested, and cobalt was shown to cure Denmark wasting disease of cattle.

Back in Adelaide, CSIR veterinarian Dan Murnane extended Thomas's surveys and his findings led Marston to enlist the

Cobalt and coast disease

At Robe, in South Australia, two sheep graze on the 'Belle Vue' property of Robert Dawson, on pasture deficient in copper and cobalt. Ewe at rear, treated with cobalt pellet, is markedly healthier than untreated ewe. Phosphate accumulating on cobalt pellets in the sheep's rumen, left, is ground off by the grub screw, centre, keeping it active. Graph shows the condition of sheep treated with cobalt pellets and their dramatic improvement after administration of grub screws.

Dr H. R. Marston and Mr H. J. Lee



help of Bob Dawson and the use of his property. The quantities and frequencies of cobalt dose rates were formulated and research teams turned their attention to another trace element —copper.

Early studies had shown that copper was also lacking in coasty sheep. But while copper deficiency could be readily overcome by adding copper salts to the fertilizers used on the pasture, the prevention of cobalt deficiency was not so easy. For some reason, cobalt didn't work when applied in this way. Sheep also failed to respond to injections of cobalt and the only satisfactory way of administering it was by drenching—a time-consuming and back-breaking task.

It was clear that dosing with cobalt only worked if the cobalt found its way into the rumen or paunch of the sheep. But why this should be so was not to become clear until the 1950s. Moreover, it was not until the 1950s that a simple means of dosing sheep with cobalt was developed.

In 1955 a visiting Fulbright Fellow named Perry R. Stout arrived in Adelaide from California, to follow up Australian studies in which sheep had been saved from a fatal condition called phalaris staggers by dosing with cobalt. Staggers, a degeneration of the nervous system, can occur at any time and without warning among sheep grazing freshly growing pastures of the grass *Phalaris tuberosa.* To prevent the condition sheep must be given cobalt when grazing green phalaris.

One morning Stout walked into John Lee's office at the Division of Animal Nutrition, pushed a pile of papers off his cluttered desk, and plumped down with the bluff announcement that he had an idea. 'Say, John', he boomed, 'why don't we go about this a different way?' The problem, as he saw it, was to keep a constant supply of cobalt in the sheep's rumen. So why not bung in a metal container, filled with cobalt, and fitted with an asbestos 'wick' which would leak out a regular supply of cobalt? Ten minutes later in the Division's workshop the two men had crafted a rough capsule of brass tubing, about 40 millimetres long, which they coated with paraffin. Using a larger tube as a blow-pipe, Lee blew the capsule down a sheep's throat. Later, X-rays showed the capsule had lodged safely in the sheep's reticulum, a sub-compartment of the rumen.

Work then began in earnest to perfect a capsule or pellet that could be made on a production line. Eventually a ceramic pellet containing 90 per cent cobalt oxide was devised.

Marston was keen to publish the news of this breakthrough but was persuaded that it should first be field-tested in an area where sheep suffered phalaris staggers. A property at Bool Lagoon, south of Naracoorte, was chosen and 200 sheep were dosed with cobalt pellets and confined to phalaris pasture along with 50 untreated sheep. Not one of the treated sheep got staggers but 49 of the untreated sheep did. Marston announced the success, patents were taken out, and commercial production under licence went ahead.

Then a few weeks later, disaster struck. Some of the treated sheep at Bool Lagoon developed staggers. At first this appeared to be a shattering setback—then post-mortems revealed that not one of the sheep affected had a pellet in its stomach. All of the missing pellets had been regurgitated.

So yet another line of research had to be followed, in developing a pellet with a specific gravity high enough for it to remain in the sheep's stomach. The solution was to mix the cobalt with heavy iron filings. But a final snag remained. Secretions in the sheep's rumen often coated the pellets with calcium phosphate which stopped the release of cobalt. The ingenious solution to this problem was to market cobalt pellets with a second device—a short length of threaded steel rod which would rub against the pellet in the sheep's rumen and grind away the calcium phosphate coating.

The laborious work of regularly drenching sheep in phalaris staggers and coastal disease country became, mercifully, a thing of the past. Robe, and the country all around it, took on a new and promising aspect. Land that men had once turned their backs on fetched up to $200 a hectare.

The final, and continuing, thread of the cobalt story lies in tracing the role of cobalt in the nutrition of sheep and other ruminants.

The first clue to this came in 1948 when research teams in Britain and the United States isolated from liver a compound which they named vitamin B_{12} and showed that each molecule of the new vitamin contained one atom of cobalt. It was later found that this vitamin is produced in the sheep by the micro-organisms that live in its rumen. Humans have no such micro-organisms and must rely on their diet to provide them with the vitamin B_{12} they need. In 1954 several lines of research came together and Marston proposed that a vitamin B_{12} deficiency in sheep caused by a lack of cobalt in their diet depressed their appetites, resulting in a vicious circle which further lowered their cobalt intake. A biochemical explanation of this phenomenon was provided later when it was discovered that vitamin B_{12} is an essential component of a particular enzyme in the sheep's liver. Lack of this enzyme leads to a build-up of propionic acid in the blood stream and consequent suppression of appetite.

Most recently investigations into the intersection between vitamin B_{12} and another B vitamin, folic acid, have cast new light on pernicious anaemia in humans. And so, in a huge sweeping circle the research that man began 50 years ago into a wasting disease in sheep has returned—to himself.

Locating aircraft

On 24 February 1939, the Australian High Commissioner in London sent a cable to the Prime Minister, Joseph Lyons, in Canberra. It read: 'Conversations have been carried on from time to time with the Air Ministry on the subject of secret research. They culminated today in the disclosure to the High Commissioners of a new development in defence applicable particularly to air but also probably capable of development for other services. The High Commissioners have been informed that if their Governments send their best-qualified physicist to England all information will be placed at his disposal for secret report to Dominion Governments. Utmost secrecy is essential and the choice of a man of the greatest discretion important . . .'

The Prime Minister called in CSIR and, on the advice of its chairman Sir David Rivett, chose physicist David Forbes Martyn for the clandestine mission. For a number of years Martyn had been doing research into the upper atmosphere and ionosphere for the CSIR Radio Research Board. He flew to London immediately and was given the entire details of Britain's secret radar network. He returned to Australia by ship with a great number of reports and essential radio valves locked in a lead-weighted cabin trunk.

From these covert beginnings was to come the Division of Radiophysics, which during the war initiated over 20 major radar projects and continued into the post-war years with pioneering applications of the techniques to radio astronomy and civil aircraft navigation.

Since 1935 Britain had been preparing a warning system of radar—an acronym for Radio Detection and Ranging—under a committee headed by Sir Henry Tizard. When Neville Chamberlain returned from Munich in 1938 with the promise of 'peace in our time', five radar stations were guarding the approaches to London. Each station sent out a stream of short-pulse radio waves concentrated by directional aerials. The radio waves scattered on striking an object, such as an aircraft, and some of the energy returned as an echo to be amplified and displayed on a cathode-ray tube. The time between transmission and echo reception gave the distance to the reflecting object. The five stations could give warning of aircraft at a height of 3000 metres out to a distance of 130 kilometres from the coast anywhere between Suffolk and the south of Kent.

On Martyn's return, a conference took place with Sir David Rivett, the Director-General of Posts and Telegraphs, Sir Harry Brown, and electrical engineer Professor John Madsen who had been closely involved in studies of the ionosphere, atmospherics and radio transmission. The conference recommended setting up an advisory board representing three major interests: scientific research, development-production and the armed services. A secret Cabinet meeting, of which no records were kept, approved this and voted £80 000 for building a radar research establishment. It was given the cover designation of the CSIR Radiophysics Laboratory.

To attract as little attention as possible, the laboratory was added to the CSIR National Standards Laboratory then being built in the grounds of the University of Sydney. It had separate entrances, guarded by Commonwealth police, and the first security-cleared staff moved in at the end of March 1940. Some of the early work was necessarily trial and error. Electrical engineer Victor Burgmann, now a member of the CSIRO Executive, later recalled how he was given a radar set known as the air-to-surface vessel (ASV). It had been sent out from England with no instructions and he was told to get it working. He knew the broad principles of radar, traced the circuit, and deduced how it worked. 'But', he said, 'it was an interesting moment when I connected it to the mains for the first time and switched it on, hoping I wouldn't destroy the first ASV set in the southern hemisphere.' He pointed a makeshift aerial out the window—and the set worked. Soon after, Burgmann and a technician from the PMG's Department installed the equipment in a DC3 from the RAAF base at Richmond near Sydney and had the pilot fly them out over the ocean. There, in an exciting experiment, they received the first echoes from a real target, a merchant ship steaming off the coast.

From the very beginning there was a strong emphasis on all-Australian manufacture of components because the country was geographically isolated and supply routes were vulnerable. The PMG's Department made some of the early hardware but commercial electrical firms, which at that time had little experience beyond building wireless sets, were soon called in. They were to produce some remarkably sophisticated equipment, particularly in the later years of the war when microwave radar had been developed.

In 1940 it seemed most likely that Australia would come under sea attack and the Radiophysics Laboratory concentrated on developing a Shore Defence (Sh.D.) set that would warn Army coastal defences of the approach of surface vessels and, by accurate range measurement, assist in gun-laying. This equipment operated on a wavelength of 1·5 metres (a frequency of 200 megahertz) and gave excellent performance out to 30 to 40 kilometres. Owing to changes in the pattern of war, Sh.D. was never used against the enemy. But the work that had gone into its development on this wavelength had profound effects later.

Towards the end of 1941, it became obvious that air attack would be the real danger to Australia and a group of physicists under Jack Piddington worked at top pressure to improvise an air-warning system based on the Sh.D. system but modified to provide the maximum possible range without using more power. Thanks to the background of Sh.D. experience, the first experimental equipment was produced in only 5½ days in late 1941. It had no safety covers and high voltages were a constant danger to the operating crew. But in its first week of trials at Dover Heights, it detected an aircraft 105 kilometres out to sea. One of the first production models was sent to Darwin in February 1942. RAAF technicians were still installing it when the Japanese staged their devastating bombing raid on the morning of the 19th. Piddington and his team flew to Darwin and assisted in getting the set operating by the morning of the 22nd, just in time to detect another Japanese bombing force. It was intercepted and scattered 32 kilometres off the coast.

By 1942 liaison with the services had improved, and a regular exchange of information with the United States was started. In the same year Radiophysics developed the Light-Weight Air Warning set (LW/AW) which was to play a vital part in the push north through the islands. It was probably the most reliable and portable set devised by any of the Allies and could detect a twin-engined aircraft at up to 140 kilometres.

During the war, the Division of Radiophysics and the PMG's Research Laboratories in Melbourne developed more than 20 different radar systems. One of the outstanding scientific and technical achievements of the Division came towards the end of the war. This was the development of air-warning and height-measuring equipment (AWH MkII) which provided highly satisfactory performance against both high-flying and low-flying aircraft. It operated at a wavelength of 25 centimetres and its development owed a great deal to basic microwave development work under the leadership of Joe Pawsey. A second late development by the Division was a flashlight-sized detector used by commandos landing in enemy-held territory to locate Japanese radar installations.

In 1945 Dr E. G. (Taffy) Bowen was appointed Chief of the Division of Radiophysics. Bowen was previously a member of the research team which developed radar in Britain in the 1930s. Under his dynamic leadership the Division began its transition to peacetime research. One project was Distance-Measuring Equipment (DME), developed by Brian Cooper, and based on the principle of the RAF's tactical Rebecca–Eureka system. (An airborne transmitter-receiver, code-named 'Rebecca', sent short pulses to a 'Eureka' beacon on the ground which responded with a reply pulse. Distance was computed from the time interval between the transmitted and reply pulses.) The DME set was more refined, weighed only nine kilograms, and had a graduated distance-indicator dial in place of the cathode-ray screen. This eliminated the confusing multiplicity of 'blips' that sometimes appeared on cathode-ray screens. The single most important factor in the rapid development of DME was that it operated in the 200-megahertz band, using well-established techniques. As a result, the first working trials were possible by mid 1945. An Anson aircraft, on loan from the RAAF, was equipped with a DME set and began overflying the Radiophysics Laboratory where a ground beacon had been built. By January 1947 two commercial aircraft were carrying DME on their regular Sydney–Melbourne runs. The commercial trials of DME were so successful that the Department of Civil Aviation decided in 1947 to go ahead with the design and installation of a nation-wide system. Amalgamated Wireless (Australasia) Ltd made electronic equipment valued at $2·5 million for 95 unattended, automatic ground beacons. The company also made the airborne equipment ordered by the airlines, incorporating the latest developments from Radiophysics flight trials. In 1953 DME became operational and within four years all domestic airliners had been equipped with sets.

Australia's choice of 200 megahertz for its system had important technical advantages: the transmissions propagated further around the curve of the Earth than microwave signals, the equipment cost was lower and the transition to transistorized equipment was relatively easy. In America, powerful commercial-political lobbying accompanied proposals for commercial navigation systems. As a result, America's 1000-megahertz domestic DME network was not operating until 1962-64.

In 1956 the Division of Radiophysics began the development of even lighter and more reliable airborne DME equipment based on transistors instead of valves. Using a scheme devised by AWA Ltd, the number of DME channels provided by the new units was increased from 12 to 48, which the Department of Civil Aviation decided would meet all requirements in the foreseeable future.

Taffy Bowen retired as Chief of the Division in 1971 and reorganization of its activities led its new Chief, Paul Wild, to look for a major project in the field of applied research. Once again the Division turned to civil aviation where modern needs had thrown up challenging problems to which the Division could apply the know-how gained in 25 years of pioneering research into radio astronomy. Following an approach from the Department of Civil Aviation the Division decided to become involved in the development of an international microwave approach and landing guidance system (MLS) for aircraft. In 1973 Australia submitted the new system, named Interscan, to the International Civil Aviation Organization (ICAO) which also received proposals from four other countries.

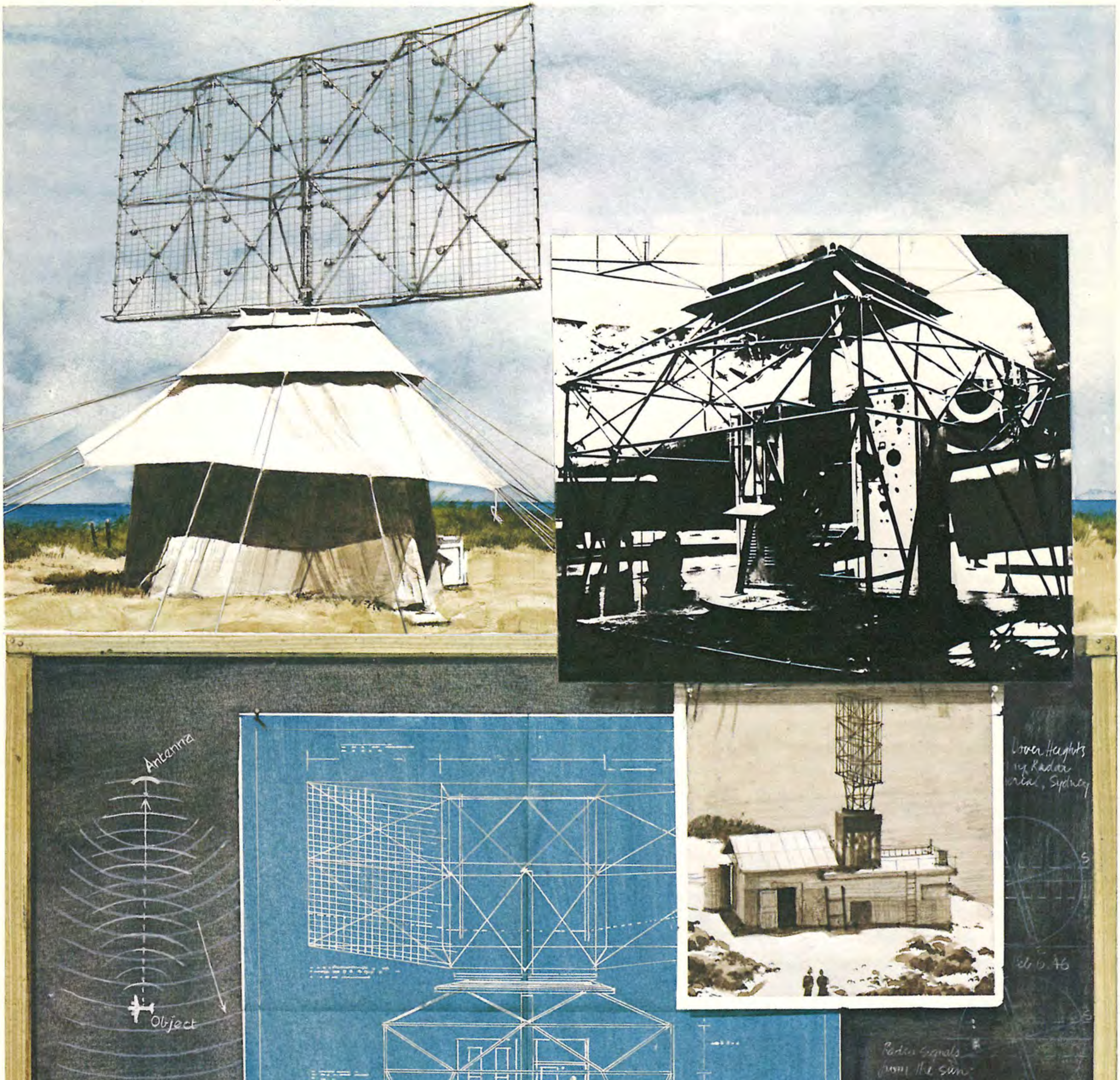
Interscan is based on a system of microwave beams which scan to and fro across the sky. By measuring the time interval between the two pulses received in the aircraft during each to–fro scan of a beam, the angular position of the aircraft relative to the runway can be determined. This is the time-reference scanning beam (TRSB) technique pioneered in Interscan. One beam scanning in a horizontal plane gives the angle from the runway centre line; a second beam scanning vertically provides the elevation angle. Distance-measuring equipment in the aircraft determines the distance to a point on the runway and, in the final landing stage, a third beam provides precise height. All this information is processed by an on-board computer to give the pilot his position twenty times a second.

Late in 1974 the United States Federal Aviation Administration decided to adopt the TRSB principle of Interscan for the U.S. proposal to ICAO. Interscan was demonstrated to an ICAO Working Group at Melbourne Airport in March 1975 and the pilot put his aircraft down only 60 centimetres from the tarmac centre line. A final decision by ICAO on the MLS system to be adopted for international use is likely in 1976.

Locating aircraft

One of the Light-weight Air Transportable Air Warning radar installations used by Australian and U.S. forces in World War II keeps watch on a beach. Capable of detecting aircraft formations at 272 kilometres or single aircraft at 240 kilometres, installations of this type protected Darwin and were used in the Pacific islands. Inset shows the operator's chair and transmitting and receiving equipment. A design blueprint and a 1945 photograph of the Dover Heights shore station are pinned to the blackboard.

Dr J. H. Piddington and Mr B. F. C. Cooper



Troubleshooter for wool

Only weeks before the first Qantas Jumbo jet left on its inaugural flight in 1971 a problem arose that threatened to dent Australia's prestige overseas. Through a phone call from the Australian Wool Corporation, the problem eventually landed in the lap of Tom Pressley, a senior research scientist at the CSIRO Division of Protein Chemistry, in Parkville, Melbourne.

The difficulty was this: Qantas intended to furnish their Boeing 747s with wool seat covers (a discreet promotion of Australia's finest product) but the Boeing Corporation in America was worried about fire hazards. A Jumbo crash could be the most disastrous in aviation history and such stringent standards had been set that wool was excluded. If Qantas had to change its plans and the story leaked out, it would damage both the airline and the Australian wool industry.

Pressley, a spare wiry man of precise and quick movements, had been working on textile flammability and was able to tackle the problem directly. Searching published information on fire-retarding agents he found the work on cotton and, in his laboratory, applied this to wool. Before the deadline expired the Wool Corporation was able to send his convincing proof to Boeing—enough non-burning wool fabric to furnish a 747. On 16 August 1971 the flagship City of Canberra took to the air on its maiden flight with its VIP passengers seated on the finest merino wool.

Evidence of the need for Pressley's earlier work on flammability had come to him in a cardboard box sent from the Burns Research Unit at the Royal Children's Hospital, Melbourne . . . a small girl's yellow pinafore burned from hem to neckline, a fancy-dress grass skirt reduced to a few ashes in an envelope. They described appalling accidents.

Work on clothing flammability (the word 'inflammability' is not much used now) was stimulated by an article in *Choice* magazine which aroused considerable public concern. An investigation committee set up by the Standards Association of Australia sought Pressley's help and typically he began by questioning what others had taken for granted—the tests for burning. He found that one test conducted on seven different fabrics rated wool with the highest ignition temperature, and cotton the lowest; another test on eleven fabrics rated wool with the lowest ignition temperature and cotton the highest. Yet he knew from experience that wool was relatively safe.

He began long and exhaustive tests, the results of which finally forced the rewriting of Australian safety standards, putting them ahead of any others in the world. The results disproved 'facts' taken for granted, like the still popular notion that in Australia girls in nightgowns are most likely to be accidentally burned. (In fact, it is boys in day clothes. They are the experimenters, likely to try the effects of petrol on fire.)

The laboratory in which Pressley did those successful tests is unusual. It is simply a workroom with rough wooden benches and concrete floor. It illustrates his attitude to his work: that he is not an academic theorist but a scientist who solves the problems of industry. 'Science is simply common sense', he has said. 'If you tackle a problem systematically, you tackle it scientifically.'

Not far from Pressley's laboratory along tree-lined Royal Parade is The Royal Melbourne Hospital. It has produced many of his trickier problems. At a meeting of the hospital's laundry committee of management in 1957 a senior medical man made a disturbing demand that the Royal Melbourne should dump all its wool blankets because they shed bacteria-carrying fluff. The *Staphylococcus* ('golden staph') epidemic was at its worst and medical journals were strongly condemning the danger of airborne fluff. The committee's chairman, Sir Harry Giddy, was alarmed by the proposal. As an industrialist with wide experience he could see beyond the doctor's concern to the likely impact on the wool industry. 'In a pastoral country this seems an extremely serious step to take', he said. He persuaded the committee to delay its decision to the next meeting and immediately rang his friend Sir Ian Clunies Ross, then head of CSIRO, who called in the Division of Protein Chemistry.

Pressley went to the hospital and introduced himself to the doctor who had made the proposal, telling him that he doubted the statements made about textiles in the medical journal articles. The doctor was polite but took him to a ward to show him evidence and then watched, bemused, as Pressley scrambled around on hands and knees collecting fibres from the floor. He put the fibres under a microscope to confirm his suspicions: nearly all had the familiar flat ribbon-like profile of cotton. He applied a simple dye test to prove it.

But that was only half the answer. Obviously the critical area of infection was at bed height. Working against time, Pressley rigged up a rough apparatus on a stand, a Ventaxia fan covered with a Terylene dust collector, and put it to work in the hospital ward. Within weeks he gave Sir Harry Giddy the proof he needed: that 96 per cent of airborne fibres were cellulose, mainly cotton, and that blanket fluff could not be isolated as a carrier of 'golden staph'—or of any other infection.

But the research could not end there and Pressley was seconded to the Department of Microbiology at Melbourne University. His ignorance in that area was total. ('For all I knew', he said, 'you caught microbes in a butterfly net.') But he went on to do elegant research which showed that bacteria spread through hospital wards quite independently of airborne fibres.

Then came the work of perfecting a wool blanket that could be boiled to kill bacteria without shrinking and felting to something like a doormat. Pressley beat the shrinkage problem in a few weeks but found that as shrink-resist blankets went through the rigours of hospital laundering they became more stained and rough until after 200 washings they were the colour of rusty iron and the texture of emery paper.

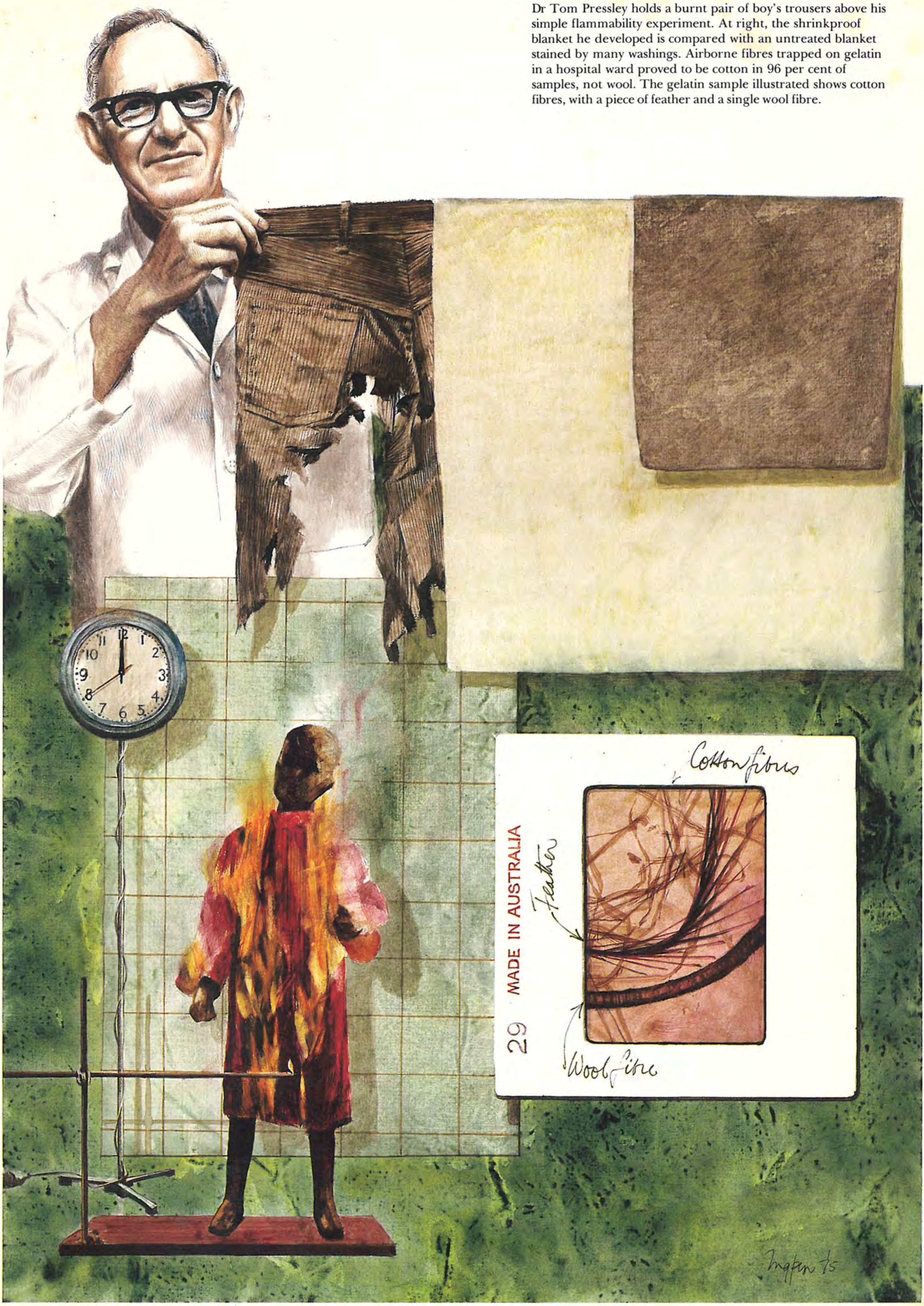
He tracked down the stain to iron in Melbourne's water supply and stopped it with a chemical agent that attracted iron particles.

Next the texture. Working with a shovel on his laboratory floor, he mixed up batches of detergents, trying to ignore the protests of the caretaker hovering in the background with a broom, who could see only a mess of spilled chemicals. Pressley concentrated on the likely formula for a 'built' detergent that would hold particles suspended in water but stay chemically neutral so the wool would not be damaged by boiling.

Not only did it work in the hospital laundry, the Unilever corporation later took up his formula and put it on the market as the best-selling product 'Softly'.

Troubleshooter for wool

Dr Tom Pressley holds a burnt pair of boy's trousers above his simple flammability experiment. At right, the shrinkproof blanket he developed is compared with an untreated blanket stained by many washings. Airborne fibres trapped on gelatin in a hospital ward proved to be cotton in 96 per cent of samples, not wool. The gelatin sample illustrated shows cotton fibres, with a piece of feather and a single wool fibre.



Pastures for the north

An ebullient Welshman, Jack Griffiths Davies arrived in Australia wearing a bowler hat and nursing an unconcealed ambition to break new ground. He stayed to become a man of the land equal to the toughest Queensland cattleman, and has a memorial as vast as his adopted country. Those who would seek his epitaph need only look around them at the grazing lands of Australia.

With his earliest work for the Waite Agricultural Research Institute at Adelaide in the 1930s he developed a comprehensive philosophy of the ecological approach to pasture research. He saw the interacting soil – plant – animal relationship as an entity long before it was common to do so. He emphasized that sheep or cattle were not only an end product and a final measure of pasture value, but agents that conditioned the pasture. His interest in tropical legumes from South America and Africa was to be the basis of his most important and enduring work.

Davies graduated with first-class honours in botany from the University College of Wales and completed his Ph.D. at the Welsh Plant Breeding Station at the age of 22. Looking for a fresh challenge, he accepted a position as a pasture scientist at the Waite Institute in 1927.

At that time scientists had looked at only limited aspects of the relationship between pastures and stock. Davies made studies of native *Danthonia* (wallaby grass) pastures and their effects on wool production and weight changes in Merinos. This was the first scientific investigation of grazing management in Australia. With a Waite Institute colleague, H. C. Trumble, he promoted *Phalaris tuberosa*, an imported perennial grass which has become one of the major pasture species of south-eastern Australia.

His comprehensive, over-view approach to his work began to change him from a research scientist to a research director. He developed a method of attack which he was to use for the rest of his career: define the problem, provide the necessary facilities in the field and the laboratory, and call in the specialists to use them. This way he could do what he was best at — plan and lead. He was one of the first to plan pasture experiments under statistical controls and to use mathematicians to help him in their evaluation. His success in leadership came from an intense belief in loyalty, an ability to infect others with his conviction and enthusiasm, and sound basic psychology in ensuring his team always received full credit for their work.

Davies was appointed as the first head of pasture research for the CSIRO Division of Plant Industry in 1938. In the following two years he made two wide-ranging tours through Queensland cattle country, driving to remote stations to yarn with graziers about their problems. These tours and a brief paper published in 1935 by William Hartley, the Division's Assistant Plant Introduction Officer, probably had most effect on his future thinking about tropical pasture legumes.

The history of pasture research in northern Australia has been dominated by the search for such legumes — legumes that would play the same role in pasture improvement as clovers and medics had played in cooler climates. (Legumes have the ability to obtain the nitrogen they need for their nutrition from the air via special bacteria which live in nodules in their roots.) Since no country in the tropics had developed systems of animal husbandry based on grass/legume pastures, there were no ready-made tropical pasture legumes that could be imported. The first step, therefore, was to find 'wild' legumes that could be 'domesticated'. In his paper Hartley emphasized the potential value of tropical legumes and noted that 'The most fertile hunting ground for promising species appears to be the extensive area from Brazil to northern Argentina, which has a climate and vegetation similar to much of tropical Australia.'

By 1952, when Davies moved to Brisbane, he had built his Pasture Section into the biggest in the Division of Plant Industry. In Brisbane he took charge of a small group of scientists he had already established there and began adding to their numbers and objectives. Eventually this group expanded into the new Division of Tropical Pastures.

One of the team, Don Norris, stressed the advantage of tropical legumes being adapted to acid, infertile, tropical soils. He attributed this adaptation to their having evolved during long periods of growth in such soils. His practical contribution was to provide the right kinds of nitrogen-fixing bacteria. Some of these strains of bacteria had to be imported together with their host legumes.

This came at a time when there was a fresh search overseas for promising tropical legumes. The Plant Introduction Section had been importing them since 1930 and botanist John Miles had grown a number of promising species at Fitzroyvale, near Rockhampton, but without the facilities for putting them into grazing trials.

In 1945 scientist Norman Shaw enlisted the cooperation of his brother Desmond who had been growing the tropical legume Townsville stylo on his property at Rodd's Bay, near Gladstone, since 1937. (This legume had been accidentally introduced into Australia from South America about 1900 and exploited by only a very few enterprising cattlemen and agricultural advisers.) The Shaw brothers' experiments with Townsville stylo and fertilizers for pasture improvement at Rodd's Bay led to the realization that it could provide pasture in country stretching from Bundaberg to north Queensland. Proof of its value in the Northern Territory came from research done by Mike Norman, of the CSIRO Division of Land Research at Katherine. In subtropical areas it became possible to run a beast to less than a hectare instead of four hectares. In the north, stocking could be increased dramatically from a beast every 12 hectares to one every hectare.

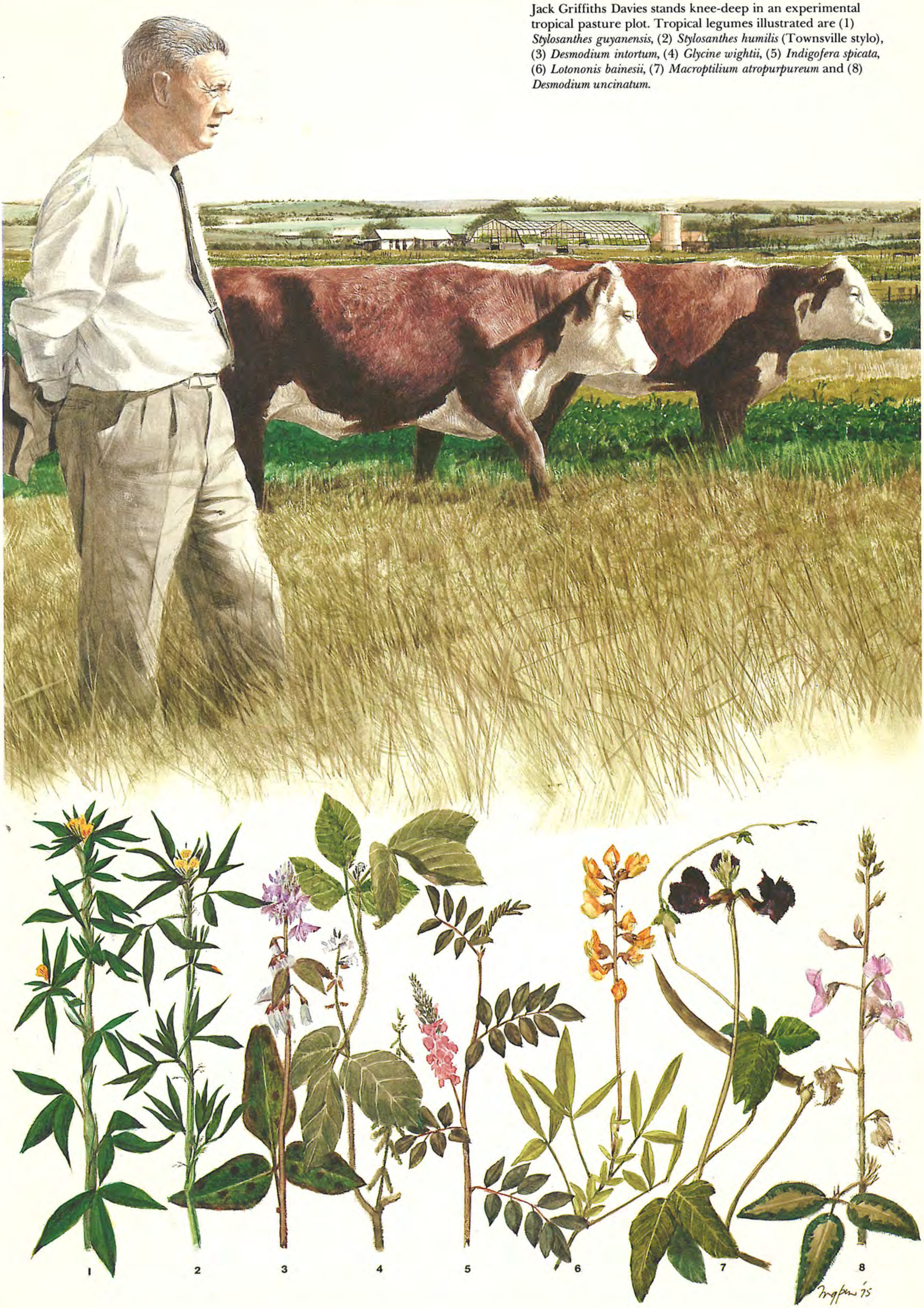
Next came the work by agronomist Wilf Bryan and nutritionist Col Andrew on the Queensland coastal Wallum country, some of the most infertile soil in the world. Stretching from just north of Brisbane to Bundaberg, the Wallum was unable to support cattle permanently. While Andrew tracked down missing soil elements, Bryan tested new foreign legumes. With the addition of a formidable combination of trace elements, plus superphosphate and potash, imported pastures thrived. Legumes like lotononis and Greenleaf desmodium from South America, combined with grasses from Africa, made it possible to carry a bullock, year-round, on less than half a hectare. This was the highest carrying capacity of any legume pasture in Queensland.

In the mid 1950s Mark Hutton investigated the possibility of breeding an improved pasture legume from the genus *Phaseolus* (now *Macroptilium*). Having seen how phasey bean, a biennial in the same genus, grew successfully in southern Queensland, Hutton crossed two perennial *Macroptilium* strains from Mexico and after selection under grazing produced the new legume, Siratro, in 1960. From southern Queensland to Townsville, Siratro has helped cattlemen fatten a beast per hectare in 27 months, instead of a beast to three hectares over four years. Siratro seed has since become a valuable export.

Jack Davies died in 1969 but the work he started has been carried on with undiminished impetus by Mark Hutton, the present Chief of the Division. Hutton is optimistic about the future. 'Up to now we have been concentrating on pastures', he says, 'but in 20 years' time we will also be writing the story of legumes in cropping systems in the north.'

Pastures for the north

Jack Griffiths Davies stands knee-deep in an experimental tropical pasture plot. Tropical legumes illustrated are (1) *Stylosanthes guyanensis*, (2) *Stylosanthes humilis* (Townsville stylo), (3) *Desmodium intortum*, (4) *Glycine wightii*, (5) *Indigofera spicata*, (6) *Lotononis bainesii*, (7) *Macroptilium atropurpureum* and (8) *Desmodium uncinatum*.



Resisting the cold

For many years scientists around the world were puzzled by the ability of certain plants and animals to tolerate low temperatures without distress, while others suffered injury and even death when exposed to the same temperatures. Why do cabbages and broad beans flourish in temperatures far below those which kill melons and tomatoes? How do reptiles, amphibia and fish survive temperatures lethal to many warm-blooded animals? Why are some warm-blooded animals able to hibernate, and others not?

The key to the mechanism that enables some plants and animals to resist cold has been found in the myriad cells of which they are composed—more particularly, in the physical properties of the cell membranes. This discovery stems from research on mitochondria—minute particles embedded in the jelly-like cytoplasm that fills each cell. Enzymes associated with the membranes of the mitochondria help break down sugars into carbon dioxide and water and in doing so release considerable amounts of chemical energy—a process known as cell respiration.

In 1968, Dr John Raison of the CSIRO Division of Food Research, who by then was devoting most of his research to mitochondria, was joined in Sydney by Dr James Lyons, Head of the Department of Vegetable Crops at the University of California, Riverside. Lyons had come to Australia to study the difference between chilling-resistant and chilling-sensitive plants. He believed that sensitivity to chilling was related in some way to an activity associated with the mitochondria. Lyons and Raison devised methods of isolating mitochondria from these plants so that they could compare the rates of respiration of the different mitochondria at chilling temperatures. They found that over a range of 30°C to 0°C the respiration rate of mitochondria from resistant plants decreased by a factor of about 2 for each 10 degC decrease in temperature —a predictable result. However, with mitochondria from sensitive plants the results below 10°C were quite unexpected. The decrease in respiration rate from 10°C to 0°C was much greater—in fact it decreased by a factor of 4.

Raison vividly recalls the day this result was first apparent. He took home the data collected during the day and that evening, with Lyons, began the drudgery of calculating the results. By 10 o'clock they had a clear picture which confirmed their belief. 'I don't think you could describe the elation Jim and I went through at that moment', Raison said later. 'I think it is the height of any biologist's career to find that you can relate the behaviour of a whole organism to the behaviour of one tiny structure in its cells . . . to predict what might happen and then see, in the final analysis, that that is what did happen.' The two scientists toasted their success with glasses of Drambuie, then worked on until 3 o'clock in the morning, working out how this discovery could help explain the changes observed in plant tissues during chilling and why valuable crops like melons, tomatoes and avocados go mushy when stored at chilling temperatures.

Before Lyons returned to California, the two workers extended their findings to animals. Mitochondria from the liver of (warm-blooded) rats showed the same response to lowered temperature as chilling-sensitive plants except that the sudden decrease in respiration rate occurred at 23°C instead of 10°C. Later, when Raison went to the University of California, Riverside, experiments with freshwater trout showed a direct similarity between the behaviour of mitochondria of cold-blooded animals and chilling-resistant plants—a constant decrease in respiration rate over the temperature range 30°C to 0°C.

From this point they began looking for an explanation for the unexpectedly rapid decline in the respiration rate of mitochondria from chilling-sensitive organisms. A study of lipids (fatty substances) in the mitochondrial membranes revealed that the lipids of chilling-resistant plants and cold-blooded animals remain semi-fluid at low temperatures. But, in chilling-sensitive plants and warm-blooded animals the lipids congeal at low temperatures—like butter in a refrigerator—causing a change in respiratory activity. The membrane walls become like an open mesh instead of a permeable plastic bag—energy production slows down, foreign substances leak in and the mitochondrial powerhouse collapses.

Further work in California showed that hibernating animals such as the golden-mantled ground squirrel have the ability to modify their membrane lipids before hibernation, so that they remain semi-fluid at low temperatures. Later work in Australia by Raison showed that the same thing happens in the echidna.

John Raison returned to Australia where he and his fellow workers have used his findings to identify chilling-resistant characteristics in plants. His results could help plant breeders select chilling-resistant plants more easily and improve the keeping quality of their fruit. Moreover, if chemical or genetic means can be found of manipulating membrane lipids, it may be possible to extend the geographic range of many important food crops, to store sensitive fruit and vegetables for longer periods at much lower temperatures, and to extend considerably the storage time of vital human organs in transplant 'banks'. Perhaps in the more distant future, it may even be possible to induce man to hibernate for surgical operations or space travel.

Campaign against pleuro

Boadle was one of Melbourne's earliest settlers and had a property on both sides of the Darebin Creek, near the present-day Preston Cemetery. In October 1858 he imported five head of cattle from England. Three weeks later, one of them, a heifer named St Bees, became sick. Boadle called in a veterinarian who diagnosed contagious bovine pleuropneumonia. St Bees died three weeks later and Boadle was advised to destroy all his herd, but the damage was done. It appeared that St Bees had infected a bullock team grazing on a neighbouring property and, like a flame running after a trail of spilled paraffin, pleuropneumonia roared up the overland route to New South Wales. From there it fanned out into Queensland, across the north of Australia and later, with shiploads of cattle, to Western Australia. Only Tasmania was to remain free of the epidemic.

Farmers felt panic and despair that is hard to comprehend these days. For many of them, living in hand-hewn huts on properties that were little better than virgin bushland, their cattle were their only asset and livelihood. Pleuropneumonia struck their stock with a swiftness and contagion that seemed uncanny. (Only quite recently it has been found that a coughing cow can spray infection for nearly 100 metres.) Diseased cattle would cough, slobber and stand with necks outstretched, gasping for air. They went off their milk as soon as they became sick. Those that did not die were often disease-carriers and would have been safer dead, but before 1925 there was no compensation and slaughtered cattle were a total loss.

Some New South Wales graziers with big herds began vaccinating them as early as the 1860s. The only available vaccine was fluid collected from the chests of diseased cattle and this carried the danger of transmitting other infections, like tuberculosis. In 1889 two French scientists from the Pasteur Institute were brought to Australia and developed a vaccine taken from artificially induced inflammation under cattle's skin. But these were merely skirmishes and as pleuropneumonia spread through the remote and trackless areas of the north there seemed little chance that it ever would be controlled. The disease smouldered for years, flaring up spasmodically and causing havoc among herds.

Towards the end of the 1920s a rash of severe outbreaks brought an appeal for help to the newly established CSIR Division of Animal Health at Parkville, Melbourne. A team of scientists under Arthur Turner began by searching for a strain of pleuropneumonia less virulent than those responsible for the most common forms of the disease—many of the live vaccines used until then had produced severe reactions in vaccinated cattle. Their search ended in 1933 when they found what Turner was to name the V5 strain, in an animal at Wodonga on the New South Wales-Victorian border. Turner then set about lengthy laboratory experimentation to create an artificial medium in which the pleuropneumonia organism could be grown in large quantities. He developed a complicated meat-digest broth which he called BVF-OS and which made possible the mass production of millions of doses of vaccine.

Turner's next move, with his colleague Arch Campbell, was to adapt knowledge from overseas to develop a highly specific and reliable diagnostic test. The test, known as a 'complement-fixation' test, detects antibodies in the blood of animals that have been infected.

From 1936, the complement-fixation test and the V5 vaccine were used in the first concentrated attack on pleuropneumonia in New South Wales. (The Victorian State veterinary service had achieved almost complete eradication by 1929 but isolated outbreaks were to occur for another 2 years.) By the early 1940s New South Wales also was cleared of the disease. Border inspection points were set up and cattle could move into Victoria only after they had been in New South Wales for six months.

But the threat of pleuropneumonia remained in the north. In those days some three million cattle, a fifth of the Australian total, roamed over 1·5 million square kilometres. Fences were few and frequently drovers brought mobs containing diseased cattle through clean areas on the way to rail-heads. Sick beasts were abandoned by the side of stock routes. Northern breeders relied on this regular droving of cattle from Western Australia and the Northern Territory across to Queensland and then down to the southern States. Southern graziers depended on these movements for their supplies of fattening cattle.

In the 1950s, the southern States began cooperating to combat these invasions of pleuropneumonia from the north. At the same time an extraordinary man, Lionel Rose, who was then Chief Veterinary Officer of the Northern Territory Administration, entered the picture. Rose admitted that the entire Territory had a very bad reputation for animal health and, with his experience as an Army colonel, conceived the bold strategy of creating a protected area in what was virtually the heart of pleuropneumonia country. This area, which centred on Alice Springs and spread into South Australia, covered some 3200 square kilometres. Cattle from both clean and suspected areas—the far north and the Barkly Tableland—would be driven into Alice Springs where they would be kept in separate yards and herded onto separate trains. At Marree, south of Lake Eyre, they would be rested and fed separately and joined by suspect cattle from the Birdsville area. In Adelaide, suspect cattle were to be sent for slaughter and clean cattle sold on the open market.

This separation of cattle into two streams was such a success that it inspired a national program. In 1959 a National Committee for the Control and Eradication of Pleuropneumonia was set up and a sub-committee under the Chief of the CSIRO Division of Animal Health and Production, D. A. Gill, defined further infected, protected and disease-free areas. Once these were established, cattle could be moved between them only under rigid control. Veterinary officers, stock inspectors and police all were called upon to put the national plan into effect. Three classifications of cattle were given special attention: all travelling cattle in diseased areas, all calves at branding time in diseased areas and whole herds on properties where outbreaks occurred. All cattle showing positive reactions to the complement-fixation test were slaughtered, either on the spot or at abattoirs. At the same time healthy cattle were vaccinated.

Mobile laboratories moved into remote regions of the north to enable quick spot-testing of cattle. In these areas it was often difficult, or even impossible, to hold large mobs in one place while the results of tests came back from laboratories in the south. Helicopters and light aircraft were used to get full musters in the most rugged areas of the Kimberleys, ensuring that no disease-carrying cattle could escape and reappear after an area had been declared safe. Road trains, hauled by mighty diesels, began to take over from drovers on horseback, effectively isolating cattle in transit from herds on the properties they passed through.

Protected areas were upgraded progressively to disease-free areas until, by the late 1960s, there were only two pockets of endemic disease remaining, in the Gulf country and the Kimberleys. In 1973, it was announced that the national eradication campaign was a complete success and for the first time in 100 years Australia could export live cattle freely.

Explosions on the Sun

The seven years following World War II were the Model-T Ford years of radio astronomy in Australia. The equipment was primitive and almost every day astronomers had to solve new technical problems, often with such sophisticated tools as a pair of pliers and a roll of chicken wire. But there was a wonderful air of exhilaration. The CSIRO astronomers shared that excitement felt by explorers at the edge of great discoveries. All still admit to a secret nostalgia for the period although today they work with some of the most advanced technology in the world. One of them, Dr Paul Wild, now Chief of the CSIRO Division of Radiophysics, has said: 'With the flow of new discoveries from a brand-new science a special atmosphere developed—perhaps, though on a smaller scale, something like that at the Cavendish Laboratory in Rutherford's time' (when the famous physicist was opening up the whole field of nuclear discovery).

Paul Wild was at the heart of this vigorous thrust into space and, in only 12 weeks of 1949, from a makeshift observatory at Penrith at the foot of the Blue Mountains, he identified, classified and interpreted the different types of bursts of radio emission received from the Sun. His classifications became the internationally accepted standards.

This new science of radio astronomy had a nervous beginning. On several successive days in February 1942 a new and unidentified noise confused reception by radar sets throughout Britain. At first radar operators feared the Germans were launching a massive bomber attack and then, when no aircraft appeared, that the Germans had found a means of effectively jamming Britain's warning system. After the war, when radar came off the secret list, it was revealed that an English physicist had identified the radio noise as coming from the Sun.

At that time the CSIR Radiophysics Laboratory in Sydney was being reorganized by its new Chief, Dr E. G. (Taffy) Bowen, who had been working on radar in Britain since the mid 1930s as an original member of Watson-Watt's research team. Dr Joe Pawsey, the Laboratory's most outstanding physicist, seized on the report of radio noise from the Sun. With a couple of colleagues he moved into the old wartime radar statons around Sydney—on the ocean cliffs at Collaroy, North Head and Dover Heights—and with some quickly assembled equipment began listening for the Sun. Within a week or two they detected the solar radiation and found it to be highly variable. Daily measurements over the next three weeks showed that the intensity of the radiation varied according to sunspot activity.

The next important step was made three months later when Pawsey and his colleagues demonstrated that the emissions came from the region of sunspots. To pinpoint the source of radio waves so accurately was beyond the capacity of the aerials then available. However, the aerial of each radar station was located on high cliffs and Pawsey realized that as the Sun rose slowly above the horizon, the recorded signal would show interference as a result of solar radiation reflected from the surface of the ocean arriving at the aerial out of phase with radiation received direct from the Sun. The first observations, made on 6-9 February 1946, were dramatically successful and pioneered the application of interferometry to radio astronomy.

In the following year Pawsey showed that, even when there were no sunspots, the 'quiet' Sun sent out a steady stream of radio waves emitted from its 1 000 000°C outer atmosphere—the corona. (Through a loudspeaker they sounded like a steady blast of wind.)

Since the 1930s optical astronomers had been making regular observations of solar flares—sudden and violent explosions in the atmosphere of the Sun that occur on the average once every half-hour or so. Flares are the most powerful form of explosion in our solar system. A very large flare—such as may occur once every few years—releases as much energy as 20 million 100-megaton H-bombs all detonated at the same time.

Even before 1947 it was known that large optical flares on the Sun were accompanied by intense but short-lived bursts of radio emission over a range of wavelengths. In March of that year three of Pawsey's colleagues, Ruby Payne-Scott, Don Yabsley and John Bolton, observed a great outburst at Dover Heights using three aerials tuned to different frequencies. The results showed that the outbursts began at quite different times according to frequency, high frequencies before low, suggesting that the source of radiation moved outwards through the solar atmosphere. Stimulated by this finding, Wild set to work developing the world's first radio-spectrograph. This instrument scanned rapidly across the frequency range 70 to 130 megahertz, producing a spectrum of frequencies every half-second and displaying it on a cathode-ray tube.

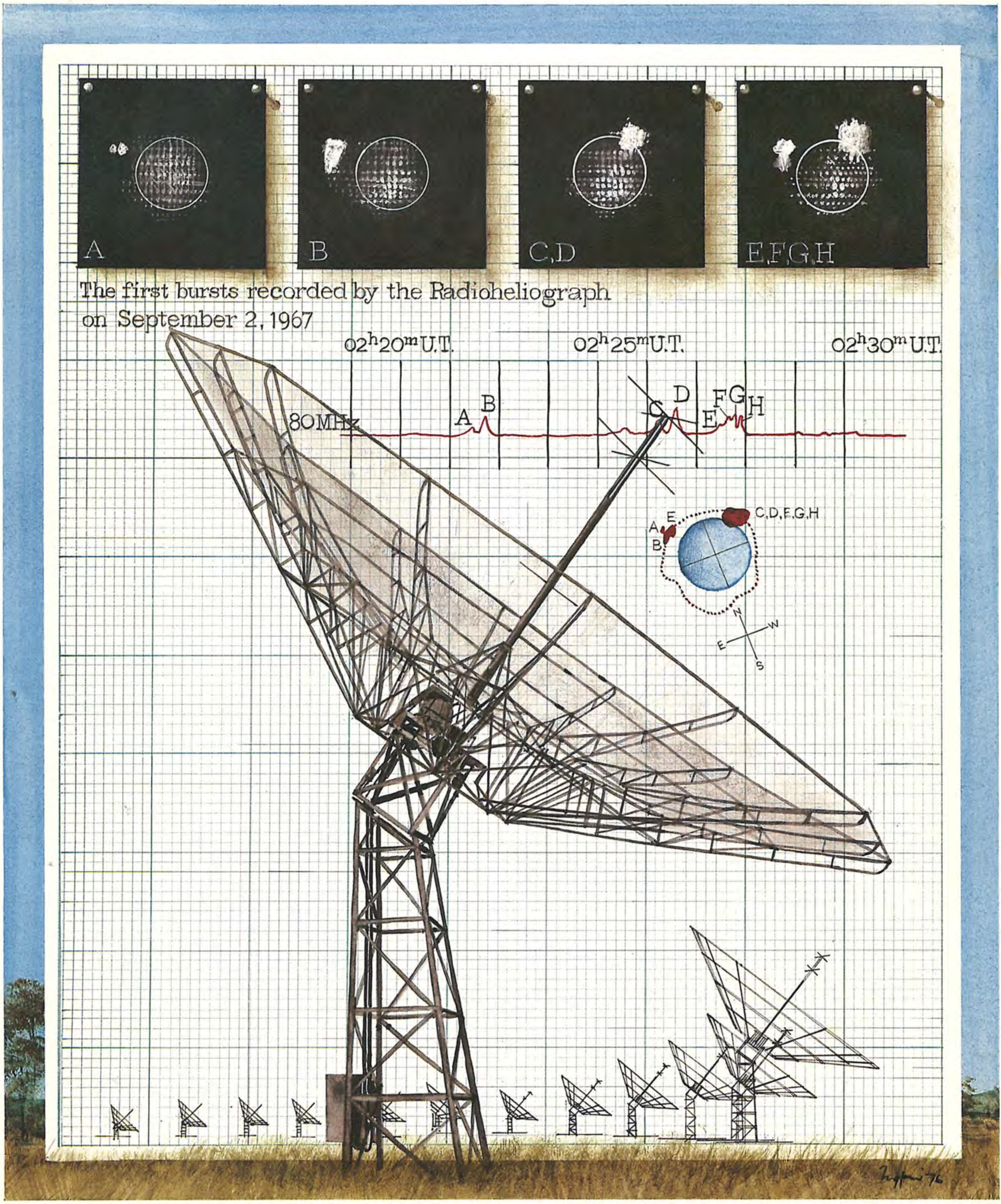
Wild and his team set up the spectrograph near the Penrith railway station in 1949. It was an unlovely apparatus with an unwieldy diamond-shaped aerial of wood and wire which had to be pulled around every 20 minutes by ropes attached to a winch. The aerial was wired to recording equipment housed in three decrepit mobile trailers where the scientists took pictures with a hand-cranked movie camera.

With this primitive equipment Wild identified three types of solar burst—Type I, Type II and Type III of the now-accepted international standard. He knew from previous work in ionospheric physics that the Sun's corona was something like the shells of an onion, each shell with its own resonant radio frequency, the highest frequency shells being closest to the Sun and the lowest, the most distant from it. The spectrograph measured the resonant frequency of the bursts and so was able to identify the height of the source of radiation in the Sun's atmosphere at any instant. In certain types of burst (Type II and Type III) a remarkably distinctive pattern shows up in the recorded spectra: the events first appear only at the highest frequencies, then steadily drift down the spectrum and disappear off the low-frequency end. This means that the source of radiation begins low in the Sun's atmosphere and moves progressively outwards. By measuring the rate of frequency

Explosions on the Sun

One of the 96 aerials comprising the CSIRO radioheliograph at Culgoora, New South Wales. The four photographs of solar bursts at the top of the graph sheet were taken on 2 September 1967 and are among the first obtained with the radioheliograph.

Dr J. L. Pawsey and Dr J. P. Wild



drift it was possible to calculate the outward speed.

The Type III burst is a common short-lived event, a radio 'flash' lasting only a few seconds. In a week of intense activity there may be 100 flashes. Wild inferred from his observations that these flashes move at about 100 000 kilometres per second (one-third the speed of light), sending electron particles racing across the gulf of 149 million kilometres to Earth in only half an hour. Years later, satellite observations confirmed this inference.

Type II bursts are bigger still and happen only three or four times a month. They are caused by a shock wave moving at about 1000 kilometres per second to reach Earth 1½ to 2 days later, causing brilliant aurora light displays in the northern and southern skies and great magnetic storms.

Type I, although very common, is not really a burst but a complex and stationary solar storm that hovers above sunspots. It still has astronomers somewhat puzzled.

These observations, simple by today's standards, were nevertheless tremendously exciting for Wild and his colleagues. Their next move was to build a more sophisticated dynamic radio spectrograph, with three times the frequency range, on a dairy farm at Dapto, 100 kilometres south of Sydney. Wild recalled that 'the wooden rhombic aerials were built by our carpenters . . . inside the observing hut there was a mass of wires, moving parts, a great deal of switchery, clatter of noise and a weird collection of improvised equipment. But to some extent *those* were the days.' At first the Sun refused to co-operate and for four months a lull in sunspots forced the team to wait, disheartened, despondent and wondering if their new equipment really would work.

Then on one memorable day a new group of sunspots appeared and the spectrograph produced a beautiful record of a Type II burst that showed a new effect destined to play a vital part in the emerging subject. The principal burst, appearing on the record graph as an elegant boomerang shape, was accompanied by what appeared to be a duplication of its own image but shifted in frequency. The astronomers set to work analysing these pairs of images and found their frequency had an exact relationship of two to one. They deduced that harmonic resonance was taking place in the electrically charged ionized gases of the plasma surrounding the Sun and this provided the clue to the physical mechanism responsible for the radiation. Shortly after they found the same effect with Type III bursts.

This is how they pictured it: when a shock wave (in the case of Type II) or a cloud of electrons (in the case of Type III) is shot out from the Sun it excites the plasma into resonant oscillation and, as it passes through each different frequency shell, the plasma oscillations there transmit radio waves of that frequency—and of its harmonic. As the disturbance reaches the outer and less dense plasma the frequencies get lower. This discovery triggered off a whole new field of activity in plasma physics which was eventually formulated by two Russian physicists in the theory of combination scattering. This explains how one wave can scatter on another wave producing a second harmonic.

The work at Dapto lasted from 1952 to 1963 when it became obvious that CSIRO's solar radio astronomers would have to take the step into 'big science' if valuable work were to continue. One of Pawsey's final achievements with CSIRO was to persuade the Ford Foundation of America to grant the $US630 000 needed for a radioheliograph—a unique radio telescope designed by Wild and his colleagues which records two-dimensional images of the Sun in the 'light' of radio waves. A fresh radio image is produced each second. Sited at the CSIRO Solar Observatory at Culgoora, 480 kilometres north-west of Sydney, the radioheliograph received its first message from the Sun in August 1967.

The radioheliograph has 96 aerials in a 9-kilometre circle. Each aerial is 13 metres across and linked to a central receiving station which effectively performs like one huge dish, 3 kilometres wide. It enabled the astronomers to record moving pictures of solar disturbances taking place in the solar corona—disturbances that are quite invisible with optical telescopes.

Aware that sunspots are regions of intense magnetic field, with each pair of sunspots acting like the poles of a magnet, the astronomers designed the Culgoora radioheliograph so that it would record oppositely polarized radiation on twin filtered cathode-ray tubes. Left-handed polarization, directed outwards from the Sun, shows red; right-handed, directed inwards, shows blue. With the two images superimposed, unpolarized radiation shows white.

With this refined equipment the astronomers are able to 'see' what is happening on the Sun instead of just observing the effects. They see a Type III burst as a small but very 'bright' patch as the pulse of high-speed electrons pierces the coronal shells corresponding to the frequencies to which the radioheliograph is tuned (43, 80, 160 and 327 megahertz). These shells lie respectively at heights of 700, 400, 200 and 70 thousand kilometres above the Sun's surface.

A Type II burst is seen as a series of great extended arcs as the shock wave from a solar explosion passes through successive shells. But by far the most dramatic events to be seen by the radioheliograph belong to another class (Type IV) in which gigantic magnetic arches filled with charged particles can be seen expanding to sizes greater than the Sun itself; and in which clouds of gas can be seen hurled out from the Sun to distances of as much as two million kilometres.

This work has contributed not only to a deeper understanding of the Sun and the solar explosions which cause widespread effects on the Earth and throughout the solar system but also to the general subject of plasma (ionized gas) physics. To the solar astronomer the Sun's atmosphere is effectively a laboratory for studying very hot, large-scale low-density plasma—a laboratory in which a whole new world is revealed of strange phenomena which do not occur on Earth, and yet the observations made in this laboratory could hold the key to the eventual harnessing of thermonuclear power.

The rain-makers

Cloud-dappled New England lay spread out below for 200 kilometres and more, yellow paddocks merging into the dimpled and slate green timbered foothills of the Great Dividing Range. The Cessna 310 buzzed towards a mountain of cumulus cloud towering south and west of Armidale.

In the aircraft cabin a CSIRO scientist tapped the pilot on the shoulder and pointed to a huge cauliflowered head of cloud drifting away from the main mass. Then he glanced back briefly to a CSIRO colleague who marked the cloud's position on a map opened over his knees.

The pilot put the Cessna into a steep climb and all three men clamped oxygen masks over their faces. The altimeter registered 24 000 feet and the billowing cloud-top loomed just below. Here the temperature gauge showed -9°C. The first scientist nodded, giving the thumbs-up sign, and in a sudden stomach-heaving movement the pilot dropped the Cessna straight through the cloud. Moments of blind, white and swirling unreality. Then a break in the mist. 'Burners on!', the scientist shouted to his colleague as the plane flattened out beneath the cloud.

Then something curious happened. Instead of reaching for the switch that would send clouds of silver-iodide smoke streaming out into the slipstream of the Cessna, the second scientist opened an envelope resting on his lap. One word stared up at him from the piece of plain card inside. 'NO'. He held his hand back from the switch as the Cessna buzzed to and fro beneath the cloud, laying out what should have been a perfect cloud-seeding pattern.

Quite independently, the huge cloud decided to unburden its tonnes of moisture on the thirsty earth below. As raindrops smacked into the aircraft windscreen, the first scientist grinned and flipped a switch marked 'Impactor'. In the nose of the aircraft a roll of aluminium tape began reeling onto a camera mechanism, with each metre of tape recording the 120-knot impact of hundreds of individual raindrops.

Not until a month later, with all the calculations of the experiment fully tabulated, did the first scientist learn that he had been deceived. It happened not once but scores of times between 1962 and 1965 as the Cessna 'scrambled' to meet cruising cloud masses as far north as Cloncurry and Townsville, as far south and west as Adelaide.

The deliberately aborted missions were, and are, part of a program rigorously designed to limit human fallibility—the subconscious temptation to get good cloud-seeding results by seeding only the most promising clouds. Of 100 seedings in the three years from 1962 only 30 were finally approved as first-class and doubt-free experiments.

The rain-makers had their first success on 5 February 1947. It was a day when deep cumulus cloud covered the country inland from Sydney. All the clouds appeared similar in type and size which was important for a clear-cut result. A plane dumped dry ice into one cloud and within minutes rain started to fall while the cloud-top mushroomed explosively. The rain lasted several hours and more than 12 millimetres fell over an area of 80 square kilometres. Surrounding clouds gave no rain. This is believed to be the first documented case anywhere in the world of an appreciable man-made rainfall reaching the ground and the first time that dynamic cloud growth had followed seeding.

In Australia, where fickle rainfall has elated and then downcast countrymen from the time the first pioneers saw once-brimming rivers and lush pastures fade to muddied waterholes and dusty earth, it was almost inevitable that the weather modification work of the Division of Cloud Physics should concentrate on rain-making. The Division's work includes theoretical, laboratory and airborne investigations of cloud structure and reaction.

Two rain-making substances—frozen carbon dioxide (dry ice) and silver iodide smoke—have been widely used. Dry ice has a temperature of -80°C or colder. If a piece the size of a pea is dropped into a supercooled cloud it will fall as far as three kilometres before evaporating completely, leaving a wake of ice crystals. In the right conditions, each crystal will feed on cloud droplets to form a large snowflake which melts to a raindrop as it reaches lower and warmer levels. This attractively simple principle was used from 1947 to 1950 near Sydney when 45-kilogram loads of dry ice were dropped into suitable clouds, their near neighbours being left unseeded to provide a basis for comparison. The principle seemed to work best with continental cumulus cloud masses where the air was dirty so that lots of small droplets were formed which were unlikely to coalesce of their own accord.

Silver iodide smoke particles can also provide 'kernels' on which ice crystals can grow in a supercooled cloud. Theoretically, grams of silver iodide will do much the same job as kilograms of dry ice, so that smaller and cheaper aircraft can be used. Silver iodide seems to work best in layer clouds formed in air coming in from the sea.

From 1955 to 1963 the rain-makers carried out four intensive experiments over South Australia, the Snowy Mountains, the Warragamba Dam catchment area west of Sydney, and New England. For each experiment there was a target area of 2000 to 8000 square kilometres and a neighbouring control area of the same size which was not seeded. A network of up to 150 rain gauges covered each area. The first year's results were tremendously heartening with rainfall increases of up to 30 per cent in the target areas. But frustration followed. Rainfall appeared to deteriorate and in all areas it became more variable than before the experiments started.

Natural variability of rain has been the rain-makers' single biggest headache. 'It makes it terribly difficult to prove anything', one of them has said. 'You can go to an area and influence rain-potential clouds so that it looks as if you have increased the rainfall. But how much rain would have fallen if you hadn't interfered with them? On one occasion you simply can't tell. But if you keep on repeating the experiment, and keep on increasing the rain, eventually you can prove you caused the increase.'

The Division of Cloud Physics works closely with State Departments of Agriculture. Each Department has regional referees to evaluate rain needs and public opinion in various areas. Before any rain-making program has started, public meetings have cast votes. But the weather is never right for everyone and the Division has received letters from irate landowners blaming rain-making experiments for unwanted downpours.

Tasmania was chosen for the most recent cloud-seeding experiments. The experiments were designed to compensate for quirks in the results of previous experiments, which had frustrated the rain-makers and led them to a serious re-evaluation of their programs. The first series of experiments from 1964 to 1970 gave an estimated increase of 15 to 20 per cent in autumn and winter rainfall and encouraged the Tasmanian Hydro-Electric Commission to start a second four-year program in 1971. The early results from this were most encouraging, showing a similar increase in autumn-winter rains and no sign of the frustrating deterioration pattern. The program was postponed when Tasmania suffered a meteorological deluge and a financial drought but by then $2 million spent in cloud-seeding had been more than recouped in increased downfall and in information which, in the long run, is likely to prove even more valuable.

Cattle for the tropics

In 1972 the first CSIRO-bred Belmont Red bulls were released for cooperative evaluation to a cattleman with a property near Rockhampton. The bulls, which were two years old, had been deliberately subjected to tough conditions since birth. They had been exposed to cattle ticks and had grazed pastures which for much of the year had little nutritional value. They were scrawny and poorly grown. The cattleman loaded them on his truck and drove straight home without daring to stop for a beer at the pub for fear his mates would see them. He herded the bulls into a remote paddock, away from visitors' sight, and for the next nine months he kept the 'Belmont' manager constantly reminded of their appearance.

Then the bulls' first calves were born. At weaning, they averaged 10 kilograms heavier than the calves of the cattleman's other stock.

The Belmont Red's consistent deep red colour is probably its least important attribute but, contrarily, one which has eased its entry into an industry which still falls for a pretty face. The breed was developed by the Division of Animal Genetics at the National Cattle Breeding Station, 'Belmont', north of Rockhampton, by crossing Africander cattle, imported from America, with Herefords and Shorthorns. The Belmont Red has many remarkable characteristics which suit it to the harsh environment of northern Australia and which are now ensuring its acceptance by the industry.

The two main British breeds of cattle in northern Australia, the Shorthorn and the Hereford, and mixtures of the two, breed well under favourable conditions, but they are susceptible to stresses imposed by high temperatures, tick infestation and internal worm parasites. They also lose weight on pastures when the protein content of the feed falls below five per cent. For these reasons, British breeds do not generally grow as well in the tropics as they do in the temperate climates to which they are adapted. On the other hand, the humped cattle of Asia and Africa, known collectively as zebus, are well adapted to tropical conditions.

In the early 1930s, the CSIR Division of Animal Health, under its first Chief, John Gilruth, decided to investigate the potential of zebu cattle for northern Australia. Much of the push for this work came from geneticist R. B. Kelley, who went to the United States to select suitable breeding stock. He selected 18 American Brahmans (9 bulls and 9 cows) and one Santa Gertrudis bull for importation. These animals were scattered on five commercial properties throughout northern Queensland with the cooperation of State authorities and cattlemen. Every year for 10 years, Kelley visited the trial properties, watching the cattle's progress and making copious notes. By 1943 when he wrote his final report, he had convincing evidence that zebus could be of great value to Australia's beef industry.

Between 1950 and 1954 a further 15 bulls and 16 cows of the American Brahman breed and fairly large numbers of Santa Gertrudis were imported. At the same time 8 bulls and 2 cows of another zebu breed, the Africander, were imported for use alongside Brahmans at 'Belmont'.

'Belmont', a 3600-hectare property on the Fitzroy River, had been bought by the Australian Meat Board in 1952 to provide facilities for studying the breeding of beef cattle adapted to the northern Australian environment. Since 1953 'Belmont' has been managed on behalf of the Board by CSIRO and operated as a research station.

The breeding program at 'Belmont' came under the direction of Dr Jim Rendel, who had worked with the famous English geneticist J. B. S. Haldane and who was later to become Chief of the Division of Animal Genetics. One evening in Melbourne, during an adjourned CSIRO Executive meeting, the Chairman, Sir Ian Clunies Ross, sat down with Rendel and mapped out the future of 'Belmont' and its breeding program.

The program, which is essentially a long-term one, began with an original stock of imported American Brahmans and Africanders, together with Herefords and Shorthorns from Queensland. From this stock, three main crossbred lines were developed — Africander – British, Brahman – British and Shorthorn – Hereford. The Shorthorn – Hereford turned out to be better in some respects than either of its parent breeds and was adopted as the standard for comparing zebu-cross lines with British breeds.

First cross animals were produced from 1954 to 1960 with numbers gradually building up. Likewise, the second generation was gradually accumulated from 1957 to 1964. In the production and mating of these generations a policy of no selection was practised quite deliberately.

It was only in the third generation when the parental characters had been well stirred to provide a richly stocked genetic pool in which to fish that selection began. The first small matings of selected animals were therefore not made until 1966, with all the emphasis being placed on performance, not looks.

'Recognized breeds', said Greig Turner, Animal Genetics breeder, 'are pre-packed parcels of genes with a trademark. But we didn't have any interest at all in a trademark. We were not concerned, as is virtually everyone who sets out to make a breed, to make it look like a breed, to get a white face, or the right shape of horns. We ignored these things completely. We were able to concentrate all our selection on fertility, growth rate, and resistance to ticks and heat.'

By 1968 the first fruits of selection among the third generation began to emerge. Even at that stage it was apparent that the Africander – British line, now known as the Belmont Red, was going to be a winner. Eight bulls, surplus to requirements and carefully tested for fertility and growth, were sold at auction that year and averaged $900 each. The Belmont Red can be regarded as approximately one-half Africander, one-quarter Shorthorn and one-quarter Hereford. From its zebu antecedents it has inherited its capacity to withstand the stresses of the northern environment while from its British ancestors it has inherited its fertility and its ability to turn grass into meat. Selection is still continuing and further improvements in the breed can be expected.

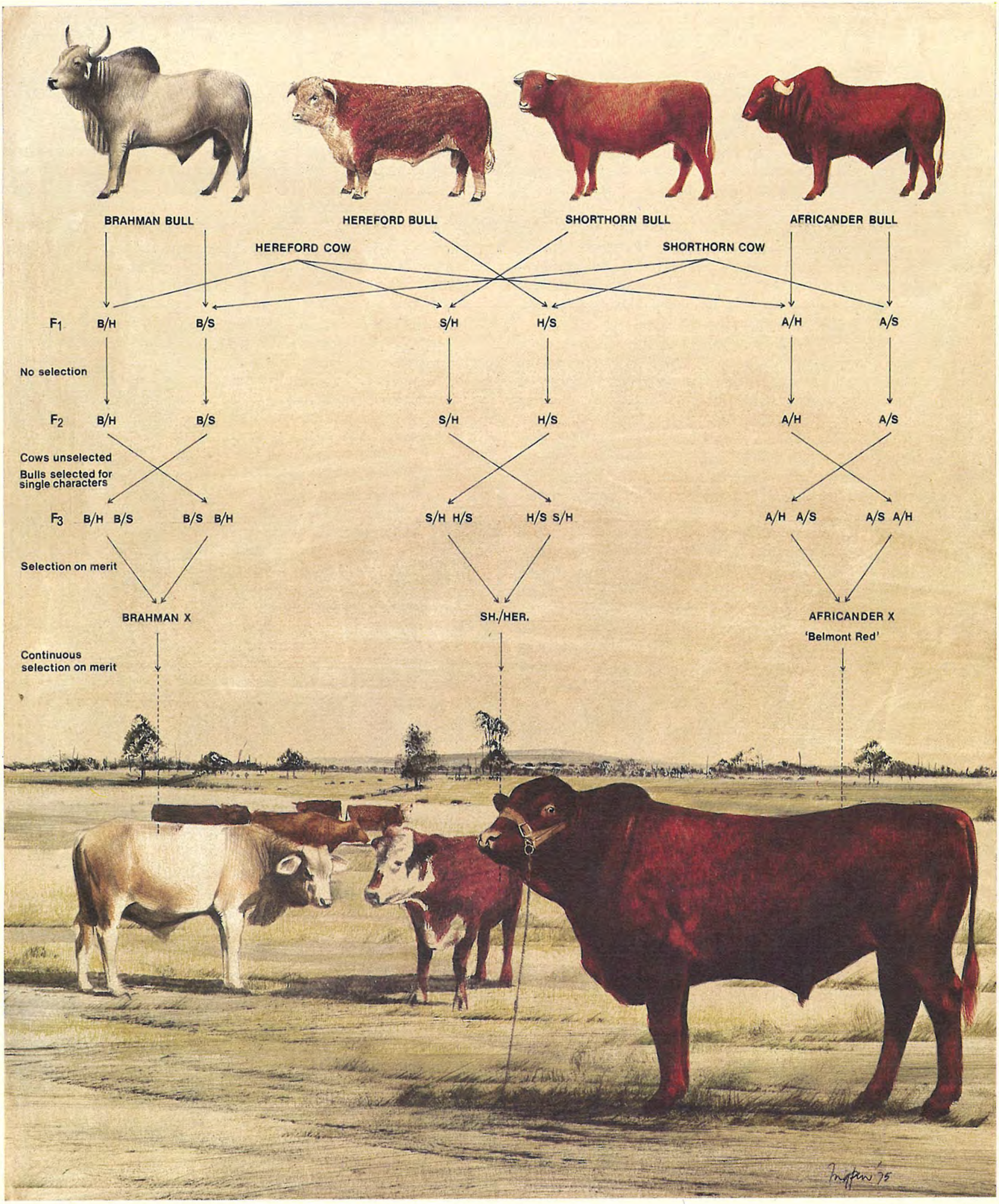
The Brahman – British line is also promising. It has a fine edge over the Belmont Red in heat tolerance and tick resistance, while its resistance to intestinal worms is superior. In growth rate, too, it is comparable, but its fertility still leaves a lot to be desired, and it has a less placid temperament. Until these deficiencies can be overcome by further selection and breeding no animals from this line will be released for commercial exploitation.

Meanwhile the Belmont Red has won admirers in many and varied ways. On a big Gulf of Carpentaria property cows of British stock were dropping their offspring in open paddocks at night and then walking to tree-lined water at sun-up, leaving their shaky calves to die in the heat. Belmont Reds were introduced and their hours-old calves got to their feet and safely followed their mothers to water. Belmont Reds are also even-tempered creatures, unlike Brahmans which need constant handling to remain tractable. A station manager at Walloon has given them their most glowing character reference. 'They are the nicest cattle I've ever had to handle. I could run this property practically single-handed with Belmont Reds.

Cattle for the tropics

Brahman Cross, Shorthorn - Hereford Cross and the Africander Cross, or Belmont Red, graze on a Queensland plain. Diagram shows the breeding procedure for the three lines, and the parent Brahman, Hereford, Shorthorn and Africander bulls.

Mr H. G. Turner, Dr R. B. Kelley and Dr J. M. Rendel



Twinning in sheep

Helen Newton Turner graduated in architecture and confidently expected it to be her career. Then, as a young graduate looking for a job, she met Ian Clunies Ross who so changed the course of her life that she will be remembered as a geneticist, and one who radically changed Merino sheep-breeding in Australia. She proved, despite pessimism by geneticists, that it was possible to select sheep for the heritable ability to produce multiple births. Her research not only showed that big increases in lambing were possible, giving graziers more sheep for sale and more scope for genetically improving their flocks, but also created a better understanding of reproduction in all animals.

In 1973 she officially retired from CSIRO but immediately took up an honorary research fellowship for 12 months. It has been renewed every year since. A brisk and humorous woman, she continually refers to her relationship with CSIRO as 'we' and then ruefully corrects herself, finding it difficult to accept that she is no longer a member of the staff.

As a geneticist, Helen Turner must trace her lifelong fascination with mathematical order to a grandfather who was an accountant. But she does not deny the importance of acquired characteristics and thinks that her co-educational schooling had a lot to do with her success in a profession that was dominated by men. She also pays tribute to her parents—she cannot remember a time when it was not taken for granted that she, as well as her brothers, would attend university, though the expenses involved meant considerable self-sacrifice by her parents.

Her father was an officer in the New South Wales Child Welfare Department and her mother, a teacher, one of the first women graduates from the University of Sydney. During her own course at the same university she found architectural design difficult but enjoyed the mathematical side. She graduated with honours in 1930 in the depths of the depression and could find no better job than that of a secretary in an architect's office. It closed a year later and she worked with the New South Wales Public Service until CSIR's McMaster Animal Health Laboratory at the University of Sydney advertised for a secretary. Her new boss was Ian Clunies Ross (who was later knighted as a CSIRO chairman). He recognized her potential and arranged for her to go to England for a year to study statistics applied to agriculture. This was to supplement the university mathematics course she had been doing at night.

Helen Turner returned to the McMaster Laboratory as a technical officer. 'It was a fantastic place to work in', she recalled. 'Everybody was under 35 and Ross was the kind of person who brought out the best in them. I was inspired by the atmosphere of the whole place.' But the war changed her outlook. Her work seemed increasingly futile as her men friends went off to fight. She switched to the Department of Home Security in Canberra and, after her brother's death at El Alamein, to the Directorate of Manpower which was being run by Ross. The war over, she returned as a consulting statistician to her old Division which had been expanded to include both Animal Health and Production. She became closely involved with Merino breeding experiments being carried out under diverse conditions at the Division's research stations at Gilruth Plains, near Cunnamulla in south-western Queensland, at Armidale in New England and at Deniliquin in the Riverina. The officer-in-charge of animal-breeding in CSIR at that time was Dr R. B. Kelley, a veterinary science graduate who had tried his hand as a horse trader on the China coast.

Kelley had no time for what he described as 'sick animal stuff' and concentrated on improving production. Research to improve wool production by selection had been inhibited since the late 1930s by a New Zealand scientist's erroneous findings of low heritability for fleece weight in sheep. But Helen Turner's earliest analysis of breeding figures from Gilruth Plains showed high heritability, over 30 per cent of variation between sheep being genetic, which made it possible to select parents for wool weight and other qualities and to do away with progeny testing. These findings, backed by statistical proof, excited both great interest and controversy when they were revealed in 1951—controversy because the use of measurement in selecting sheep was new.

Helen Turner was particularly interested in the possibility of selecting for wool quality by measuring the average fibre diameter of the fleece instead of trying to estimate it from crimp—the wavy configuration of fibre which graziers considered to be all-important in judging fleeces. This emphasis on diameter anticipated the Objective Measurement revolution in wool assessment by 20 years.

The research into reproduction, which was to result in Helen Turner's pioneering twinning experiments, had a fortuitous beginning. 'A happy accident', she was to call it. In 1951, Kelley had sent ewes from Cunnamulla to the Division of Plant Industry's station at Deniliquin, where they showed a remarkable increase in reproduction rate. From an average of 13 sets of twins to every 100 ewes they went to 50 sets. At this time geneticists generally were sceptical about the heritability of such characteristics. But regardless of what the pundits might think, the officer-in-charge at Deniliquin, Ron Prunster, knew just two things—the ewes had extraordinary lambing percentages and, in the usual course of events, they would be sent to market. He pleaded with the animal breeding scientists, 'Do *something* with these ewes—we can't just sell them.'

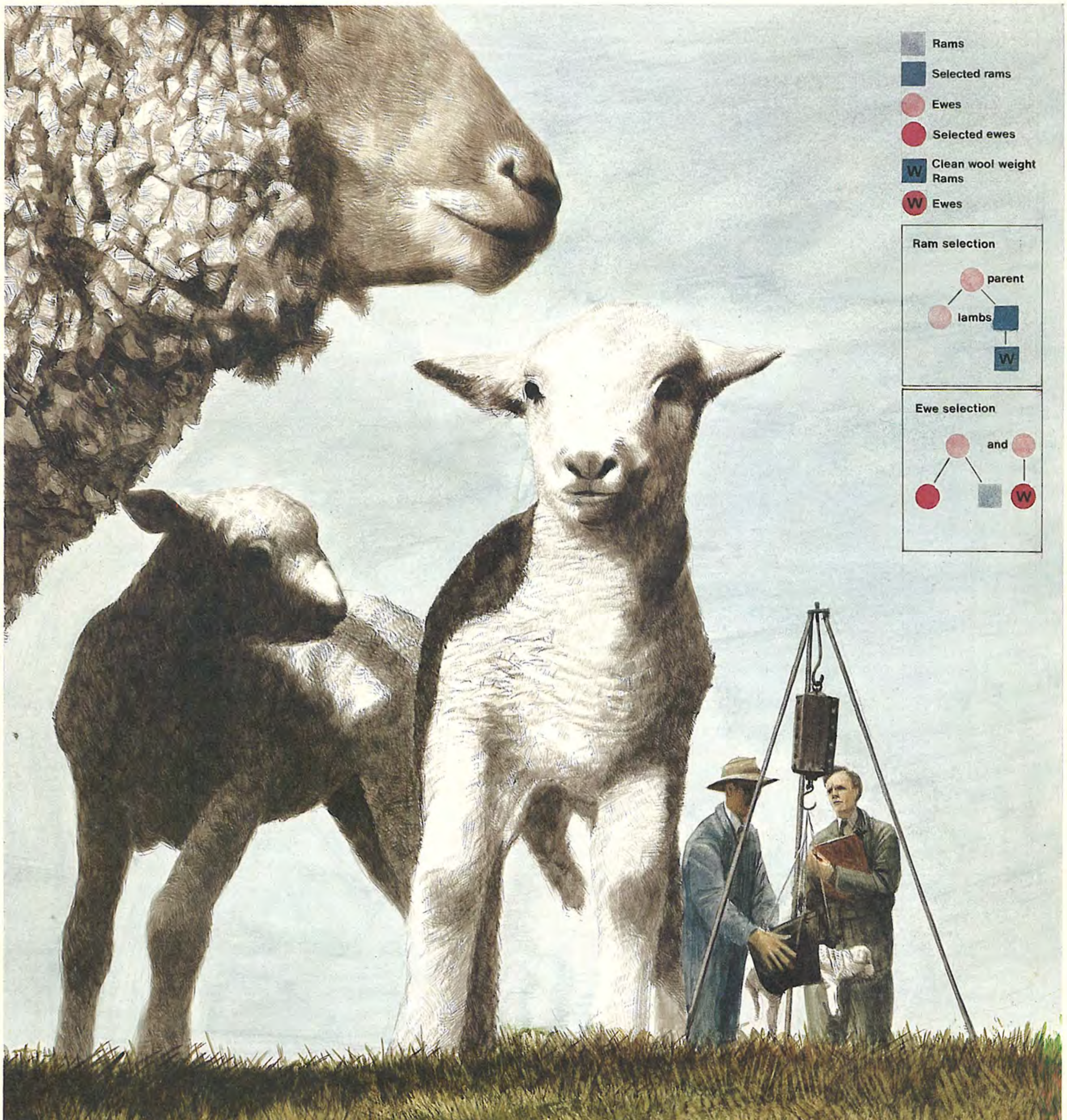
So the twin-bearing ewes among the group became the T (for twin) group and the single-bearing ewes the O group of what expanded into the notable Experiment AB9. Helen Turner, acting on not much more than a hunch, selected twin-born and single-born rams from the same stock at Cunnamulla. She put 2 twin rams to 53 T ewes and 2 single rams to 53 O ewes, and kept on selecting for high and low incidence of twins respectively in the T and O groups. With the 1956 lambing these matings gave striking evidence of multiple-birth heritability. By 1958 the figures were remarkable. The original T ewes had produced 91 multiple births and the O group only 31. The first daughters of the T ewes had produced 21 multiples (including two sets of triplets) and the O daughters only 4 (all twins). 'Geneticists around the world sat up and took notice', said Helen Turner. But closer to home there was an even more positive response. Two brothers named Seears, of 'Booroola' near Cooma, wrote to CSIRO offering a Merino ram born in a set of five, all of which had survived. Helen Turner doubted that the ram could be pure Merino but drove down to Cooma and found to her delight that it was, one of a small flock the brothers had selected for multiple births, although without any selection on the ram side. She also bought 12 'Booroola' ewes, born as triplets or quads. Another 90 ewes were bought in 1965 when all the twinning groups moved to Armidale. In 1972 the B group from 'Booroola' produced an average of 210 lambs for every 100 ewes. 'Quite fantastic for Merinos', reported Helen Turner.

A number of rams and a few ewes from the B and T groups have been sold to breeders, the rams being the first in Australia to be sold on measured performance. The B, T and O flocks, numbering now respectively 200, 200 and 100 breeding ewes, exist as an invaluable resource for studies of reproduction processes leading to further exciting possibilities for the Australian sheep industry.

Twinning in sheep

As scientists field-weigh lambs, a Merino ewe stands with newly born twins produced by careful selection for twinning. The diagram illustrates the most successful of 28 theoretical systems of ram and ewe selection, combining high reproduction rate through multiple births with optimum wool weight.

Dr Helen Newton Turner



Myxomatosis

A plague of rabbits ravaged vast areas of Australia in the years immediately after World War II. In places not a blade of grass remained and even bushes were stripped bare of leaves and bark. Farmers and graziers had been away at the war, unable to carry out normal trapping, shooting and poisoning which kept rabbits to manageable numbers. Rabbits swarmed around waterholes like a seething carpet of brown fur. Where rabbit-proof fences existed it was as if they separated two halves of a surrealist painting of devastation: on one side lush growth, for these were the good years, and on the other naked earth often scarred by erosion.

In 1919 the Brazilian virologist Aragao had suggested that myxomatosis, a virus disease of rabbits, might be used in Australia to control rabbits. But while the rabbit was regarded as a serious pest by many, it was a source of income to others, and the suggestion was opposed. The New South Wales Department of Agriculture conducted laboratory experiments with the myxoma virus in 1926, but the results were not encouraging.

The use of myxomatosis was again advocated in 1934, this time by Dame Jean MacNamara, a distinguished authority on poliomyelitis. CSIR arranged for laboratory tests with the myxoma virus to be carried out in England by Sir Charles Martin. These were followed in 1936 by laboratory experiments in Australia by Dr Lionel Bull of the CSIR Division of Animal Health. Having confirmed that the virus would not adversely affect domestic stock or native animals, Bull commenced a lengthy series of field trials in South Australia. The results were disappointing; although it proved possible to exterminate rabbits in warrens in which the virus had been introduced, the infection failed to spread from one warren to another.

In 1944 Bull and his colleague Bill Mules concluded that 'myxomatosis could not be used to control rabbit populations under most natural conditions in Australia with any promise of success.' They did, however, say that it might be possible to use the disease with some promise of temporary control of a rabbit population, but only under 'special conditions, including the presence of insect vectors in abundance and the absence of predatory animals.'

By 1949 the situation was desperate. The traditional methods of control were quite inadequate. New and radical measures were called for. Dame Jean MacNamara once more took up her advocacy of using myxomatosis, campaigning vigorously in the Melbourne-published *Stock and Land* and the *Herald.*

Dame Jean had been particularly provoked by an article which quoted Francis Ratcliffe, head of the newly formed CSIRO Wildlife Survey Section, as saying, 'Myxomatosis has failed because very close contact with rabbits is needed for its spread.' Ratcliffe seemed on safe ground. Both man and animals develop immunity to virus infections and an initially high mortality rate is often followed by a quite rapid recovery. Australia's rabbit population numbered hundreds of millions, spread over huge distances. Seven years of intensive and painstaking research by Bull and his colleagues had failed to provide any evidence to suggest that myxomatosis would control this widely distributed population. They were aware of the importance of stick-fast fleas and mosquitoes as carriers of the infection, but were disappointed by their lack of effectiveness.

There seemed little scientific justification for further research. But the situation was serious and late in 1949 Ratcliffe decided that further trials should be made to test the practical advantages of the known limited capacity of myxomatosis to spread. His proposal had the enthusiastic support of Ian Clunies Ross, the newly appointed Chairman of CSIRO.

This time, however, the area chosen for the trials was not the dry inland of South Australia but the Murray Valley. An irrigated dairy farm at Gunbower in the Murray Valley, 240 kilometres downstream from Albury, was selected for the experiments. The first inoculations were a failure because of faulty virus material. Then, in May 1950, the infection was successfully released in several warrens. Soon after the start of the experiment 77 diseased rabbits were counted in an estimated population of 4000. But sightings became fewer and by the end of July not a single sick rabbit had been seen for weeks.

The research workers then introduced the disease in late August on four grazing properties within a 65-kilometre radius of Albury: at Wymah, Rutherglen, Coreen and Balldale, 24 kilometres from Corowa. A check at the beginning of December showed that the disease had apparently died out, except at Rutherglen, and even there it was fading fast.

A few days later the owner of the Balldale property phoned CSIRO to say that his men had seen numbers of sick rabbits while out fumigating. Unfortunately, by the time an investigating team arrived a few days later, the men had completed their job and destroyed the evidence.

Then a trickle of reported sightings began coming in from other points up and down the Murray. By the end of January 1951 the trickle had become a flood. Every day elated farmers called to report diseased rabbits. Reports came from along the Murrumbidgee, the Lachlan, and even up the Darling.

A CSIRO press release of 29 January 1951 reported outbreaks at points up to 290 kilometres apart (Corowa and Hillston) and said: 'The disease tends to be confined to the river flats and frontage country. In the Corowa – Rutherglen area, where the most detailed observations have been carried out, there is a very obvious and clear relation between the activity of the disease and proximity of weedy lagoons. These are the breeding places of the dusk-biting *Culex annulirostris* mosquito.'

By mid February, nine weeks after the Balldale outbreak, the disease ranged over an area 1760 kilometres by 1600 kilometres. The Melbourne *Argus* carried a headline: 'Farmers' New Ally Kills 90% of Rabbits.' The *Herald* ran a story saying: 'Along the river flats the stench of death lies heavy these hot days — myxomatosis is striking at the millions of rabbits that swarm along the lagoons and river reaches.'

The reason for the epidemic spread of myxomatosis was to be found in the unusually heavy rains which fell during 1950. These had resulted in a massive build-up of mosquito numbers along the Murray – Darling river system, thus providing the 'special conditions' that Bull and Mules had earlier stipulated as being necessary for the successful use of the virus.

In 1952 – 53, Australia's wool and meat production jumped by $68 million as pastures recovered from the ravages of rabbits. In the two decades since, myxomatosis has brought incalculable benefit to Australia, despite the appearance of less lethal strains of the virus and rabbits with a degree of genetic resistance.

Today at 'Gungahlin', the Division of Wildlife Research headquarters outside Canberra, research continues into rabbit behaviour and physiology to provide more effective and efficient means of control. Just one possibility of future attack is the synthesizing of a 'rabbity' odour which rabbits secrete to mark out their home territories, and which may be used to repel them from selected areas. Research will go on as long as rabbits remain in potentially destructive numbers.

Myxomatosis

On a property in the Albury - Corowa area, a farmhouse and shearing shed are surrounded by bare ground denuded by rabbits. This scene was typical of the pre-myxomatosis era. Maps show the spread of myxomatosis in the years 1950 - 52. Illustrated is a collection of items used in the field to inoculate rabbits with the disease.

Dr F. N. Ratcliffe and Dr L. B. Bull

Sizing up wool

In a sky-lit whitewashed room, the size of a Jumbo jet hangar, a thousand and more bales of wool stand in ordered rows with their opened tops frothing a creamy richness of fleeces. It is early, only minutes after 8 a.m., but already a score of wool-buyers are making their way up and down the rows, dipping into the bales for samples which they test with practised fingers and judge with knowing eyes. They are casually dressed in open-necked shirts and well-worn jumpers yet there is an odd formality about this preparation for the day's sale. Even more so in the jargon they use: words like 'suint', 'shive', 'kemp', 'moit' and 'fribs' with an eighteenth-century ring, for tradition pervades the wool business.

This is a typical brokers' show floor, one of the many found in every wool-selling centre of Australia. A recent innovation is the line of several hundred shallow cardboard boxes placed in a corner of the room. They, too, contain wool but this wool has been tested before reaching the show floor. Moreover, the samples in the boxes represent as much or even more wool than the thousand or more bales in the room.

Above the boxes are certificates stating the vital information of fibre diameter and yield—the proportion of clean, usable wool in each sample. This enables buyers to tell if the wool will meet the demands of their clients, the wool processors.

Here is the evidence of a discreet but sweeping revolution that is changing Australian wool-selling. Discreet, because at all stages it has required tact, discussion and diplomacy to gain acceptance by a conservative and cautious industry. Sweeping, because in only three years since its introduction sale by certified sample has soared from 20 per cent to 40 per cent to 60 per cent of the total offering of wool for auction. It is a revolution that could save tens of millions of dollars a year in transport and handling costs.

Wool sold by this new method has been objectively measured by techniques which give a precision of measurement that cannot be matched by the subjective assessment of buyers, no matter how skilful and true their hands and eyes. These techniques have been developed by the CSIRO Division of Textile Physics in continuing collaboration with the Australian Wool Corporation and all sections of the industry.

The Division of Textile Physics began research into better testing methods in 1960. One of its most successful inventions has been a sonic tester for the important characteristic of wool fineness (average fibre diameter) which is measured in microns (millionths of a metre). The testing machine is accurate to within half a micron. It works on an air-drag principle and was developed from a method which pumped air through a wad of wool: the finer the wool, the greater the resistance. Instead of a continuous flow of air the sonic tester uses a small oscillating movement of air through the fibres. A portable version can be used by graziers to measure fleece samples as an aid to selecting breeding stock.

Wool yield is also an important characteristic. Nearly half the weight of an average bale of greasy wool is grease, dirt and vegetable matter and the amount of these impurities is difficult to assess. Eleven years of trial and development by the Division of Textile Physics produced an automated washing-machine for testing samples. One of Australia's two commercial testing houses now uses four of the machines, each capable of removing dirt and grease from 30 samples an hour without loss of fibre.

Then comes the difficult process of testing for vegetable matter. About a quarter of Australia's clip that comes to brokers is contaminated with vegetable matter such as grass seeds and burrs. Processors want to know how much of this is included in each sale lot because its presence causes loss of wool during processing. The conventional test method dissolves the wool in hot caustic soda but this also dissolves some of the vegetable matter. A CSIRO prototype machine has been devised which separates wool from vegetable matter by chopping the washed sample, immersing it in a liquid in which wool floats and vegetable matter sinks and then spinning the liquid in a centrifuge.

Other machines are being developed for testing staple length and staple strength.

But these tests would be useless unless the chosen samples were representative of all the wool sold. Textile Physics has designed a machine that grab-samples bales, making accurate measurement of staple length possible, and another machine that core-samples bales by boring through them to obtain a representative sample of the contents for yield and fineness testing.

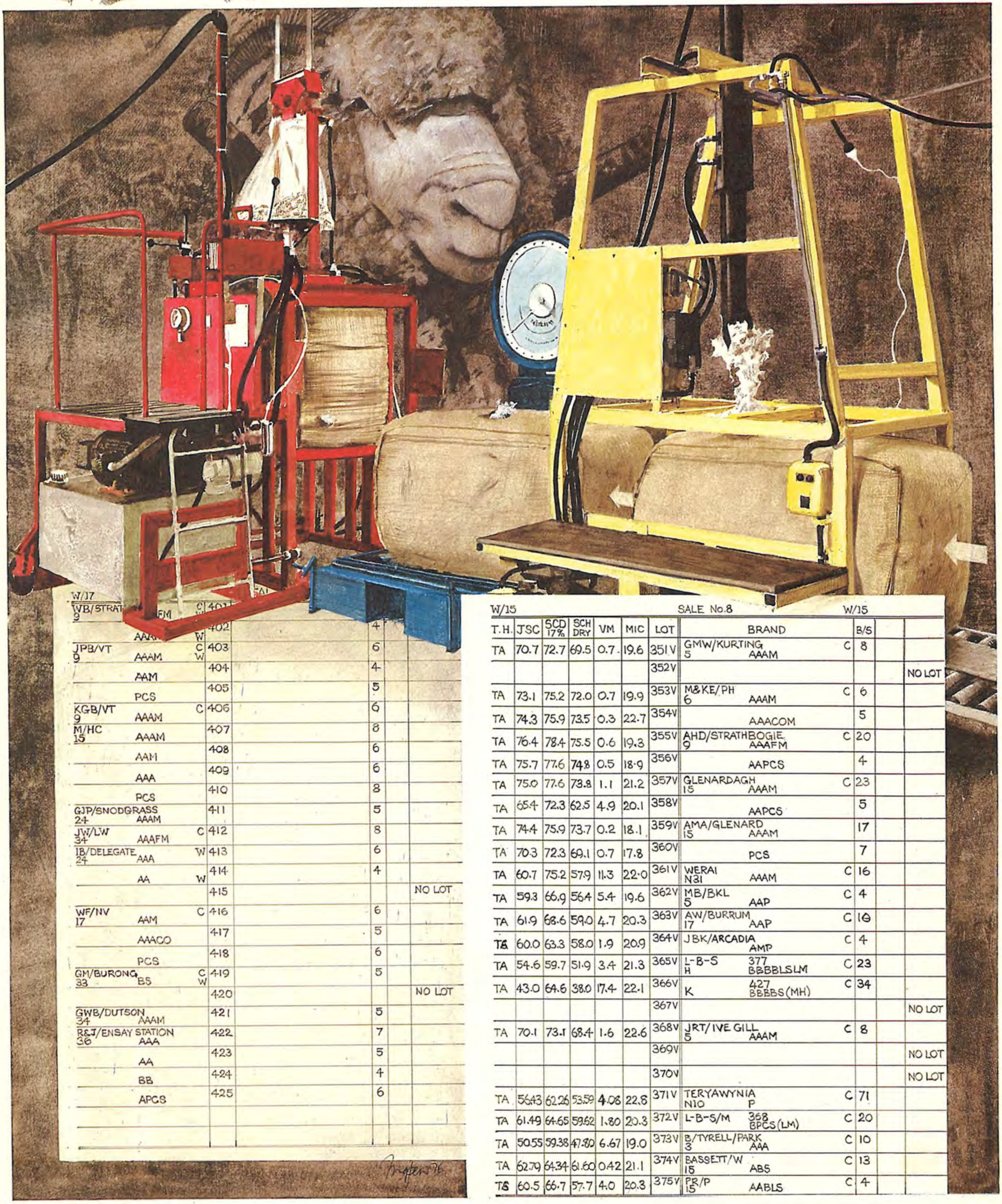
In 1970 a series of trials known as the Australian Objective Measurement Project was established to investigate the technical and economic feasibility of sampling and testing greasy wool and selling the wool by sample. The Project, which was undertaken by the Australian Wool Corporation in association with CSIRO and a number of other bodies, ran for two years and cost $1·5 million. It was to prove a major step in overcoming many of the technical and commercial obstacles that lay in the way of changes in wool marketing. Two people closely associated with the Project and with the development of objective measurement techniques during the1960s were Mr John Downes, Chief of the Division of Textile Physics, and Mr Bruce Mackay, a Principal Research Scientist with the Division. Mackay became Manager of the Project, steering it through to a successful conclusion in 1972.

The wool industry, which had handled as separate items the one million lots of wool sold each year, is ripe for change. Objective measurement can reduce handling costs by rationalizing wool varieties into broader but better categories—and come closer to giving the processors the information they need about the raw material they use.

Sizing up wool

Objective measurement of wool requires two sample types from each bale. First, the jaws of a grab-sampling machine (*right*) take an uncut sample from a bale for appraisal. The bale is then weighed and proceeds to a coring machine which takes a core traversing the bale's full length. Core samples, stored in plastic bags, are analysed for fineness and vegetable matter (VM). A page from the Merino Catalogue offered at the Wool Exchange in Melbourne on 4 February 1976 compares the results of this method with a typical catalogue page from the era of subjective assessment of wool.

Mr J. G. Downes and Mr B. H. Mackay



W/17

WB/STRAT 9	FM	C W	401				
	AAA	W	402		4		
JPB/VT 9	AAAM	C W	403		6		
	AAM		404		4		
	PCS		405		5		
KGB/VT 9	AAAM	C	406		6		
M/HC 15	AAAM		407		8		
	AAM		408		6		
	AAA		409		6		
	PCS		410		8		
GJP/SNODGRASS 24	AAAM		411		5		
JW/LW 34	AAAFM	C	412		8		
IB/DELEGATE 24	AAA	W	413		6		
	AA	W	414		4		
			415				NO LOT
WF/NV 17	AAM	C	416		6		
	AAACO		417		5		
	PCS		418		6		
GM/BURONG 33	BS	C W	419		5		
			420				NO LOT
GWB/DUTSON 34	AAAM		421		5		
R&J/ENSAY STATION 36	AAA		422		7		
	AA		423		5		
	BB		424		4		
	APCS		425		6		

W/15 SALE No.8 W/15

T.H.	JSC	SCD 17%	SCH DRY	VM	MIC	LOT	BRAND		B/S		
TA	70.7	72.7	69.5	0.7	19.6	351V	GMW/KURTING 5 AAAM	C	8		
						352V					NO LOT
TA	73.1	75.2	72.0	0.7	19.9	353V	M&KE/PH 6 AAAM	C	6		
TA	74.3	75.9	73.5	0.3	22.7	354V	AAACOM		5		
TA	76.4	78.4	75.5	0.6	19.3	355V	AHD/STRATHBOGIE 9 AAAFM	C	20		
TA	75.7	77.6	74.8	0.5	18·9	356V	AAPCS		4		
TA	75.0	77.6	73.8	1.1	21.2	357V	GLENARDAGH 15 AAAM	C	23		
TA	65.4	72.3	62.5	4.9	20.1	358V	AAPCS		5		
TA	74.4	75.9	73.7	0.2	18.1	359V	AMA/GLENARD 15 AAAM		17		
TA	70.3	72.3	69.1	0.7	17.8	360V	PCS		7		
TA	60.7	75.2	57.9	11.3	22·0	361V	WERAI N31 AAAM	C	16		
TA	59.3	66.9	56.4	5.4	19.6	362V	MB/BKL 5 AAP	C	4		
TA	61.9	68.6	59.0	4.7	20.3	363V	AW/BURRUM 17 AAP	C	10		
TA	60.0	63.3	58.0	1.9	20.9	364V	JBK/ARCADIA AMP	C	4		
TA	54.6	59.7	51.9	3.4	21.3	365V	L-B-S 377 H BBBBLSLM	C	23		
TA	43.0	64.6	38.0	17.4	22.1	366V	K 427 BBBBS(MH)	C	34		
						367V					NO LOT
TA	70.1	73.1	68.4	1.6	22.6	368V	JRT/IVE GILL 5 AAAM	C	8		
						369V					NO LOT
						370V					NO LOT
TA	56.43	62.26	53.59	4.08	22.8	371V	TERYAWYNIA N10 P	C	71		
TA	61.49	64.65	59.62	1.80	20.3	372V	L-B-S/M 358 BPCS(LM)	C	20		
TA	50.55	59.38	47.80	6.67	19.0	373V	B/TYRELL/PARK 3 AAA	C	10		
TA	62.79	64.34	61.60	0.42	21.1	374V	BASSETT/W 15 ABS	C	13		
TS	60.5	66.7	57.7	4.0	20.3	375V	PR/P 15 AABLS	C	4		

Green cathedrals

'There is a giant tree, prominent in a forest that stretches to the skyline. On its canopy birds and butterflies sip nectar. On its branches orchids and mistletoes offer flowers to other birds and insects. Among them ferns creep, lichens encrust and centipedes and scorpions lurk. In the rubble that falls among the roots and stems, ants build nests and even earthworms and snails find homes. There is a minute munching of caterpillars and the silent sucking of plant bugs. Through the branches spread spiders' webs. Frogs wait for insects and a snake glides . . .'

—From 'The Life of Plants' by E. J. H. Corner

The quote is one of Len Webb's favourites. It reaches towards the complex and, at times, inarticulate feelings he has about the teeming and tumultuous life of tropical rain forests. They —along with the cold and the hot deserts—are the last vast areas of earth to resist the imprint of man.

Len Webb and Geoff Tracey, of the Rain Forest Ecology Section of the CSIRO Division of Plant Industry, have spent years of their lives deep inside the huge green cathedrals of Australia's coastal north. They have come to see the rhythms and patterns, the intricate harmonies and interrelationships of symbiosis in which every plant and creature has its dependent place. They have understood the elegant order beneath the apparent confusion—that nothing exists in isolation and that every species is a part of the whole.

The 2000 million hectares of tropical rain forest in the equatorial regions are located almost entirely within the developing countries of the world and are the home of more than 2500 million people. Under the mounting population pressure in these countries, the fragile ecology of the rain forests is being subjected to increasing stress as they are cleared for food and timber and wood-chips. The disappearance and degeneration of the tropical rain forest, greatly accelerated by modern technological methods, are attracting international scientific concern—not only because of the inadequacy of many of the systems of land use replacing the forest, but also because of the irretrievable loss of world genetic resources and possibly detrimental effects on global climate.

In this dawning crisis of the tropics, Australia is in a specially important position to study the intricate ecology of rain forests and pass on her findings to the rest of the world. The eastern Australian coastal region is, in fact, the only place in the world where the continuous variation of rain forests can be observed from the tropical humid and monsoonal zone to the subtropical and temperate zones, without the intervention of deserts. Australia's rain forests are therefore an excellent and accessible laboratory in which to study the ecological processes involved in the distribution, development and regeneration of tropical vegetation. Australia too has special social and scientific advantages for this work: it has experienced ecologists, biologists and other experts in the environmental sciences, and highly sophisticated computer facilities for analysing complex data.

Australia's tropical and monsoonal rain forests now cover little more than two million hectares. This is less than half the area that existed before the first European settlers arrived and it is still diminishing with the assaults of logging, mining, clearing for agriculture and pasture, real-estate development and damage by tourists. Yet these forests are part of Australia's heritage which must be preserved.

Len Webb, one of Australia's leading authorities on rain forests, first worked as a clerk-typist for Government Botanist C. T. White in the Herbarium of Brisbane's old Botanic Gardens and from him learned of man's deep involvement in nature.

In 1944, as a member of the Division of Plant Industry, he took up the phytochemical survey that had been started early in the war by CSIR and the Universities of Sydney and Melbourne, to identify plants producing such vital drugs as morphine, cocaine and strychnine. Working as a field botanist, Webb went into the rain forests collecting leaves, bark and roots of plants that might show traces of these and other alkaloids. He followed up leads provided by medico and botanist Joseph Bancroft, the hearsay of graziers whose stock had been poisoned, the experience of timber-cutters who knew, for example, that the wood dust of certain trees caused headaches, and a knowledge of Aboriginal bush medicine. But many plants were unknown hazards. While he was collecting bark of the 'poison walnut' on the Atherton Tableland he was smitten by nausea and swollen eyes and glands that lasted for days. Sap from the same plant squirted into Geoff Tracey's eyes and he was in hospital for a week. By the early 1950s they had skimmed the cream of rain forest drug sources, proving them 10 times richer than other native vegetations. Organic chemists identified the structure of 500 alkaloids of which 200 were new. Not many had immediate application, but the survey swelled a valuable pool of information for further use.

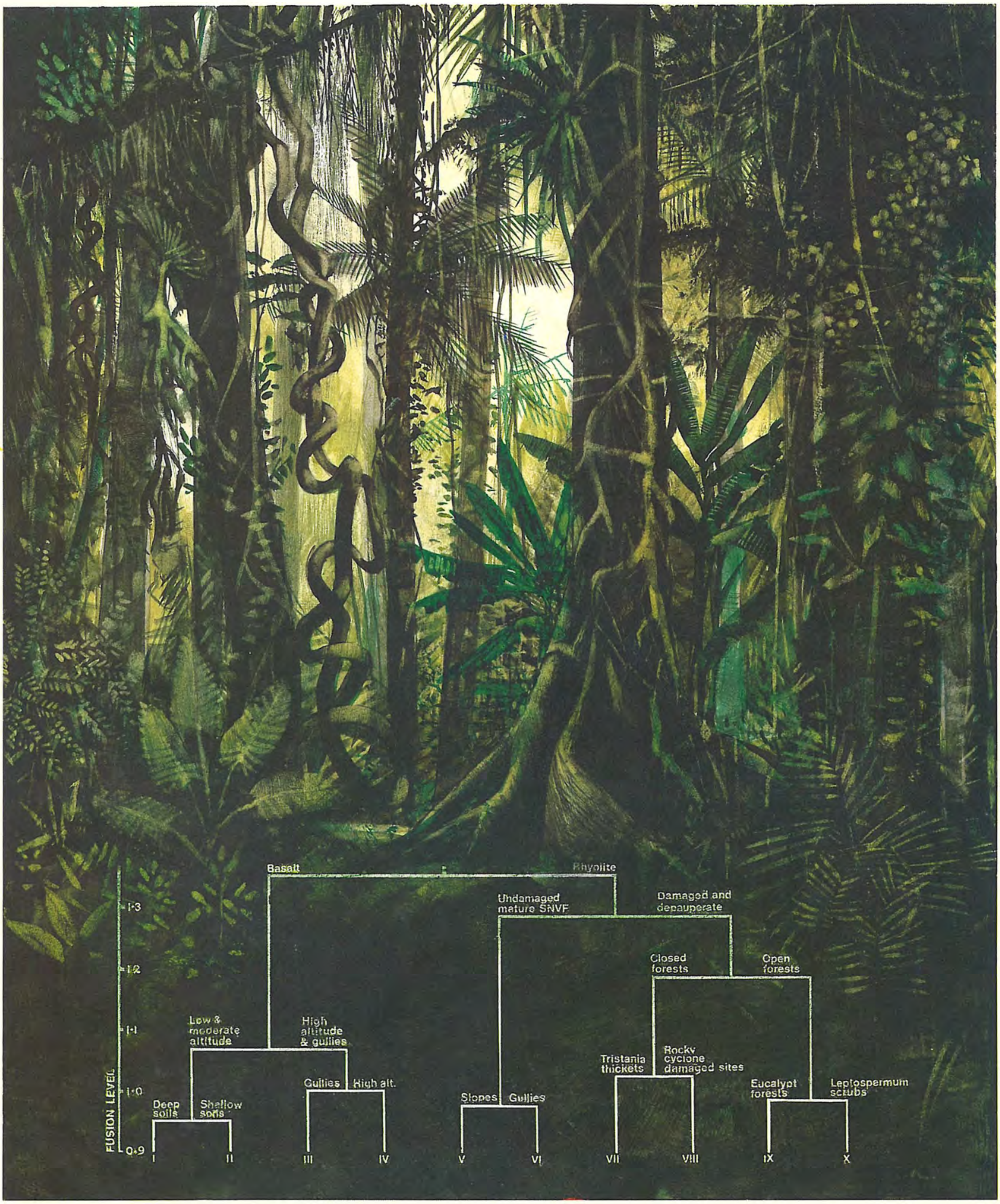
Rain forest ecology had become Webb's passion and he turned next to studying the factors that controlled the nature and distribution of rain forest. 'At that time', he said, 'my work fell outside the main stream of the Division's activities, which were mostly oriented to agriculture. But the Chief, Otto Frankel, supposed that the Division was big enough to afford a mad idealist like me. Tracey and I started off in an old building in the Botany Department of Queensland University, which was then in George Street, Brisbane. We had little official support, not even a typist, and we were nearly swamped by our research material.'

Webb and Tracey conducted their investigation at three levels. The first was mapping the broad diversity of rain forests over 30 degrees of latitude, from Cape York to Cape Otway, noting the effects of geography, climate, soil composition and fire. The second was the more detailed study of a particular area, the Moreton District in south-east Queensland, which they covered by foot and four-wheel drive. The third was the internal examination of the Whian Whian State Forest, in northern New South Wales, where they and Geoff Stirk of the CSIRO Division of Soils measured moisture, soil elements and plant types and came to grips with the sophisticated interactions of the rain forest. From this came their findings which reversed the previous notion that climate was more important than soil for the growth of rain forest in eastern Australia, and provided the beginning of a system of forest classification.

Green cathedrals

Living banks of genetic material, the world's dwindling rain forests are complex and fragile ecosystems. Some of the life-forms depicted in this Australian rain forest are the bird's-nest fern, elkhorn fern, robust woody liane, orchid and hanging tassel fern, cauliflory, strangler fig, wild banana, cunjevoi, wild ginger, plank buttresses and tree fern. A schematic model of the complex rain forest is shown.

Dr W. T. Williams and Dr L. J. Webb



Working mostly in northern New South Wales and around Cairns, Webb and Tracey collected plant samples, seeking patterns in the seeming chaos of the rain forests. By the early 1960s they had gathered a vast quantity of data, intimidating in its complexity. Then Bill Williams, a former Professor of Botany at Southampton University with a background in computers, joined CSIRO. Webb asked for his help and immediately the study of rain forests took on a new and exciting dimension.

Williams fed data on 818 species of plants from 18 sites into the Control Data 3600 computer in Canberra. In just 13 minutes it suggested that these 18 sites were best regarded as being of six groups, each of three sub-sites. The divisions reflected climate, prevailing moisture, soil-minerals and altitude. Later work with a bigger computer analysed 1147 tree species from 265 sites and identified seven major vegetation regions. A classification grid was developed which has enabled people with even the most limited botanical knowledge to identify rain forest types anywhere in the world, using a spot-check list of readily recognized leaf and plant structures. Numerical analyses using the computer have also provided new ideas about the reality of plant associations, and a new understanding of the factors controlling regeneration and pattern in complex rain forests.

In collaboration with ecologist Jiro Kikkawa of the University of Queensland Webb has extended this classification of rain forest types to fauna habitats by using bird species as 'markers' for other forms of wildlife.

A number of rain forest areas recommended by Webb have been proclaimed National Parks by the Queensland Government. Most recently he and Tracey have completed a vegetation – ecological map of Queensland's wet tropical areas as a guide for future development. Already it has provided evidence to help stop a proposed wood-chip industry in an area of fragile and rare rain forest. Recently Webb was seconded to the Papua New Guinea Government to assess the environmental implications and ecological effects of clear-felling for wood-chips in rain forests. He suggested a mosaic pattern of felling dictated by natural seed dispersal.

Webb's friendship with Francis Ratcliffe, who decried Australia's 'big country mystique', and later with poet and conservationist Judith Wright, has given him a deep and abiding sense of man's responsibility to maintain his natural environment. He was a member of the Australian National Estate Committee of Inquiry which reported in 1974: 'Remaining rain forests in Australia are of international significance as ancient and isolated reservoirs of a great variety of plant and animal species which, especially in northern tropical areas, have as yet been little studied by science. They are a non-renewable resource ... In some areas their species are in danger of mass extinction. The sustained productivity of their soils for agricultural and pastoral use is in doubt, the high rainfall causes them to become infertile or eroded once the forest is removed. Yet in the face of modern scientific knowledge, drastic changes in the national landscape of the tropics, including northern Australia, are occurring within a few decades in an unplanned and haphazard way ... These changes represent a loss of world heritage of genetic resources and indeed a loss of the biological perspective for the evolution of man himself.'

Prawn harvest in the Gulf

The Gulf of Carpentaria is an inhospitable place.

A great 300 000 square kilometre bite out of the north-east coast of Australia, it discouraged interest from the time the earliest Dutch explorers sailed into it in 1623 and named it for the then governor of the Dutch East India Company, Pieter Carpentier.

Its shimmering green and often muddy waters, bordered by mangroves merging into marshes and salt pans, were a breeding-ground for the fever that virtually wiped out the first settlement at Burketown, 242 years later. In the summer wet season 500 millimetres of rain can fall in a day and the humidity is intolerable.

Normanton was established as the port of north-western Queensland in 1867. For many years the only activities to disturb the Gulf's torrid lethargy were the discovery of copper at Cloncurry, a brief flurry of gold-mining at Croydon, and the taking up of isolated cattle leases the size of English counties.

It might have remained so for a lot longer but for an informal lunch in the elegant surroundings of The Chalet restaurant in lower Pitt Street, Sydney, in September 1962. The host was Bob Mostyn, chairman of Craig, Mostyn and Co. Pty Ltd, owners of a fishing and exporting business. The humpback whaling industry had just closed down in Australia and New Zealand, and during the meal, conversation inevitably drifted to the possibility of alternative ventures. Mostyn mentioned he had sent two prawn trawlers to the Gulf early that year. But they had managed only limited catches of juvenile prawns and prospects seemed dim.

One of the lunch guests, Geoff Kesteven, Assistant Chief of the CSIRO Division of Fisheries and Oceanography, was optimistic. He said he believed the Gulf had a vast, untried potential as a prawning ground. 'Kesteven was an enthusiastic battler for Australian fishing', Mostyn was to recall later. 'The suggestion for Gulf prawning really came out of his fertile brain. If we hadn't started then it might be dead even today.'

Events moved quickly. Within a month the Queensland Treasurer, Tom Hiley, wrote to the Commonwealth Government stating that Craig, Mostyn and three other companies were interested in Gulf prawning and that Kesteven had given his private opinion to the Queensland fisheries authorities 'that the continuing haul of prawns from the Gulf could equal Australia's present production'. Hiley suggested that the Commonwealth should finance an exploratory project as most fishing would be outside State waters, and that a potential and conservation survey should be made at the same time.

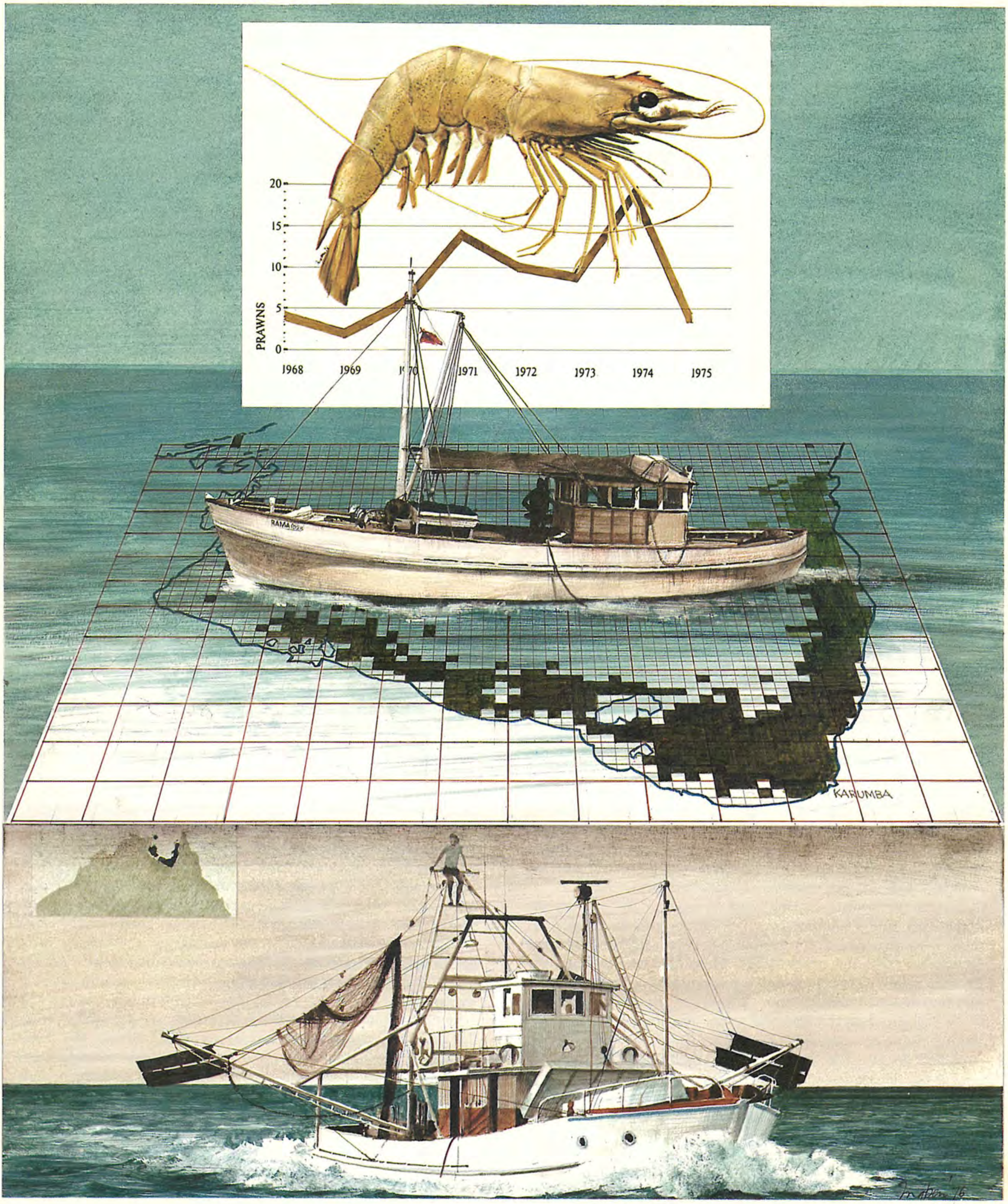
In November 1962 Mostyn wrote to both the Commonwealth and Queensland governments saying his company proposed to start fishing and processing immediately after the coming wet season. Karumba, on the south-eastern corner of the Gulf, appeared the most suitable operations centre. 'In our opinion', he wrote, 'it would be appropriate to conduct a survey of fishing potential and investigation of other pertinent factors by CSIRO in conjunction with fishing operations.'

The following week a meeting was called of representatives of government departments, fishing companies and CSIRO. The official minutes reported that 'Dr Kesteven drew an analogy between the ecology of the Gulf of Mexico and the Gulf of Carpentaria and stated that he saw no reason why an extensive prawn resource should not exist in the Gulf of Carpentaria. On what he claimed were conservative assessments of the experience in the Gulf of Mexico, he estimated

Mr I. S. R. Munro and Dr G. L. Kesteven

Prawn harvest in the Gulf

The research vessel *Rama* stands in marked contrast to the commercial prawning trawler below. Associated with the *Rama* is a map showing the distribution of prawn fishing grounds in the Gulf of Carpentaria. Above is a banana prawn superimposed upon a graph showing banana-prawn catches in the Gulf in millions of pounds between 1968 and 1975.



that an annual take of up to 26 million pounds [12 000 tonnes] of raw prawns might prove to be possible.'

In conjunction with Craig, Mostyn and Co. Pty Ltd, the Commonwealth Department of Primary Industry, the Queensland Department of Harbors and Marine, and CSIRO reached agreement on the survey in May 1963. The survey party comprising scientists and technical officers from CSIRO and the Queensland Department was led by Ian Munro, a principal research scientist of the CSIRO Division of Fisheries and Oceanography. The party flew into Karumba on 26 July and started work three days later with the arrival of the survey vessel *Rama*. Five small Mostyn-sponsored trawlers and an independent boat, *Kestrel*, arrived the same day.

Karumba, an overseas flying-boat service base before the war, consisted in 1963 of two government houses and 'The Lodge' which was run by Ansett Hotels to cater for the small number of tourists visiting the area. Once a week, if weather permitted, an Ansett DC3 flying the famous 'station run' landed on a grass strip, which first had to be cleared of goats. Normanton, a sleepy little town on a broad red-gravelled main street, was 80 kilometres away over a dirt road. In the 'wet' the road disappeared under grass three metres high and became impassable.

The survey team's headquarters, home and laboratory was a small cottage on stilts, rented from 'The Lodge'. For two years up to eight men at a time lived and worked in these cramped conditions for three-month stints. The stress was to prove too much for some of them.

The south-eastern survey area represented about 8 per cent of the Gulf. All of it was within the 20-fathom (36·5-metre) depth contour and three-quarters was less than 10 fathoms (18 metres). The two existing charts were based mainly on soundings taken by Matthew Flinders in 1801 and Commander Stokes in 1841. Mirages appeared to lift the coastline so that boats could be several kilometres further out to sea than their crews believed. Even in 1965 the Australian Encyclopaedia described the Gulf as a place where 'navigation is hazardous except for skippers of small craft with extensive local knowledge.'

The survey vessel *Rama* was a chartered 15-metre commercial prawn trawler which cruised at 8 knots. She was designed as a day-trip trawler and not for prolonged surveys in the tropics. Her fish holds were not refrigerated and accommodation was poky and poorly ventilated with no lavatory or washing facilities. A small awning gave only limited deck cover from the blazing sun. Yet for six days at a stretch her crew (skipper, mate, observer) hauled back and forth over the lonely waters of the Gulf. Her only navigation aids were a steering compass and an unsophisticated echo-sounder.

Her shakedown cruise was used to educate the crew in the apparently odd requirements of scientists and to show technicians the procedures for sampling prawns and benthos (flora and fauna from the ocean floor). They also had to learn the drill for collecting water samples and bottom-sediment samples and for observing temperatures and other environmental data.

The original survey grid was ruled out in neat squares of 6 minutes latitude and longitude to give a statistical coverage by area and season. But tides were stronger than expected and forced trawling traverses out of alignment. A 44-gallon drum of formalin was ordered to preserve samples; a half-empty 4-gallon drum was delivered. Shallow trays of ice made in 'The Lodge' cold room only just saved the samples from completely putrefying.

The sitation on shore was no better. Munro later recalled that 'instead of a standard laboratory set up with gleaming chrome and stainless steel plumbing, there was only the bare earth and the shade of the cottage overhead. The only furnishings were a makeshift bench fashioned from a discarded door and a sheet of galvanized iron. Putrefying samples being processed here nauseated the biologists and attracted swarms of blowflies.'

Morale was not good. The Queensland fisheries men and the CSIRO men found themselves working under different salaries and awards for identical work. This, and boredom, caused friction and dissatisfaction. Tempers were shortened by high humidity and mosquitoes during the 'wet', and stifling heat and sandflies during the 'dry'.

There was no recreation – swimming was ruled out by sea snakes, crocodiles and sea wasps – and in 'The Lodge' bar a bottle of beer cost three times as much as it did in Sydney. Munro had to play diplomat and judge to keep the team together. He cheered them with his confidence in the ultimate success of the survey.

Then, slowly, working conditions began to improve. Munro drove a utility truck from Brisbane loaded with building materials that helped the team build a rough-and-ready, fly-proof laboratory. A reference collection of preserved organisms – fishes, prawns, sponges, corals, shells, starfish – was assembled. The truck made it possible to visit Normanton for weekly shopping trips.

An ice-making machine meant *Rama* could undertake longer trips and return with better specimens. (*Kestrel* made a couple of forays and a fleet of large trawlers arrived from Western Australia on a private survey. None of them located anything promising.)

In December the wet season started, flooding the country around Karumba. *Rama* ran into eight weeks of troubles. She had to run for cover in two cyclones, was damaged by fire, and had to be located by plane and towed 160 kilometres to port when her engine broke down. Lightning damaged her radio and magnetized many of her metal parts, making her compass useless. These parts had to be replaced and a new compass fitted. However, by early May a shore transmitter had *Rama* in constant radio contact; it became possible to plan regular operating schedules and modify them according to conditions and new information.

Although *Rama* had taken some prawns in nearly every trawl, including commercially valuable species such as banana, blue-leg king, tiger and Endeavour, catches were disappointingly small. The big hope had always been banana prawns, but it was May before the first important catch of this species was made. The catch was a complete surprise. *Rama* was working 32 kilometres off shore in the middle of the survey area: previous experience in Bundaberg indicated banana prawns were most likely to be caught within 3 kilometres of river mouths.

A Department of Primary Industry gear expert, Peter Lorimer, was on board *Rama* experimenting with the echo-sounder. About midnight some interesting shadows appeared on the screen – a school of banana prawns. *Rama* swung through the school twice. The first time she lifted 270 kilos of banana prawns and the second time 72 kilos of banana and king prawns.

Back at Karumba the radio crackled and Munro answered the call sign. *Rama's* skipper called 'You owe me that magnum of champagne!'

The prawns were caught in a huge, massed ball emerging from the ocean floor in a 'boil' of mud. Experience was to show that these balls could weigh 4 tonnes and more. Spotting 'mud boils' from light aircraft became a ready way of fixing catch areas.

Scientists deduced that banana prawns in the balling stage were mating, but not necessarily spawning. Schooling was likely to occur in depressions on the ocean floor that marked the outward flow of rivers. Spawning apparently occurred in deeper waters during summer and after the eggs hatched the larvae rose to the surface, migrating towards the coast as they developed further and entered river estuaries as postlarvae. Here they settled, developing into juvenile prawns, feeding and growing for three to four months. As the next crop of postlarvae entered the estuaries, the now adolescent prawns began an off-shore migration. In the survey area it was found that males matured before females. They were adult, with a carapace length of 22 millimetres, before they reached the sea. Females reached maturity at the ocean mating grounds, with a carapace length of over 31 millimetres.

Much of the information for this came from surveys made in the mangrove prawn nurseries from a 4-metre outboard. Juvenile prawns were caught and dye-marked in cages.

In March 1965 *Rama* and the Mostyn-owned *Toowoon Bay* began following migrating prawns seawards from the river estuaries, trying to locate the balled schools.

They succeeded—with three lifts of 675–850 kilos—in depressions out from Smithburne River. They also found a relationship between schooling behaviour and periods of minimal tide flow. Excitement was intense. Two commercial trawlers joined the team. The four vessels between them lifted more than 5 tonnes of banana prawns, using the scientists' predictions of time and place. Other good catches followed. A new fishery was born.

The vessels now began testing to see how long the prawns were likely to be available. But they were hampered by bad weather. Engine trouble forced *Toowoon Bay* to drop out. Others were caught in a gale and one had to be found by an air-sea search. On the 122nd cruise, during the 2234th trawl, *Rama* broke down.

It was 29 July 1965, the second anniversary of the day *Rama* first wet her nets in the Gulf, and two days before the survey was scheduled to end. The weather was foul and the crew had had enough. On shore there had been an increasing turn-over of staff. 'People just couldn't stick it out', Munro recalled. 'In places like that people go troppo in some degree. Some nice troppo, some nasty troppo.' The Karumba station closed down on 13 August and the team returned to civilization.

The survey had been remarkably cheap—a total outlay of about $300 000 plus scientists' salaries and equipment. Since then the size of the Gulf prawning fleet and its catch has varied widely from season to season. Even so, since 1970 the catch has never fallen below 2500 tonnes. In 1971, nearly 300 trawlers lifted 3690 tonnes live weight of prawns – about 90 per cent of them banana prawns. And 1974 saw a record catch of 6415 tonnes. At an average price of around $1.50 a kilogram that's a rich harvest.

Further reading

CSIRO scientists produce more than 1500 papers and books each year on the results of their research. Most of these are technical in nature. However, the following publications, which are available from public libraries, contain information of general interest on CSIRO or on topics dealt with in this book.

Currie, Sir George, and Graham, John. 'The Origins of CSIRO: Science and the Commonwealth Government 1901-1926'. (CSIRO, Melbourne, 1966.)

Currie, Sir George, and Graham, John. CSIR 1926-1939. *Public Administration (Sydney)* **33** (3), 230-52. (1974.)

Fenner, F., and Ratcliffe, F. N. 'Myxomatosis'. (Cambridge University Press, 1965.)

Frith, H. J. 'Waterfowl in Australia'. (Angus and Robertson, Sydney, 1967.)

Mellor, D. P. 'The Role of Science and Technology'. Australia in the War of 1939-1945, Ser. 4 Vol. 5. (Australian War Memorial, Canberra, 1958.)

Rivett, Rohan. 'David Rivett: Fighter for Australian Science'. (Rivett, Melbourne, 1972.)

Underwood, E. J. The Cobalt Story. *Records of the Australian Academy of Science* **2** (2), 23-8. (1972.)

Waterhouse, D. F. The Biological Control of Dung. *Scientific American* **230**, 100-109. (1974.)

Watt, R. D. 'The Romance of the Australian Land Industries'. (Angus and Robertson, Sydney, 1955.)

Webb, L. J., Whitelock, D., and Le Gay Brereton, J. 'The Last of the Lands'. (Jacaranda, Milton, 1969.)

White, Sir Frederick. CSIR and CSIRO: The Events of 1948-49. *Public Administration (Sydney)* **34** (4), 281-93. (1975.)

Wild, J. P. The Beginnings of Radio Astronomy in Australia. *Records of the Australian Academy of Science* **2** (5), 52-61. (1972.)

CSIRO also publishes a number of popular or semi-popular accounts of its research activities in the CSIRO Annual Report, *Rural Research* (published quarterly), *CSIRO Industrial Research News* (published bi-monthly) and *Ecos—CSIRO Environmental Research* (published quarterly). All of these publications are available from public libraries and from the libraries of high schools, colleges and universities. Copies of *Ecos* and the CSIRO Annual Report may also be purchased from Australian Government Bookshops.

Enquiries for technical information may be forwarded to the CSIRO Information Service, 314 Albert Street, East Melbourne (P.O. Box 89, East Melbourne, Vic. 3002) and subscription requests to the Editorial and Publications Service at the same address.

CSIRO Divisions and the location of their laboratories and field stations as at March 1976.

Animal Genetics

Sydney, with a laboratory and field station at Rockhampton, Qld., field stations at Armidale and Badgery's Creek, N.S.W., and a field investigation unit at Wollongbar, N.S.W.

Animal Health

Melbourne, with laboratories in Sydney, Brisbane, Perth and Townsville, and field stations at Maribyrnong, Sungarrin, Werribee and Tooradin, Vic., Badgery's Creek, N.S.W., and Jimboomba and Magnetic Island, Qld.

Animal Physiology

Sydney, with the Pastoral Research Laboratory at Armidale, N.S.W., the Beef Cattle Research Unit at Townsville, Qld., and the Bloat Research Unit at Melbourne.

Applied Geomechanics

Melbourne, with a laboratory in Adelaide and a field station at Cobar, N.S.W.

Applied Organic Chemistry

Melbourne.

Atmospheric Physics

Melbourne.

Building Research

Melbourne.

Chemical Engineering

Melbourne.

Chemical Physics

Melbourne.

Chemical Technology

Melbourne.

Cloud Physics

Sydney.

Computing Research

The Division operates a computer network which has its centre in Canberra and is linked by Australian Post Office lines to subsidiary installations in Adelaide, Brisbane, Melbourne (various locations), Perth, Sydney (various locations), Armidale and Griffith, N.S.W., and Rockhampton and Townsville, Qld.

Entomology

Canberra, with laboratories in Brisbane, Perth and Sydney, and field stations at Armidale, Trangie and Wilton, N.S.W., Rockhampton, Qld., Hobart, and Port Moresby, Papua New Guinea. The Division also has biological control units at Curitiba, Brazil; Montpellier, France; Tehran, Iran; and Pretoria, South Africa.

Environmental Mechanics

Canberra.

Fisheries and Oceanography

Sydney, with laboratories in Brisbane and Perth and field stations at Darwin and Groote Eylandt, N.T., Karumba and Weipa, Qld., and Sams Creek, W.A.

Food Research

Headquarters and Food Research Laboratory, Sydney; Meat Research Laboratory, Brisbane; Dairy Research Laboratory, Melbourne; Tasmanian Food Research Unit, Hobart.

Horticultural Research

Adelaide, with a laboratory and field station at Merbein, Vic., and a laboratory at Hobart.

Irrigation Research

Griffith, N.S.W.

Land Resources Management

Perth, with laboratories at Deniliquin, N.S.W., Alice Springs, N.T., Canberra, A.C.T., and field stations at Baker's Hill, W.A., and Deniliquin, N.S.W.

Land Use Research

Canberra, with a laboratory at Lawes, Qld.

Mathematics and Statistics

Adelaide, with officers stationed with a number of Divisions at Brisbane, Canberra, Hobart, Melbourne, Perth and Sydney, and at Townsville, Qld., and the University of Melbourne.

Mechanical Engineering

Melbourne.

Mineral Chemistry

Melbourne, with a laboratory in Sydney.

Mineral Physics

Sydney, with a laboratory in Melbourne.

Mineralogy

Perth, with laboratories in Canberra and Sydney.

National Measurement Laboratory

Sydney, with an optical observatory at the CSIRO Solar Observatory, Culgoora, N.S.W.

Nutritional Biochemistry

Adelaide, with a field station at O'Halloran Hill, S.A.

Plant Industry

Canberra, with cotton research unit at Narrabri, N.S.W., ecology units at Brisbane, Qld., Waste Point and Broken Hill, N.S.W., and an experimental farm at Canberra.

Protein Chemistry

Melbourne.

Radiophysics

Sydney, with the Australian National Radio Astronomy Observatory at Parkes, N.S.W., and a radio observatory at the CSIRO Solar Observatory, Culgoora, N.S.W.

Soils

Adelaide, with laboratories in Brisbane, Canberra, Townsville, Qld., and Hobart.

Textile Industry

Geelong, Vic.

Textile Physics

Sydney.

Tribophysics

Melbourne.

Tropical Agronomy

Brisbane, with laboratories at Townsville and Lawes, Qld., and field stations at Beerwah, Mareeba, Mundubbera, Samford and Townsville, Qld., Katherine, N.T., and Kununurra, W.A.

Wildlife Research

Canberra, with laboratories at Perth and Darwin, and staff located at Alice Springs, N.T.

In addition to the Divisions CSIRO has five smaller research units. They are:

Agro-Industrial Research Unit

Canberra.

Australian Numerical Meteorology Research Centre

The Centre, which is located in Melbourne, is jointly operated by CSIRO and the Department of Science.

Marine Biochemistry Unit

Sydney.

Solar Energy Studies Unit

Melbourne.

Wheat Research Unit

Sydney.

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