CHAPTER 7

STANDARDS AND STANDARDISATION

RECOGNITION of the importance of accurate measurements in industry has often been associated in the past with the needs of defence, and has in varying degrees been responsible for the setting up of national organisations designed to maintain standards of measurement. Not long after the Franco-Prussian War, the German Government established the Physikalisch-Technische-Reichsanstalt with the object among other things of providing all those industries requiring them with standards of length and other physical quantities. At the turn of the century the Royal Society of London set up the National Physical Laboratory in an old country house at Teddington. Among its earliest tasks were investigations of problems arising out of the supply of munitions during the South African War, when difficulties arose from failure to secure interchangeability of shell fuses.

On the outbreak of the first world war the National Physical Laboratory was able to meet the calls made on it by industry to an extent unequalled by any other organisation or institution in Britain. In 1917 it was taken over by the Government and placed under the Department of Scientific and Industrial Research. It was no coincidence that the American Government set up the National Bureau of Standards in Washington about the time of the Spanish-American War. The threat of a second world war had its share in hastening the establishment of Australia's National Standards Laboratory, though the first attempts to set it up had been made as early as 1912. Though empowered under the Constitution to do so, the Commonwealth Government did not at the time of Federation introduce legislation dealing with weights and measures. The result was that each State continued to have its own laws relating to weights and measures, all substantially the same since they were based on the British *Board of Trade Act* of 1870, but quite inadequate for modern engineering industry. For example the most accurate commercial yard was required to be not more than 0.03 inch longer than and not more than 0.015 inch shorter than the Imperial Standard Yard. None of the Departments of Weights and Measures was equipped for making measurements of the precision required for mass production of munitions.

Valuable pioneer work in educating industry to see the importance of standards had been done by the Standards Association of Australia, whose formation has already been discussed in some detail. The nucleus from which these ideas could be implemented was contained in the Metrology Section of the Munitions Supply Laboratories. In organising this section Leighton had been fortunate in securing the services of Mr. Esserman,[1] who had, while on duty in England during the 1914-18 war, been given the

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[1] N. A. Esserman, BSc. Physicist Munitions Supply Labs 1920-38, Assistant Superintendent 1938; Chief, Division of Metrology, CSIR, since 1939. B. Sydney, 24 Jul 1896.

opportunity of studying at the National Physical Laboratory those aspects of war production associated with metrology. On his way back to Australia to take charge of the section he spent some time on similar studies at the National Bureau of Standards in Washington. During the next few years the section was well equipped with precision instruments and provided with a staff trained to calibrate the gauges essential for replicating components of small arms, guns and their ammunition. The section was intended to serve primarily the government factories and firms under contract to them. If, in time of war, a large part of commercial industry was to be engaged in the mass production of munitions, as envisaged in the general plan of defence, it would be necessary to have facilities for calibrating gauges in terms of a common standard of length in all important industrial centres in the Commonwealth.

Consideration of the requirements of defence was, however, not the only motive that inspired endeavours to obtain uniform standards throughout Australia. The strongest motive was the need for standards in the industrial development of the country. The desire on the part of a few scientists to have reliable standards for their researches was perhaps of secondary importance, though it was the earliest of the three motives to manifest itself. The first public advocate of a national standards institution appears to have been Professor Madsen,[2] who felt the need for such an organisation in his own field of electrical engineering.[3] The only way of checking electrical resistance boxes that no longer agreed with one another was to send them back to England, and in the days before commercial air services this involved long delays.

In spite of Madsen's continued advocacy of an Australian national standards laboratory, many years elapsed before there was any promise of its realisation. The prospects seemed favourable in 1926 when, as Madsen was about to leave on a visit to Europe, he was asked by the Chairman of the newly-formed Council for Scientific and Industrial Research (Mr George Julius) to visit the National Physical Laboratory and also the American National Bureau of Standards, to find out exactly what would be required in the way of equipment, accommodation and organisation in setting up a standards laboratory. Madsen brought back with him full details, extending even to a rough draft furnished by the British Board of Trade of the legislation that would be required for proclaiming national standards. When the Committee on the Maintenance of Standards set up with the approval of the Executive Council of the C.S.I.R. made its report and recommendations in 1928, it did so largely on the basis of the information Madsen had collected. Although the scheme put forward by the committee and referred to the Commonwealth Government was based on the far too modest outlay of £10,000, the proposal died. Industry was not yet ripe for it, and even if it had been,

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[2] Sir John Madsen, BE, DSc. (Major, Offr i/c Engr Officers' Training School, 1915-19.) Prof of Electrical Engineering, Univ of Sydney, 1920-48; Chairman Radio Research Board since 1927. B. Lochinvar, NSW, 24 Mar 1879.

[3] J. P. V. Madsen, "Australian Standards", *Proceedings of the Institution of Engineers of Aust,* Vol. 9 (1928), p. 91.

the economic depression of the early thirties would no doubt have seriously jeopardised its early life.

With the return of economic prosperity proposals for a national standards laboratory were revived by the Secondary Industries Testing and Research Committee.

As any engineer of experience may testify (said the committee in presenting its case) the position in Australia is simply chaotic, not because of any lack of efficiency on the part of the Australian manufacturer, but because he is not afforded the gauging and calibration facilities which can only be given by those in authority. There can be no assurance under the present conditions that components made in different factories will fit together with precision, because the master gauges in those factories are *not calibrated at a common source* and therefore do not agree with one another.[4]

The committee emphasised the importance of this disability in defence preparations by a reminder that one of the reasons why Australian engineering industry could not undertake large-scale manufacture of munitions at the outbreak of the first world war was that it did not have the means of measuring with sufficient accuracy to ensure interchangeability of components made in different factories. Events were to prove that in the second world war guns, small arms, ammunition, aircraft, tanks and torpedoes would have to be made not in a few large centres but in hundreds of factories in every State of the Commonwealth.

The Secondary Industries Testing and Research Committee, having before it the work of the earlier Committee on the Maintenance of Standards and the results of its own painstaking investigations, and aware of the plans then being discussed for the manufacture of internal combustion engines for automobiles and aircraft, unhesitatingly recommended the establishment of a national standards laboratory as a matter of the greatest urgency.[5] In this way, the committee believed, the Government could make a most useful contribution to the development of Australian secondary industry.

The importance of establishing standards as a basic feature for the sound building up of our industries (it declared) permits of no half measure. The Australian standards representing a final court of appeal in matters of measurement in the Commonwealth must be of the highest quality and accuracy, since anything less than this would be valueless. Even these could not be of value to industry unless supplemented by the full range of sub, working and industrial standards through which the process of calibration is brought down to the routine requirements of production. The situation demands that the problem be dealt with comprehensively and adequately.[6]

In their detailed report the committee gave careful consideration to the probable cost, estimated to be about £80,000 for the building and £10,000 per annum for operating costs—much nearer to reality than the

[4] From the Report of the Secondary Industries Testing and Research Cttee (1937), p. 9.

[5] Other recommendations made by the committee, such as the establishment of an aircraft and engine testing and research laboratory (which led later to the setting up of the Div of Aeronautics, CSIR), a division of industrial chemistry, and an information service, will be dealt with in later chapters.

[6] Report, p. 12.

estimates of the earlier committee. No time was wasted in further argument. The Government agreed to establish a national standards laboratory under the control of the Council for Scientific and Industrial Research. Fittingly enough Madsen, who for so many years had worked untiringly to bring such a laboratory into being, was made chairman of a committee to advise the council on planning, erecting, equipping and operating the new laboratory.[7] The committee, the majority of whose members lived outside New South Wales, seldom met, but by dint of consulting his colleagues by telephone and by letter Madsen was able, in between his duties as Professor of Electrical Engineering and Chairman of the Radio Research Board, to guide the fortunes of the new laboratory in its infancy. Esserman, as the only man in Australia with the knowledge and training needed in establishing and running a metrological centre, left the Munitions Supply Laboratories to take charge of the new laboratory, in particular of the Metrology Section; Dr Briggs[8] was appointed Officer-in-Charge of the Physics Section and Dr Myers[9] of the Electrotechnology Section.

Plans for the building had been drawn up in consultation with authorities of the National Physical Laboratory of Great Britain, and on a site made available by the University of Sydney, excavation for the building was begun on the eve of the outbreak of war. While the building was being erected the three section heads, together with six other officers, were sent overseas to gain experience in the special fields in which their interests lay. Maintenance of a standard implied a great deal more than mere care and custody. It entailed a ceaseless search for any alteration in the material of the reference standards, a search for materials of greater permanence and stability for use as standards, and the development of equipment and methods for increased accuracy in comparing the standards with the measures used in commerce and industry. The staff of the National Physical Laboratory gave much help to the visiting Australians on matters of equipment and the general facilities that would be required in the new laboratories.

Though the building was complete and occupied in September 1940, the National Standards Laboratory did not, owing to the war, immediately attain the full status of a national standards institution. Acquisition of much of the equipment considered necessary for this purpose and the enactment of Commonwealth legal standards were deferred until a more appropriate time. Money originally intended for the purchase of basic national standards was diverted to equipment more immediately useful for solving problems likely to arise from the war.

The result of establishing the National Standards Laboratory under these conditions was to provide the munitions annexes and commercial

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[7] Members of the committee were: Prof J. P. V. Madsen (Chairman), Prof O. U. Vonwiller (Dept of Physics, Univ of Syd), N. K. S. Brodribb (Contr-Gen of Munitions and Supply), F. J. Shea (Dept of Supply and Development), G. Lightfoot (CSIR), and F. G. Nicholls (CSIR), Secretary.

[8] G. H. Briggs, PhD, DSc. Assistant Prof of Physics, Univ of Sydney, 1928-38; Chief, CSIR Division of Physics, since 1938. B. Concord, NSW, 23 Mar 1893.

[9] D. M. Myers, DScEng. Research Fellow in Elec Engineering, Univ of Sydney, 1937-38; Chief, CSIR Division of Electrotechnology, 1938-49; Prof of Elec Engineering, Univ of Sydney, since 1949. B. Sydney, 5 Jun 1911.

(*Australian Aluminium*)

Heat treatment furnace.

(Australian Paper Manufacturers)

A few of the wide range of paper and paperboard products used for war purposes, many of them made from waste paper.

industry of New South Wales and Queensland with services similar to those provided to Victoria and South Australia by the Munitions Supply Laboratories. With its rapidly growing staff of physicists and engineers trained in making accurate measurements of all kinds, the National Standards Laboratory became in effect a second vital centre for the diffusion of these techniques to industry. That it was not able immediately to set up a series of national standards and to secure the passage of the legislation necessary for proclaiming them was, as far as wartime industry was concerned, of little moment. What did matter was that it was able to share with the Munitions Supply Laboratories a burden that might otherwise have been insupportable. The Metrology Section at Maribyrnong had, it is true, been expanded in anticipation of the greatly increased activities that would be necessary to assist industry in the event of war, but these extensions, completed early in 1940, were insufficient to cope with all the work at the height of the great drive for munitions.

The metrology sections of the Munitions Supply Laboratories and the National Standards Laboratory helped industry in a number of ways: by acting as staff training centres, by giving advice on the specification, design and manufacture of working gauges, and by checking the accuracy of gauges when made. At the peak period (October 1941 to September 1942) the Munitions Supply Laboratories checked over 100,000 gauges; for the whole of the war the total was 316,460, of which 100,000 were inspection gauges for the Services, 150,000 were working gauges for annexes, and the remainder were working gauges for aircraft production and other purposes. All gauges manufactured in New South Wales were examined and distributed by the National Standards Laboratory, which also calibrated the measuring machines used by the gauge-making industry.

As the war progressed the demands made on the two main metrological laboratories became so great that some testing had to be delegated to other centres. Much of it was done in workshops of the South Australian Railways, the steelworks of the Broken Hill Pty Company Ltd (Newcastle), Generals Motors-Holden's (Woodville, South Australia), and the Sutton Tool and Gauge Manufacturing Company (Melbourne). Decentralisation of gauge testing greatly speeded up the work.

An organisation undertaking the control of standards of length required:

1. A reference standard[1]
2. Working standards
3. Industrial standards
4. Inspection gauges
5. Working gauges.

The reference standard determined in terms of the Imperial Standard Yard was, on rare occasions, compared with working standards, which in turn were used for the comparison of industrial standards. Industrial standards were used for the control of the inspection and working gauges

[1] Neither the reference standard at Maribyrnong nor the one later held at the National Standards Laboratory constituted an Australian National Standard, but each was known in terms of the Imperial Standard Yard to within 1 part in 1,000,000.

employed in industry. Working gauges, being in constant use, were subject to wear and had therefore to be periodically checked against an inspection gauge which because of its higher quality, less frequent and more careful handling, retained its accuracy for a longer time. Since all the standards were determined in a direct sequence from the Imperial Standard Yard, strict interchangeability of components from all parts of the British Commonwealth was possible. This condition was assured for Australia by having the reference standard at the Munitions Supply Laboratories, and later at the National Standards Laboratory, certified by the National Physical Laboratory at Teddington.

Before 1939 the manufacture of gauges by Australian commercial industry was practically unknown. Consequently when the great drive for munitions began, factories capable of making the many thousands of different types of gauges essential to mass production had to be organised at short notice. Responsibility for the general direction and coordination of manufacture fell on the Directorate of Machine Tools and Gauges, an organisation whose activities will be described at greater length in the next chapter. The Munitions Supply Laboratories and National Standards Laboratory made the unusual gauges that were, as a rule, not required in great numbers. The greater part of the large-scale manufacture of gauges was shared between government instrumentalities, mainly State railway departments, and firms such as the Sutton Tool and Gauge Company, General Motors-Holden's and many others.[2]

Of the kinds of gauges required in large numbers, the screw plug and screw ring caused most concern owing to the extreme shortage of thread-grinding machines. Even though the number of thread-grinding machines increased from 12 before the war to 80 in 1944, it was impossible to cope fully with demands for this type of work. Shortage of thread-grinding capacity was, however, not peculiar to Australia; it was acute also in Britain and the United States.

From a technical point of view probably the most interesting among the special gauges made in this country for the first time during the war were the "slip gauges" made at the National Standards Laboratory. These were pieces of steel in the shape of a rectangular solid of which two surfaces were flat and parallel to within five to ten millionths of an inch and whose distance apart was known to about the same degree of accuracy. They were the most accurate of all precision gauges and could be adopted as either working standards or inspection gauges, according to the quality of the gauges and the frequency of their use. The metal surfaces were so nearly perfectly flat that when one piece of metal was placed in contact with another they adhered strongly and could only be broken apart by a sliding, or slipping, motion. This method of combining gauges by using their adhesive tendency was known as "wringing" and the thickness of any lubricant film existing between the two surfaces was small enough

[2] Other firms were: Stanger and Co Ltd (West Preston, Vic); Rodd (Aust) Ltd (St Kilda, Vic); Cooper Engineering Co Pty Ltd (Mascot, NSW); Automatic Totalisators Ltd (Sydney); Warren and Brown Pty Ltd (Footscray, Vic); Litchfield Engineering Co. (Adelaide); Patience and Nicholson (Melbourne).

to be neglected when reckoning the distance between the outer surfaces of two or more pieces of metal. The conditions necessary for wringing to take place were: (*a*) the surfaces must be flat to within .000010 inch or less; (*b*) surface finish should be of high quality; (*c*) no raised metal or burrs should occur anywhere on the surface.

Slip gauges were made up in sets so that any desired length within particular upper and lower limits could be produced by an appropriate combination of gauges. One of the sets in common use as a precision standard for toolroom production or inspection contained forty-nine pieces, whose dimensions were so chosen that any length from 0.3 inch to 12 inches in steps of 0.0001 inch could be built up, the distance being that of the opposite extreme faces of the set.

Slip gauges were first made by the Swedish engineer Johansson by a process not divulged except incompletely through a patent (the English patent was taken out in 1901) until about 1930 when the secret was sold to Henry Ford, the car manufacturer. The first set of slip gauges reached England in 1908 but it was not until the first world war that their great usefulness in precision engineering was fully appreciated. Steps were taken at the National Physical Laboratory and at the National Bureau of Standards to devise methods for making the gauges, and two different processes were developed independently.

Owing to the great demands for slip gauges in the early part of the war, Great Britain and the United States were unable to supply Australia's needs. The only way out of this difficulty was to make them locally. Late in 1940 Esserman, then Officer in Charge of the National Standards Laboratory, agreed to have twenty-five sets of slip gauges made for the Department of Munitions. There being no staff capable of undertaking the work, Esserman's first job was to train someone. Among the applicants for positions in the laboratory was a plant pathologist, Mr Greenham,[3] from the Division of Plant Industry. Plant pathology seemed an unlikely training ground for a maker of slip gauges, yet Greenham displayed considerable aptitude for the work and was later successful in introducing a number of important innovations in making and using gauges. The secret of his success lay not so much in his professional training as in his hobby of grinding telescope mirrors, an operation requiring infinite patience and skill of a kind most useful in making gauges.

It was obvious that to supply the large numbers of gauges that had been ordered a large staff of workers would be required, and for this purpose it was decided to recruit young women. The Metrology Section was fortunate in obtaining as supervisor Miss B. Paine,[4] a former district commissioner of the Girl Guide movement in New South Wales, who with great tact and skill built up a well-disciplined and enthusiastic team consisting, at first, entirely of Girl Guides, none of whom had ever seen

[3] C. G. Greenham, MSc. Research Officer, Division of Plant Industry, CSIR, since 1945. Plant physiologist; of Canberra; b. Brisbane, 20 Jul 1910.

[4] Mrs R. Stuart. District Commissioner for Girl Guides, Manly, 1939-42; Supervisor Metrology Section CSIR 1940-44; National Emergency Service Ambulance Driver 1939-45. Of Sydney; b. Windsor, NSW.

a slip gauge before. In spite of numerous technical troubles in the early stages of the work, the girls became highly proficient in the art of making slip gauges. At first much of the finishing work on the slabs of stabilised high-quality steel was done entirely by hand, but as experience was gained and the orders for gauges increased, novel machine methods were introduced. With machines it was possible after some trials to make gauges with a surface finish equal to that of the best English hand-made gauges.

A number of new types—half-sized, stepped and tapered slip gauges—permitting a wider range of uses was devised. Work on taper gauges was begun at the National Standards Laboratory before similar gauges were made, by an undivulged process, in the United States. Perhaps the most notable and ingenious of the innovations introduced by Greenham was the saw-tooth gauge used for checking the accuracy of screws.[5]

Altogether 200 complete sets of gauges, calibrated in terms of the Imperial Standard Yard, together with an equal number of specially hard protective gauges (to minimise wear) were supplied by the National Standards Laboratory to different industrial concerns. The production of slip gauges, more especially the very fine ones down to one hundredth of an inch (about the thickness of a safety razor blade), represented a high order of technical achievement and did much to set the standards of length throughout precision engineering industry. As a compliment to Mr Essington Lewis the locally-made gauges were known as "E.L." gauges.

Other outstanding achievements of the National Standards Laboratory were the construction of 40 pitch measuring machines, 200 workshop projectors, 38 bench micrometers, and a gear and hob testing machine.

For the most part gauges were used manually when testing components, but this was too slow for some kinds of manufacture and the tendency, as in other parts of the world, was to make the gauging an automatic process where practicable. In Britain during the first world war machine gauging was applied to the .303 brass cartridge, and at the conclusion of the war one such gauging machine was brought to Australia by Professor Barraclough. For years this machine had lain idle in the Department of Mechanical Engineering at the University of Sydney, but some time after the outbreak of war it was sent down to the Ammunition Factory at Footscray where it once more gave good service.

The principle of air gauging afforded another convenient method of speeding up the gauging process; in this method the clearance between a known gauge and an unknown component was determined by the rate at which air would flow between them. Air gauging not only reduced the amount of skill required for the operation of gauging, it also reduced wear on the gauge. General Motors-Holden's, using pressures up to 30 pounds per square inch, extended the principle of air gauging to new uses and new degrees of precision, claiming that it was adaptable to the detection, when applied to the checking of slip gauges, of differences of as little as three millionths of an inch. "So well was this development received

[5] C. G. Greenham, "Slip Gauges: Their Manufacture in Australia and Some New Types Devised During the War". *Discovery*, Vol. 8 (1947), p. 216.

that a special stand [illustrating their method] was shown by the British Ministry of Supply at an exhibition held in London in August 1943."[6] This principle was developed by the National Physical Laboratory and incorporated in an air-gauging machine which made it possible to gauge all the elements of a cartridge case simultaneously.

Many chemical and metallurgical processes were carried out at high temperatures, and it was often important, if maximum efficiency was to be attained, that the temperatures should be accurately known and controlled. The temperatures most suited to different industrial processes were determined either by factory experience or in research laboratories. Only by close attention to detail could these temperatures be accurately reproduced. The importance of temperature control may be illustrated by an example taken from the metal industry. In order to develop the maximum strength and hardness of an aluminium alloy, such as duralumin, it was necessary to subject it to heat treatment, a process in which the alloy was heated to a predetermined temperature fixed within 5 degrees of 500 degrees centigrade, then quenched and allowed to stand for some days. A whole batch of the alloy material could be spoiled by some quite small departure from the temperature schedule set out for its age-hardening. In the early part of the war many firms were unable to control with any exactitude the temperatures required in processes of this kind.

Fortunately the Munitions Supply Laboratories had, since 1936, taken an active interest in industrial pyrometry. In the Ordnance Factory, where heat treatment for the hardening, strengthening and toughening of steels was an integral part of gun making, control and measurement of temperatures was effected by means of pyrometers calibrated and installed under the supervision of the Munitions Supply Laboratories. These facilities were extended to all government munitions factories, so that by 1939 the laboratories had gained considerable experience in the accurate measurement of high temperatures. Very little had been done along these lines in commercial industry, and when it first turned to making munitions there was a great dearth of instruments capable of accurately measuring relatively high temperatures. Efforts by local firms to make these instruments did not meet with much success and it was not until an annexe was built (near Melbourne) to make pyrometers under licence to the Cambridge Instrument Company of England that the shortage was overcome. The need for the facilities existing at the Munitions Supply Laboratories for standardising temperatures was first felt acutely by industries in Victoria but soon extended to other States and on a scale that necessitated decentralising the work. With help from the Maribyrnong laboratories, industrial pyrometry centres were formed in the departments of physics of the Universities of Adelaide and Western Australia and in the Physics Section of the National Standards Laboratory.

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[6] N. A. Esserman, "The National Standards Laboratory", *Proceedings of the Institution of Radio Engineers (Aust)*, Vol. 12 (1951), p. 44.

At the last centre Dr Briggs directed the setting up of the International Temperature Scale—a scale calibrated in terms of the melting or boiling points of a number of pure substances (oxygen, water, sulphur, antimony, silver, gold and platinum). Under accurately defined conditions these melting and boiling points were reproducible in any part of the world. Though the whole scale was not completed until after the war, the range of greatest importance to industry was covered and by 1942 the section became independent of other laboratories in the standardisation of glass thermometers and pyrometers measuring up to 1,000 degrees centigrade.

At regular intervals members of the Physics Section of the National Standards Laboratory, under Mr Harper,[7] inspected industrial furnaces throughout New South Wales to ensure proper installation of pyrometers and the accuracy of their recordings. One common but easily corrected fault in the early days of the war was that many pyrometers were installed in such a way as to indicate the temperature of the furnace lining rather than of the material being treated. Assistance was given to the major steel-making companies in applying a special method devised by the National Physical Laboratory for measuring the temperature of molten steel—a type of measurement that proved to be of great value.

Not all the measurements of interest were in the region of high temperatures. For example, the vacuum freeze-drying of blood serum carried out by the Red Cross Society required accurate control of low temperatures in the region of minus ten degrees centigrade. Guidance in this work was given by the National Standards Laboratory.

Ambient temperatures were also of interest, particularly those of wooden aircraft operating in the hotter regions of Australia. Information about the temperatures in the wings of these aircraft, which reached 80 degrees centigrade at Cairns and as high as 90 at Alice Springs, and also about the moisture content of the wood used in construction, was essential for intelligent design since both temperature and moisture content greatly influenced the strength of timber and glued joints.[8] This work paved the way for investigating the dangerous stresses that might develop in aircraft flown immediately after standing in the sun for hours. Here again the Physics Section was able to provide assistance in making thermocouples suitable for measuring temperature.

A little-known but none the less significant development in which the National Standards Laboratory participated was the beginning of a scientific glassware industry by Australian Consolidated Industries. Manufacture of high-quality glassware for volumetric chemical analysis, which had previously been imported, was firmly established during the war.

Maintenance of the electrical standards of the Commonwealth was the joint responsibility of the Sections of Electrotechnology and Physics of the National Standards Laboratory. The Physics Section maintained the

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[7] A. F. A. Harper, MSc. NSW State Physicist to Hospitals Cancer Research Dept, Univ of Sydney; Research officer, CSIR Division of Physics, since 1940. B. Sydney, 5 Jul 1913.

[8] W. L. Greenhill, "Temperatures and Moisture Content Attained by Wooden Aircraft in Service in Australia". Report 23 of the Aust Council of Aeronautics.

standards of electromotive force and electrical resistance while the Electrotechnology Section was responsible for all other electrical standards as well as for test work involving multiples and sub-multiples of the ohm.

In the first year of the war the only laboratories organised for chemical, mechanical and metrological testing of materials used in the manufacture of munitions were those at the Munitions Supply Laboratories. Every sample of bronze for chemical analysis, every piece of steel for tensile tests, and every gauge to be checked, had to be sent to them. The great waste of time involved can be well imagined. After September 1940 some of the burden—chiefly the checking of gauges and industrial pyrometers—was taken over by the National Standards Laboratory in Sydney.

The amount of testing required for the many new kinds of manufacture introduced by the expanded munitions program of June 1940 and later, was far too great to be handled by these two centres. The process of decentralisation begun with gauge testing and pyrometry was carried to its logical conclusion by extending it to all the main kinds of testing. On the suggestion of Group Captain Harrison,[1] a scheme of test houses was approved by a meeting of representatives of the Munitions Supply Laboratories, the National Standards Laboratory, and the Australian Chemical Institute held at Maribyrnong on 9th July 1940. Scientific and industrial laboratories in different cities were registered for the purpose of conducting limited ranges of tests and calibrations to a specified degree of accuracy decided upon after the inspection of the laboratory by experts from the above organisations and the Inspection Branches of the Services. The scheme had much to recommend it: it permitted a fuller use of the country's scientific and technical manpower, and it greatly speeded up the work of testing because this could usually be carried out near to the point of manufacture. Its success would depend on the degree of confidence felt by manufacturers in the competence of the staffs.

In all 150 test houses were registered. Laboratories of Commonwealth and State Government departments, of universities and technical colleges, and of private firms, undertook work ranging from the mechanical testing of materials, chemical analysis, X-radiography (of aircraft castings) and electrical testing, to the testing of gauges and pyrometers. Naturally enough difficulties were experienced in the early stages of operating the scheme but in the course of ironing them out the work in the laboratories and in the factories themselves greatly improved. On the whole the scheme was most successful.

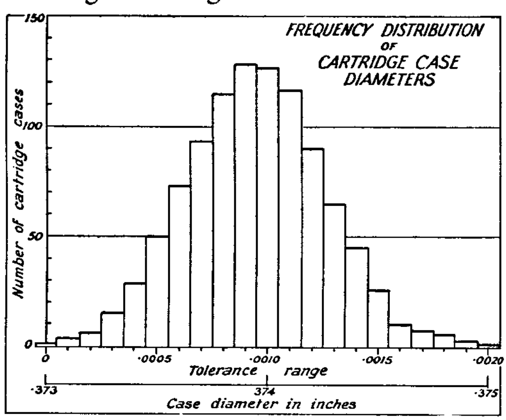
One of the more subtle forms of gauging was that which appraised production processes and the performance of machines engaged in repetition work. The gauge used for this purpose was the technique known as statistical quality control. During the war active steps were taken to widen application of this technique in the United States where in December 1940

[1] Gp Capt E. Harrison. (Served AN & MEF and 1st AIF.) Director of Aeronautical Inspection RAAF, 1928-45. Of Melbourne; b. Castlemaine, Vic, 10 Aug 1886. Died 5 Sep 1945.

the American Standards Association at the request of the War Department began to study the application of statistical methods to the control of the quality of raw materials and manufactured products. Between May 1941 and April 1942 the association issued three American War Standards dealing with the subject. About the same time professional engineering institutions in Great Britain, and the British Standards Institution, began to encourage the use of quality control. In March 1942 the British Standards Institution published a war emergency standard which was essentially a revision of an earlier British Standard published in 1935, and at the same time endorsed the first two of the newly issued American standards.

Following the lead given by the national standardising bodies of Britain and America, the Standards Association of Australia formed representative committees late in 1942 for the purpose of familiarising industry with a technique that promised greater efficiency not only in manufacturing but also in the inspection of finished products. The technique of statistical quality control was by no means a new one, but war provided the great incentive to its wider application.[2] The Department of Munitions, especially its Directorate of Ordnance Production, was quick to grasp the implications of quality control and did a great deal to encourage the propaganda of the Standards Association.

A simple illustration of the technique taken from the manufacture of small-arms ammunition will serve to give a rough idea of how statistical methods were applied to quality control. A cartridge case, for example, was required to have an external diameter lying between the limits of 0.375 inch and 0.373 inch (that is, a tolerance range of 0.002 inch). If when the diameters of, say, 10,000 cartridge cases made during a single run of a well-adjusted automatic machine working to the specified limits were accurately measured, the frequency of the various diameter measurements observed was found to be distributed in a manner conforming closely to the frequency distribution characteristic of purely random or chance variation, the production process was said to be stable in the statistical sense. The frequency distribution of the diameters measured might be as shown in the accompanying figure.

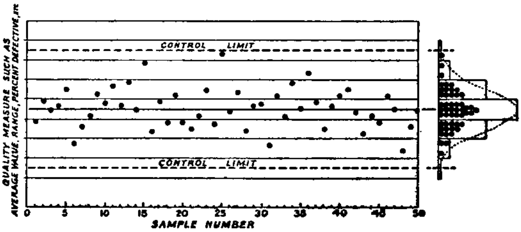


Actually it was not the observed diameters of a large number of cartridge cases, but rather quantities such as average value or dispersion, derived from *small* sub-groups or samples of observed diameters that provided the necessary data for statistical quality control. It was the fact

[2] It was first used in 1924 by Schewhart of the Bell Telephone Labs in the United States.

that such derived values, obtained from a statistically stable production process, had a frequency distribution closely approximating the "normal" one[3] that made possible the practical application of the techniques of quality control to data obtained from samples of a product taken *during manufacturing operations.*

The control chart, as shown in the accompanying figure, provided a simple, direct means by which the degree of variability in the quality measure (for instance, the diameter) was kept under observation during the production process. The horizontal scale represented the time interval between the taking of samples, which were inspected in order of production. Plotted vertically for each sample was the measure of the quality computed from inspection of the sample. These measures of quality might take the form of the average value of the measured diameters of the sample of cartridge cases, or the dispersion (in terms of range or standard deviation) of these measured diameters. The control limits on the chart were placed in positions which were calculated on the basis of previous stable and satisfactory performance.



So long as the machine or process continued to operate satisfactorily, quality measures from the inspection of products sampled at intervals in order of production, when plotted in the control chart, would continue to fall within the control limits, indicating that the variability in the product was inherent in the process, and due to chance causes only. Any departure from this state of affairs was immediately revealed in the control chart and indicated trouble: faulty adjustment of the machine or a worn-out tool, perhaps. One of the great advantages of statistical quality control was that since it was applied during actual production, corrective action could be taken promptly before any serious amount of defective material accumulated. The control chart provided a running commentary as it were on the performances of machines or processes and their operators.[4]

Professional organisations such as the Institution of Engineers, the Australian Chemical Institute and the Institute of Industrial Management provided opportunities for spreading a knowledge of quality control among their members. The subject evoked great interest. A symposium under the general title "The Application of Statistical Methods to the Quality Control of Materials and Manufactured Products"[5] held at the University of Melbourne on 9th December 1942 attracted an attendance of 500.

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[3] That is, the Gaussian distribution observed with large numbers.

[4] A. L. Stewart, "Statistical Quality Control: Theory and Application to Production", *Manufacturing and Management,* Vol. 1 (1946), p. 17; and *Quality Control,* a pamphlet published by the Institute of Industrial Management of Aust (1944).

[5] Papers were presented by Assoc Prof M. H. Belz (Univ of Melbourne), E. A. Cornish (C.S.I.R.) and A. L. Stewart (Standards Association of Aust).

Early in 1943 the Standards Association published Australian Emergency Standards,[6] which were in effect an endorsement of the three American War Standards already referred to. These served as a basis for courses of instruction on elementary principles of statistical quality control given in universities and technical colleges. A meeting of the Standards Association's Quality Control Committee held in Melbourne in January 1943 decided that in view of the potential benefit to war production, the Commonwealth Government should be urged to sponsor the sending of a special mission to the United States to acquire first-hand experience in the application of statistical methods to quality control. Acting on representations made by the C.S.I.R., the Production Executive of the War Cabinet approved the sending of two delegates, one to be nominated by the Department of Munitions, the other by the C.S.I.R.

Between June and November 1943 the two delegates, Mr Moore[7] and Mr Stewart,[8] studied the application of statistical methods to quality control in American industry, particularly in relation to the production and inspection of munitions. Methods used in training men to initiate, supervise and operate the procedures of quality control were also investigated. On their return to Australia, Moore and Stewart made a report in which they emphasised the great advantages that the Service inspection authorities might expect to gain by adopting the techniques of quality control in the acceptance of munitions.

In due course the educational efforts of professional associations and the work of Moore and Stewart bore fruit. Government and private factories began to apply quality control to such diverse operations as spot welding, milling and enamelling of wire, manufacture of small arms and ammunition, and the filling of explosives. In general the new system not only reduced the losses in material, time, labour and productive capacity arising from the manufacture of defective articles, but also exercised a positive influence by improving standards of manufacture.

From a small beginning early in 1944 there was a steady increase in the application of quality control to the problems of inspection, especially in connection with the filling of munition stores with explosive charges. Thus in filling factories it was in many instances possible to replace former 100 per cent inspection—that is, inspection of every item—by systematic sampling based on statistical quality control. The work of sampling, measuring, recording and plotting was undertaken by the staff of the Inspection Division. The resulting control chart, which was in effect a continuous record of the process, was available both to the production staff and to members of the Inspection Division. The former took any action that was thought necessary on the process itself, while the latter

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[6] "Guide for Quality Control", "Control Chart Method of Analysing Data", and "Control Chart Method of Controlling Quality during Production".

[7] R. G. Moore, BE. Engineer, Govt Ammunition Factory, Footscray, to 1939, Senior Engineer to 1941, Factory Manager to 1945; Assistant Controller, Machine Tools and Gauges, 1940-41. Of Melbourne; b. Sydney, 7 Nov 1905.

[8] A. L. Stewart, BSc, BE. Asst and later Construction Engineer, B.H.P. Steelworks, Newcastle, 1932-41; Tech Officer, Secretary (Southern Section), 1942-46; Dep Director, Standards Assoc, 1948-53, Dir since 1953. B. Broken Hill, NSW, 13 May 1909.

made up their minds whether the product was acceptable or needed further inspection. In this way quality control forged a new link between production and inspection through the common interest in quality. The link was further strengthened by the appointment of quality-control officers to the production staffs, as was done in a number of government explosives filling factories. Experience indicated that where the responsibility of maintaining control charts fell on the Inspection Division it was not only more satisfactory from the point of view of production and inspection but led to striking overall improvements in quality of production.

Quality control did not absolve or reduce the responsibility of either the production or inspection staff; installation of a control chart did not mean that all worries immediately ceased; it revealed often that the production system was not so efficient as had previously been thought, and occasionally that the effectiveness of earlier inspection was not as great as had been imagined. Had a knowledge of the principles of quality control been gained earlier and applied during the period of peak production of munitions in 1943 the task of the Inspection Division of the Branch of the Master-General of the Ordnance would have been considerably lightened.

Once the pressure of war disappeared, interest in the application of quality control in commercial industry slackened—for a time at least.

The handling of materials—before, during and after manufacture—was an important factor in production costs; 50 tons of materials might be lifted, moved, loaded and unloaded for every ton of the finished product. Expansion of production and the need for greater speed and efficiency brought home to Australian industry the need for giving more attention to this phase of its activities. In order to provide an advisory service, Lewis created within the Department of Munitions a Materials Handling Branch. Coming rather late in the field of industrial engineering, Australia was able to profit considerably by the experience of other countries, particularly that of the United States. An instance of the work done by the branch was the design of a standard tray, 46 inches square, on which materials and components were made up into unit loads at the point of manufacture and moved in this form in and out of store and on to process and assembly lines. Pallets (or trays) of this size were adopted throughout the Commonwealth and replaced the wide variety of sizes that had previously been in use. By promulgating and standardising the principles of handling and packaging, the branch gave valuable help, particularly to government departments and the Services, but also to industry. After the war it became part of the Department of National Development and continued its work in conjunction with the Standards Association of Australia.[9]

Six months before the outbreak of war the Council of the Standards Association of Australia had urged upon the Commonwealth Government the

[9] D. L. Beattie, "Materials Handling and Terminal Arrangement and Operation", *Journal of Institution of Engineers (Aust)*, Vol. 24 (1952), p. 111.

wisdom of preparing a wide range of specifications for defence needs. The association was thereupon given the task of preparing specifications for commodities of interest in the manufacture of munitions. The aircraft industry provided the heaviest program of wartime standardisation. The basis for much of this work was supplied by the British Aircraft Standards (issued by the British Standards Institution) and the Directorate of Technical Development specifications of the Ministry of Aircraft Production (formerly the British Air Ministry).

The number of alloy steels in use in Great Britain and the United States in the aircraft and automobile industries was very large. It would have been quite impossible for Australian industry to manufacture all these alloy steels, and it became the task of the Standards Association, through its appropriate committees under the direction of Professor Greenwood, to select, adapt or originate a limited range of specifications for such steels as were most suited to local requirements and within the ability of the industry to manufacture. Aluminium and other non-ferrous alloys used in the aircraft industry were treated similarly.

When the aircraft industry was obliged to substitute Australian for imported timbers, the Standards Association in collaboration with the Munitions Supply Laboratories, the Division of Forest Products (C.S.I.R.) and the Division of Wood Technology (N.S.W. Forestry Commission), drew up specifications enabling timbers and aircraft plywood from certain indigenous trees to be used in the full assurance that they would serve their purpose as satisfactorily as timbers from Britain or the United States. Since the requirements for aircraft timbers were as exacting as those for alloy steels, it will be evident that the substitution of local for imported timbers had to be carried out with the greatest care.

Codes were prepared for the protection of civilians against possible toxic gases, from enemy bombing, for the rot-proofing of sandbags used in air raid precautions, for packaging of goods, and for many other processes. Many specifications for camouflage paints, based on exhaustive experimental work, were produced. A variety of matters relating to civil defence received attention. Many existing standards had to be reviewed and approved relaxations were allowed in order to permit the use of substitutes for materials which had become unprocurable.

Owing to the shortage of technically trained men, the association experienced considerable difficulty in carrying out all this work. Notwithstanding this disability, over 300 emergency and interim specifications specially designed to meet wartime requirements were prepared.

The work of the Standards Association did not, however, end with the provision of specifications for Australian manufacturers. One of the most important pieces of work it did arose from the fact that Australia was a base for operations in the South-West Pacific Area and so was required to service aircraft and land vehicles of British, American and Australian origin which might on occasion need a minor replacement at any one of a large number of depots. To stock parts for even one make of aircraft was a considerable undertaking, but to do so for many makes was a very great task. Substitutions of one kind of replacement for another were inevitable. To have allowed depot staffs to make these substitutions on their own initiative would have been to run serious risks, and could not therefore be allowed. The staff of the Standards Association, working long hours, compiled a schedule of standard parts tabulating details of great numbers of items for which spares might be required, with safe equivalents interchangeable in respect of both dimensions and strength. With the help of this schedule, staffs of the repair depots were able to discover for any of the parts listed a number of approved alternatives which might be safely substituted, if necessary. By this simple expedient, the capacity of a depot to repair aircraft at short notice was greatly increased.

Furthermore, the Standards Association had, in the course of its own specifications work, found it necessary to correlate large numbers of oversea and local specifications for the materials from which the spares necessary for the maintenance of service aircraft were made. The association also published a schedule listing specifications of materials and providing a guide to their similarity for substitution purposes. Not long after this schedule had been published in Australia, the Allied nations dealt with a similar problem but on a much larger scale. Those responsible for that project were greatly impressed with the work of the Australian association and made much use of it.

A significant part of the association's war effort was the contribution made by its technical library. Australian industry became standards-conscious to a remarkable degree as a result of the munitions orders with which it had to deal, involving compliance with the large number of specifications, most of which were unfamiliar to industrialists. Their first experience of a new specification was usually a reference to it by some complex classification number. In order to cope with the innumerable inquiries about these, the association's librarian collected and indexed the many series of service and other specifications, and secured copies of most of them for filing. The library soon became recognised, both by Government and by industry, as the information centre on such matters, and a valuable service was thus established.

Another and less tangible benefit resulting from the association's activities was the direct contact established in the course of its work between government officials and industrial executives. The value of these contacts extended beyond the range of actual standards work, and led to better understanding, closer cooperation and the solution of many technical difficulties.

On a still wider scale, the standards bodies in Australia did much, by the exchange of information on research and experience, to strengthen the bonds between scientific and technical institutions in other countries. As a recognition of the service it had rendered in peace and in war, the Standards Association was granted a Royal Charter in 1950.