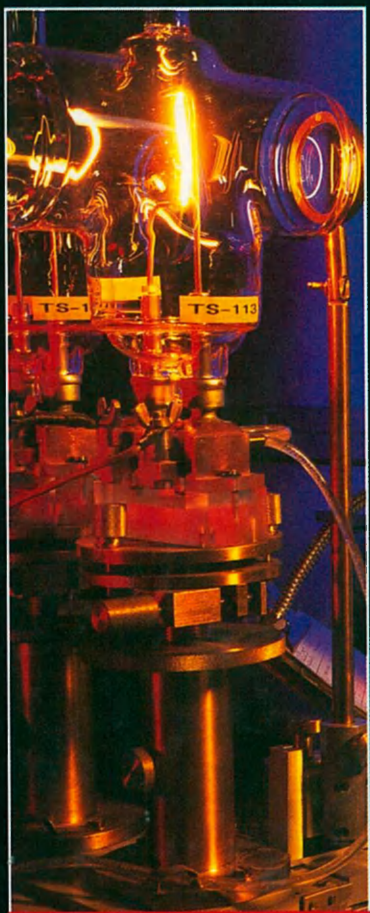
metrology

THE NATIONAL METROLOGY LABORATORY OF SOUTH AFRICA



MAURICE McDOWELL

50

- THE FIRST 50 YEARS (1947-1997)

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This special limited-edition publication

THE NATIONAL METROLOGY LABORATORY OF SOUTH AFRICA – THE FIRST 50 YEARS (1947-1997)

is presented to

Bertus Theron

on the occasion of the golden anniversary of the laboratory and in appreciation of your special contribution to the development of metrology in South Africa and the southern African region.

DR BRUCE FOULIS
MANAGER
NATIONAL METROLOGY LABORATORY

THE NATIONAL METROLOGY LABORATORY OF SOUTH AFRICA
– the first 50 years (1947-1997)

Maurice McDowell

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Design and layout by: Wendy Moulton
Cover design by: Jenny Foulis
Edited by: Jill Segev

Published by: The National Metrology Laboratory
First published 1997

ISBN 0-7988-5360-3
Printed and bound by The Natal Witness Publishing and Printing Company (Pty) Ltd, Pietermaritzburg, KwaZulu-Natal

Acknowledgements

Although as with any history the preparation of this manuscript required extensive use of written records, it became a living reality only through the generous time granted by many individuals to fondly reminisce over a cup of coffee. Virtually every member of the NML and NCS has made some contribution, but special thanks must be extended to Bruce Foulis, Marié Wimmers, Franz Hengstberger, André van Tonder, Neville Robinson, Ireen Field, Joëlle and Gerard Pialat, François Denner, Cyril Dodd, Mike Peet, Sean McCurtain, Marietjie van Zyl, Eric Dressler, Margie Grant, Lesley Merrington, Tinkie Swart and Marie Chilcott.

The time spent with former colleagues and metrologists from the NML was invaluable and they contributed much of the visual material used and recounted the many anecdotes. In particular, I would like to express my gratitude to Roy Smith, Willem Marais, Stoffel Kok, Cor van der Hoeven, Lorene du Preez and Ron Lake, who introduced me to many mysteries of the early days of metrology in South Africa. The pride that these specialists felt in his contributions to the development of measurement science was obvious and I hope that their spirit of enthusiasm has contributed to bringing the written words alive.

My appreciation is also due to Dr Niko Stutterheim, Dr George Ritter and Ernst Hecker, all once members of CSIR's capable staff, with involvement in the development of standards and metrology. Nicoline Basson provided me with many ancient and valuable records and Janie van Zyl uncovered many more through her intimate knowledge of CSIR's archives. John Wilson (Spescom) shared insights into the early days of the NCS and MIG, while some time with nonagenarian Frederick Rowland brought the early history of weights and measures into perspective.

From DTI the encouragement, support and contributions of Waldo Penzhorn, Eric Kruger and Arthur Boettcher (with whom I shared an office in my early days in South Africa at the NPRL) are gratefully acknowledged.

For myself, the preparation of the text allowed me to relive many wonderful memories of CSIR, particularly from what many of us like to refer to as 'the good old days'. While writing has for many years provided both diversion and excitement, *this* task has been both one of the most difficult and the most stimulating and psyche rewarding of the hundreds of manuscripts I have prepared. I thank my wife and family for the patience they have had with the many hours spent after work in drafting these words, and for their encouragement.

To the NML itself I can only add some words from an old Irish saying:

"May the roads rise with you, may the wind be always at your back and may the Lord hold you in the palm of his hand."

Maurice McDowell, Pretoria, South Africa, June 1997

Foreword: Alec Erwin, Minister of Trade and Industry

"For all people, for all time."
The Metric System, 1799

Use of measurement as a basis of trade has been a feature of society since time immemorial. Type and accuracy of measurement depends on the commodity being sold, becoming increasingly complex with the level of manufactured or value-added input. Raw ore may be bartered on the basis of a sample assay and mass, but the sale of even a simple bolt will depend on accurate measurements of thread separation, angle and other dimensions. Trade can only occur between two parties who are satisfied with each other's measurement capability and once a product is specified, it must remain identical irrespective of location of manufacture, be it Siberia, Japan or Africa!

International traceability is only made possible through existence in the more developed countries of a national measurement system, itself vitally dependent on the maintenance and continued development of a set of national standards which are traceable to those accepted internationally as maintained by the BIPM in Paris. Access to the facilities of the BIPM is realised by ratification of a diplomatic treaty referred to as the Metre Convention, which was established in 1875. In Africa, only three countries have adhered, namely South Africa (1964), Cameroon (1971) and Egypt (1962).

Following the original signing of the Convention by 17 countries, international uniformity in mass and dimension was ensured through the distribution of artifacts in 1889. One of the first national standards organisations, the PTB in Germany, was established in 1883, the objective, true to this day, being to support local industry in its attempts to produce high quality goods and service. The example of the British counterpart, the National Physical Laboratory (1900) was followed by many of its former colonies, including Canada, India and Australia. Similar plans for South Africa were put into abeyance by the onset of World War 2, but this was remedied in 1945 with the creation of the CSIR, followed more importantly in 1947 with the establishment within that organisation of the forerunner of today's National Metrology Laboratory (NML).

In 1980 developments in the manufacturing industry led to the creation of the National

Calibration Service (NCS), which remained under the leadership of the NML until its maturity and privatisation in 1993. While the NML maintains all standards of measurement and ensures through regular intercomparisons their international traceability, the NCS facilitates the transfer of measurement capability and traceability (at lower and more appropriate levels of accuracy) onto the factory floor.

Audit results show that since 1980 industrial measurement accuracy has improved consistently in line with the quality of the measuring instruments available. Recognition of the NML internationally ensures that certificates of calibration and conformance issued in this country are accepted by trading partners as proof of measurement standardisation.

Besides simply maintaining standards, international recognition is also highly dependent on the credibility of the national laboratories to develop new standards and adapt existing standards to improve international measurement capability and to suit local conditions and environment. In this regard, and in celebrating its 50th anniversary the NML has much to be proud of. South Africa was the second country in the world to adopt a new (locally developed) radiometric standard in 1976 and was an early pioneer of use of the iodine-stabilised laser for length measurement, becoming a member of the exclusive Iodine Club. This development also resulted in the discovery of a new type of standard capacitor, extremely stable and insensitive to changes in ambient temperature.

Other standards including those for resistance and voltage, although depending on artifacts dating back to the 1940s, were maintained meticulously and values compared very favourably with those of the first world countries at the frequent international intercomparisons. From an accuracy of a tenth of a second after the war, time is today disseminated to better than a millionth of a second and novel local time-transfer methods have been developed. All of this was achieved despite limited and often erratic financial support and a continued inability to adequately remunerate world-class metrologists.

Today new terminology is used to describe and qualify the processes of manufacture, of which global competitiveness, quality, zero defects, first pass rate, out-sourcing, tolerances and part-commonality are but a few. At the heart of all of these is the ability to measure, accurately and traceably in terms of the SI units, length, mass, frequency, temperature, electrical current and optical and chemical properties. The global nature of manufacturing implies that a final product such as a motor vehicle comprises components and sub-systems sourced from multiple suppliers in a multitude of countries. If these suppliers were not manufacturing to the same tolerances and to the same scales of measurement for all physical properties the results would be catastrophic and the concept of the global manufacturing village would be merely an unattainable dream.

The assurance of measurement traceability to the BIPM would for any private company (even if permissible) not be economically feasible. For this reason, this function is and will remain a core responsibility of the Department of Trade and Industry, being totally congruent with the declared intention of this government to provide full support to manufacturers and exporters through the creation and maintenance of supply-side measures and incentives.

No less important is the role that this country must play in the development of the region and recent developments have seen realisation of our full membership of the Southern Africa Development Community (SADC). A prime objective for this whole area is a shift in emphasis from the export of agricultural and low value-added non-beneficiated mineral products to high value-added manufactured goods. This implies an accelerated shift in culture towards quality and adoption of ISO 9000 quality management practices, which in turn dictates accurate and traceable measurement capability. While most SADC countries have some metrology infrastructure, traceability itself has been achieved through costly and irregular overseas comparisons. Through a new ruling of the BIPM, the NML will in future be able to coordinate intercomparisons at regional level, making use of its own established international traceability to the BIPM and other standards bodies.

At a recent landmark meeting, a new regional metrology authority, SADCMET, was formed, operating under NML leadership. It will participate in intercomparisons with other peer regional groupings, including those of Europe and North America. While industry and exports are a major benefactor, the work of the NML affects the lives of every person in South Africa, in every aspect of their existence, from the simple setting of their watches to the signals of the SABC, to the purchase of goods by weight in the supermarket and to maintenance of their health through the measurement of vital signs including blood pressure, pulse rate and body temperature. Without metrology and the work of NML and its international peers, civilisation as we know it could not exist.

In commemorating fifty years of scientific measurement in South Africa, I look forward to the same personal effort and unselfishness being put into the next fifty. With this personal endeavour and with the full support of the DTI, it is expected that the NML will assist southern African industry to attain global competitiveness with quality manufactured products. Government, through the DTI, will ensure that the standards maintained meet the critical expectations of our foremost trading partners and the needs of our SADC partners.

For their contribution to the establishment of a new and winning relationship with the NML, designed to promote the leadership position of South Africa in the region, I would like to thank the staff of my Department. Much of the success has been as a result of the efforts of Waldo Penzhorn, who retired at the end of 1996. His place and the responsibility for the future now lies in the hands of Eric Kruger and Arthur Boettcher. The latter, through the insight from his early career at CSIR's National Physical Research Laboratory, has contributed significantly to the creation of a shared vision between government and the country's metrology community.

A recent book on the history of the CSIR as a whole was entitled "Passage to Progress", equally apt to describe the future of the NML, for which I wish fair winds, calm seas, a good captain and crew and God speed!

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Introduction

"When you can measure what you are speaking about and express it in numbers, you know something about it, but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind."

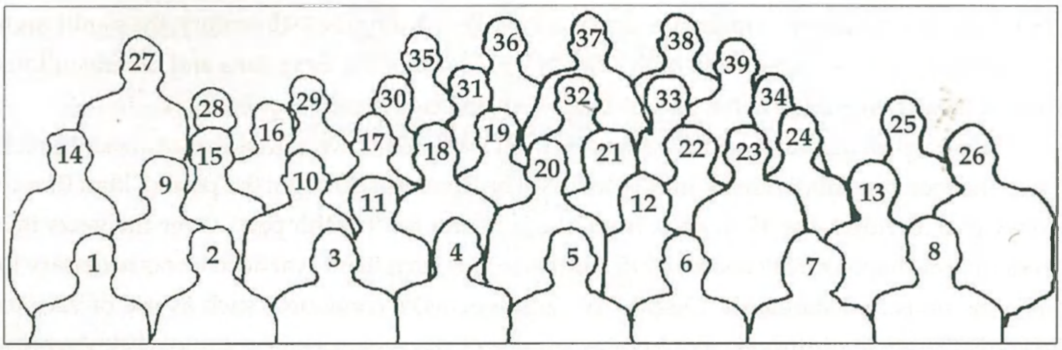
Lord Kelvin.

While the need for accurate measurement became salient during the 19th century, the significance of metrology can be traced back to the the ancient world of the Egyptians and the ubiquitous unit of measurement the cubit, standardised using a black granite royal master.

The English measurement system came from the Romans, who emulated an ancient Greek unit, the foot, but subdivided it into 12 inches. The Romans also begot the pound, libra (hence lb weight), divided into 12 ounces, from 'uncia', Latin for 'twelfth part'. Over the years this system grew haphazardly and by 1215 AD abuse was such that royal decree was necessary to redefine units and standards. Despite this, idiosyncrasies continued, such as use of various pounds (Troy, Avoirdupois and Apothecaries) and discrepancies in volume, with America using Queen Anne's gallon, abandoned by the British in 1824.

It remained for France to develop a lucid scheme, the 'metric system', based on multiples of ten, which became reality in 1799 and which was proclaimed to be "for all people, for all time". World measurement standardisation began in 1875, when France convoked the Conference Diplomatique du Metre, which culminated in the signing of the Metre Convention by 17 nations. A consequence of this was the creation of the Bureau International des Poids et Mesures (BIPM), which is controlled by a multinational committee and is responsible for the maintenance and development of international standards of measurement.

The year 1875 thus represents the birth of international measurement traceability, the science of metrology and the death of the multitude of other arbitrary systems based on local tradition.



Mr S Mossop (1), Dr J van Niekerk (2), Dr J Heydenrych (3), Dr EC Halliday (4), Dr SM Naudé (5), Dr O Brune (6), Miss T Alper (7), Dr EJ Marais (8)
Mrs A van der Westhuizen (9), Mr S Tosio (10), Miss J Schroeder (11), Miss D Reeler (12), Miss L du Preez (13)
Mr RF Smith (14), Mr P de Valence (15), Mr J Filter (16), Mr N van der Walt (17), Mr T Hugo (18), Mr J van der Walt (19), Mr J Louw (20), Miss C Bierman (21), Miss I Reeler (22), Mr R Jamieson (23), Mr C du Plessis (24), Mr R Keddy (25), Dr Verleger (26)
Mr F Anderson (27), Mr JK Basson (28), Mr AE Carte (29), Mr K Maruszewski (30), Mr P Butler (31), Mr A Pretorius (32), Mr A Smit (33), Mr de Wet (34)
Mr AI Archer (35), Mr CAJ Kritzinger (36), Mr C Kidson (37), Mr N van Deventer (38), Mr MC Boshoff (39)

NPL staff, 25 April 1949. Photographer: Mr J Kirstein who was in the process of setting up a photographic section of the NPL

A history of scientific measurement in South Africa

"The BIPM's intended mission is to achieve uniformity of physical measurement throughout the world, at the highest level of accuracy; this uniformity, recognised as necessary in 1875, is in the best interest of scientific and industrial expansion which controls our civilisation."

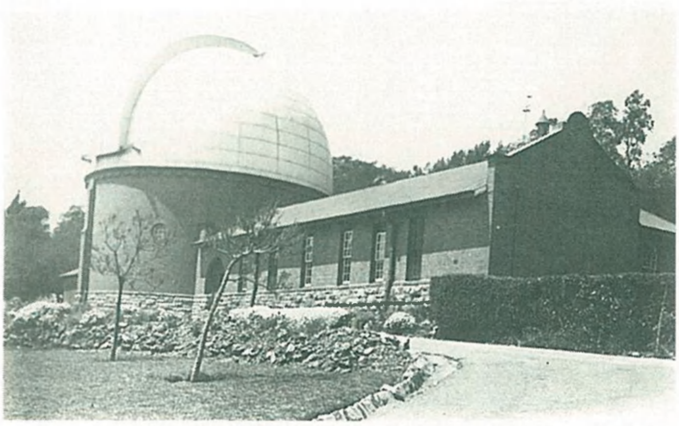
Director of the BIPM on the occasion of the organisation's centenary, 1975.
(translated from the original French text)

Measurement in the early days of South Africa

During the 19th century South Africa, as a consequence of its excellent 'seeing' conditions, and its southern hemisphere location, was to become a major centre for astronomical observatories, funded from both European and American sources. The Royal Observatory in Cape Town (established in 1820) was the first scientific institution in the country and together with Johannesburg's Union Observatory was to become responsible for the national time standards, time being critical for astronomical observation.

As a British colony, the system and units of measurement were avoirdupois, with the pound weight and the yard having been introduced by Queen Elizabeth I at the end of the 16th century. Greed for gold eventually led to the Anglo-Boer war between the South African Republic and the colonial power from 1899 to 1902. Just eight years to the day after the Boer generals had signed the surrender of their republics, the Union of South Africa was born on 31 May 1910. In 1961 the era of British colonialism came to an end with the transition of the state from a monarchy within the Commonwealth to an independent entity through the creation of the Republic of South Africa.

The end of British influence on measurement units in South Africa came with the acceptance of the metric system and its rapid implementation during the late 60s and early



Republic Observatory in the 60s

70s. The new unit of currency, the Rand, was introduced by the 1961 Republic, having already been defined as metric, ie made up of 100 cents. In its wisdom the Metrication Board followed the French system very closely, adopting the comma in place of the decimal point * to the chagrin of many scientists.

Funded by government, the Transvaal Observatory was opened in 1908 and renamed the Union Observatory in 1910. From this date it also provided a time service and was officially responsible, although the function continued to be shared with the Royal Observatory for many years. With the responsibility for astronomical research being assumed by the Council for Scientific and Industrial Research (CSIR) in 1964, and the establishment of the South African Astronomical Observatory (SAAO) in 1972 the obligation for maintenance of the time standards was transferred to the CSIR's National Physical Research Laboratory (NPRL).

Jan Hers with South Africa's first official timekeeping instrument

The origins of the Transvaal Observatory in Johannesburg make interesting reading. The institution was established initially in 1903 as a meteorological one, but in 1905 a number of European astronomers were to visit Johannesburg and were very impressed with the clear night sky in the city (at that time!). The Imperial Russian Astronomer, one Professor Backlund, suggested that the Observatory become part of the southern hemisphere chain of latitude stations. Shortly thereafter in 1907, a small (2,625 inch) transit telescope, obtained on loan from the Observatory of Pulkovo arrived and a

*Following a decision by the Decimalisation Board in the late 60s, the convention used in South Africa follows that of France (and the BIPM) where the decimal comma (,) is used instead of the more common point (.). This protocol has been used throughout this text. Use of a point in an equation represents multiplication. SI units are used in South Africa and the system of measurement is metric. ISO 31-0 also specifies that "The decimal sign is a comma on the line".

sidereal clock was acquired. Nothing much further (in regard to time) occurred until 1910 when a generous grant of £200 allowed the subsidising of two part-time observers. As almost an afterthought the telescope was used to determine (transit) time. In 1912 the time service was extended to Natal and at noon every day a time ball would drop at the Bluff in Durban following a signal from Johannesburg. By 1923 it was discovered that better accuracy could be obtained, with far less trouble, using radio signals transmitted from Rugby in England spelling the death of local astronomical transit-time observations. The change in function of the observatory from meteorology to metrology is inspiring considering the general public confusion between these two terms.

Weights and measures

"The Cape measures of length and area are not intended for normal use, except for the measurement of land for registration of title, and then only in such parts of the Union as are admitted by the Survey Act 9 of 1927."

Act 32 of 1922, as amended.

The early history of measures of length in South Africa is fascinating and is in itself the epitome of why standardisation and traceable intercomparisons are today so essential. It should be noted that while the historic signing of the Metre Convention took place during 1875, the metric system itself had been in use in France since 1799 and had been introduced by decree in several countries as early as 1820. Even Great Britain authorised use of the metric system in parallel with the imperial one in 1866. The difficulties which arose in South Africa (and elsewhere) were as a result of the need to convert to British measure and the fact that two 'metric' standards existed in 1820, Borda's 1795 Metre of the Archives (copies of which formed the basis for the international 'prototype metres' constructed in 1882) and the French legal metre, related to an earlier standard called the Toise.

The Cape foot*

The first anachronism was the existence from 1859 of a 'Cape foot', whose origin can be traced back to a Dutch unit known as the Rhynland Rood, an artifact in the form of a 12 foot long iron bar embedded in the courthouse wall in Leiden (Netherlands), which dated back to the triangulation measurements of Snell in the 17th century. In 1807 a comparison had been made between the Rhynland Rood and the French legal metre and a conclusion was reached that one Rhynland foot was 0,31395 metres, defined legally as such by the King of Holland in 1908. This did not agree with the British Act of 1824 where the foot was defined

*Full details of the Cape and SAG feet can be found in the Trigonometrical Survey Special Publication No 2 of 1956.

as the better known 0,3048 metres. Thus 1000 Rhynland feet were equivalent to 1030 English imperial feet.

In the Cape at the beginning of the 19th century there was no length standard and surveyors were using their own rods and chains. The Government surveyor appointed in 1800 was a gentleman called Thibault who possessed two Rhynland Rood rods. After his death in 1815 it was decided that as his surveying work was the most extensive, his rods should be used as the standard of reference for the colony. An extensive investigation by a Commission (using the No 17 copy of the British imperial standard yard) was to culminate in 1858 with the outcome that 1000 of the feet in use were rounded off, within the required accuracy for surveying, to be equal to 1033 British feet and this unit, to be known as the Cape foot, was passed into law in 1859.

This was to remain legal measure from 1859 until the Weights and Measures Act 32 (1922), as amended by Act 13 (1933), redefined the Cape foot more accurately as 1,032 999 914 7 British feet. The 1922 Act also established the metre as the standard of South Africa, with the definition of the standard yard for South Africa becoming the same as the British imperial standard yard.

The South African Geodetic foot

During the 19th century South Africa became an important centre for astronomy and the Royal Astronomer at the Cape from 1879 to 1907 was Sir David Gill. In 1839 two 10 foot iron bars had been brought to the Cape, originally to check Lacaille's measurement of the first arc of a meridian in South Africa in 1752. At the commencement of the Geodetic Survey in 1885 Sir David decided to use one of these (referred to as the Cape Standard Bar A) to standardise his base-line measuring apparatus. This bar (the length originally represented by two dots in small embedded plugs of gold) was duly sent to France in 1886 to be correctly compared against the International Metre of the Archives.

The length of this bar was now converted to British feet and the relationship used was that derived in 1866 by Clarke, which unfortunately, although very accurate, connected the foot to the legal not the international metre. This error arose as a result of Borda's successor inappropriately issuing the toise to several countries in place of the official metre. The metric lengths of the Cape standards were thus not converted to British feet, but to a fictitious unit to be referred to as the South African Geodetic (SAG) foot. All records of this survey which are published in feet thus refer to the SAG rather than the British foot.

Department of Assizes

The historic Act of 1922 also saw the creation of a Department of Assizes (Weights and Measures) on 7 May 1923, one of the original employees being Frederick Edward Rowland, probably today South Africa's oldest living metrologist. Rowland was to spend the rest of his career in the service of the Department, rising to the highest rank of Superintendent in 1953. One of the earliest metrologists in the country, he was to retire twice, 1963, when he was encouraged to return to take control of the calibration laboratory and finally in 1979. Today as a thriving 96 year old, with two genuinely earned pensions, he possesses an unequalled collection of old copper and brass imperial measures with artifacts dating back to the Cape of Good Hope and the Oranje Vry Staat. Following metrication these priceless objects had been sold off, according to public service policy, for the value that the weight of the base metals would fetch.

In his early days Rowland travelled all over South Africa checking scales and volumetric measures of retailers for the first time ever. One of his photographs from this era shows his first boss, a Mr Meijer, with the original mode of transport, a wagon pulled by a span of oxen. A motor vehicle, an old Dodge van, came only in 1925, and while it may have been reliable, it was hardly suited to the dirt roads in those days where mud and drifts were a recurring nightmare, oxen still often having to be used to retrieve Henry Ford's pony. Nevertheless this vehicle carried 10 fifty pound sets of weights around the country. By 1928 technology had advanced through the introduction of a railway weigh-bridge test carriage, which was to carry a large number of these ubiquitous 50 pound weights.

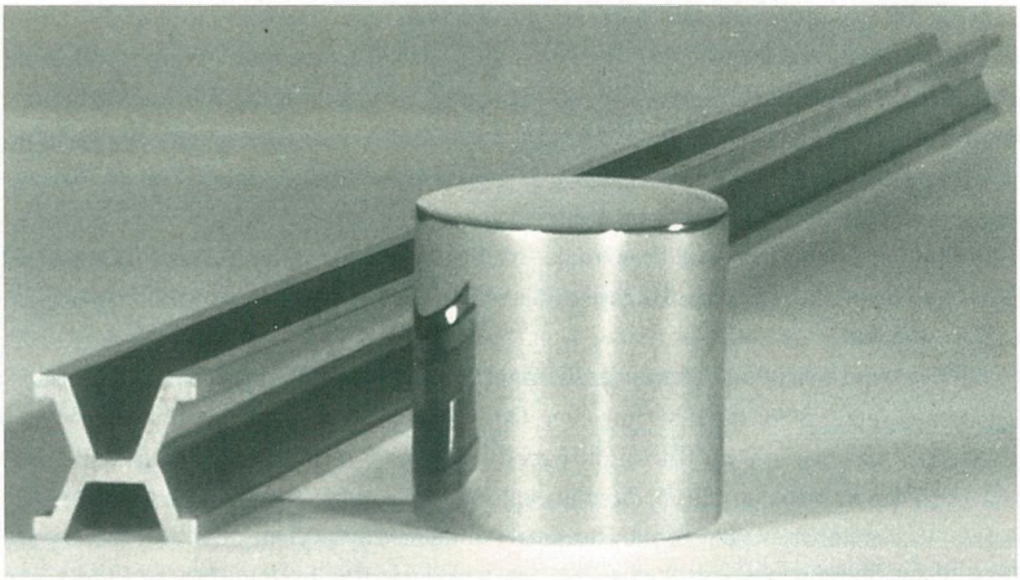
In each magisterial district the local police station or court house would be used to set up a temporary office, to which local traders had to apply for certification, and sealing with wire and an embossed lead clamp, of scales and other artifacts of measurement.

As trade metrology was the legal requirement and the country was still part of the dwindling Empire, the South African weights were compared on a regular basis (war excluded) with the standards maintained in London by the Board of Trade (BOT), the imperial units being used exclusively. While South Africa then possessed a BOT certified pound it never obtained an official copy of the imperial pound as other previous colonies such as Canada had done. At this time although the official units used were imperial, the official standards were still the metre and kilogram as derived from the BIPM.

Following metrication and the first retirement of Rowland, the NPRL was to accept responsibility for maintaining standards for the Department of Weights and Measures and also provided assistance with the calibration facilities until the transfer (privatisation) of the Department into the control of SABS, which was able to levy charges for a service once performed as a government responsibility.

Industrialisation

In the early part of this century the SA economy was based on agriculture and mining. By 1945 the Department of Agriculture was conducting research at several local R&D institutes,



The international metre and kilogram of the BIPM

including the now renowned Veterinary Research facility at Onderstepoort. The Department of Mines was meanwhile operating the Mechanical Laboratory in Johannesburg and the Government Metallurgical Laboratory. The Mechanical Laboratory had a close connection to physical standards in that it was responsible for the statutory testing of mine hoist ropes for the deep gold mines of South Africa. This facility, still located at Cottesloe in Johannesburg, is today part of CSIR's Division of Materials Science and Technology.

The importance of coal as a fuel and the vast unmined local resources saw the creation of the Fuel Research Institute in 1930, partly funded through a levy on coal sold. In the post-war era this would lead to the creation of Sasol, the world's only economically viable oil-from-coal facility. Meanwhile the growing importance of the fishing industry saw the establishment of the Division of Sea Fisheries in 1932.

Industrial-oriented research was initially to be driven by the needs of specific sectors, hence the establishment of a Sugar Experimental Station in Natal in 1925 and the Leather Industries Research Institute in 1941 at Rhodes University.

The First World War had created an international awareness of the significance of leadership in science and technology. Britain and several of its former colonies set up organisations for scientific and industrial research based on the model of the UK's NPL, established in 1900. The scientific adviser to the South African government at that time, Dr H J van der Bijl, proposed a similar organisation, but a decision languished until 1938 when a National Research Council was established. The potential of this Council was thwarted by the onset of World War 2.

Birth of the CSIR

As was the case with many other former British colonies, the war provided tremendous impetus to the manufacturing industry and many products of war were produced for the Allied forces. The war ended with 'mammoth science' in the form of the atomic bombs dropped on Japan. The war effort and shortage of resources had also spawned many other novel scientific products, such as nylon, penicillin, the jet engine and the wonder pesticide DDT.

The Prime Minister during this period, General Jan Smuts, recalled Dr Basil Schonland (a professor at the Johannesburg-based University of the Witwatersrand before the outbreak of war) from active service in Europe and appointed him as his Scientific Adviser as from 1 January 1945. Schonland's proposals for a national research organisation, which was to be called the Council for Scientific and Industrial Research (C.S.I.R.)*, went before parliament in May that year. Schonland accepted the position of first President of the new body and the inaugural meeting of the Council was held on 8 October 1945.

The formative years of the NML, 1947 to 1964

"Since its inception in 1947 **[note date used]** ***the National Physical Research Laboratory in Pretoria has been steadily building up standardization (sic) facilities. The task is never-ending: new developments in physics constantly make greater precision possible and at the same time demand not only better, but also entirely new standards."***

S M Naudé, 1960.

The origins of South Africa's National Metrology Laboratory (NML) date back to Dr (later Sir) Basil Schonland's sage vision for a National Physical Laboratory (NPL) to form an integral part of the proposed new CSIR. Schonland had resolved in 1945 that the NPL would be one of the first laboratories to be established and he approached Professor Stefan Meiring Naudé of the University of Stellenbosch to become Director.

After some deliberation Naudé accepted the offer and took up the new position in January 1946. In the early discussions between Schonland and Naudé, standards were a point of some argument, as Naudé learned that a South African Bureau of Standards (SABS)

*The name Council for Scientific and Industrial Research (often abbreviated to the CSIR or C.S.I.R.) was used during the period 1945 to 1988. Following a major restructuring in 1987/88, the official name became CSIR, with no reference to a Council. The Council (the governing body) of the CSIR, was at the same time renamed in business parlance, the Board. For simplicity CSIR is used as the name for the research organisation throughout this text, except in verbatim quotations.

Drs Schonland and Naudé, 1953

was to be established simultaneously with CSIR. Although he believed this to be a mistake, citing overlap of responsibilities, consensus was obtained on Schonland's assurance that CSIR would be responsible for fundamental research and standards, while the mission of SABS would be commercial standards.

The dilemma of having both the NPL and SABS came to a head in 1956 when the Bureau was amalgamated with CSIR. An unpopular decision with SABS staff, it was to be 1962 before they regained their autonomy. Typical of those rigid times, Naudé himself in 1956 was to post a notice warning that "under no circumstances should the staff of the CSIR tease their colleagues from the Bureau".

One of the first appointments made by Dr Naudé was that of Dr Eric (E C) Halliday, who was to play a key role in the evolution of the NML. The first year of CSIR's existence was occupied by extensive visits by staff to comparable overseas bodies existing at that time in the UK, USA and Canada, including the NPL at Teddington, the NRC in Ottawa and the NBS in Washington. In regard to these extended visits it should be remembered that travel in those days was by ship, the voyage to Europe taking up to two weeks. 1947 saw the embryo NPL with a small nucleus of experts which included Dr Halliday in charge of physics of matter and with representation in the fields of electricity, optics and spectroscopy, geophysics, heat, X-ray diffraction, radioactivity, electrical engineering and acoustics. On his first official visit to England and America during that year one of Halliday's objectives was to investigate the possibility of establishing standards of mass, pressure and length.

Dr Naudé's report to the Council which covered the period October 1946 to September 1947 indicated that little had been achieved in the first eight months of existence of the NPL as "difficulties in obtaining supplies of all descriptions were very great". This, combined with the extended periods spent overseas by the founding members of the laboratory (only 9 people on 1 October 1946) meant that little real progress was made until 1947. In this same report the first reference was made to the setting up of heat standards under Dr S Mossop and the appointment of fellow South African Otto Brune (from MIT, Boston) as a Senior Research Officer and the sole staff member in the Electrical Standards Section.

The history of the NML thus effectively began during 1947, the date of the first calibration records and not at the date of creation of the Council (CSIR) itself (1945) or the NPL (1946). 1997 thus represents the fiftieth or golden anniversary of both the NML and of formal scientific measurement in South Africa.

Dr Eric Halliday in the 1960s

Eric (Doc) Halliday (who passed away peacefully in 1996) was the father of national standards in South Africa. His appointment to the new NPL was influenced by Basil Schonland, the two having worked together on pioneering research into lightning. In those days a physicist was just that and was expected to be able to adapt to any task within the scope of that discipline, be it nuclear, optical or metrology. As Naudé's second in command, Halliday found himself in charge of nuclear physics, biophysics, heat and physics of matter. Halliday unknowingly probably contributed to the confusion that was to resurface periodically regarding the role of the NPL* and SABS. As far as he was concerned, CSIR's role was development and maintenance of primary standards, while he viewed secondary standards, being a more repetitive type of work, as more appropriate for the less scientific SABS. The continuing motivation used to retain the NML at CSIR, rather than at SABS, was the fact that CSIR through its staff and equipment possessed the right environment for fundamental scientific research.

Under Naudé himself Otto Brune was taking good care of the early electrical standards, the heat section was operational and biophysics was, as all new sciences, receiving special attention from Tikvah Alper (who was to leave CSIR just before completion of the Biophysics building in 1955). The physics of matter section had to address the most fundamental areas of standards (namely mass, length and pressure) and to help him achieve this objective Halliday appointed Roy Smith in 1948. Despite the well-publicised mission of the NPL to develop measurement standards, Roy soon found that even in these early days, the principle of 'publish or perish' applied.

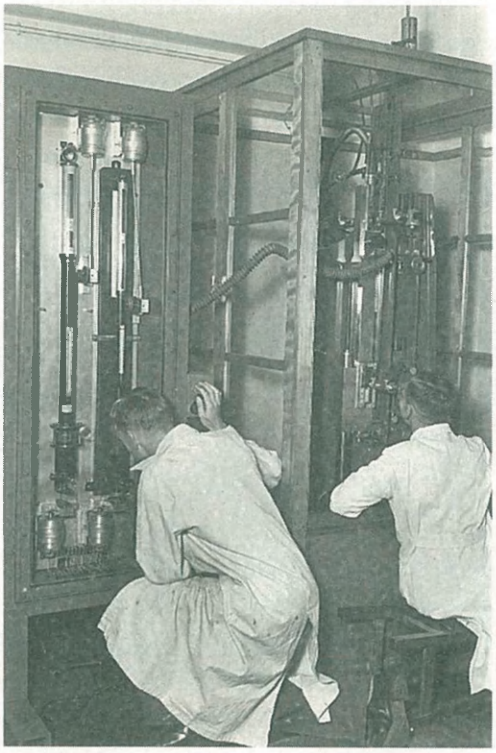
Far from focussing on standards, everything else appeared to be a priority, but the work was exciting. Thus the fledgling NPL became involved with SAA

Ilmary Reeler with the early film badge system

* In this publication it is the history of measurement which is being addressed and depending on the period being covered the names NPL, NPRL, Productiontek, NML and CSIR all refer to metrology activities unless otherwise specified, see page 50.

in the measurement of turbulence on the new commercial aircraft routes, the highly classified (at that time) determination of the uranium content of the gold mines and even very early work in air pollution (an area in which Halliday himself was to eventually specialise). The work for SAA led to the development of a data recorder for the SAAF (the first aircraft black box?), which was also to be used on both SAA's Skymaster and Viscount aircraft. All the on-board data was recorded on film for later visual analysis and tedious hand-correlation to the navigator's log. Amongst the many intriguing projects was one to determine why locally made 78 (rpm) gramophone records were wearing out needles so fast.

Roy's first standards-related task was to address the measurement of mass. As there was only one air-conditioned laboratory in the NPL at that time, that of Jack Whittaker (electrical), he was allocated a corner of this room. Jack's apparent generosity was qualified with the requirement that Roy would then accept responsibility for maintenance of the air-conditioner. An old chemical balance was acquired from somewhere, was suitably modified with a silver mirror and projection system and within three months basic weight calibrations were possible.



Roy Smith and Alan Morris (r) with the primary barometer in the new NPRL building, 1957

After mass Roy was set to work on pressure and as a result of the lack of space, this time he was put into Dr Halliday's office. The precision manufacture of the barometer was the work of Ivan le Sueur of the NPL's workshop. It should be observed that in the early days the NPL, Teddington, was used as a role model and the barometer was a suitably modified copy of an earlier NPL device of the 1930s. The pressure calibration work was initially carried out for the Weather Bureau, but from 1957 South African Airways became the technology driver. It was from that time required by the international airline association to demonstrate traceability in regard to its pressure calibrations for cockpit instrumentation. With the increased cruise altitude of the new jet airliners a long range barometer was required in the late 1960s. As was often the case, the money was not available to purchase one and a tilting cylinder barometer was designed locally and built by Ken Rees of the metrology workshop.

During the early years of the CSIR, supplies of any kind were difficult to obtain as a result of the disorganisation caused by the end of the World War. The fledgling standards activities were fortunate to receive assistance from their British and American counterparts, particularly in regard to electrical standards. Dr S M Naudé acknowledged help received from the NPL, Teddington, the National Bureau of Standards (NBS), Washington, the National Research Council (NRC) of Canada and the Council for Scientific and Industrial Research of Australia (later CSIRO). Strong links were maintained with these organisations over the next fifty years and several skilled metrologists joined CSIR from the NRC.

The first certificate of calibration in the electrical area was issued in 1947 for a pair of standard cells submitted by a local university engineering department. Another area which received early attention was heat, with a standard temperature bath for thermometer calibration being constructed during the same year. At the end of 1947 the total staff of the fledgling NPL was only 28 people, of which 16 were graduates. Despite this diminutive complement nine major areas of activity had already been identified. At this stage in the development of the laboratory all activities relating to standards were incorporated into the relevant department. Staff were appointed to the new departments for spectrochemistry, optics and X-rays in early 1948. The early work on physical standards during 1947 was mainly focussed on electrical standards, particularly in regard to voltage, and a thermo-electrically controlled box had been constructed which could control internal temperature to better than 0,01 °C for room environment fluctuations of ±1 °C. The first AC transfer standards were also received during this period while a Rayleigh Disc Tube had been constructed using the CSIR workshop which could be used for the absolute calibration of microphones. A calibration service for weights and balance was also offered.

In his annual report dated October 1948, Dr Naudé saw the previous 12 months as one of consolidation of the NPL, with equipment now more readily available and required building modifications complete. Standards work was primarily confined to the electrical area, although mention was made of the calibration of two radiation meters, one of these being for SABS. As for optics, a discipline where the NPRL was to play a major international role in later years, all equipment was in a partial state of completion. From the organogram of the NPRL in 1949 it is evident that measuring and standards pervaded the activities at that time, although still incorporated within discipline-related sections.

The new CSIR was located in a building in Visagie Street in the centre of Pretoria. A brochure on the National Research Laboratories published in 1950 indicated that the NPL was responsible for "the ultimate standards of length, mass and pressure" as well as fundamental electrical and temperature scale standards. Calibration services were offered for electrical sub-standards and instruments, thermometers and pyrometers as well as for electro-acoustic instruments, microphones and loudspeakers. Availability of scientific


NPL Visagie Street in the early years

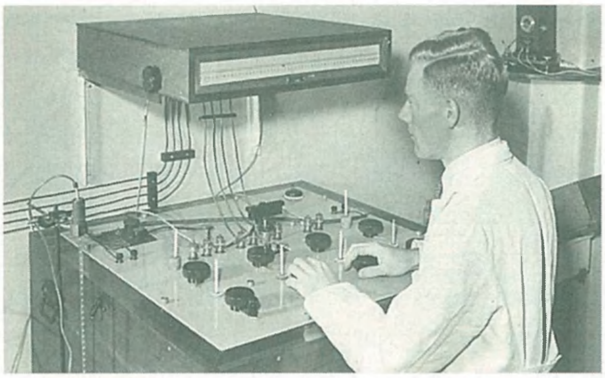
standards of colorimetry and photometry were also touted.

Records for 1950 include a letter, (written in Afrikaans) dated September 22, to the Secretary of Foreign Affairs from Dr S M Naudé, then Director of the NPL. In this Dr Naudé stressed the urgent need for the Union to become a signatory to the Convention of the Metre and the requirement for a BIPM-certified standard kilogram. It is interesting that he emphasized that the annual membership fee would be based only on the 7 million indigenous population of the Union and as was the cases in France and Britain, the country would not have to pay for residents who had immigrated from the colonies.

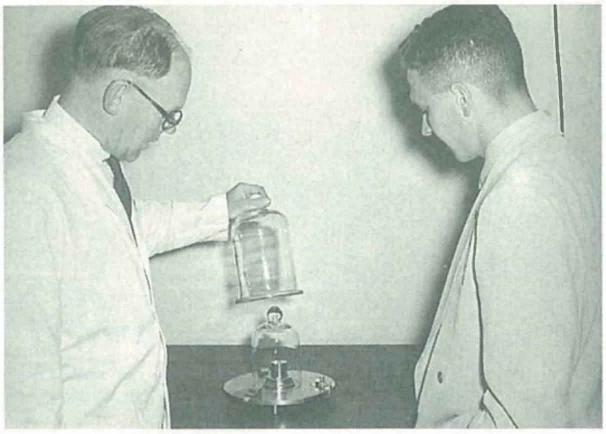
Standards soon outgrew the temporary Visagie Street premises (and Doc Halliday's office) and when work began in 1951 on length, additional space was required for this and the mass activity. A suitable building (colonial-style house and servants' quarters) was located in a timber yard in near-by Struben Street. Measuring standards got the treatment it was to expect over the next decades, with the comfortable house being allocated to the new Bituminous Binder Research Unit and Physics of Matter being rewarded with the servants' quarters. To the scientists of those days that was not a problem and they soon acquired and fitted an old air-conditioner into one of these rooms, which then accommodated the balances and a new Hilger interferometer.

CSIR's Research Review of September 1953 contained a feature on physical standards, with authors Halliday, Marais and Brune. By this time two sets of metric weights (1 mg to 500 g) were in use and a standard kilogram and four working copies were on order. The red cadmium line was being used for the length standard, while the primary standard barometer was in full operation. Standard lamps had been acquired and calibrated by the NPL, Teddington, while the latter had also provided thermopile radiometric standards. Electrical standards included a group of 22 Weston cells and six Thomas-type resistors. Temperature standards were also being maintained to cover the range -180 °C to 2000 °C. The article concluded with the statement:

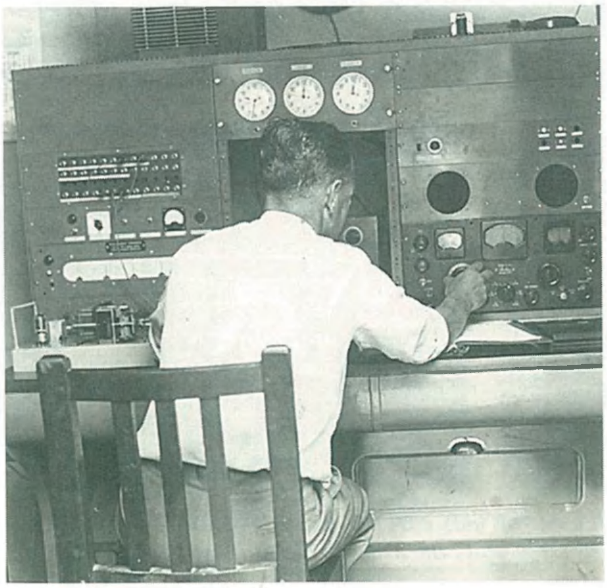
"It will thus be seen that the N.P.L. (sic) already maintains a large range of physical standards which are available for standardising measurements in science and industry as accurately as may be desired."



Ernst Carte calibrating Pt resistor thermometers



Eric Halliday showing No 56 to a visitor



Thomas-type resistor, early 1950s

Stirred oil bath for resistance calibration with Thomas-type resistor in place, 1955

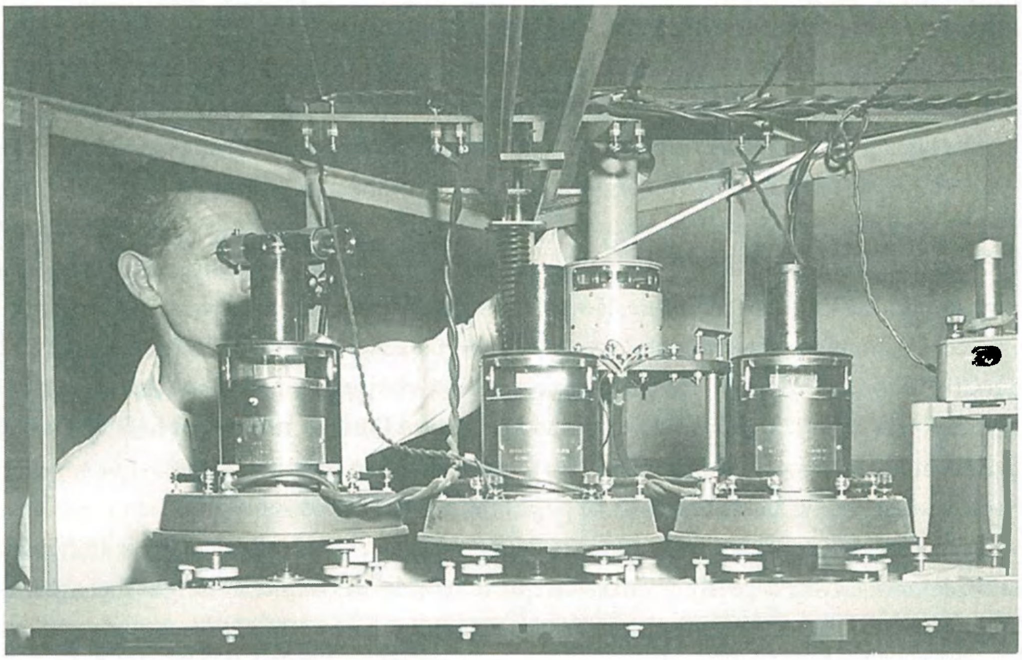
The 1950s

Left: Jan Hers at the original time comparison console, 1955. Clocks display sidereal, SAST and GMT. The radio receiver he is adjusting was war surplus

The front cover of a booklet on the services of the National Physical Laboratory published in 1955 showed an artist's sketch of the new Scientia premises, although these were not to be finally occupied until 1957. The description of the role of the South African NPL makes interesting reading as the opening paragraph stated that the task was the maintenance of basic standards of physical quantities such as units of mass, length and time and those connected with heat, colour, sound, electricity and many others. The problem of confusion between the role of the NPL and the SABS, which still exists to this day, was clearly elucidated. It was emphasized that the NPL's standards were those of physical quantity and could not be confused with standard specifications of quality or performance, which were functions of the SABS.

In the very first sentence of this booklet it was emphasized that measurement is the

NML staff 'walking' the 50 m steel length bar from the CSIR workshops and passing it into the tape tunnel through a secret hole in the steps up to the new NPRL building (Jan 1960)



Jack Whittaker with the reflecting dynamometer instruments used for calibrating AC instruments (photo taken in the original electrical laboratory in Visagie Street)

basis of all science and the checking of accuracy of measurement was a basic function of any national scientific body. The importance of international comparison and traceability was also well understood and it was clearly stated that the quality of NPL's master standards would influence the accuracy of all measurements made in South Africa.

In the year of the NPL's move to the Scientia site, 1957, Halliday's Physics of Matter section was renamed the General Physics Division.

Mission of the NPL (Report to Council, 25 August 1952)

- Basic research is regarded as fundamental to the functioning of the laboratory
- Physics is essentially a science of measurement. The laboratory's second important function is to supply standardising and specialised testing facilities to science and industry
- The ultimate objective of the laboratory is to render service to the country through the scientific and industrial applications of physics

Dr Naudé had a clear vision of the future long before the popularity of this concept and that of a mission as used in modern business circles. The mission of the NPL was clearly defined around physics, the science of measurement and the need to provide standards to which industry could work. This gifted vision of Naudé would many years later become the goal which drove the creation by the NML of the National Calibration Service (NCS).

Long road to BIPM membership

Although SA only became a signatory to the Metre Convention in 1964, this was not due to a lack of interest from Halliday. Dr Naudé first wrote to the BIPM in July 1950 to enquire about its background and requirements for membership. In September that year in a memo to Schonland he recommended that "steps be taken to make CSIR a member [sic] of the BIPM as from January 1951."

This request was conveyed to External Affairs but the reply obtained was non-committal, indicating that all interested parties should first confer and a recommendation be made as to which government department should assume responsibility. The urgency from CSIR's viewpoint was obvious, with a meeting, chaired by Naudé of representatives from CSIR (Halliday), SABS and Weights and Measures (Meijer) being held in February. At this meeting Brune was asked to obtain further clarification from the BIPM.

The letter sent indicated that of the population of the Union, only 2 million were at the level of civilisation comparable to Europe, with 8 million judged lower by these standards. The Director of the BIPM, a Mr Perard, was quick to reply and to point out that there was no discrimination between different categories of inhabitants, which would embody natives, as with the membership at that time of France and Algeria which included the total Arabic population of Algeria.

Following another meeting of all the interested parties, Dr Du Toit, CSIR's President, wrote to the Secretary of Commerce and Industry on 22 May petitioning him to take the necessary steps for accession. Using the population of the country as 10 million the annual subscription was estimated to be £230, with an entrance fee of £690. A response was to be deferred until February 1952 and was to kill any CSIR hopes of early membership. It tersely stated "the Minister has now estimated that in view of the financial emergencies and the instruction from Treasury to reduce expenditure, it is his wish that the above matter (accession of the Union to the Metre Convention) be left in abeyance for this period."

All correspondence with the BIPM regarding membership ceased forthwith, although interaction did occur in regard to explaining how South Africa was implementing the metric system. In one letter it was indicated that in terms of Act 32 of 1922, this country although applying metric units as the standard, "allowed use of avoirdupois and Union measurements for trade, as metric units would cause confusion and probably lead to fraud and exploitation."

The immediate needs of the NPL were satisfied through purchase of a prototype kilogram* (No 56) from Oertling in the UK and its subsequent standardisation by the BIPM. While the true story surrounding this may never be known, it would appear from discussions

* The terms in use today, kilogram and metre were a compromise between British, American and French sides, the British wanting to reserve the word meter for a measuring instrument and the French accepting kilogram (instead of kilogramme) in exchange for their 'metre'.

with Halliday's colleagues that when it was ordered in 1951 the signing of the Convention was assumed to be a formality. In the event it was to be allocated the BIPM number, 56, imprinted by Oertling, whose assignation was normally reserved for the 'national prototypes' of member states. No 57, which was manufactured along with 56, was only later *allocated* to India, while 56, according to its certificate *belonged* to South Africa, a subtle difference. At that time No 56 was the only copy of 𝕶 issued to a non-member state. Although unusual, correspondence with the BIPM confirms that a serial number could be assigned to an 'official' copy, even though purchased by a non-member state.

The question of membership remained in suspension until 1959 when NPRL Director, Dr Marais, raised the matter again with the Department of External Affairs. In February 1959 CSIR also offered to pay the initial membership fee and annual subscription. Once again the wheels of bureaucracy were to move slowly and it was late November that year before an answer was received which indicated that while the Minister had agreed in principle, as it was a question of the government joining, the funds would have to be made available out of government sources. In a handwritten note attached to this response Halliday in frustration recorded: "This present position brings us back to where we were in 1950 or thereabouts!"

Further urgent representation led to an indication that Cabinet would consider the matter and make a decision towards mid 1960, but Cabinet was more concerned with the impending withdrawal from the Commonwealth. BIPM membership was only raised again in a Cabinet memo of February 1963, when note was made of the responsibilities of the CSIR (in terms of the new Act 32 of 1962) and its responsibility for standards. Finally on 8 October 1963 Cabinet resolved that South Africa should become a signatory, with formal adherence following in 1964.

The period 1964 to 1981 – Precise Physical Measurements Division

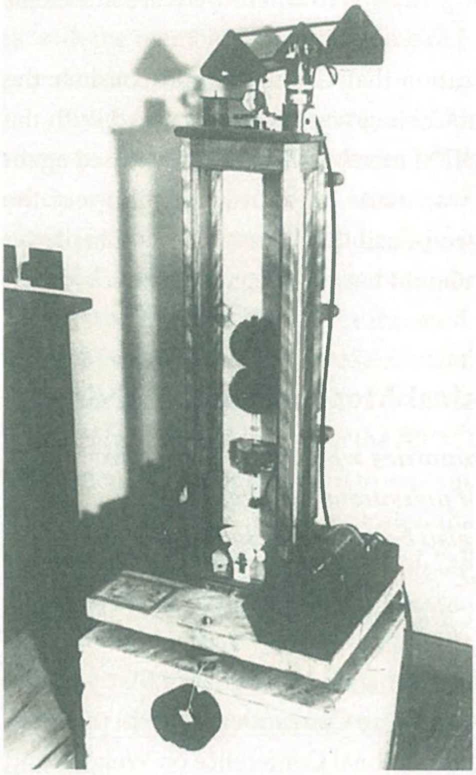
"It is no accident that in the past those countries which have given the closest attention to physical standards of measurement, Great Britain, Germany* [and] *the United States, have also been leaders in industrial development."

S M Naudé, President, CSIR, 1964.

1964 was to be a watershed year for South African metrology. In August of that year the country became the 40th signatory to the International Metre Convention in Paris, pledging full support for the BIPM. Following this the 12th International Conference on Weights and Measures in October that year was attended by Dr Halliday.

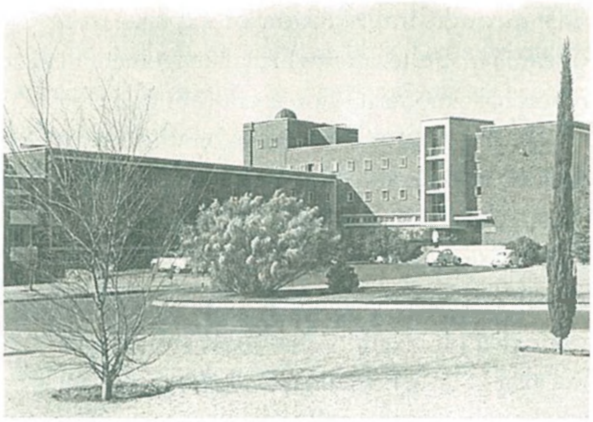
The other event of significance was the revisiting of one of the NPRL's most important tasks as defined in CSIR Act 71, as amended in 1964. This was clearly spelt out as the need to maintain primary standards of physical quantities. When the efficacy of the NPRL in this area was reviewed it was found that as secondary standards had been easy to obtain, most independent divisions (which looked after the specialist areas of metrology) spent their funds on their other research work and little effort had been made in the development of primary standards. The NPRL Annual Report for this period also shows that CSIR was very aware of the threat which impending political isolation could have on the acquisition of secondary standards in the future. It was also noted that standards were multi-disciplinary in nature and absolute measurements in the field of electricity were in turn dependent on the accuracy of measurement in mass, length and time, and that measurements in temperature involved accurate electrical measurements.

As a result of these facts a decision was made to consolidate all (notable exceptions were time, acoustics and ionising radiation) standards activities into a single new section, to be called the Precise Physical Measurements (PPM) Division. While most people have given no second thought to the naming of the new Division, it was of great significance to Halliday, as its initials, PPM (or ppm) also exemplify the more common term used in comparison, namely parts per million.



The AC/DC transfer instrument developed by Jack Whittaker in 1951

Dr Halliday became the first head of this division which, initially comprised nine research staff. These 'original' metrologists included Tinus (M C) Boshoff, Otto Brune, Stoffel Kok, Willem Marais, Roy Smith, Onno Weidema and Jack Whittaker, all of whom were to make significant contributions to South Africa's measurement capabilities. Although not shown in the records, the NPRL Director also provided more freedom to the new standards unit by excusing it from the rigid requirement placed on other divisions to publish physics research articles of international standard. Despite this special dispensation the work of the new division was to be of such a high standard that many papers were published over the following decades. This epoch saw the foundation of the expertise in photometry by Boshoff, Winch and Kok which would lead to eventual world



NPRL in the 60s, as viewed from the SW

leadership in the area of radiometry and the first local precision measurements of daylight, which would result in questioning the international D65 source standard. Jack Whittaker continued his pioneering work in local electricity standards, both AC and DC, using his young novitiate Willem Marais.

It is interesting to note that while standards were in principle the responsibility of PPM from 1964, a brochure from this period still refers to standards of flatness and refractive index (using a precision goniometer), which were maintained by Ernst Hecker who remained with the optics activity.

Over the years there was a continuing battle between the scientists and the astronomers for the control of time standards and the side of the latter was strengthened in 1958 by CSIR's own publication *Research Review*, which in an article by Mr D Ryle Masson (then Head of the Information Division), was to state:

> ***"Unfortunately the lack of funds*** **[for the Union Observatory]** ***has prevented the purchase of equally accurate instruments*** **[as the quartz crystal clocks]** ***for the astronomical observations essential for checking these clocks...in terms of actual time as indicated by the rotation of the earth."***

With the creation of the PPM Division, Halliday made a strenuous but unsuccessful effort to have CSIR assume responsibility for the time and frequency standards.

In 1964 those laboratories concerned with length, mass, pressure and temperature moved into the basement of the new National Research Institute for Mathematical Sciences (NRIMS) Building adjacent to the existing NPRL and linked with a walkway. Although the poorly-lit basement was shunned by the mathematicians, this location provided a much more stable environment for accurate measurements. A significant improvement in measurement accuracy was eventually observed, although the move (and disturbance of equipment) resulted in all measurements in these areas virtually ceasing for a year. This purpose built facility with refined temperature and humidity control created new problems. The basement was in fact especially gloomy as it had been fitted out with old 'cold-cathode' type lamps, which lost brightness without actually expiring. Estates meanwhile refused to replace lights that still worked, irrespective of brightness, resulting in an impasse resolved

Dick Turner

only through intervention of experts from CSIR's Building Research Institute, after which management made funds available to purchase modern fluorescent fittings.

At the General Conference on Weights and Measures held in Paris in 1967, South Africa was appointed as a member of the Consultative Committee on Photometry. This would lead to the work being carried out at the NML on devising a new unit for the intensity of light becoming part of the international studies being conducted on behalf of the BIPM at that time. 1967 also saw the first visit of British scientist Dr Richard (Dick) Turner to the NPRL. During that year the NML was experiencing problems with its 0,5 m wave-count interferometer, the early helium-neon laser being used showing both instability and a lack of coherence. It was hoped that Dick would be able to assist with this problem, but in effect he was to be fully used by his former colleague, Dr George Ritter, in the construction of a one metre carbon dioxide laser.

The Halliday era came to an end in 1970, with his retirement and Dick Turner, then at Canada's National Research Council was appointed to head up the Precise Physical Measurements Division. While Halliday (affectionately referred to as Doc) had been greatly admired by all his staff, the time had probably come for radical change. It is perhaps of significance to note that in the NPRL Annual Report of 1970, no reference was made to the activities of the PPM Division in the Director's (Dr Strasheim) review of important events at the laboratory. Halliday had also been preoccupied since 1960 with the activities of the Air Pollution Research Group, which he had established. On Halliday's retirement, the total research staff under him was still only seven, and only four of these (Stoffel Kok, Willem Marais, Roy Smith and Onno Weidema) would remain for any time after Dick Turner's appointment.

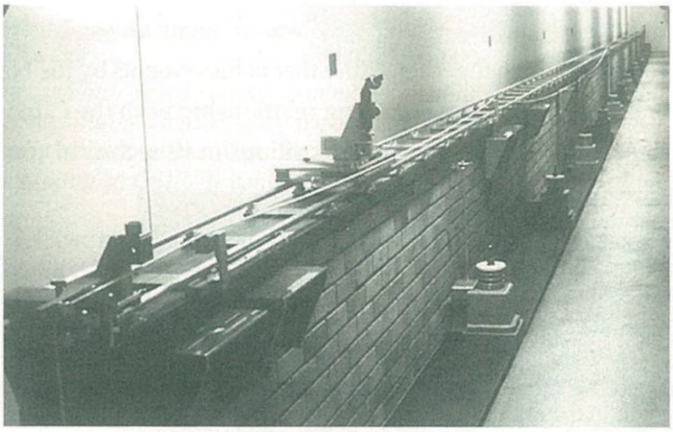
Dick in turn convinced his colleague, Cor van der Hoeven* (who had been closely involved in early gas laser development work at the NRC), of the pioneering and challenging opportunities in South Africa and Cor joined NPRL in 1970 as a member of the PPM Division. While the war had deprived Cor of a university education, he was a natural scientist and experimenter. His talents were to be used with great effect by the NPRL over the next two decades in both dimensional and electrical metrology, holography, laser technology and electro-optical system development.

While Dick was to make a tremendous and undisputed contribution to metrology in

* Cor van der Hoeven had worked with Hanes and Baird of the NRC who published the first research paper on the iodine stabilised laser in *Metrologia* in 1969.

South Africa, his appointment in 1971 was to say the least, unexpected*. It was common knowledge that Halliday himself had attracted Boshoff back to the PPM Division on the tacit understanding that he would be his successor. What then had persuaded the Director, Dr Strasheim, to appoint a 'rooinek'? Dick was in fact highly sought after, not for his knowledge of metrology, which was at that time limited, but for his expertise in a more critical strategic technology at that time, the laser. It was George Ritter, his acquaintance and colleague at Oxford and the NRC, who was to persuade Strasheim of this importance, significant enough to pass Boshoff over. No doubt George also knew the role that optics, and in particular the laser, was to play in measurement science.

Whatever the reasons, Dick was indubitably a judicious choice and his ability to rapidly recover from below the belt punches was to prove invaluable for the development of South African metrology. While Halliday was the 'father' of measuring standards, Dick during his tenure was to ensure that traceability and calibration became a way of life in the manufacturing industry. Although their personalities were as different as chalk and cheese they both were to be 'the right person, in the right job, at the right time.'



The NPRL tape tunnel, 1982

Although the appointment of an Uitlander (an alien) to this critical position was somewhat controversial at the time, time itself proved the decision to be a sound one, as Dick was to become the champion of the National Calibration Service (NCS) and its later recognition, before other first world countries, by the WECC. Following his appointment Dick's ambition to see South African metrology achieve its rightful place in the world community soon won over his antagonists and for the rest of his career at CSIR he was to enjoy the powerful support of many stalwarts from the local metrology community, including the old-timers Roy Smith, Willem Marais, Stoffel Kok and Lorene du Preez. Boshoff, after trying to work for a period with Dick, resigned and joined the standards group at SABS.

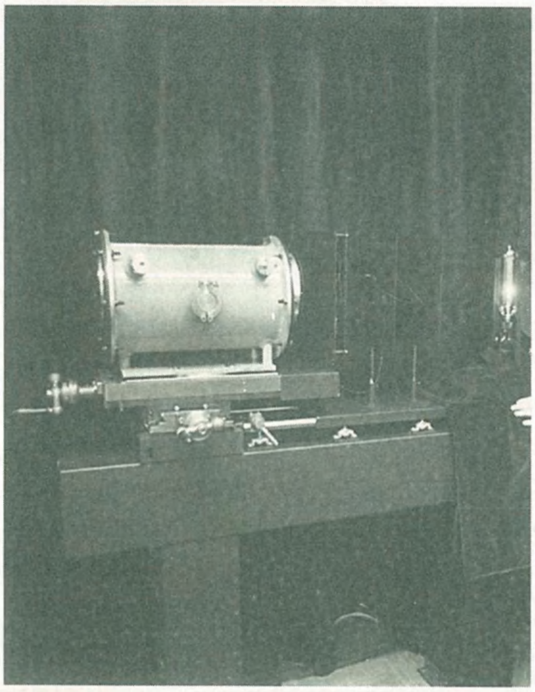
Under Dick's leadership a new Act (Measuring Units and National Measuring

* While CSIR favoured the overseas recruitment of scientists and engineers, management was still monopolised by 'politically correct' South Africans. Even Naude is reputed to have only accepted the position of NPL Director under threat that an 'Englishman' might be appointed instead.

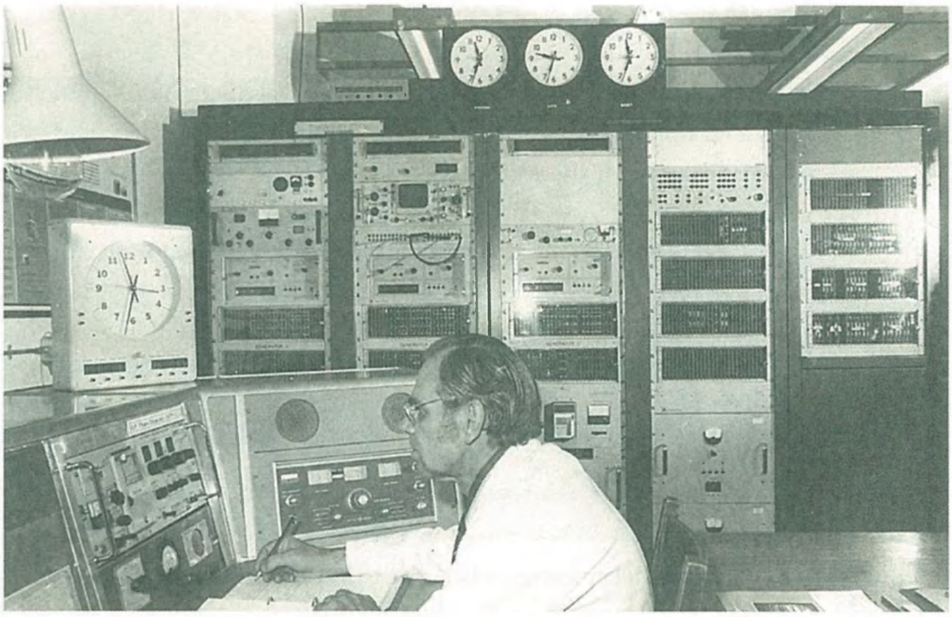
Standards Act 76 of 1973) was to be promulgated, funding for the NML (unconnected with the CSIR's parliamentary grant) was to be secured from the Department of Trade and Industry and the NCS was to be established and grown to the stage where it was to become an independent Section 21 company. It would report directly to government through the Department of Trade and Industry. What Dick had done was to re-establish the status of metrology back to where it had been in the period of CSIR's infancy. He often achieved his objectives by unconventional means, not allowing the system to thwart his objectives, sometimes creating enemies in the 'establishment' in the process.

Franz Hengstberger

1971 was also significant in that it saw the appointment of Franz Hengstberger, who together with Dick was to play a major role in the development of measurement science through the crucial decades of political and economical pressure. Franz in his early years at the NPRL was to focus on establishing a radiometric standard for the candela, which together with other achievements by the NML in radiometry and photometry, was to lead to a close ongoing relationship with the CIE, which has resulted in the elevation of several South Africans to positions in its technical committee structure. While the BIPM



Mark 2 and Mark 3 versions of the NPRL radiometer, 1976



Chris van den Burg with the Caesium oscillator-based timing system installed at the NPRL during the period 1977 to 1978.This photograph contains a wealth of information regarding the time service. The control console had been designed and built at the Republic Observatory, but had never been installed because of the impending relocation to CSIR. It contained all the international radio time signal intercomparison equipment.

The five rack Astrodata Timing System in the background was acquired from the Americans following the closure of the Stadan Satellite Tracking Station at Hartebeeshoek near Pretoria. Chris had worked at this station, so he was in a way 'inherited' with the equipment. The Astrodata provided timing pulses for the time scale, UTC (NPRL), which was in turn controlled by the original Caesium Oscillator Type 5060. The analog clocks on top of the Astrodata are of particular interest as they display Eskom, UTC and South African Standard Time (SAST). Eskom time refers to the public electrical utility, which, through the frequency of its power distribution, controlled all mains-powered electrical clocks and timing systems in the country. In the original print Eskom time can be seen to differ from SAST by some seconds, this difference changing as the network load varied. The analog clock on top of the console, which also had a digital display of astronomical time, was the first experimental step towards the introduction of more modern integrated circuits into the timing system.

The Astrodata system consumed 5 kW of electrical power and was to cause a complete breakdown of the building's air-conditioning system. The only solution was to punch a hole through the outside wall and install an extraction fan to vent all the hot air (presumably including that generated by Dick and the metrologists!).

defines and maintains the fundamental standards of photometry and radiometry, the task of the CIE lies in ensuring common standards of measurement and illumination levels for work, sport, safety and other applications.

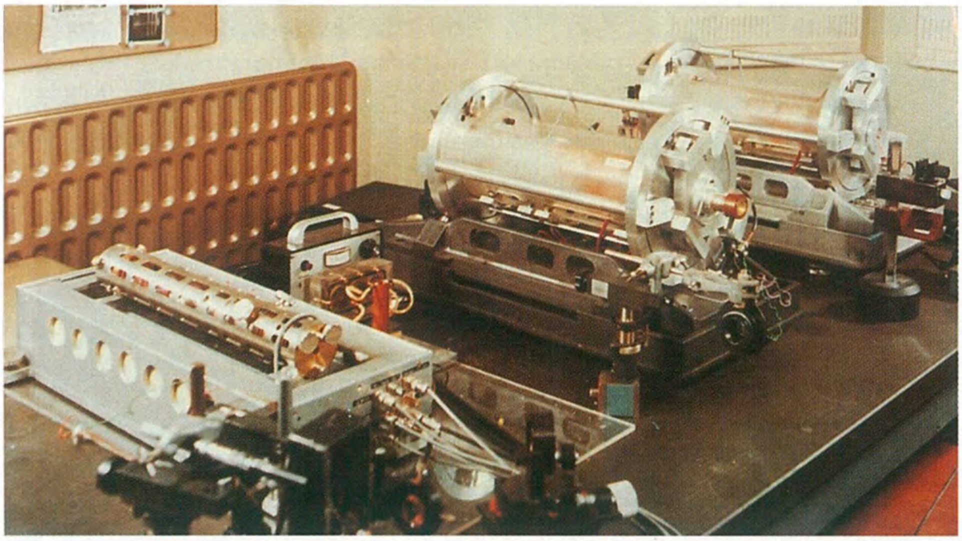
Franz was later to become the *de facto* deputy for Dick, assuming responsibility for all metrology-related R&D activities, providing Dick with the necessary freedom to focus on the implementation of the NCS. Following the successful international acceptance of the absolute radiometer, Franz went on to develop a local luminous flux standard to link the candela and the lumen. This was followed by the development of a new RF power standard based on the absolute radiometer technology. Other major R&D activities which he led included the implementation of a novel PC-based telephone time service, and with the introduction of microprocessors, the automation of the operation of many standards, including those used for AC/DC transfer and radiation dosimetry.

During 1972 the responsibility for maintenance of the time standard was at last transferred to metrology. At this time the major astronomical facilities in South Africa, with the exception of the Boyden Observatory in Bloemfontein, were consolidated to form the South African Astronomical Observatory (SAAO) under the control of CSIR, with a new observing location on a remote koppie (hillock) near Sutherland in the Karoo. The staff from the Republic Observatory in Johannesburg who were involved with time standards maintenance moved, together with their equipment, to the NPRL. It is interesting to note that while time remained the responsibility of the observatories until 1972, by 1940 astronomical and clock-time measurements had started to diverge and by the late 40s the physicists and engineers were demanding frequency, not time.

CSIR had continued to grow during the sixties and seventies with the creation of many more research institutes. With the 70s and the increasing impact of international trade sanctions the emphasis in many areas became strategically oriented. Within the NPRL itself standards appeared to have taken lower priority to both strategically focussed research and the growth in often capital-intensive 'blue-sky' research programmes which should have rather been the mission of universities than an industrial-focussed, government-funded research laboratory.

The metrology activities found themselves under more and more financial pressure during this period and the inability to upgrade national standards to keep pace with international developments became more pressing. The mission of necessity became one of retaining and recruiting staff, rather than using the limited budget to provide new capital equipment. During his tenure Dick worked assiduously at cajoling both CSIR (through George Ritter) and DTI to increase their financial support. While the staff complement had remained relatively fixed during the later Halliday era, it increased dramatically from ten in 1970 to forty by 1986. This was a remarkable achievement bearing in mind the strict budgetary constraints of this period.

In the end it became clear that a new national mandate was required for the maintenance and development of standards which were crucial to the long-term industrial development of South Africa. After much lobbying by all parties The Measuring Units and National Measuring Standards Act of 1973 was promulgated by parliament. The significance of this Act was to transfer effective financial responsibility for the maintenance of standards to the



NML's early iodine-stabilised laser (left) being compared with the NPL standards at Teddington, 1977

Department of Trade and Industry. Through the enactment of Act 76 of 1973, CSIR became legally responsible for all national measuring standards. While this had been the status quo for some time, the new act provided a clear legal definition, required gazetting of changes made to the measuring standards and removed some of the ambiguity concerning the roles of CSIR and SABS.

It was not until 1984 that the responsibility for the implementation of Act 76 was formally accepted by the Department of Trade and Industry. At this time the Department was to accept the obligation to provide the funding for the establishment and maintenance of national measuring standards, although for many years understanding regarding more fundamental metrology research was not mutual. This was despite the fact that the signing of the Metre Convention twenty years earlier carried with it a commitment to the BIPM (and the international community) to assist in the ongoing development of new and more accurate standards.

While Act 76 of 1973 was an important enactment, many erroneously view it as the beginning of measurement standards in South Africa. In fact a clause in the original Act (No 33 of 1945) establishing the CSIR and describing its functions reads:

"...to maintain standards of physical quantities including length, volume, weight, mass, capacity, time, heat, light, electricity, magnetism, sound and other forms of energy and to arrange for their comparison with international standards from time to time."

This clause was retained in Act 32 of 1962. The interpretation at that time was, however, that while the establishment and maintenance of the fundamental standards was entrusted to the NPRL, the dissemination of these standards into scientific, industrial and commercial activity was undefined, a 1964 publication merely stating that this would occur through a multitude of channels. Act 76 removed any confusion regarding what a national measuring standard was, as this would be defined and updated as required in the Government Gazette. Furthermore CSIR would keep and maintain these standards, and would define the value in terms of international comparison.

The final clause (5) is one of the most significant as it referred for the first time to traceability as related to the extant national measuring standard. This latter clause was to cause many headaches for Dick, as in repeated court cases involving speeding motorists, the traceability of both wire and radar trapping devices was to be called into question. Dick was often summoned by defence counsel to appear (unwillingly) on behalf of the accused. This skirmish between measuring standards and the road traffic authorities probably had much influence on the development of many of the measuring devices (traceably certified) by Productiontek in response to the Consolidated Road Traffic Regulations of 1990.

In the NCS Newsletter of August 1992 Dick expressed his frustration regarding speed traps and ended with the comment:

> ***"With the existing* [South African] *speed-trapping system, anyone with any knowledge of quality whatsoever (and there are many) is more or less bound to want to defend himself in court. It's almost a challenge!"***

1975 saw the centennial celebration of the signing of the Metre Convention and a special conference was held at CSIR in April that year. Organised jointly by the NPRL and SABS,

Measuring Units and National Measuring Standards Act No 76, 1973

7 (1) The Minister may by notice in the Gazette designate any measuring standard described therein by him as national measuring standard.
(2) The Council for Scientific and Industrial Research mentioned in section 2 of the Scientific Research Council Act, 1962 (Act No 32 of 1962),shall –
(a) keep and maintain all national measuring standards;
(b) arrange for the comparison, from time to time, of the said measuring standards with the corresponding international measuring standards recognised as such and see to the correction thereof, if necessary;
(c) keep and maintain the equipment necessary for bringing national measuring standards into being, and see to the procedures connected therewith.
(3) The value of a national measuring standard in relation to the corresponding international measuring standard, shall be the value as determined from time to time by the said Council for Scientific and Industrial Research.
(4) The value of a national measuring standard, determined as contemplated in subsection (3), shall be deemed to be the most accurate value.
(5) A measuring standard which is not a national measuring standard shall for the purpose of any law or any legal purpose, be traceable to a national measuring standard or national measuring standards.

Speakers at the NCS 10th anniversary in 1990 included (foreground l to r) Manfred Klonz (PTB), John Stoddart, UK, Dick Turner, Kai-Li Ko (ITRI), Joe Ruffino and John Wilson (MIG)

overseas visitors included Joe Ruffino (Italy), Bill Blevin (Australia), Guy Sutcliffe from Guildline in Canada and Fred London from Hewlett Packard, who brought with him its latest interferometer.

1976 was also auspicious for other reasons. It saw the completion of the first iodine-stabilised laser which was to be compared favourably with those at the NPL, Teddington in the following year. It also saw South Africa follow the leadership of Australia and set an example for the rest of the world, with the Hengstberger absolute radiometer becoming the national standard. The CSIR Annual Report for 1976 was to proudly state "South Africa has now become independent of overseas light intensity standards." Unbeknown at that time was the fact that this radiometer would also become the standard adopted by many other countries.

The NCS came into being in 1980 under the control of CSIR (through the NPRL) and with Dick Turner as Manager. Its necessity was greatly influenced by the expansion of the local armaments industry and the critical need for a proper quality assurance system and also by the decision to build the Koeberg atomic power plant. The latter was constructed with the assistance of the French who were extremely sensitive to the need for international traceability and proper measurement procedures when it came to man harnessing the power of the atom, where the slightest deviations from good practice have elsewhere proved catastrophic.

The events which led to the creation of the NCS can be traced back to the local electrical community becoming conscious of the lack of confidence in local certifications. Several meetings over a considerable period of time were held between the prime movers Eskom, Atlas Aircraft (in the person of Bart van Oostrom, now in charge of the NML's AC/DC metrology standards), NEERI (Cyril Dodd), Marconi (later ESD) and the PPM division. At one of these meetings it was decided that an equivalent to the British Calibration Service (BCS) should be created and that the initiative lay with the CSIR and Dick.

While the NCS was only created in 1980, a brochure on the NPRL's standards of physical measurement dated 1964 emphasized that a second responsibility (after the development and maintenance of standards) of the NML was to disseminate measurement techniques to enable other laboratories to get the most out of their instruments. This obligation was deemed to be covered through "reports, publications, discussions, visits and interchange of personnel". These early ideas would be subsequently taken further by the NCS (through the participation of NML staff) in the form of the ongoing metrology workshops and Technikon training courses for metrologists.

The interest of the armaments and nuclear industries is indicated by the fact that at the beginning of 1985 one third of the 40 or so accredited laboratories came from these sectors, while six, including Fluke (with the Laboratory Head now being John Wilson of Metrology Instrumentation Group (MIG) distinction), represented overseas electronic measuring equipment and oscilloscope suppliers.

The standards activities were also to benefit from the generosity of Armscor, which for example provided funding in 1984 for an RF piston attenuator. The rise in prominence in the NCS of the Barlows ESD (now Reutech) Laboratory can also be attributed directly to the requirements of Armscor. South Africa's national air carrier, SAA, recognised throughout the world for its outstanding maintenance and repair record also became an early staunch supporter of the development of metrology. In those days SAA's Boeing aircraft (denied over-fly rights on the African continent) flew some of the longest non-stop commercial routes around the bulge of Africa without any major incident.

The birth of the NCS also followed on the heels of the introduction of the concept of the quality management system, with SABS having introduced its 0157 scheme during 1979, following the example of the UK with its BSI 5750. The ISO 9000 series, with which every manufacturer today is familiar only appeared in 1987. The implementation of a quality management system implied *inter alia* traceable measurement capability, which only the NML could provide.

The benefit that industry has derived from the assistance of the NML and the NCS in transferring good measuring capability is well illustrated by examples from dimensional and electrical metrology, as to how measurement accuracy has improved with time (see pages 63,114 and 115). It is clear that despite a growing number of laboratories from 1980 to 1990, the accuracy with which gauge blocks could be measured improved in an exponential fashion. The plateau reached indicates a fundamental limit for the instruments being used. This same characteristic was observed for the measured emf of standard cells over the 1982 to 1986 period.

1981 to 1987 – the last years of the NPRL

In 1981 the Precise Physical Measurements Division was renamed the National Measuring Standards and Metrology Division on the recommendation of the national sub-committee on measuring standards. During this period Dick Turner was to become increasingly frustrated regarding the financial and other support of the NPRL/CSIR towards standards, a situation possibly exacerbated by the NPRL practice of permitting the Director to run his personal laboratory, where he had more freedom to allocate funds according to his own choice. This was viewed by many as a conflict of interest situation which impacted on less exciting research activities such as standards development. To be fair, the financial constraints imposed on CSIR during this period were severe, and any application for capital expenditure required up to three years for final approval. The only divisions of NPRL to thrive in this timeframe were those such as Optical Sciences which could access funding from Armscor to conduct R&D in support of the local defence industry and which with dexterity could use this technology for other purposes.

Some semblance of independence for metrology occurred in 1984/85, with the completion of a new wing to the Biophysics Building located (to the north) across the service road from the Mathematics Building. The new ground floor extension provided office accommodation for many of the NMS&M staff, while several activities, including electrical, temperature and force were to occupy the available basement space where they joined their radiation dosimetry colleagues. Perhaps most important was the fact that the NML now possessed its own tea room, an essential for enhanced productivity, as the time taken to walk to the NPRL's tea room in the south-west wing was considered excessive! In those difficult times this venue provided a common (and exclusive) meeting point for the metrologists.

The old cliche 'out of sight, out of mind' is probably applicable and the metrologists became visibly more comfortable with their own premises. Although NPRL Annex 1 (as it was called) was attached physically to the Cyclotron Building, the cyclotron itself was scheduled for decommissioning following the start-up of the new National Accelerator Centre in the Cape. The building and the basement were also ideal for metrology, following certain floor modifications, as it had been designed and constructed in a period of traditional craftsmanship and extreme caution regarding the effects of ionising radiation.

Dick showed his frustration in many ways, but one of the best known (to his peers) was his behaviour at the NPRL's monthly divisional heads' meeting, on the few occasions when he did not have a legitimate excuse for non-attendance. Using body-language to perfection, Dick would be last to arrive, would find the most distant corner of the long table, noisily open the adjacent windows as a reminder to the smokers of his detestation for the habit, and then slump into the chair as if asleep, responding to only direct questions regarding the NMS&M. On closure of the meeting he would spring back to life, gather his papers and be out of the door before the Chairman completed his thanks for attendance.

The creation of the NCS at this point in time has remained somewhat contentious. While in retrospect the timing was opportune, it was viewed by many as a further draining of an already critical funding level, reducing further the ability of metrologists to carry out any meaningful research into primary standards. The NCS itself was in fact primarily a secretariat, with staff members of the NML providing the resources for laboratory accreditation, training courses and other activities. A common pool of funding was available and it became difficult to separate NML-based activities from those required by the NCS.

In theory the conception of accredited laboratories removed the necessity for CSIR's metrologists to perform many of the repetitive, lower accuracy calibration tasks. In practice a conflict situation was occasionally perceived with private-industry laboratories, who sometimes viewed CSIR as a government-subsidised competitor for calibration income.

A memo from Dick to the NPRL's Director, Dr Jan van Zijl, dated June 1983, reflects the sentiment of that time. It was inferred in this document that the NCS was "completely self-supporting from the income derived from membership fees". This was far from reality, but yet not hypocrisy, as Dick had knowingly added earlier in this document a statement that his comments were based on the (CSIR's) "current bookkeeping practices". Under this system all permanent staff salaries (including his own) were paid directly out of the NPRL's parliamentary budget and did not have to be specifically accounted for. At this time industry fees for the NCS were deliberately kept low, both to encourage increased membership and to overcome the resistance industry felt towards charges levied on them by CSIR. In this era CSIR was viewed as a luxury paid for out of government-raised

Delegates to the 1975 Centennial of the Metre Convention in Pretoria taxes. The common view was that all services, including those related to metrology, had already been paid for out of company taxation.

In this memo Dick reminded the Director that while the Department (Trade and Industry) had recently advised that it would provide financial support for national measurement standards, and other responsibilities implied in Act 76 such as international intercomparisons, it still viewed research as a task for which CSIR bore responsibility through the original Research Council Act.

1987 to 1993 – the Division of Production Technology era

The major restructuring of CSIR which began in 1987 saw the disappearance of the 21 discipline-oriented research laboratories and institutes (including the NPRL) and the creation of some 11 (13 in 1988) market-focussed Divisions (Divisies in Afrikaans)*. All the activities carried out by the National Measuring Standards and Metrology Division of the NPRL were incorporated into the new Division of Production Technology (Productiontek), with Dr Maurice McDowell as Director.

The restructuring process which took place at CSIR probably has no equal for an R&D organisation, at any time or place in the world, before or after. With the appointment of the Division Directors in late 1987, the rest of the CSIR staff and existing management hierarchy became a resource pool. The new structure adopted was flat and non-bureaucratic, with the hundreds of rule books (Codes of Standards) being nullified and replaced with sets of Guidelines. The new divisions were created bottom-up using group and team techniques and management and technology consultants. New structures and positions were created, to be filled without reference to previous positions or level of responsibility. With an eventual staff of some 200 personnel, the Division of Production Technology evolved around the concept of small, dynamic groups with direct line management. With the allocation of staff it became clear that the metrology functions should again be separated in a way which would allow synergy, but more personal growth opportunities for research staff.

After much discussion, the metrology activities were reconstructed around the Engineering Metrology Programme under the leadership of Dr Dick Turner and the Electromagnetic Metrology Programme under his protégé Dr Franz Hengstberger. The management of the NCS remained with Dr Turner, with Franz becoming an additional permanent member of the NCS Board, now under the Chairmanship of Maurice McDowell.

The original 1987 CSIR Master Plan would have seen the new Division being relocated to another building on the Scientia site, which would have had major implications for

*There is a subtle difference in the Afrikaans language between the words 'Afdeling' and 'Divisie', which both translate into English as division. Prior to the 1987 restructuring, the divisions of the research laboratories were called afdelings. The new divisions following this were much larger autonomous units and the Afrikaans term used was divisie.

Productiontek's main building, 1988

continued measurements, traceability and calibrations. Fortunately the new Executive was to be convinced that consolidation of the Division around the existing buildings of the NPRL, the adjacent NRIMS, Annex 1 and the original Cyclotron Building was a more practical solution. With acceptance of this proposal by the Top Management Team, changes within metrology amounted to moving offices and secondary facilities such as the mechanical and electronic workshops.

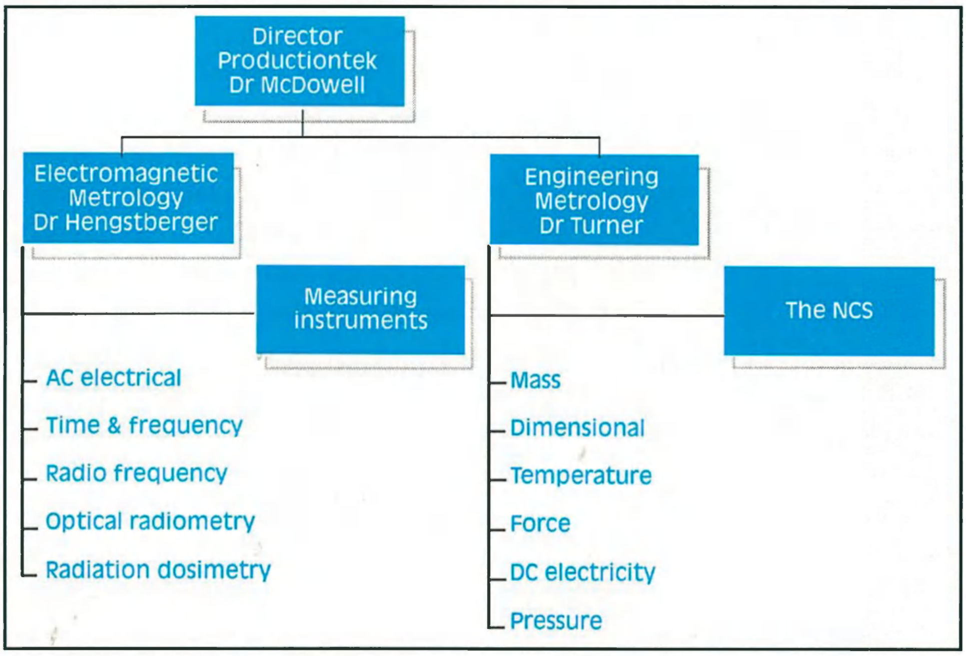
While the NMS&M had possessed its own dedicated mechanical workshop, machines and staff, all these activities were to be consolidated in the new Productiontek under the leadership of Peter Trendler. While the metrology programmes still had access to the same individual artisans, new advantages included access to better equipment, including the locally developed diamond-turning facility which was to be used to produce metrology polygons. To the dismay of some (frightened of losing their virility) the new expanded workshop was to be located in the control hall immediately above the now entombed and dormant cyclotron.

Whereas this workshop consolidation was viewed negatively by Dick, it was in fact a strategic necessity to allow Productiontek itself to maintain workshop facilities, as pressure had reached a peak again to have all such resources consolidated under Technical and Site Services (TSS). An independent external audit commissioned by Executive confirmed the need for Productiontek and metrology to have personal control over their own instrument makers and skilled artisans.

The CSIR restructuring had a technological impact on metrology as the staff of the NPRL's acoustics activity ended up being divided between two divisions, Productiontek and Mattek. This resulted in great dissatisfaction amongst the personnel and within a year much of the expertise had been lost as key staff found new positions outside of CSIR.

ITRI delegation at Productiontek, March 1989 (part of the 1991 mutual recognition agreement)

Prior to 1987 the activities supporting the maintenance and development of measuring standards had received financial support both from CSIR's parliamentary grant (via the Department of Education) and from the Department of Trade and Industry. The strategic direction taken after restructuring was less dependence on direct government funding, which gave CSIR and other statutory



Metrology programmes, 1987 to 1993

councils more freedom to pay market-related salary packages to their scientists and engineers. The down-side for metrology was a CSIR executive decision that Trade and Industry must assume full responsibility for the maintenance of the national measuring standards in terms of Act 76 of 1973. The supplementary funding from the parliamentary grant was withdrawn over a two year period from the Division of Production Technology budget, starting in the 1988 financial year. This forced the re-direction of measuring standards activities into more commercial areas in order for the programmes to generate additional income to be able to maintain their existing staff levels.

During this period the Goldilux™ range of light measuring instruments was developed by the Electromagnetic Metrology Programme under the guidance of Dr Franz Hengstberger. These patented products were industrialised and resulted in the creation of a new private sector company, Measuring Instruments Technology (MIT) (Pty) Ltd. MIT manufactures the Goldilux range of instruments under licence to CSIR and while supplying local market needs, currently exports its products to Europe, America and Australasia through internationally recognised distributors.

Another positive result of the CSIR pressure was the successful involvement of Trade and Industry as a partner in the development of metrology, a process which was to bear significant fruit following the involvement in metrology of Waldo Penzhorn and Arthur Boettcher. The stance of Trade and Industry (DTI) towards metrology took a giant leap forward during 1991 following Waldo's appointment as the Director in charge of the Systems Coordination Directorate (Standards and Environment from 1996). He was responsible for the implementation of both the Measuring Standards Act 76 as well as the legislation which defined the functions of SABS. Since joining DTI in 1961 Waldo had a special interest in standards activities and the NML could now talk to someone who understood the difference between standards of measurement and product standards or trade metrology and measurement science. Together with Dick, Waldo was to persuade CSIR to drop a significant proportion of its iniquitous corporate levy on the Trade & Industry metrology funding.

While the harsh edict of the Executive regarding metrology was initially strictly adhered to by Productiontek, in the latter years financial support was provided (through the autonomous decision of the Productiontek management team) to specific metrology projects for the development of new standards which met the criteria as defined by CSIR's new STEP* funding process.

With the increasing use of optical fibre in telecommunications and the diversification of the Brits cable manufacturer ATC into the manufacture of single and multimode fibre, it became clear that the metrology infrastructure had to be established to cope with this

* STEP is an acronym which is used to describe the allocation of government funds to motivate projects with well defined objectives, goals and milestones and which are used for strategic technology positioning.

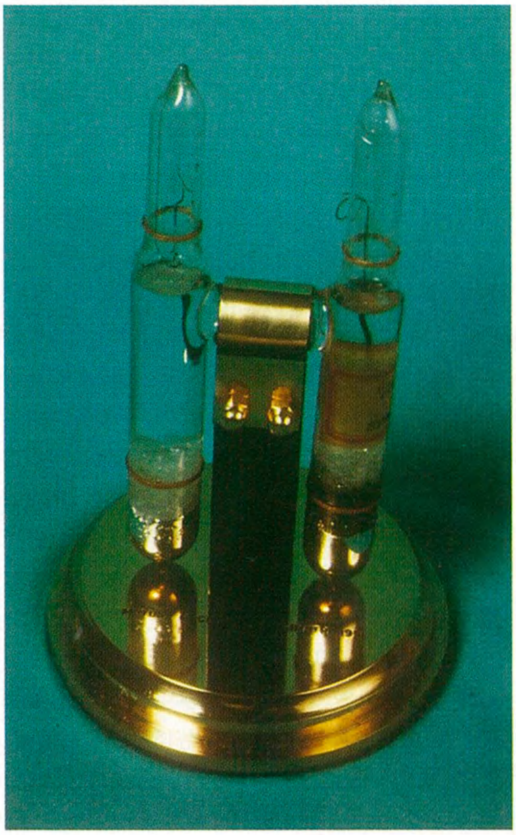
technology. The first steps in this regard were taken in 1986, with objectives including a standard optical fibre. During 1988 the West Tower wing of the Productiontek main building was structurally modified to accommodate an expanded optical fibre activity.

From 1988 onwards CSIR continued to change as dictated by new market opportunities. During 1992 a team appointed to investigate CSIR's manufacturing industry-related activities recommended consolidation of the activities of Productiontek and the Division of Aeronautical Systems Technology (Aerotek). Despite its name, the latter had been the equivalent of a national defence research institute (it had been created in 1988, virtually without change, out of what was once called the National Institute for Defence Research).

While Productiontek had many commercial clients, it lacked resources in terms of qualified engineers. Aerotek on the other hand had multitudinous human resources but an uncertain future defence client. The two divisions were formally amalgamated in 1993, creating a huge division, which required larger programmes in terms of staff. The activities of the measuring standards and the NCS were thus consolidated under Dick, while Franz took some of his staff to form a multidisciplinary programme tasked with the development of measuring instruments. Without the close support and cooperation of metrology the efforts of this group were less effective and Franz rejoined the new National Metrology Laboratory in 1995 following the retirement of Dick Turner.

Split in the responsibilities of the NML and NCS

With his new autonomy and retirement looming, one of the first moves made by Dr Turner was to lobby for independence of the NCS from the authority of the CSIR. This was in line with developments in Europe, where accreditation bodies had to be seen to be responsible directly to government, so that there could be no conflict of interest. Immediately following the successful acceptance of the NCS by the WECC, Dick with the assistance of DTI persuaded Geoff Garrett (then the Executive member responsible for Productiontek) of the need for independence



Weston cells as presented to ITRI, 1990

Marié Wimmers

Dr Bruce Foulis

of the accreditation body and DTI provided funding to the NCS to make this practical. While this independence was officially declared on 6 October 1993, the new NCS effectively came into being at its first AGM on 16 March 1994. The courageous acceptance by CSIR of the need for the NCS to become independent laid the foundation for the further development of the South African National Accreditation System (SANAS).

Both SABS and CSIR had over the years vied for the right to control accreditation, but the market need for transparency had destroyed the privilege of any organisation being able to accredit its own laboratories. Shortly after its own independence the NCS took over test house accreditation, formerly in the domain of SABS. For the NML, after a short period of some CSIR-aimed retribution, a good working relationship was attained under the new management. The NML itself was now for the first time able to function completely separately from the NCS, with full financial transparency.

On the retirement of Dick from the CSIR in 1994 he remained as Chief Executive of the NCS until early 1996, when he was succeeded by Mike Peet as Chief Executive and Sean McCurtain as Executive with special portfolio for international accreditation.

1994 to 1997 –the birth of the National Metrology Laboratory

In Dick's place CSIR appointed Marié Wimmers from outside the established metrology community. The appointment of Marié to replace Dick as the champion of South African metrology came as a surprise to the close-knit metrology fellowship. Marié was not a metrologist, and moreover possessed a degree in genetics! Her choice was, however, a rational decision by CSIR, as it was recognised that management skills rather than technical ability were the imperative. Marié's task was to rebuild the national metrology infrastructure to address the needs of the future, unencumbered by the problems and personality differences of the past.

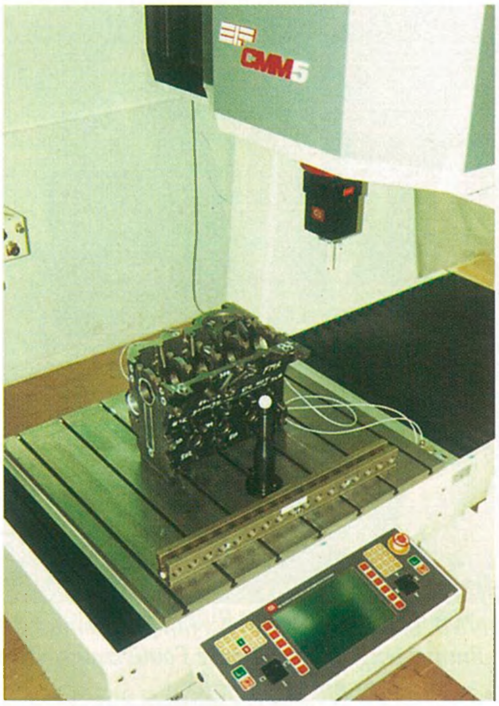
One of her first moves was to re-establish a new international identity through the use of the name National Metrology Laboratory (NML) to replace the name Metrology Programme. The laboratory association, a parlance which had been suppressed since the 1987 reorganisation of CSIR, still has great significance in the international metrology community. Marié also revitalised the metrology activities by tempting back some of the key individuals who had for various reasons of frustration left the metrology activity. These people included François Denner, who took control of the somewhat decimated radiometry and photometry project and Franz Hengstberger who became Section Manager of Electrical Metrology. Other key personnel including Willem Marais were encouraged to remain on as contracted consultants following their retirement. At the same time she was to prudently be a mentor to Bruce Foulis in the skills of management.

The NML management team, François Denner, Franz Hengstberger, Bruce Foulis and André van Tonder

While there was an obvious discord between the NCS and the NML, this was skilfully handled, with the result being the full commitment of her staff to her leadership. The appointment of Mike Peet as the new Chief Executive Officer of the NCS finally ended an ongoing conflict of interest between this body and the NML. Both SANAS (under which the NCS falls) and the NML, report directly to the DTI, and both now operate autonomously. The increased level of funding provided by the DTI now allows the NML the opportunity to acquire the required capital infrastructure necessary for it to act as the centre for southern African metrology, acting as the link to the international community through its BIPM membership.

Having fulfilled her objectives of restructuring and revitalising metrology at CSIR and of ensuring adequate funding for its continued development, Marié Wimmers took leave of absence during 1996 to attend an Advanced Leadership Programme and complete an MBL degree. In her absence she appointed Bruce Foulis as acting Manager of the NML, with the capable technical and scientific support of Franz Hengstberger, François Denner and André van Tonder. In late 1996 she accepted a position offered to her as Aerotek's HR and Quality Manager.

It came as little surprise to anyone when the appointment of Bruce Foulis as the new Manager was announced at the end of November 1996. Bruce had been a CSIR bursar and his interest in metrology had been aroused following vacation projects at Aerotek. He graduated with a PhD (Electronic Engineering) from the University of Natal (Durban) and joined the NML in 1993, his first assignment being contact thermometry. In his new role and with the fresh emphasis on regional metrology, Bruce will be assisted by Franz who will act as the regional coordinator of SADCMET (see page 49). The status of Franz in the international metrology community and his station in the CIE (Director of CIE Division 2, Physical



VW engine block being measured on the CMM

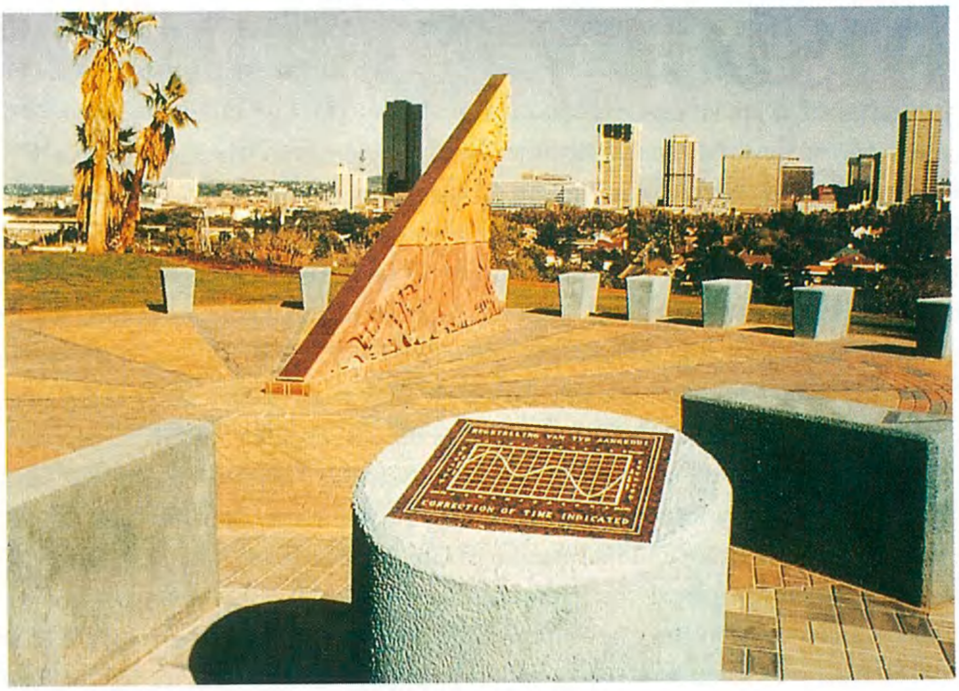
Measurement of Light and Radiation, since 1991) will no doubt facilitate the acceptance of SADCMET by the world community and the BIPM. Bruce's first task in his new position was to oversee the final negotiations with DTI regarding a R10 million capital injection into the metrology activities for use during the 1996/97 financial year. This special allocation was to allow the NML to address elimination of the technology backlog in terms of the primary standards maintained – an essential precursor to allow it to perform appropriately in its new regional metrology role.

Perhaps Waldo Penzhorn's period at the helm of the standards activities will best be remembered by his successful breakthrough in the creation of an independent SANAS which finally demolished the 'protection of turf' barriers which had unwittingly been created by SABS and CSIR, largely as a result of privatisation pressure on these bodies. Government itself, particularly following the appointment of Alec Erwin as Minister of Trade and Industry, has become increasingly aware of the role being played by metrology, both in terms of a critical supply-side requirement of local industry as well as South Africa's regional role. As a member of SADC, it has been realised that SA has a core responsibility. In terms of metrology and international measurement traceability and acceptance, the NML and SANAS are the keys.

A new relationship between Trade and Industry is now in place and a formal Memorandum of Agreement (MOA) is being negotiated. In terms of this both the NML and SANAS could be managed by DTI through a three to five year (annually reviewed) contract, which will allow much better forward planning of metrology developments, particularly strategic following the recent regional (SADC) agreements.

Since January 1997, the management of metrology activities at DTI has fallen under Eric Kruger, who succeeded Waldo on the latter's retirement. Eric brings with him many years of overseas experience with DTI, most recently an extended period with the EU in Brussels, where he spent a large amount of time advising exporters on how to comply with new directives. Arthur Boettcher, whose early career had been with the NPRL's Optical Sciences Division, also remains in close contact with the NML's financial needs.

The staff of the NML, March 1997



Large diameter sundial at Pretoria Zoo, with central city in the background

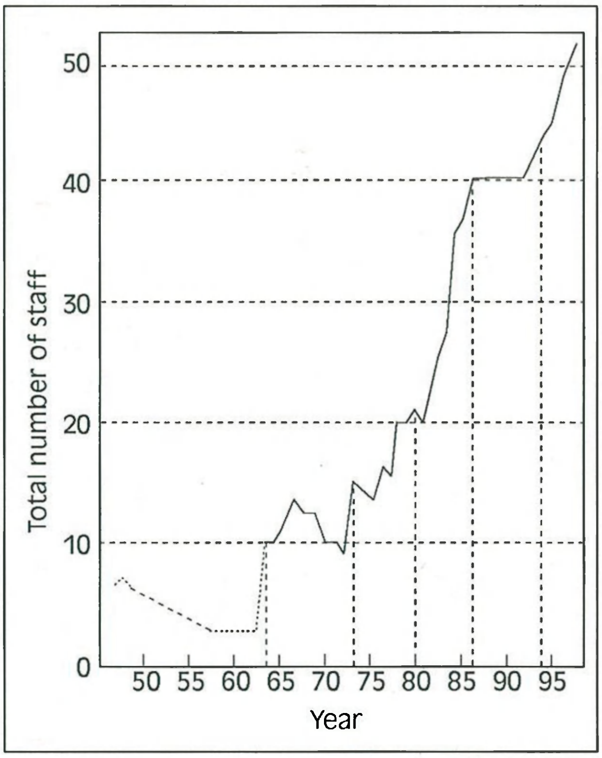
Delegates to the 1996 SADC metrology workshop

Beginning of a new era

While the period covered by this historical review equates to the first fifty years of the National Metrology Laboratory and scientific measurement in South Africa, it also coincides with the end of an epoch where South Africa was basically isolated from the rest of the world and its African neighbours. Although informal links have existed within the metrology fraternity for many years, the NML's formal representations for relationships were with Europe (WECC), America (NIST) and Taiwan (ITRI).

In the early 1990s the face of international metrology began to change. At its 81st meeting in September 1992 the Comite International des Poids et Mesures (CIPM) recognised both the impracticality of the BIPM working in all fields and at all levels as well as the existence of regional groups (including Euromet, Noramet and the Asia/Pacific Metrology Programme) of cooperating national standards laboratories. It was thus suggested that the BIPM could carry out comparisons with one or more of the regional reference laboratories which were signatories to the Convention du Mètre, while these in turn would organise regional intercomparisons, with these results being given wider international recognition.

This resolution reflected the exponentially increasing cost for individual BIPM member countries to continue to remain at the cutting edge of measurement technology in all areas of metrology and in principle allowed for regions to allocate their resources more cost-effectively. It also created new opportunities for developing countries to obtain internationally recognised traceability without the need for full membership of the BIPM.



NML staff complement

For metrology the realisation of a democratic South Africa in 1994 was opportune, as it provided the opportunity for the country to become a full member of the Southern Africa Development Community (SADC). Much work behind the scenes by the NML, NCS (now the NLA) and SABS led to a historic meeting of SADC metrology delegates in Pretoria in October 1996. It was then decided to create three regional umbrella organisations to represent respectively National Metrology Laboratories, Accreditation Bodies and Legal Metrology Organisations in the SADC region.

The regional organisation for the National Metrology Laboratories (Institutes) was given the acronym SADCMET in line with the European and North American precedents. The objectives of SADCMET include the achievement of international traceability for all metrology institutes in the region. South Africa (as the sole signatory of the Metre Convention within the region), through the NML, accepted a nomination to run the secretariat and appoint a regional coordinator for an initial period of three years. The choice of Franz Hengstberger as the regional coordinator was an obvious one by Bruce Foulis. SADCMET will coordinate all intercomparisons on a regional basis and report back to the BIPM to close the international traceability loop. It will also assist in the establishment of metrology infrastructure in the member states, and coordinate training.

The future

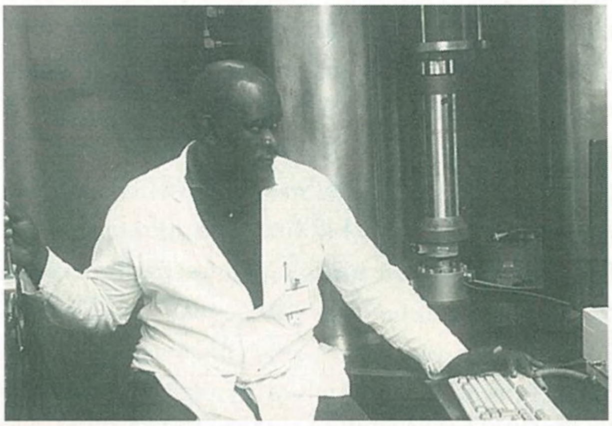
Whereas the existence of the NML in the past was based on the need to maintain standards and the existence of various historical Acts, the focus today is on how the Laboratory can be of assistance in making the local manufacturing industry more globally competitive. Without a growing export-based industry the reason for the continuation of the NML ceases to exist. With the full financial commitment of the DTI, the NML will now actively pursue a new goal, the establishment of a standard for the quantity of substance and the realisation of the SI unit, the mole.

NPL, NPRL, CSIR, Productiontek, NML – what's in a name?

Today the Institute which is known as South Africa's National Metrology Laboratory has the questionable distinction of having possessed more names and acronyms in its fifty year history than any other national standards laboratory.

At its inception, standards were the responsibility of the National Physical Laboratory (NPL) of the Council for Scientific and Industrial Research (abbreviated in the early days to C.S.I.R. and later CSIR). The NPL itself underwent a name change in 1957 to the National Physical Research Laboratory (NPRL). From 1947 to 1964 standards were maintained in the different discipline-oriented Sections of the NPL/NPRL, but in 1964 most standards activities were incorporated into a new Division of Precise Physical Measurements (PPM). In 1981 this Division was renamed National Measuring Standards and Metrology (NMS&M).

This situation remained until 1987/88, when CSIR itself underwent a major restructuring, the discipline-focussed Laboratories and Institutes being replaced by thirteen market-focussed Divisions. CSIR also changed its official name to the acronym only, being referred to as CSIR, or the CSIR. The metrology and standards activities from 1987 formed part of the Division of Production Technology (sobriquet Productiontek), but another change in structure resulted in two metrology programmes, Electro-magnetic (EMM) and Engineering (EM) Metrology. To add to the confusion, an unofficial acronym, DPT, was adopted by Productiontek in its early days, and this has appeared in some records of the BIPM.



Willy Magagula with the force system

In 1993 Productiontek was combined with another CSIR Division to form the Division of Manufacturing and Aeronautical Systems Technology (Aerotek) and the previous two programmes were combined into a single Metrology Programme. Following the appointment of Marié Wimmers in 1994 as Manager, this programme (a term not

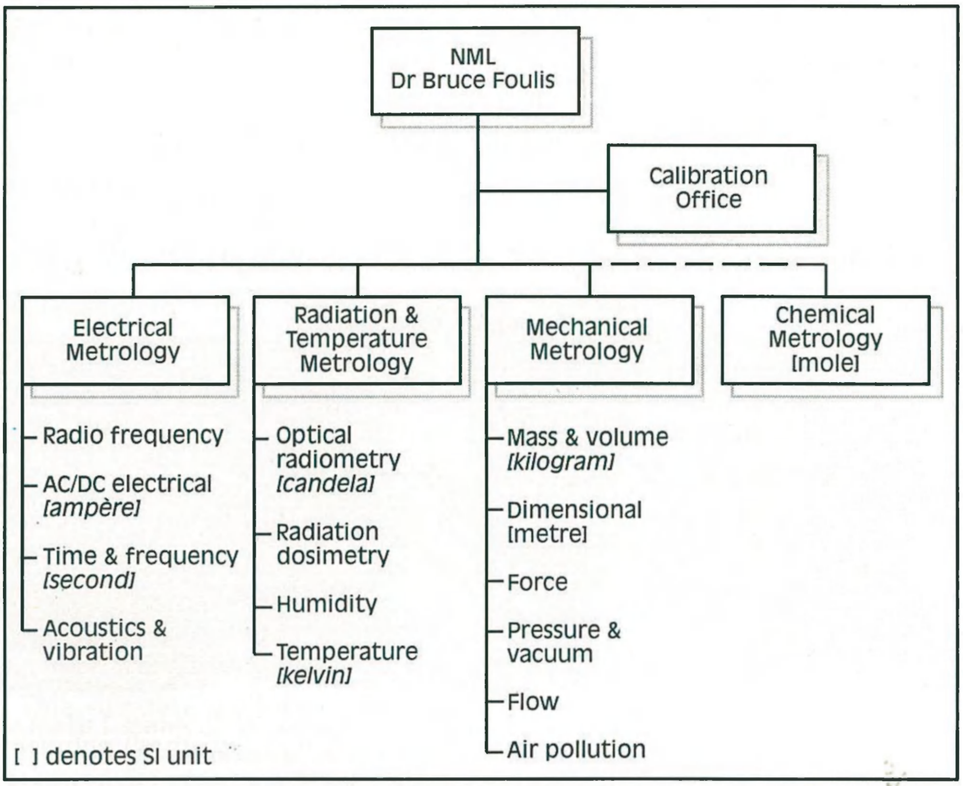
The main NML building in 1997 as viewed from the roof of the old NPRL Annex 1 which still houses many metrology laboratories in its basement

well understood internationally) was renamed the National Metrology Laboratory (NML). This terminology is in line with that accepted worldwide for metrology/standards bodies (eg NPL, Teddington, the National Research Laboratory of Metrology in Japan, and the Measurement Standards Laboratory of New Zealand). For the hard-pressed BIPM which has had difficulty keeping up with all the changes in names and acronyms, it provides a unique identity, NML, by which South Africa can be denoted in the results of international comparisons.

In this publication, it is the history of measurement which is being addressed and this is correctly the history of the NML, but depending on the period being covered the names NPL, NPRL, Productiontek, NML and CSIR are used and all refer to metrology activities unless otherwise specified.

Current structure of the NML

The order in which the areas of metrology are addressed in this history is arbitrary and does not reflect the current organisational structure of the Laboratory. For management purposes each of these fields operates as a project, with these being logically grouped as shown above into three sections managed by Dr Franz Hengstberger (Electrical Metrology), Francois



Structure of the NML, 1997

The calibration office with staff Obed Rapholo, Margie Grant, Leslie Kutumela, Leslie Merrington and Bennet Maepa

Denner (Radiation and Temperature Metrology) and André van Tonder (Mechanical Metrology). The SI units realised at the NML are shown in square brackets, with the mole yet to be achieved. The other areas of metrology realise a number of derived units which are of practical importance to industry. The calibration office administers the receipt and delivery of instruments and artifacts for calibration and is responsible for maintaining the records of calibration certificates issued.

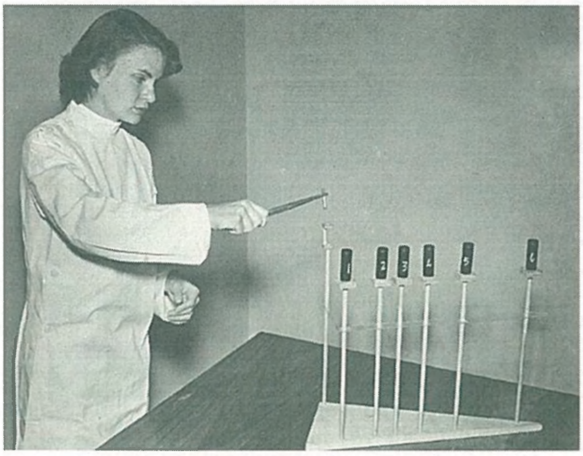
Radiation dosimetry

CSIR was born into the era of nuclear physics and "the NPL was required to take steps to ensure that South Africa would be provided with a group of specialists in nuclear energy and the use of radio-isotopes. It was in fact felt that there was a grave danger of abuse in the use of the new radioactive materials."

CSIR Council Meeting, October 1947.

Health hazards

The radiation age was ushered in by the discovery of X-rays by Roentgen in 1895 and of radioactivity by Becquerel in 1896. While X-rays were used as a medical diagnostic tool from 1895, early workers had no idea that radiation could cause damage to cells and tissue. It was to be well into the 20th century before the real danger was recognised and steps were taken to minimise the exposure of patients and radiation workers. In South Africa and Namibia an interesting application is the use of X-rays to screen employees leaving diamond mines after their working shifts (for possible presence of stolen diamonds). Before the Department of Health introduced its mandatory control regulations for the protection of all persons exposed to radiation, the CSIR provided a protection service for De Beers at the latter's request. Another area of mining in which radiation exposure is of importance is gold mining. In the local reefs there is a high uranium content and this can cause a significant radiation hazard.



Ilmary Reeler calibrating early film badges

The Biophysics Division, 1948 to 1955

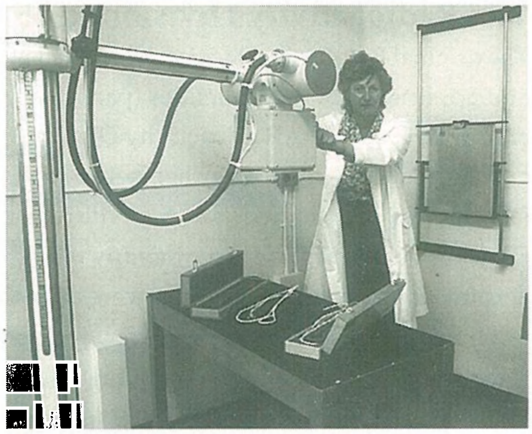
At the 7th CSIR Council meeting held in October 1947 it was reported that Dr Schonland had informed the Medical and Dental Council that the NPL was taking steps to ensure that South Africa would be provided with a group of specialists in nuclear energy and the use of radio-isotopes. It was in fact felt that there was a grave danger of abuse in the use of the new radioactive materials.

As such, nuclear physics was a strong focus for the NPL and the laboratory moved rapidly to establish the basic techniques and necessary control measures. A biophysics activity was initiated on 1 April 1948 under the leadership of Tikvah Alper, who had some basic expertise in this area from her previous work in the UK. By 1949 the section had grown to include Lorene du Preez, Phil de Valence and Jack Wakeley. Lorene was to remain with CSIR for the rest of her career and is widely known for her contribution in this area.

Just about this time artificially produced radio-isotopes started to become available and Tikvah managed to get hold of some of these exotic materials. The two main sources of supply at that time were Harwell in the UK and Oakridge in the USA. The major problem for CSIR was how to rapidly transport short half-life radio-isotopes from overseas destinations, with carriage in an aircraft passenger cabin being out of the question. It was Eric Halliday who was to come forward with a unique and simple solution whereby they were carried in lightweight containers located in the wing-tips of passenger aircraft, allowing rapid transportation both within South Africa and internationally.

At that time one of the most common isotopes imported was Iodine-131, which was then being used worldwide in the diagnosis and treatment of thyroid problems, including excessive iodine secretion. The NPL staff would receive fortnightly consignments of this radioactive concentrate, prepare and measure doses according to the requirements of doctors and supervise in many cases the oral administration. This was the era before the medical physicist and the NPL was expected to provide such a complete service to hospitals. Measurements of radioactivity were made using Geiger counters which were calibrated against the activity of the imported substance after dilution into a sub-set of known activities. Stories abound of those days when the NPL appeared more

Halliday's scheme for transporting radio isotopes in lightweight containers in aircraft wing tips like a hospital out-patients department, than a physics research laboratory. In later years the role of the NPL diminished as hospitals acquired in-house skills and importation of isotopes reduced following the creation of a local production facility at the Atomic Energy Corporation. Cobalt and other specialised isotopes are still imported and most of the NML radiation sources were acquired from overseas.



Dorothy Schmidt with CSIR's X-ray facility in the late 80s

Another isotope in which there was significant interest in South Africa was Fe-59. The human body excretes the iron absorbed which it does not require and its progress through the body could be followed using this isotope as a tracer. The Fe-59 used was obtained from two sources, Oakridge and Harwell and at an early stage Lorene du Preez noticed an unusual discrepancy in the half-life of these two products. After significant effort, which contributed towards the bestowing of a Masters degree on Lorene, it was found that the American product was contaminated with a second iron isotope, Fe-55.

A 'film badge' service was introduced almost immediately after 1948 to determine radiation exposure of NPL scientists, a facility later extended to other radiation workers and hospitals. In the report for the year ended 5 October 1950 the following was recorded: "The film badge service is now being used throughout the Union. During the past year 346 badges have been used for standards and the protection of National Physical Laboratory staff, while 2355 have been issued to staff of 36 radiological departments, to whom reports have been issued each week of dosages received by staff members". The sensitive material in these badges was just strips of X-ray film, calibrated (by density) using a radium source at fixed distances. While the accuracy was low, the exposure was usually overestimated.

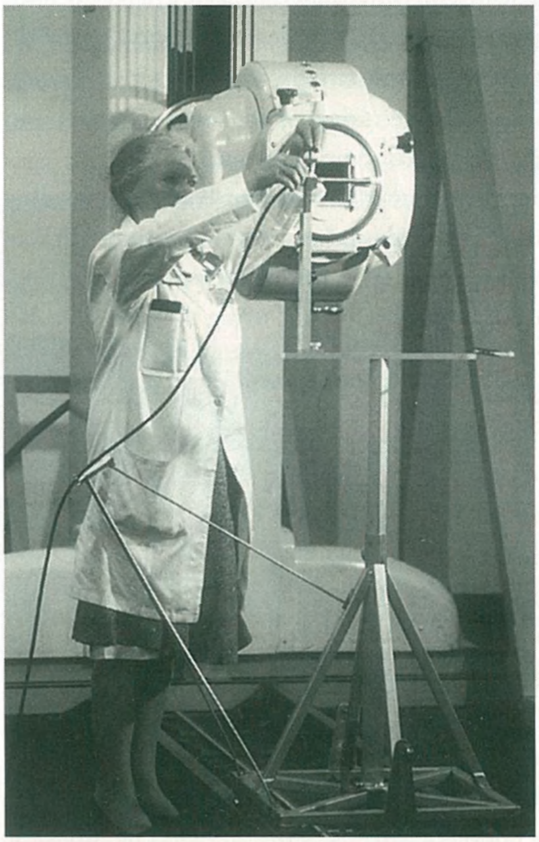
Over the years the film badge system developed in line with the technology developments in the UK (particularly at Harwell). New film holders which incorporated filters providing a more accurate representation of exposure were introduced. Advantage was taken of new X-ray film materials developed by both Ilford and Kodak.

The Biophysics group was to move to the new Scientia site before the rest of the NPL, as a high priority had been placed on the building of the cyclotron. The premises for this were completed in 1955, with further extensions in 1973 and 1984, the latter specifically for the biophysics activities, permitting the construction of purpose-built shielded facilities for the radiation dosimetry sources.

The Radioactivity Division, 1955 to 1964

The original Biophysics Division which had pioneered the importation, handling, distribution and application of radionuclides (particularly for medical applications) underwent a name change in 1955 to the Radioactivity Division. A primary reason for this was that the medical and agricultural institutes themselves had over time acquired their own radio-isotope laboratories and the work of the NPRL was to shift towards physical science. While the Division's activities in cancer therapy with Co-60, absorption of radio-iodine in the thyroid and tracer work with radio-iron were at an end, it was still called upon where the skills of these other institutes were inadequate, particularly in the area of instrument calibration, radiation protection and the handling of large quantities of radioactive material.

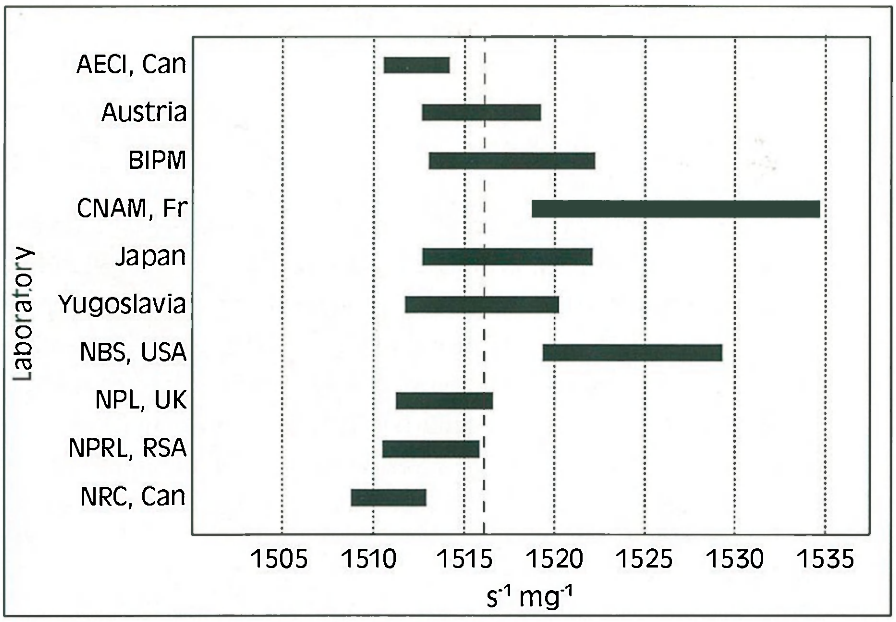
In 1956 the CSIR and the SABS were amalgamated and routine tests such as the badge service became an SABS responsibility. Lorene du Preez was at this time transferred into CSIR's X-ray standards activity. In 1962 SABS once again became an independent council and continued to take responsibility for routine X-ray exposure testing. By 1955 the NPRL's cyclotron had run for the first time and was used extensively until through time, technology and the creation of the National Accelerator Centre at Faure in the Cape, it became redundant. The cyclotron itself was only dismantled recently, the magnet now being a display piece at Faure.



Lorene du Preez with therapy Co-60 source

In September 1959 it was decided by government that 'peaceful' uses of atomic energy, particularly for the generation of electrical power, required a separate, autonomous research facility and what is known today as the Atomic Energy Corporation was born. The radiation measuring activities however remained the responsibility of the NPRL.

Attempts at the realisation of an X-ray dose standard suffered a severe set-back in 1962 when the rails of the ionisation chamber trolley tore loose from the floor. A new mounting system using special railway tracks and a cast concrete base was brought



International comparison of a Co-60 solution in 1963

into operation the following year.

By 1964 the Radioactivity Division was combined with the remainder of the NPRL's Nuclear Physics Division, which was responsible for operating the cyclotron. A major reason for this organisational change was the better utilisation of the expensive capital equipment. At this time the NPRL also reported that it was now in a position to supply standardised samples of most radionuclides. During the period 1963/64 extensive investigations were carried out for the Chamber of Mines into the concentration of radon in the uranium-producing mines.

The wider use of neutron sources, the Safari reactor at the AEC (1965) and the upcoming Koeberg nuclear power plant resulted in the need for exposure measurement capability for this radiation for protection purposes. An Americium-Beryllium (Am-Be) neutron source was thus acquired in 1965 from Harwell in the UK to maintain as a neutron standard. This was absolutely calibrated in a manganous sulphate bath and found to emit 6,327 X 10^6 neutrons per second with an accuracy of 1%. An intercomparison was made during 1965 with Canada's NRC using one of their Be sources. Results of the measurements on the neutron emission rates made in Pretoria and Ottawa agreed to within 1%.

During the 1960s the NPRL took part in an extensive international intercomparison of the nuclide Co-60, organised by the BIPM. A report on the results of this study was published in 1967 by the Bureau. From the CSIR's viewpoint the overall results were highly satisfying as the results from 23 of the 25 participants agreed to within ±0,5%, while the NPRL results were within 0,25% of the grand average.

1978, Radiation Dosimetry becomes part of Metrology

It was only at the beginning of 1978 that the Ionising Radiation Laboratory became a part of the Precise Physical Measurements Division. The PPM Division's responsibilities included dosimetry standards for X-rays, γ-rays and β-rays, and the checking of devices worn by radiation workers to measure their exposure.

The acquisition of the first Co-60 source by the NML in 1972 has a story surrounding it. The first such unit in the country had been acquired by the HF Verwoerd Hospital in Pretoria, but after some years' use it experienced wear problems in the mechanical parts used to perform patient scanning. Local company Siemens wanted to supply a competitive quote for a replacement up-to-date system and to improve its competitivity offered CSIR the old unit at a price less than that of the shielding required for a source of this size. Although the cobalt source itself has been replaced several times (Co-60 has a half-life of over 5 years), the complete system, for which the NML did not require the defective mechanical positioner, is still in use.

Radiation dosimetry today

Radiation dosimetry received a confidence boost in 1995 when DTI allocated R1,8 million for upgrading and replacement of aging equipment. A new X-ray unit was acquired as well as a new source for the Co-60 unit and a new therapy standard for X- and β-rays. Since the beginning of the 90s the activities have moved away from trying to maintain primary standards (costly in both money and manpower). Instead they have focussed on the provision of a high standard secondary calibration service, with international traceability to the NPL, Teddington. At present primary standards are maintained only for low energy β and X-rays.

Following the 1992 introduction of the Council for Nuclear Safety as the regulatory body for mines and mining activities, the protection level calibration facility activities were significantly boosted and all equipment used in this industry is required to be calibrated on a regular basis, allowing a proper assessment of the radiation hazard for workers. While the measurement of personal doses is the task of SABS, its measurement equipment still requires calibration by the NML. The process here is a fairly simple one in which Thermo-Luminescent Dosimeters (TLDs) provided by SABS are exposed by the NML to known doses, with SABS calibrating its specific instrument readings against these sub-standards.

The future

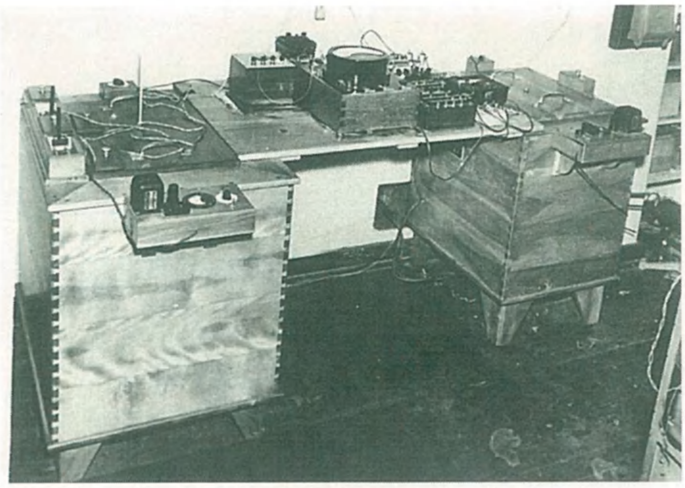
Despite the high levels of radon activity in local mines, standards are lacking and a prime focus of the project in the next few years will be the establishment of such an internationally traceable standards facility of which very few exist in the world today. It is particularly

South Africa's Atomic Energy Corporation produces radio isotopes for medical and industrial applications including Iodine-131, Molybdenum-99 and Caesium-137

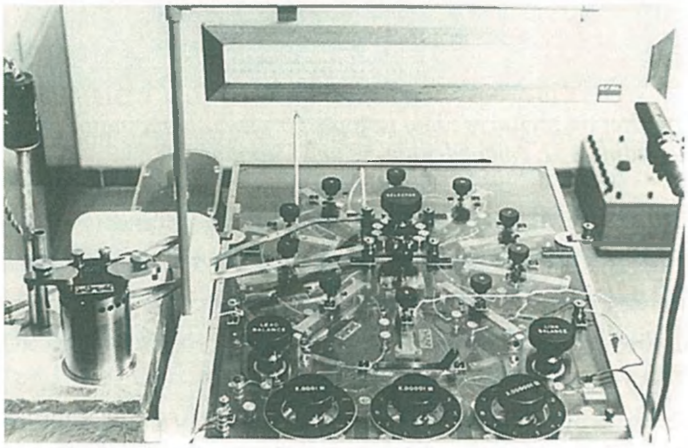
important to South Africa because of the high levels of this gas in the gold and uranium mines. The need for such a national facility has been heightened by government concern regarding (lack of) safety in the mining industry. CSIR now controls the previous Chamber of Mines Research Organisation, now known as Miningtek, which will cooperate with the NML in this regard.

Project leader Joëlle Pialat also sees an opportunity for the NML to play a major role in radiation dosimetry standards for southern Africa. Few southern African countries possess any well-established capability in this area and entry costs in terms of capital expense and training of manpower are high. Just as the NML relies on NPL for its traceability, members of SADC will be able to make use of South Africa's established capability in this area. While the CSIR withdrew many years ago from direct involvement in the use of radiation in hospitals, it is still responsible for the annual calibration of instruments used by medical institutions for the treatment of cancer. The National Accelerator Centre also obtains its traceability from the NML.

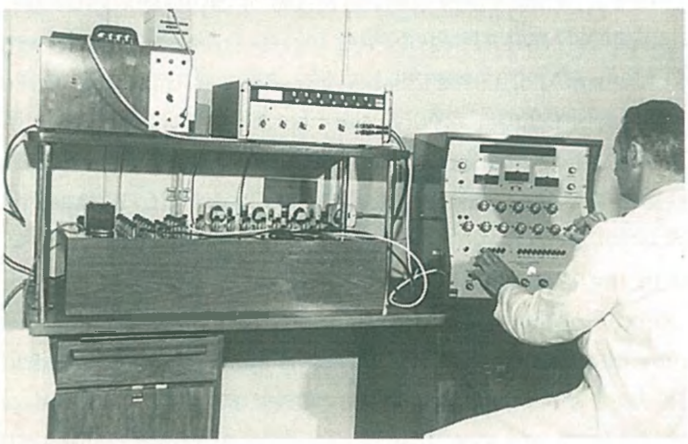
It is interesting to note that in the 1940s the theft of gold from mines was as big a problem as it is today. In the NPL Report for the year ending 5 October 1948, it was suggested that the mercury amalgam which contains the gold and which is stolen, could be made radioactive and could thus be detected on any person as he passes a sensitive detection instrument at the gate.



Two locally developed constant temperature enclosures used for standard cell comparison, 1948



The National group of 1 Ω resistors with Thomas-type on the left hand side, 1955



Willem Marais with the DC voltage standard, 1969

Electrical standards

"The practical unit of voltage (emf) is maintained in South Africa by a reference group of standard cells. Four of these cells were transported to the BIPM in Paris where it was found that the difference between the actual value of the cells and that assigned to them by the BIPM was 2 μV."

CSIR Annual Report, 1969.

In retrospect it was natural that the new NPL would place a strong initial emphasis on electrical standards. Dr Otto Brune, who at that time was a Professor at MIT (from which he had received a DSc in 1931), was appointed almost immediately to head up the Electrical Standards section. As a Senior Research Officer, he was the fourth most senior staff member in 1947 after Naudé, Guelke and Halliday. The section that Brune was to build up from nothing would eventually result in the birth of a new Institute of Electrical Engineering (NEERI), although the standards activities remained with the National Physical Laboratory. Brune was the Acting Director of the NPL from 1950 to 1952, retiring in 1966.

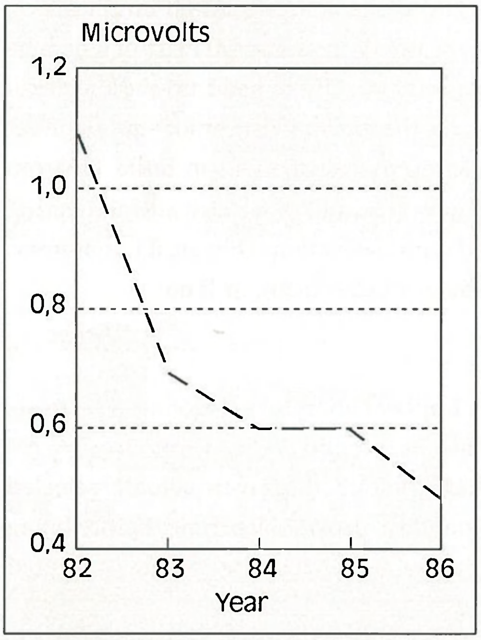
Voltage

One of Brune's first acts was to persuade America's Eppley Laboratory to donate a set of six Weston cells, which had originally been constructed in the mid 1920s. While for normal assets this would have been considered a 'secondhand handout', these were actually selected by Eppley because of their age and their inherent stability, proven over time. Before being brought to Pretoria in November that year (1946) by Dr Guelke, these cells were calibrated by both the NBS and the NPL, Teddington.

Apparatus for the comparison of these new voltage standards only became available in May 1947. In his laboratory notebook Brune commented on the lack of a sensitive galvanometer making it difficult to measure differences less than 5 μV. Today the same cells are measured by the NML with a precision of 10 nV. It is perhaps significant that the original measurement date, 20 May 1947, to the day represented 72 years from the signing of the Metre Convention.

These standard cells, referred to in the NPL's records as Group 453, were the beginning of a DC voltage standard for South Africa. It should be noted that while this cell was first produced by Weston in 1892, it is still widely used today as a primary standard, although most major national laboratories have converted to solid-state Josephson Junction technology. The timing of the acquisition of these standards was fortunate in that they incorporated the internationally accepted changes to the volt to make it compatible with SI units. Although the necessity for this change had been recognised in the 1930s, implementation had been delayed until after the end of World War 2.

By 1950 the standard cells had been augmented by two further groups of six cells (Eppley 471 and 481), calibrated by the NBS in 1949 and 1950 respectively. These cells had a long period of duty with CSIR and it is a tribute to the workmanship of the early 20th century that they are still mostly in working condition. Two of this original group departed too far from the average value and were removed from the temperature regulated enclosure in 1957 and 1961. The 453 group was removed from the national oil-bath group (typically 20 cells) during 1976. One of this original set was presented to ITRI, Taiwan, on the occasion of the mutual recognition of both countries' standards in 1993, and yet another is used as a display item on special occasions. The rest remain within the NML itself, a permanent reminder today of its 50-year history.



Average change in emf (at annual calibration) of 23 standard cell enclosures in South Africa

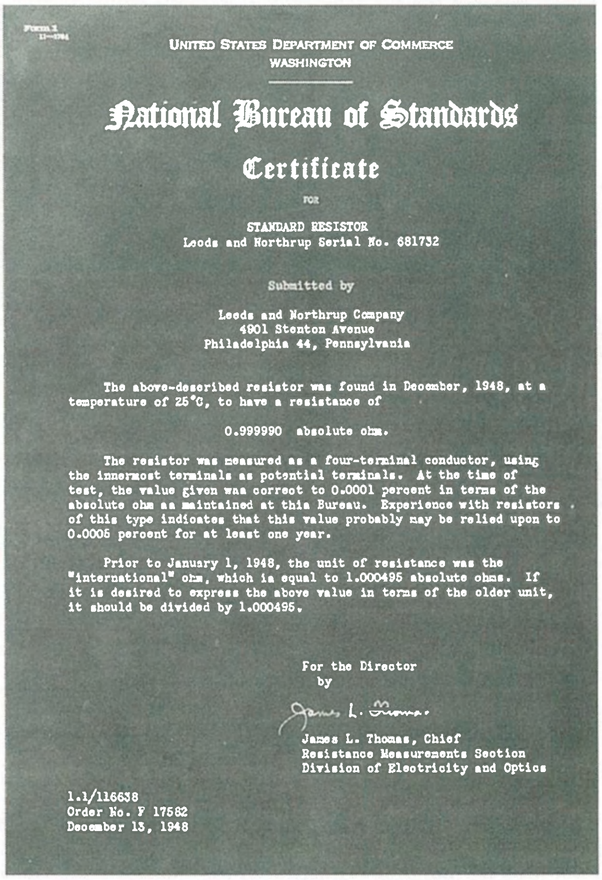
During 1969 another change to the volt was made by the BIPM and it became necessary for CSIR to check how far off its standard was. In July of that year Willem Marais was to hand carry a constant temperature enclosure with four cells and its battery supply to Paris for an intercomparison. The results of this were that South Africa was required to change its voltage unit by 9 μV and all countries started again from the same voltage reference.

In 1973 the SA volt was checked once more against the BIPM, a difference of +1,6 μV being recorded. Just after 1973 the BIPM switched to the use of a Josephson effect standard, and it was against this that the NPRL was to be compared in 1977. This time the recorded deviation from the BIPM was -1,8 μV. What this inferred was that between 1969 and 1977 the South African volt had effectively remained constant!

Intercomparisons of the volt (and other DC standards) now took place on a regular basis (every 3 to 4 years), but in the late 1980s the portable comparison standard was changed to one using solid-state technology. In 1986, recognising the achievements of the NPRL in electrical standards the laboratory was invited to become a member of the CCE (the BIPM's advisory committee on electricity) with Willem Marais as the South African delegate.

In 1989 the Weston cell was replaced as the international reference standard by the Josephson Junction. In the theoretical equations which describe the Josephson effect, the generic constant, K, is related to the ratio of elementary charge (e) to Planck's constant (h) through $K = 2e/h$. In late 1988 the BIPM recommended that all laboratories use the same value for this constant, and the new assigned value came into effect on 1 January, 1990. This necessitated a further change in the national volt by -8,6 μV.

The NML first operated its own 1,018 V Josephson Junction in February 1993, largely as a result of the efforts of Owen Cramer who received substantial assistance from both NIST, USA and the PTB. Although the average of the Weston cell group (18 cells) remained until recently the national standard, the stability of this group was regularly monitored using the Josephson as a primary reference standard. Corrections are then applied to the national volt as required. The Josephson is in the process of being declared a national measuring standard and will be used to maintain international traceability without the need to transport other electronic



UNITED STATES DEPARTMENT OF COMMERCE
WASHINGTON

National Bureau of Standards

Certificate

FOR

STANDARD RESISTOR
Leeds and Northrup Serial No. 681732

Submitted by

Leeds and Northrup Company
4901 Stenton Avenue
Philadelphia 44, Pennsylvania

The above-described resistor was found in December, 1948, at a temperature of 25°C, to have a resistance of

0.999990 absolute ohm.

The resistor was measured as a four-terminal conductor, using the innermost terminals as potential terminals. At the time of test, the value given was correct to 0.0001 percent in terms of the absolute ohm as maintained at this Bureau. Experience with resistors of this type indicates that this value probably may be relied upon to 0.0005 percent for at least one year.

Prior to January 1, 1948, the unit of resistance was the "international" ohm, which is equal to 1.000495 absolute ohms. If it is desired to express the above value in terms of the older unit, it should be divided by 1.000495.

For the Director
by

James L. Thomas, Chief
Resistance Measurements Section
Division of Electricity and Optics

1.1/116638
Order No. F 17582
December 13, 1948

1948 NBS certificate of Thomas-type resistor, signed by the inventor voltage references to the BIPM. The best measurement capability for DC voltage in late 1996 was 0,5 ppm at both 1,018 V and 10 V.

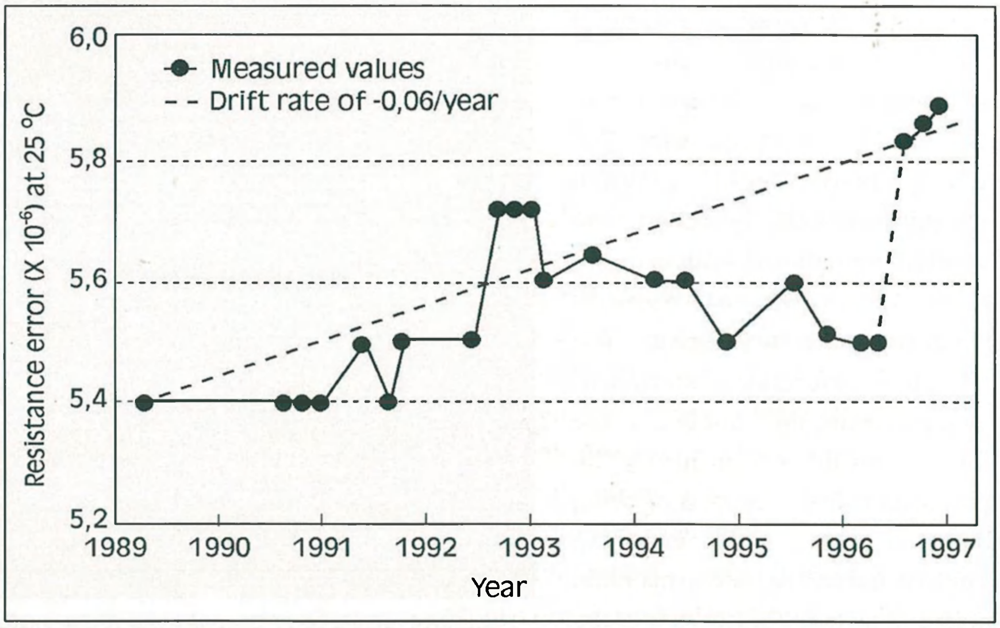
During the initial period of operation of the Josephson, a number of Fluke 732A electronic references were calibrated at 1,018 V. In a comparison with the bank of Weston cells the agreement was better than the uncertainty level at 0,1 µV.

Resistance

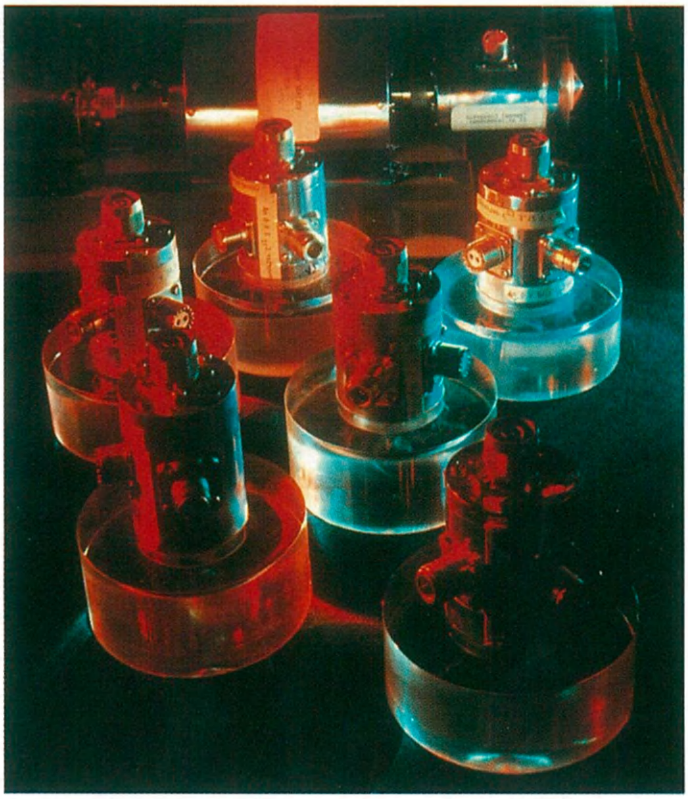
The first working standards of resistance were brought to South Africa shortly after the Weston cells. These Muirhead resistors had been manufactured in the UK and calibrated by the NPL during late 1947. They were carried to Pretoria by Dr William Rapson (first Director of CSIR's National Chemical Research Laboratory) in October of that year.

Another early purchase was a number of 1 Ω standard resistors from Leeds and Northrup, of which the first arrived in January 1948 (ten in total with the last arriving in 1962). These were to remain the national standards for resistance. The carefully preserved original NBS calibration certificate of one of these, serial number 681732, is signed by James L Thomas, the original inventor of this legendary standard, which was manufactured under licence by Leeds and Northrup.

The NML took part in its first international comparison of the national 1 Ω resistance standards during 1973. While twelve standards laboratories took part, including the BIPM, some of these submitted up to four standards of their own, which were compared against



Measured resistance of 1 Ω Thomas-type resistor number 1146606 each other. As a result this international exercise involved 42 standards, with 198 comparisons being made. The huge amount of work involved in this intercomparison is one of the justifications for the more recent introduction of regions. This same intercomparison at the uppermost level would have involved only four sets of standards, with a single country representing the regional areas of Europe, North America, South East Asia and Southern Africa.



A set of national AC/DC transfer standards (single junction thermal converters), 1986

The spread of values obtained from this comparison was excellent*, being in the region of 2 μΩ, with NPRL at the upper and the NRC at the lower extremes. The CSIR results are particularly good as in order to get a better international uniformity the PTB, NSL, NRC, LCIE and NPL had all adjusted their national references to the BIPM value in 1969, while in 1957 the ASMW decreased the value of its 1Ω resistance by 16,9 μΩ.

The Thomas-type resistor was a very stable standard compared to the Weston cell. In 1995/96 two were subject to an intercomparison with the BIPM, one of which was serial number 1146606, originally acquired in 1957. The resistance error over the period 1989 to 1996 is shown in the figure opposite, which includes its previous BIPM intercomparisons in 1989 and 1992. The adjustment required in 1996 was 0,35 μΩ which had an uncertainty of 0,15 μΩ. From the figure it is clear that the change of resistance over time can be explained through a constant drift rate of 0,06 μΩ per year, an outcome which provided Willem much personal satisfaction.

One of these original Thomas resistors was eventually found to exceed CSIR's strict

*Intercomparisons with the BIPM were complicated by the need to make a temperature (the high ambient temperature of Pretoria requires resistors to be maintained at 25 °C rather than 20 °C as at the BIPM) and a pressure correction.

DC electrical laboratory, 1985

stability requirements in the early 1960s and through normal practice was disposed of by tender. Willem Marais, who had joined the group in 1957, purchased this artifact for a mere ten SA cents. Not appreciating at that time its true historical value, he was eventually persuaded to sell it (at exorbitant profit) for R10 to a friend of Jack Whittaker. The Thomas resistor was to disappear from sight for many years, only to reappear at the Eskom Laboratory in the town of Witbank. Today it is a treasured item in the museum and is still regularly calibrated by the NML. The rest of these resistors remain carefully preserved in their thermostatically controlled oil bath and Willem, now semi-retired, still believes there is nothing better. Over their lifetime the drift as measured by numerous international intercomparisons with the BIPM and elsewhere has been less than 0,1 ppm per year.

Until the end of 1989, the reference standard of resistance maintained by the BIPM was also a group of 1Ω manganin resistors and intercomparisons were carried out using wire-wound standards. As of January 1990 the Quantized Hall Resistance (QHR) was adopted as the reference standard. In late 1996 DTI made the finances available to the NML to acquire a QHR system including a cryogenic current comparator resistance bridge as developed by the NPL, Teddington and now produced under licence by Oxford Instruments of the UK. This instrument, complete with a Heliox Helium insert to provide a temperature range of 300 mK to 300 K will be fully operational by late 1997.

The calculable capacitor

"The calculations and experiments of Dr Lampard and Mr Thompson (NSL) confirmed the possibility of creating a calculable standard whose capacitance could be calculated from a single length measurement."

Nature, 1956.

During the formative years the electrical activity was fortunate to acquire the services of J A (Jack) Whittaker in 1947. He had come into contact with CSIR staff on overseas visits and was responsible for building some of the instruments ordered from the UK in those days.

Being naturally inquisitive he was lured by that subtle attraction of Africa and was to contribute significantly to activities in electrical standardisation and measurement. One of Jack's first initiatives was to create a system for the meticulous recording of all work in carefully kept hard-backed notebooks, which still exist to this day. This system was continued by his successors, with incorrect entries carefully stroked out and signed for authenticity.

Jack Whittaker was a brilliant metrologist and was involved in the development of a calculable capacitor. The first example was demonstrated during 1965 and was found to be stable as predicted. Arrangements were immediately made to bring to South Africa a fixed condensor made by the NBS for an intercomparison. Whittaker had hoped to achieve a stability of better than one part per million, but experiments during 1966 dashed his hopes, revealing a design error which resulted in a new derivative being developed. This advanced work for its time received a devastating blow during 1969 with the untimely death of Jack when further work was abandoned. His death and the loss of his irreplaceable expertise was to lead to a change in focus in electrical metrology away from development and more towards the maintenance of existing standards within the limited budget and later the transfer of such standards into industry through the NCS.

The objective of the calculable capacitor development had been to produce a fixed capacitor with a stability of better than one part in a million and to enable South Africa to carry out intercomparisons with other national standards of capacitance. The capacitance was to be determined by means of a single measurement of length, for which local traceable standards already existed. This work was based on the earlier (1950s) pioneering efforts of Thompson and Lampard of the National Standards Laboratory (NSL) in Australia.

With the acquisition of a Quantum Hall resistance standard in 1997, the NML is now planning to resume work on an independent capacitance standard. It will be devised from the resistance standard by means of a quadrature bridge.

AC/DC transfer

"For the accuracy required, the choice between the various types of standards to perform a.c./d.c. (sic) transfer duty was not easily made."
Jack Whittaker, NPL, South Africa, 1953.

One of the many successes achieved by Whittaker was the development of a precision electrodynamic AC/DC transfer instrument, this work being published in 1954[1]. The standards of voltage and resistance were the Weston cell and Thomas-type resistor and were compared using DC measurements. Jack's objective was to develop a standard instrument, as accurate with DC as AC, to transfer the readings of an AC instrument to the equivalent DC values. After carefully weighing up the options available, Whittaker decided to develop an electrodynamic instrument similar to that described by the NBS in 1940. The instrument could be used as a wattmeter, voltmeter, ammeter and milliammeter with an accuracy (full scale deflection) of 0,01% on both 50 Hz AC and DC supplies.

In his description of the construction, the craftsmanship of that era is reflected by the portraiture of the supporting framework: "The frame and base of the standard are made from white Italian marble. This material is physically stable and its electrical properties are adequate for the purpose. A close-fitting wood and glass case protects the standard from draughts and excludes dust".

In another publication[7] Brune and Whittaker referred to the use of this instrument as a primary standard wattmeter, where the combination of voltage and current requires an instrument rather than a material standard. Once again the need was for measurement of AC power. The accuracy was quoted as better than 1 part in 10^4, which at that time was considered to be limited by the available AC power supplies. It was indicated that the design of the South African standard was influenced by the need for greater ruggedness, ease of use and freedom from external influences rather than greater accuracy or long-term stability.

The ULE capacitor

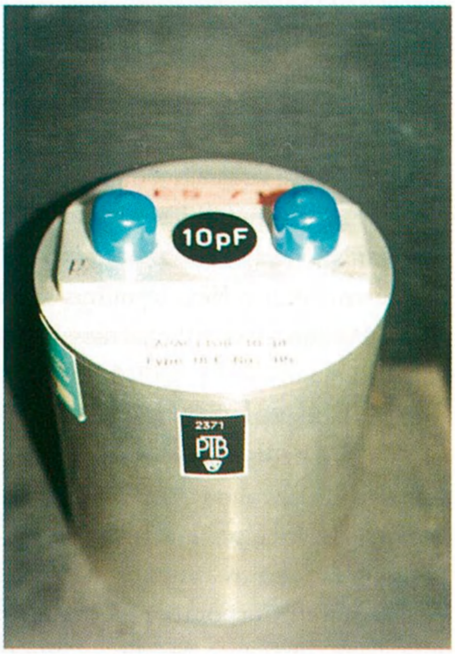
"The possibility existed for CSIR to make a material contribution in the field of standard capacitors with this local design and preparations were in progress to patent the concept."

NPRL Annual Report, 1975.

Part of the story of the stable capacitor is recounted under dimensional metrology. The development of this capacitor was a multi-disciplinary team effort, with the group consisting of Willem Marais, Cor van der Hoeven and Ben van der Wagen. Willem first suggested the use of a capacitive probe to solve a dimensional problem. Cor used his ingenuity to come up with a completely new capacitor design, as the NPRL could not afford to buy a commercial item. Cor and Ben then tackled the complex manufacture including various quartz to metal seals, while Willem added to this the essential electrical knowledge.

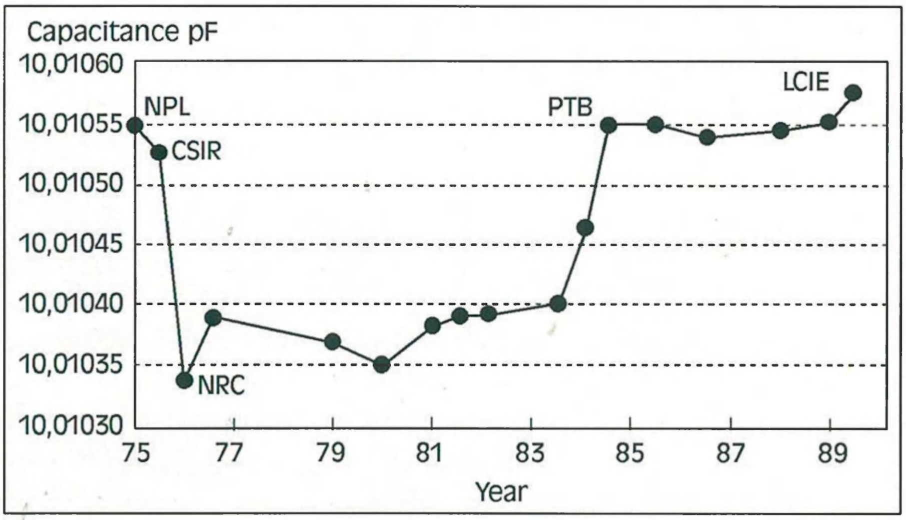
The capacitor was constructed from ultra low expansion (ULE) quartz. The plates were of concentric cylinder form, with a gas dielectric and metal conductive coatings on the quartz. The work, although original, was never written up or published (as yet!) for various reasons, including the long period of time which was to elapse before the true potential was realised. Six of these novel capacitors were constructed in the early 70s, the metal coatings and dielectric being varied. One of these, designated B5 and constructed in 1975, was to travel widely throughout the world over the next 15 years. B5 was constructed using nitrogen gas as dielectric with gold-plated electrodes. Attempts to use a vacuum dielectric were abandoned at an early stage in development as a result of the tendency for this to leak over time.

1975 was the occasion of a special workshop held in Pretoria to celebrate the centennial of the signing of the Metre Convention. One of the overseas guests was Guy Sutcliffe, the owner of Guildline in Canada, a well-known manufacturer of measuring instruments. He expressed an interest in the CSIR development and B5 was tested at the NRC in Ottawa. The NRC measurement indicated a significant deviation from the early measurements at both the NPL and CSIR. Repeated measurements at CSIR over the following decade were consistent with the poor Canadian results and it was almost a decade before measurements at the PTB confirmed those of 1975.



ULE capacitor No B5, 1997

The problem was that the measurements at CSIR, following the return of B5 from the NRC had been made against a new standard GenRad capacitor, without realising that this device tended to be unstable during its early life. Exactly the same characteristic was observed in measurements carried out on ULE capacitor No 1 (which had a gold outside and chrome inside electrodes) over a period from



10 pF ULE capacitor No B5 at 23 °C

1978, with high stability after 1985. In fact it has been confirmed that over 21 years the change in capacitance did not exceed 4 ppm and combined with its extremely low temperature coefficient of capacitance (less than 1 ppm per °C) it is an ideal design for a comparison standard.

For South Africa it today fulfils that role and was used as such during the WECC audit of the NML's capabilities prior to recognition of the NCS. The lesson to be learned from this and the NML experience with the Thomas-type resistor is that metrology is still a science where systematic, long-term measurements are required to ensure correctness and where some standards actually become better with time, not unlike some fine wines.

The CSIR calibration centre for electronic instruments

"The state of measurement science and practice in a country is one of the surest signs of its technical efficiency."

Cyril Dodd in CSIR's TI (Technical Information for Industry), March 1971.

Long before the creation of the NCS, certain industries, particularly Eskom, Marconi and Atlas Aircraft Corporation, recognised the need to be able to calibrate their own electronic and electrical instrumentation. Within the CSIR itself, a similar requirement was identified by what was to become the National Electrical Engineering Research Institute (NEERI). In fact the demand for more routine calibrations was indicated in the 1964/65 Annual Report of the NPRL which stated: "The demand for the calibration of electrical instruments by this Laboratory continues to increase....92 instruments were calibrated, an increase of 30% over the previous year....Fees for the calibration of electrical instruments totalled R1750 for the year under review."

As was often the case in those days, local expertise was lacking, but Cyril Dodd, Head of the Naval Calibration Laboratory in Portsmouth fortuitously applied for a position at CSIR. He was immediately appointed and commenced work at the Scientia site in February 1969, his task being the creation of a calibration laboratory for electronic instrumentation, with CSIR's Institutes being the identified primary customers. On his arrival his laboratory accommodation in the Mathematics building was hardly auspicious, the expected air-conditioning turning out to be a one-speed electric fan. By the end of that year, however, Cyril had properly established himself in a suitably equipped laboratory in the Heat Mechanics building. The Calibration Laboratory was to remain here until the completion of the new NEERI building on the South side of the Scientia campus in 1976.

Whereas one of the motivations for the NEERI facility was to provide for calibration of CSIR's electronic instruments, the scientists were too canny to spend their precious running money on calibration, preferring to believe the manufacturers' specifications and test results. The original concept that all instruments on-site would be calibrated and kept up-to-date through a proper re-calibration register failed to materialise, and the service soon found industry more receptive to its services.

It is interesting to note that Cyril's results of an analysis of new instruments passing through the calibration centre between 1969 and 1971 found that over 50% were out of specification and often had to be returned to the manufacturer for correct setting. It is not known whether this was peculiar to South Africa, but certainly less reputable manufacturers often viewed this country as part of Darkest Africa and did not expect to be confronted with internationally-traceable results which indicated non-compliance with specification.

As originally conceived, NEERI's Electronic Instrumentation Division was intended to be complementary to the national standards activities of the NPRL, providing calibrations traceable (but of lower order of accuracy) to the latter. The CSIR's TI newsletter of March 1971, clearly indicated "that all measurements made in the air-conditioned calibration centre were directly traceable to the national standards at the NPRL". Following the creation of the NCS in which Cyril's lab was one of the founder members in the electrical area there was some conflict as to whether through its calibration work CSIR was not robbing private industry of such income.

Despite being wooed on several occasions by Dick Turner, the calibration centre remained with NEERI until the reorganisation of the CSIR in 1987, when Gérard Pialat, André Louw and Cyril joined the Electromagnetic Metrology Programme of Productiontek under Franz Hengstberger. As CSIR's (state-subsidised) calibrations were still of some concern to certain NCS members, the non-specialist calibration activities of this group were discontinued. Cyril was now to focus on RF work, while Gérard returned to the field of time and frequency in which he had specialised while at the Paardefontein Tracking Station.

In retrospect it is of note that NEERI had promulgated many of the ideals that the NCS was to turn into reality. The TI document stated: "It is essential that any technologically advanced country, particularly one wishing to export sophisticated goods, should have its own comprehensive system of national standards of measurement, tied to recognised international standards (as per Act 76 of 1973) and also facilities for checking and calibrating measuring instruments against such standards so that their accuracy can be authenticated."

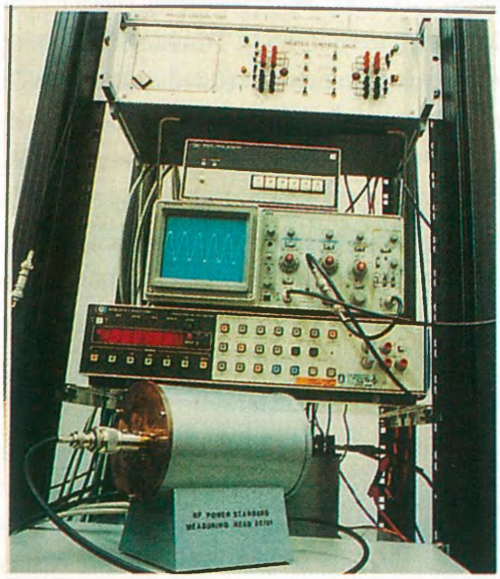
George Poray in the AC laboratory, 1981

Radio frequency (RF)

Work in RF only started within the NML following the appointment in 1977 of George Poray from SABS. Prior to this Cyril Dodd and NEERI had been in discussions with Armscor which had identified the need for calibration facilities in both the RF and microwave regions. RF was recognised as a field which was highly capital intensive and the defence procurement agency could have been the ideal partner. In the event these negotiations with CSIR floundered and an arrangement was made with a private sector company. It was however Armscor which provided funding for CSIR's purchase of a piston attenuator and in the late 70s and early 80s basic calibration standards (commercial equipment) were established for RF power, impedance and attenuation. At the same time the NEERI calibration lab continued to provide general RF services.

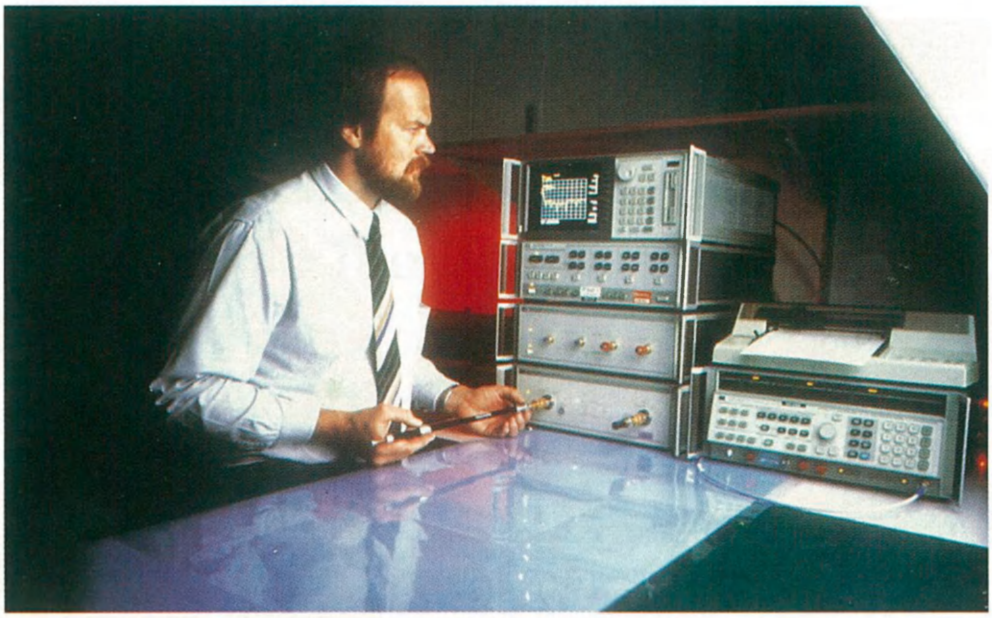
During 1982 Erik Dressler was appointed to RF metrology to complement Poray. Not an RF specialist, he was initially to work in radiometry, specifically to investigate the possible use of the absolute radiometer technology for RF power standards. By 1986 he had a 50 Ω national standard for RF power operational. Although by now more involved with other RF activities, Erik continued this development, which resulted in a 75 Ω head being available in 1991, with a completely new electronics system usable for both the radiometric and RF systems. This system was constructed as part of a joint venture with SIRA in the UK, who were at that time interested in commercialisation of this radiometer.

By the mid 80s a vector network analyser (VNA) for impedance measurements had been acquired, although it was to be somewhat later before coaxial air-dielectric transmission lines were purchased, which subsequently were gazetted as the national RF impedance standards. As George was approaching retirement age, Daan van Rensburg was appointed to join Erik but he resigned in 1989. By this time CSIR had undergone its reorganisation, and Cyril Dodd, who had initially transferred his calibration laboratory facilities to Franz Hengstberger in 1988, joined Erik to handle RF. This team was complemented in April 1996 with the appointment of a former bursar, Chris Matthee, whose specialist expertise lies in computer software and automation of measuring systems.



50 Ω RF power standard, 1986

During 1993 the frequency range covered



Eric Dressler calibrating the vector network analysis system, 1996

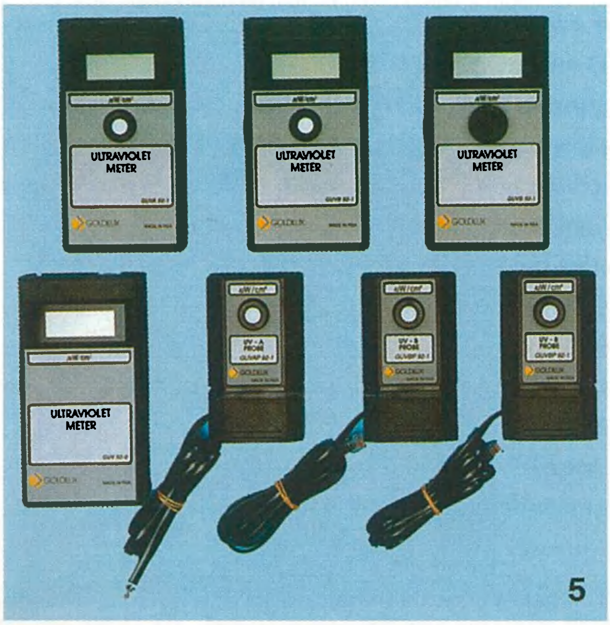
was increased from 18 to 26,5 GHz, with a parallel update of the VNA into S parameter measurement. Pressure from the local RF community has resulted in the acquisition during 1996 of a 50 GHz source and full operation in this band is envisaged by late 1998. The recent capital equipment upgrading programme, funded by DTI has also seen the acquisition of a spectrum analyser (26,5 GHz) and an additional VNA (30 kHz to 3 GHz) to facilitate automated measurement of 50 and 75 Ω devices below 45 MHz.

While RF has benefited from the support of the DTI, Aerotek itself has significant interest in such capabilities, and it was CSIR capital funding which in 1996 enabled the replacement of obsolete equipment in attenuation facilitating measurements up to 100 dB at frequencies up to 26,5 GHz. The local interest in RF can be illustrated by the fact that in 1995 there were 13 accredited laboratories operating in this field of metrology.

While international links up to 1990 were mainly with the PTB, successful intercomparisons have been carried out in recent years with the NPL, Teddington, ITRI and the LCIE. The latter two formed part of the process of establishing the mutual recognition agreements with both Taiwan and the WECC. More recently (1995) Erik was invited to participate in the RF Working Group of the BIPM, of which he is now a permanent member. He is involved in the regular meetings of the RF working groups of EUROMET and EAL.

As elsewhere in this monograph the recording of the history of electrical standards has been limited by available space. It is for this reason that only a few of the more intriguing tales have been recounted.

Some of the Goldilux range of optical radiation measuring instruments, developed by the NML and manufactured by MIT of Pretoria.
1) Roy Smith with tail light brightness meter,
2) Stoffel Kok with windscreen transmissometer,
3) microprocessor-controlled light meter,
4) early light meter with built-in probe and
5) range of UV meter and probes.



Commercial products

"The Division of Production Technology's goals are...to develop and promote new and improved manufacturing and processing systems, as well as specialised products and services."

Extract from Mission and Objectives of Productiontek, 1988.

In terms of the above goal of Productiontek the metrology activities were to set an outstanding example to the rest of CSIR in the development of a wide range of commercial measuring products. These were produced under a variety of registered trade names, including Acumet and Goldilux.

Goldilux light measuring products

One of the most successful commercialisation efforts of the Productiontek era was the development by the Electromagnetic Metrology Programme (EMP) of a range of optical radiation measuring instruments, today manufactured under CSIR's Goldilux trade name.

The name Goldilux was derived from the appearance of the unique yellow diffuser/ filter that the lightmeter incorporates and from the unit of measurement, the lux. This patented filter was the ultimate conclusion of much research carried out by CSIR on both the development of filter glasses and Fabry-Perot type interference filters which could closely simulate the V(λ) response characteristic. The Goldilux range made use of a commercially available yellow light-transmitting material, which when combined with standard filter glasses of selected thickness gave near perfect emulation.

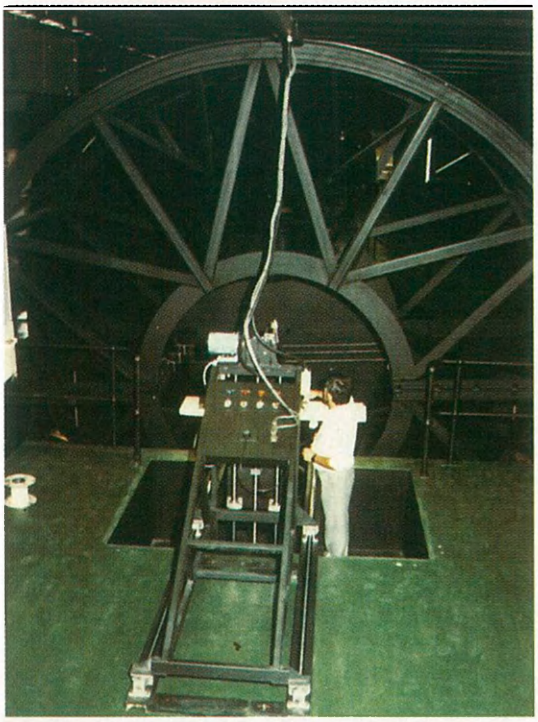
This patented low-cost method of accurately simulating the V(λ) photopic response characteristic resulted in the development of a series of light meters, which was expanded using more conventional filter technology to include some of the first UV meters to correctly simulate the spectral characteristics of the CIE-defined A, B and C regions. The Goldilux was one of the first handheld lightmeters to be specified in terms of the CIE quality parameters, a trend which has now been adopted by leading manufacturers of luxmeters worldwide. This use of the these parameters was not coincidental as Hengstberger had played a major role in the committee responsible for this directly comparable method of specification.

More recent developments of the Goldilux range include laser power meters and UV and near-UV meters with special characteristics, including one covering the spectral range for bilirubin. The commercialisation of these products has evolved through several manufacturers, but since 1993 all products have been manufactured under licence to CSIR by Measuring Instruments Technology (MIT) of Pretoria. More than half of its current production is exported, major markets being North America and Europe.

Road traffic devices

The new South African Consolidated Road Traffic Regulations of 1990 were to introduce two relatively unique requirements in terms of motor vehicles. The first was the enforcement of a minimum transmission limit on tinted windows in vehicles for both safety and security reasons. The second was the specification of minimum visual brightness of both tail and brake lights. South African law now permits traffic officers to check for contravention of these regulations as part of their routine duty, while testing is mandatory for roadworthy checking.

A special handheld portable transmissometer (tint meter) was developed and is widely in use throughout South Africa today, having been sold to most of the country's vehicle testing stations. A tail-light meter, capable of measuring the brightness of tail and brake lights has also been successfully marketed.



The Lascon light measuring robot

Commercial light measuring robot

Following the completion of the laboratory's own goniophotometer in 1983, CSIR was approached by Lascon Lighting, part of the Altech Group, to develop an industrial system suitable for light measurements on its range of lighting products, including luminaires. This unit of a novel wheel-type construction, in which the luminaire (or other light fitting) remains fixed, was completed in 1987. The system is fully automated and was built at some 50% of the cost of an imported system, while being technologically superior. This unit has been in continual use since installation and Lascon remains the only NCS-accredited photometric laboratory in South Africa outside of the CSIR itself.

Tyre tread depth monitor

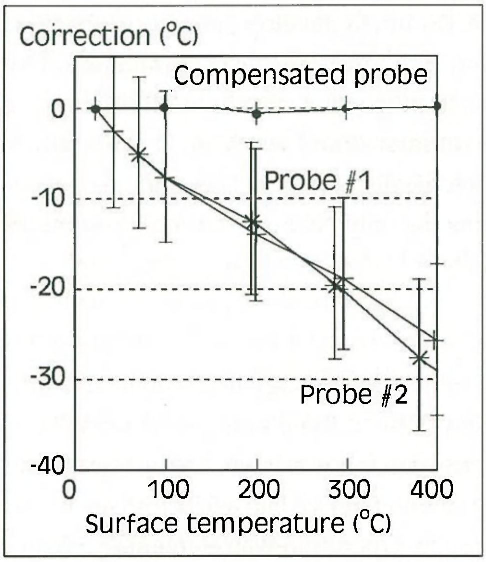
The EMP was more active during the days of Production Technology in commercialisation taking over some ideas from Engineering Metrology. One of these was the Acumet™ tyre tread depth monitor. The introduction of this device also followed new traffic regulations specifying minimum tyre tread depth as 1 mm. The Acumet device had a 0,02 mm resolution and was offered complete with a calibrated test gauge. Operation was elementary, with a green LED indicating a depth of more than 0,9 mm, while a red light and buzzer would convey an illegal tread with a depth of less than 0,85 mm.

Lamp quality monitoring

An example of the respect that local industry had for the capabilities of the CSIR in light measurement is illustrated through the development of a novel light bulb measuring system for Consolidated Lamp Manufacturers (CLM). CLM is the sole manufacturer of tungsten filament light bulbs in South Africa, packaging its products under several well known trade name brands.

The full implementation of the RDP (recontruction and development programme) in terms of the home electrification programme would have created a capacity problem for CLM and would also have made imports more attractive. A bold decision was thus taken to significantly increase the capacity of the local plant to make it more internationally competitive. All of the lamp assembly equipment was fully imported, but when it came to testing CLM decided on an indigenous approach. Its requirement was 100% bulb testing at high speed. While several parameters are measured to ensure compliance with specifications, CSIR designed and built the equipment to

The Acumet tyre tread depth monitor



Comparison between thermally compensated probe and standard probes

measure the lamp brightness, based on some integrating sphere principles.

Novel contact thermometer

Commercial products can also result from more fundamental studies. The best example of this involves the NML work on contact thermometry, reported on in the chapter on temperature. The studies of Bruce Foulis attracted the attention of the UK-based Isotech, a company led by one of the world's top experts in temperature metrology, John Tavener. Isotech commercialised the experimental prototypes developed by the NML during 1994/95 and has been manufacturing the new probes under licence since early 1996, with the marketing slogan "True surface temperature measurement system".

An additional benefit has been that South Africa has a new visibility in temperature metrology and is the only non-European country invited to participate in a more detailed EUROMET study on contact thermometry.

Earlier commercial developments

While the era of the 'new CSIR' encouraged commercial spin-offs, many other products were developed in the earlier years. During the late 1970s these included an instrument for calibrating laboratory glassware, an ultraviolet spectroreflectometer and an electronic level capable of detecting tilts of less than one second of arc. During this same period a project was completed which allowed the measurement of the electrical resistivity of reducing agents such as coal and coke.

During the 70s ICI in the UK purchased the electronic mikronmeter prototype, development work was carried out for Iscor (the State-owned Iron and Steel Corporation) on a dust monitor, while work on a spectrophotometer to measure the reflectivity of human skin was initiated for a skin specialist at the University of Pretoria.

This trend (for industry, universities and other parties) to approach the NML with any measurement problem has continued to this day and is an area in which the laboratory continues to play a major role. As recently as 1995 the NML was involved in the development of an optically-based device to measure the wear on overhead electrical conductors used by Spoornet ('spoor' is Afrikaans for rail).

Pressure, vacuum, flow and force

"The need for accurate, repeatable pressure measurements was driven by the meteorologist for weather forecasting and the commercial aviation industry for altitude (above sea level) determination."

The primary barometer

While a few highly specialised companies exist today to satisfy the needs of international metrology and standards bodies, in the post war era in many areas of physics it was necessary for laboratories to build their own equipment. An example of this was pressure standards, which were also the responsibility of Dr Eric Halliday's general physics group. Halliday and Henry Richard (Richard returned to his first love, farming, in 1954) based their barometer design on an instrument constructed in the early 1930s at the NPL, Teddington by Sears and Clark. Once again mutual cooperation in the field of standardisation saw that the full working drawings were made available to the NPL. Ivan le Sueur of the CSIR workshop started building the precision instrument in 1950, a task which was to take him 18 months.

On completion, the barometer initially had to be set up in one corner of Halliday's office as there was no other space available. Here it was used by his assistant, Roy Smith, to calibrate barometers for the Weather Bureau and others. The new primary standard was described in articles published in 1955 and 1956[5,6,8]. While the original NPL instrument in theory satisfied the requirement for a national facility, the low atmospheric pressure (655 mm mercury or 87 kPa) at the altitude of Pretoria posed new problems. These were solved by dimensional and other modifications to allow for lower barometric pressure readings. Other changes resulted from the decision to construct the instrument in such a way that barometers could be subjected to a wider range of pressure, namely 600 to 780 mm mercury.

The Sears and Clark design was such that readings could be expected to be correct to within 5 µm. In the initial tests of performance, the outstanding workmanship of the CSIR staff was authenticated, with deviations over time being +4 µm and -3 µm at a pressure of 656,1 mm Hg (0,86 atmospheres). Halliday and Richards noted in their paper[6] that "it was not possible to obtain an entirely reliable check of the repeatability, as there was no superior instrument with which it could be compared". Over extended time periods the almost continuous fall in pressure could be attributed to rise in ambient temperature.

The final conclusion made by the metrologists was that the calibration technique using this standard was capable of calibrating commercial barometers with an accuracy limited only by the precision with which the barometers themselves could be read. The ultimate of any standards laboratory in any physical measurement, had at that point in time (mid fifties) been achieved! In between its more mundane tasks, the primary barometer was used by Roy during precise mass intercomparisons using the primary standard balance and the No 56 kilogram, to measure the ambient air pressure. Despite its age this instrument today remains the national primary standard barometer. For a short period from the late 50s to 1965 it was designated as the primary pressure standard for all countries south of the Sahara.

Temperature effects on barometers

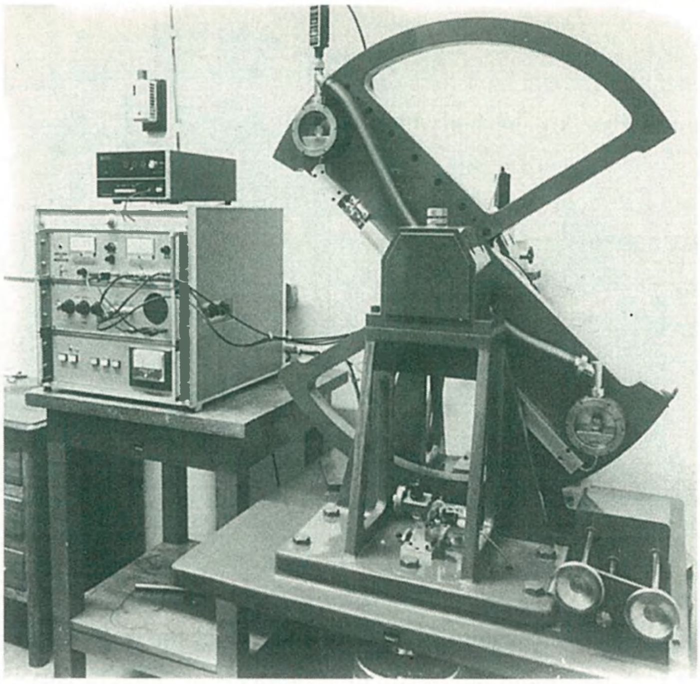
"What will happen when a barometer is taken from an environment at one temperature and quickly placed in an environment at another temperature – as may happen in a gold mine?"

This was the question posed to Halliday in 1955. At that time he was aware that commercial barometers of the Fortin type could be read fairly reliably to 0,05 mm, but when a correction is made for the thermal expansion of the mercury it was found that an error of 0,36 °C could cause an inaccuracy of 0,05 mm in the corrected height. Together with his assistants Smith and Richards, Halliday carried out a study during 1955 on the effect of sudden environmental changes on the readings of Fortin-type barometers. This was an extension of earlier work in the UK by Evans who had addressed the effect of a steady rise in temperature.

The results of the study, which was of particular importance to the high-temperature, deep-level mines of South Africa was published in 1956[8]. It was found that for a barometer starting at just 3 °C above room temperature, some 38 minutes had to elapse before the temperature difference between the mercury and its brass sheath was less than 0,3 °C. For the Fortin barometer which was used in most laboratories at that time, it was also found that a temperature change of 2 °C was sufficient to cause an error of 0,05 mm in the reading. It was also concluded that the temperature difference between the mercury and the brass sheath would reach a maximum some nine minutes after the environmental temperature 'shock'.

The long range barometer

When the NML moved to the new Scientia premises in 1957, the primary barometer was used together with a hypsometer in the Temperature Laboratory to produce the 100 °C point used for calibration of platinum resistance thermometers. This was also the time at which the NML began calibrating SAA's transfer pressure standard on a regular basis. This allowed the airline to comply with regulations imposed by the International Airline Association to be able to demonstrate traceability in regard to cockpit instrument calibration.

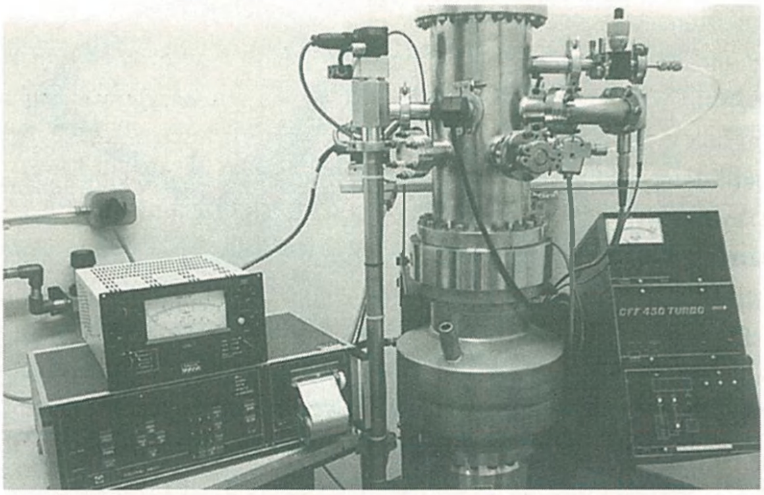


The locally designed long range barometer, 1970

With the increasing cruise altitude of commercial jet aircraft (the ill-fated De Havilland Comet made its first commercial flight from London to Johannesburg in 1952) SAA in 1968 requested that NPRL look into obtaining a long range barometer so that its transfer standard could be calibrated to the equivalent of 50 000 feet to meet new ICAO regulations. As usual the funds were not available to purchase one from overseas at a cost of about R100 000. Roy Smith was thus requested to develop an instrument locally, being generously provided with R10 000, plus the services of the Laboratory's instrument maker 'par excellence', Ken Rees, for one year. A tilting cylinder device was designed and was operational in somewhat over a year (1972). In comparison with the primary barometer it was established that the absolute accuracy of this was 0,025 mbar. The total operating range was 0 to 800 mm Hg.

More recent developments

The facilities for pressure were enhanced during the 1970s with the purchase of both gas and oil pressure balances. These standard pressure balances were calibrated by the NPL, Teddington. In addition to a 100:1 pressure divider they provide pressure standard capabilities in a range from a few kPa to 120 MPa. A vacuum capability was established in the 1980s with the acquisition of a high vacuum turbo pump. Calibration of vacuum gauges is achieved by comparison against secondary standards (including a capacitive pressure



The vacuum standard, 1989

transducer and a spinning rotor gauge), these in turn having been calibrated by the NPL, Teddington. The quoted accuracy today of the primary barometer is ±2 Pa, with the long range instrument having an uncertainty of ± 5 Pa. The capabilities which include gas and oil pressure measurement and vacuum meet the majority of the needs of South African industry. Pressure metrology is now in the capable hands of Ken Moore (who took over responsibility for pressure in 1991) and Belinda Dawson.

Future work

As with the other areas of metrology, pressure will also benefit significantly from the new capital investment being made by DTI. Major improvements will be made to the existing gas and oil pressure capabilities. In terms of gas pressure the recent acquisition of a Ruska pressure balance will allow extension of capability from 300 to 700 kPa absolute, with gauge pressure measurements up from 5 to possibly 20 MPa. The current oil pressure Desgranges et Huot standard is inadequate for a few local clients, including SAA, who require 350 MPa. Before the end of 1997 the NML's capability is planned to be 500 MPa.

While the current vacuum calibration is dependent on comparison against capacitance gauges calibrated every two years by the NPL, Teddington, this process is becoming increasingly expensive and a longer term objective is to build a vacuum series expansion system, thus effectively creating a local vacuum standard. Although the primary barometer will remain the national pressure standard for the foreseeable future, most barometric calibration work is carried out using the gas pressure balances. Intercomparisons between these two methods provided an accuracy in the region of 6 to 8 Pa, well within the measurement uncertainty.

Flow

Flow is a very special area of metrology and in South Africa the standard has always been maintained by the electrical utility Eskom, with traceability through the NML to the National Engineering Laboratory (NEL) in the UK. Eskom is believed to have the largest flow calibrating facility in the world, which operates on a direct weighing principle with a high capacity of 2 m^3/s and an accuracy of 0,1% on flowrate. In the future it is expected that flow standards will become of greater significance and plans are already being formulated to establish a fuel flow calibration facility for use by airlines, including the national carrier SAA.

The CSIR today possesses very extensive wind tunnel facilities, of which one of the earliest was a medium speed wind tunnel with a 0,6 m octagonal cross section designed primarily for the calibration of airflow velocity meters and pitot tubes for use in the main testing tunnels. Since 1952 this has been operated be Aerotek to calibrate air velocity equipment for both in-house and industrial use. Under the guidance of André van Tonder traceability is achieved by validating the measurements using an internationally calibrated pitot tube and vane anemometer to cover a range of 0,4 to 30 m/s.

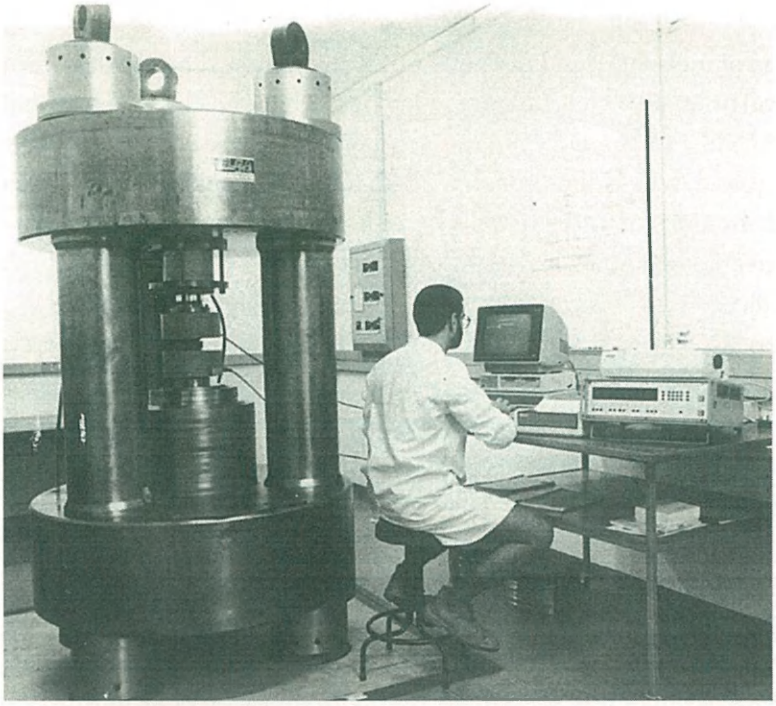
Force

"The inaugural force course was presented by **[the NML's]** *Mr Quinton Olver at the CSIR during December 1991."*

NCS Newsletter, No 7, 1991.

While not one of the fundamental standards maintained by the BIPM, the need for a national standard for force became evident in the 1970s. At this time funding for the expensive equipment required for this standard was to prove difficult to obtain. In fact SABS had set up a force laboratory in 1968 to the consternation of Halliday who felt that these expensive facilities should have been at the NPRL. Obviously it became more difficult to motivate for a second force capability at that time in South Africa.

The work on a force standard initiated in 1982 was based on international results which indicated that load cells were much more reliable, accurate and stable than previously considered. It was thus established that the national measuring standard for force would be based on a set of load cells to be calibrated in Germany, using a locally designed load cell comparator. To address the need for a force standard, Professor J Ferenczy was appointed during 1982 on a contract basis. The 1983/84 Annual Report of the NPRL indicated that while the load cell comparator to be used to establish the force standard was almost complete, the basement laboratory in which it was housed was not. It was impossible to work with the machine under existing conditions which included "dust, dirt and lack of temperature control" – a possible reflection on the lack of urgency with which the CSIR's Estates Department handled building modifications.



National force comparator in use, 1985

This machine was designed by Joe Ferenczy in consultation with other local experts. The special steel required was produced by the Union Steel Corporation and machining was carried out by Elga Engineering in Johannesburg. Completed in 1984 the measuring frame weighed 20 000 kg and was designed so that large load cells in the range of 1 MN could be accommodated as well as proving rings up to 0,5 m diameter. By 1985 the system was fully operational, using load cells calibrated by the PTB and NPL, Teddington. Professor Ferenczy's contract ended in 1985 and in 1986 it was reported that calibration work for industry was being carried out with a high degree of precision.

The first load cells used with the device were type C4, manufactured in West Germany and calibrated by the PTB. The electronic measuring unit has an accuracy of 0,0005% with a resolution of 10^6 digital steps. One set of load cells is currently in the process of being gazetted as the national standard.

Force is now in the hands of Benny Burke, who took over from Quinton Olver. In regard to the latter he is remembered by the NCS for his association with a new unit of force, conceived by Charles Ho, a metrologist from Taiwan. The new unit was the 'Quin Ton', which Dick Turner was to define as the force exerted by a person five feet tall! No doubt in reference to himself.

As for the future the opportunity has now arisen whereby the NML may be able to acquire the redundant deadweight standard previously used by the NPL, Teddington.

The metrology craftsmen and workshops

"When the CSIR established the NPL, Dr Meiring Naude......insisted that qualified and experienced instrument makers should be recruited from overseas. In his view artisan training in South Africa did not at that time cater for the high degree of precision required for research in physics."

'The CSIR, the first forty years', D G Kingwell.

No history of the NML would be complete without mention of the craftsmen who served it from its creation and without whose precise work and pride-in-workmanship, the scientists' dreams would have remained in their fertile imagination. The efforts of these instrument makers is reflected today through the many examples of instrumentation illustrated in this book. Until 1949 each new NPL appointee was presented with a toolbox and was expected to use the staff workshop to build up their own equipment. This workshop had two old lathes and some other written-off equipment and NPL designer, Kazik Maruszewski saw that the machines were not abused. In 1947 an NPL workshop was created to which only the best instrument makers were appointed, the first apprentice starting his training in 1948. An optical workshop, initially under Eric Tappere (ex NPL, Teddington) was started shortly thereafter, being taken over by Ernst Hecker in 1951.

When the mechanical workshop was moved to the Scientia site in 1955, it became the CSIR's Central Workshop and scientists and their assistants, who were often skilled instrument makers in their own right, were prevented from using metal-working and other machinery. When Halliday was asked to form the PPM, he used the opportunity to include an inflexible proviso, namely that it should once again have its own dedicated workshop facility and skilled craftsmen. Ben van der Wagen and Ken Rees were to be allocated and while they were to initially remain in TSD's facilities, a dedicated metrology workshop was established during 1966. During the later days of Production Technology it was Gerrie Dorlas

Workshop staff: Joseph Moseri, Roko Popich, Tommy Mokomane

and Ivor Gilson who were to continue this tradition of excellence. In more recent years Roko Popich, assisted by Joseph Moseri and Tommy Mokomane, have been working to even more exacting standards of innovation and precision.

It is interesting to note that one of the first acquisitions of the new PPM workshop was a very accurate French lathe which was used to machine standard weights from stainless steel ingots, 2, 5 and 10 kg being produced locally in this way.

Many of the successes of metrology over the era are attributable to the skills and dedication of these workshop staff, who often worked from Stoffel Kok's illustration on the back of an old cigarette pack. Roy Smith even borrowed a page from the notebook of Ken Rees to sketch his ideas for the long range barometer, this pencilled relic existing to this day. Rather than Naude's comment on "the precision required for research in physics", reality became "research into the limitations of lathes and milling machines" and the working properties of new and unconventional materials. The dexterous skills of these individuals was further demonstrated by the fact that the equipment used was often obsolescent and was hand rather than NC-controlled.

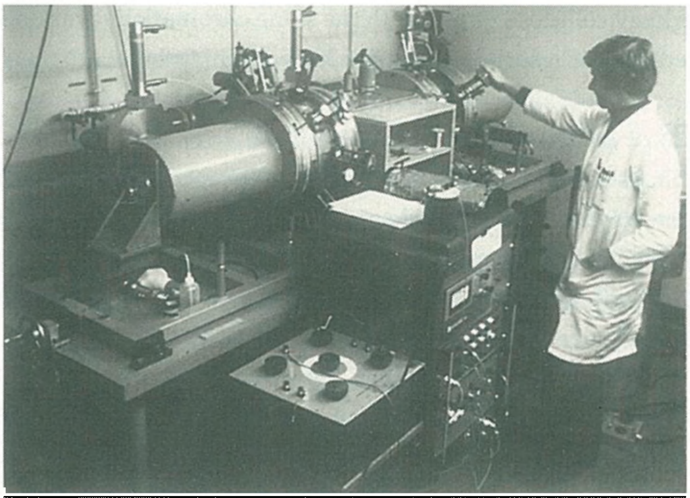
With the formation of Productiontek, all CSIR staff and facilities were placed in a pool and this was seen as an opportunity to again centralise all CSIR workshop facilities. The strategy used by the Division was to combine all existing workshops within the Strategic Unit, under Peter Trendler, but with specific staff still acting as standards-related resources. This move was to prove successful and despite several attempts to re-establish a centralised facility the NML kept its outstanding group of craftsmen and artisans.

It is interesting to note that the 'new CSIR' system still did not address the question of adequate remuneration of these dedicated staff, who were compared to a database of normal (relatively unskilled) industry workers. Special measures were taken to reward them in kind, one example being the hire of a luxury coach to whisk them and their families to the famed Sun City for a well-earned weekend of team fellowship and fun, organised by the Groman team building virtuoso, Ian Dean. Ian, as a strategic management consultant had formed a close relationship with the Division and used his special team building skills to keep the management, including Dick and Franz, focussed on the bigger picture.

Radiometry and photometry

"As happens with conspicuous frequency in science, the problem [of absolute radiometry] *was solved simultaneously by two researchers working independently of each other, namely Kurlbaum in Germany and Angström in Sweden."*

Franz Hengstberger, in the book Absolute Radiometry, 1989.



Franz Hengstberger with an early version of the absolute radiometer, 1974

An optics activity was created at the NPL in 1948 under E G Marais, the cousin of Willem Marais of later electrical metrology renown. The Annual Report for the year ending 1949 indicated that a photometric laboratory was under construction and that photometric sub-standards (namely lamps) from the NBS had arrived. Bossie Boshoff joined Marais in 1949 before completing a doctorate under the supervision of one of the optical greats of that period, Professor Wright of Imperial College. Marais was appointed Director of the NPRL in 1955 and was succeeded for a short period by Dr Wilsdorf, followed by Tom Hugo, who remained with the Optics and Spectroscopy Division until appointed Director of the new Institute of Defence Research in 1965. Boshoff, who had a personality clash with Marais, left to head up the Sasol Physics Laboratory. With the creation of the Precise Physical Measurements Division in 1964, it was Stoffel Kok, first appointed in 1959, who was transferred with the optical standards activities.

Since the Second World War, and particularly following the development of the laser, progress in optical standards was rapid. It was the area in which the NML was to exert the most international influence. Much of this work has been published in scientific literature. As such this chapter has been treated somewhat differently from others, the history being presented as a series of historical snippets of important developments and research.

Painted surface gloss scale

Some of the earliest industry-related work was that of Martinus Boshoff, carried out during the period he spent during the early 1950s at Imperial College, London. While gloss measurements are today commonplace, and are essential in areas such as automotive manufacture, in the 50s it was still difficult to obtain correlation between instrumental and visual gloss assessments.

Boshoff's work[9, 10] described a system whereby 'just visually noticeable' differences in gloss could be expressed in terms of the difference in measured specular luminance factors. It is interesting to note that preparation of the samples in the form of mixtures of matt and glossy cellulose paints with the same chromaticity was one of the more exacting tasks in an era where colorimeters as we know them today were unavailable.

The photodermoplanimeter

The name of this instrument with its complex combination of both Latin and Greek terms is more typical of the Afrikaans language, where new words are created by joining together many simple terms into a complex descriptor. The photodermoplanimeter[12, 13] was in fact an instrument which was designed using the optical and other expertise of the standards staff to measure the effective radiation area of the human body.

Mining (particularly at deep levels) is part of South Africa's history and the present, being visible today in the form of the Great Hole of Kimberley and the gold tailings dumps in the environs of Johannesburg. As part of its activities during the early 1950s the Applied Physiology Laboratory of the Chamber of Mines was conducting a study on the effect of heat transfer from miners at work. At that time only numerical methods were available to estimate the physical area of the human body and the NPL was commissioned to develop a rapid and reliable real measurement.

The principle used was based on the fact that the effectiveness of a surface for radiating can be directly determined by measurement of its capability for absorbing energy. To the photometric people this immediately suggested use of integrating sphere techniques. In practice the light-integrating device constructed was only an approximation to a sphere, being based on a 3,048 metre cube with an access door, ventilation holes and an optical window. The sphere was further approximated through the insertion of 1,83 metre equilateral wooden triangles in each of the corners and by chamfering the edges with hardboard strips. These strips had incandescent lamps at each end, which were baffled to avoid direct illumination of the test object, a stripped miner.

The subject to be measured was sprayed before entry with a suitable (easily removable) high absorption black paint. The measurements, made with the man in a standing, but spread-eagled position, took approximately two minutes. The actual surface area was then determined using the well-known substitution principle. After making corrections for known inaccuracies, it was found that surface area measurements were correct to within 1%, yielding an area greater than that obtained by the best calculation methods by between 5 and 9%.

Spectroradiometry of daylight

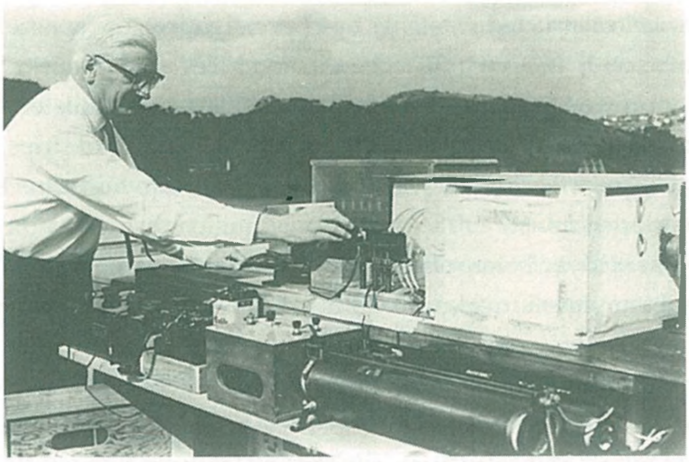
"Prior to the establishment of the Division ... very little original research was done in this field* [photometry and radiometry]. *The work was mainly confined to routine comparisons with standard lights."

Ten year Review of Optics Division, 1955 to 1965.

South Africa's NML has made a significant contribution to a better understanding of the spectral content of daylight. The first such measurements in the southern hemisphere were made during the period 1964 to 1965, with the results being published from 1966 onwards[14,17,25,26,29]. The spectroradiometer for the daylight measurements was developed with the help of Gordon Winch* from the UK, who had considerable expertise in this area and joined the NPRL temporarily during the period 1964 to 1965. The observation site was the roof of the NPRL at the Pretoria Scientia site, at an altitude of some 1 400 metres. Pretoria itself is located at latitude and longitude of 25,8° and 28,2° respectively.

These early results created something of a controversy, as they showed values for the ultraviolet and blue regions of the daylight spectrum which were much higher than those cited for the northern hemisphere, the latter eventually being used to define the new D65 illuminant in 1972. The erroneous conclusion initially reached was that the difference was due to the high altitude of the test site. On the other hand the measurement technique using integrating sphere-based radiation gathering was known to be theoretically more correct than previous methods. At the 1975 session of the CIE some doubts were expressed by others regarding the validity of the existing D65 standard illuminant at wavelengths below

*Winch, a colorimetrist, had been very active in the CIE, but on being forced to retire was invited by Tom Hugo to go and work at CSIR.



Gordon Winch on the roof of the NPRL with the apparatus used for measurement of daylight

400 nm. As a result of these uncertainties, the NML was asked to repeat the measurements in South Africa but using a sea level test site. The port of Durban was chosen, the measurements being made at the University of Natal. At this location (latitude and longitude 30°) Kok and Chalmers performed measurements over a period of fifteen months between 1976 and 1977[53,54,56].

The new measurements (with a best spectral resolution of 1 nm over the 295 to 315 nm band) were made between 295 and 775 nm. Once again the ultraviolet and blue irradiance, while somewhat lower than the previous Pretoria measurements (now indicating the true effect of altitude), was considerably higher than most of the accepted northern hemisphere results. The NML results were on this occasion accepted by the CIE and confirmed the fears that the UV and deep blue values of D65 were on the low side.

The proven authenticity of these new measurements resulted in a revision and update of the CIE publication 20 of 1972, which was re-issued as CIE publication 85 of 1985, entitled Solar Spectral Irradiance. This Durban data has been used many times since by scientists creating new atmospheric transmittance models.

Mask photometer/colorimeter

In the era before the microprocessor, one of the most accurate and effective methods of measuring colour was the use of a mask photometer to measure the CIE tristimulus values. Such an instrument, based on a double Ebert-type monochromator was developed by CSIR in the late 1960s[20]. For use as a colorimeter three masks were cut to match as closely as possible the requirements of the CIE equal energy chromaticity functions. The required shapes of these masks was calculated taking into account the dispersion and absorption of the monochromator as well as the spectral sensitivity of the detector. The manufactured masks were then carefully altered until the closest approximation could be obtained. The maximum deviations from the ideal for continuum sources was less than 2%, while special care was taken in the mask shape in the region of the strong mercury lines so that for discharge lamps of this type the accuracy on chromaticity was better than 1%.

International lamp intercomparison

Luminous intensity is one of the seven basic SI physical quantities for which most developed countries maintain their own primary standards. As uncertainties regarding individual accuracies always exist, the intercomparison procedure is used. As practised by the CSIR from its inception, standards have been mostly hand carried (with seats provided when required for the instruments by South Africa's national airline SAA) to the BIPM. Their staff then measure these national standards against the international ones maintained by them.

Occasionally an alternative procedure is used, where a number of laboratories are invited to participate and each of these receives a similar set of standards. Such a major international intercomparison was organised in the early 1970s to measure the spectroradiometric output of a number of different types of lamp, including fluorescent, metal-halide and high pressure mercury vapour (HPMV). With its established reputation in the fields of photometry and radiometry, CSIR was invited to participate and act as the project coordinator for the HPMV test series.

Fluorescent lamps had been the subject of a similar intercomparison in the early sixties but the results at that time were less than satisfactory with differences in flux measurement as high as 5%, with substantial variations in the measured chromaticity. This time some 22 laboratories were invited to participate but while the specified measurement range was 300 to 800 nm only half of these labs, including CSIR, could measure below 350 and above 700 nm.

The general conclusions from this intercomparison was that agreement of the results between 400 and 620 nm was excellent, but deviations below 350 and above 620 nm were still excessively large. As an example the world standard deviations at 300, 500 and 750 nm were 85,1, 0,6 and 11,4% respectively. It was interesting to note that Stoffel Kok and his co-worker Bossie Boshoff commented on the problems experienced with their quartz-prism spectrometer in that wider slit widths (reduced spectral resolution) had to be used in the low energy UV while narrower slits were used in the lower dispersion near infrared.

In terms of chromaticity, much better agreement was obtained between the various laboratories. One of the NPRL 'standard' lamps had been broken in transit and was replaced by a lamp from a different batch. If the results from this unit were excluded then the CSIR results compared very closely with the seven world laboratories which showed the lowest deviation in the chromaticity coordinates.

In a follow-up photometric intercomparison, three incandescent lamps, together with three photopically-corrected silicon detectors, were circulated to eight national laboratories including the NPRL. This programme was coordinated by Germany's PTB. Of the eight laboratories one obtained results which had very large deviations. For several reasons these measurements were omitted from the final analysis and the NPRL displayed excellent agreement with the average of the remaining measurements.

Both the NPRL and one other test laboratory obtained measurements of the detector sensitivity with large relative deviations from the other participants. Although this was to be partially attributed to the decrease in the detector sensitivity with time (found to be up to 2% over two years), it identified a more important need, namely for future provision of unambiguous measurement instructions in future intercomparisons of this type.

The original CIE plan was to follow these measurements up with an intercomparison of high pressure mercury arc lamps with their strong line spectra. This part of the programme was to be managed by the NPRL and some preliminary measurements were carried out in Pretoria during 1971 on such lamps (UV normal and standard 75) through comparison with quartz-iodine standard lamps from both the NBS and Eppley Laboratories. The accuracy of the initial results was somewhat low, with the certification accuracy of the Eppley standard being only 3%. A comparison with the PTB on one lamp for the irradiance of the 365,1 nm Hg line provided agreement within 1,5%. After discussion of the preliminary results at the CIE Congress in Spain in 1971, a decision was taken that spectroradiometric measurement of metal-halide lamps was more pertinent.

The CSIR had, however, carried out pioneering work on the spectroradiometry of multi-line sources, including the mercury lamp. The NPRL was again tasked to develop a method of measurement which could be used by participating laboratories. The measurements were carried out in 1973 by which time a Jarrell Ash Czerny-Turner grating scanning spectrometer had been acquired. The results obtained with this new instrument were compared with those from the older Zeiss prism double monochromator as used in previous spectroradiometric studies. Three different metal-halide lamps which had been aged for more than sixty hours were tested.

Recommendations were made on the measurement procedure, which included use of a constant dispersion monochromator and the use of a narrower (1 nm) bandpass than the 5 nm recommended by the CIE at that time. It was however concluded that as a result of the relative instability of metal-halide lamps of that period, measurements with the same accuracies as those obtained with incandescent or mercury lamps could not be achieved. The superiority of grating instruments for broadband spectroradiometric measurements was also confirmed, with serious errors being possible on prism instruments at longer wavelengths. The work on these lamp intercomparisons is dealt with in detail in published work[23, 24, 32, 44].

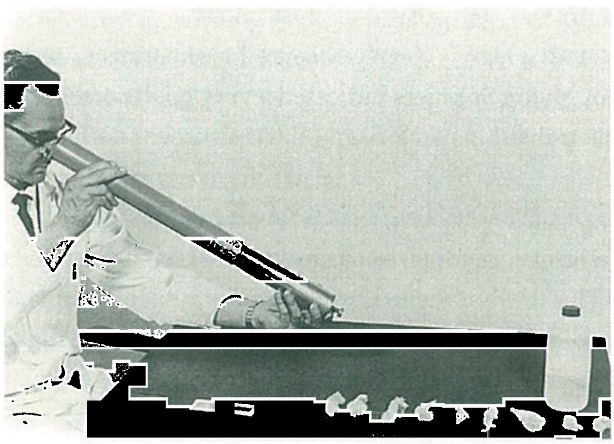
Mikronmeter

Wool was for most of this century one of South Africa's most important agricultural export products. The impact of the development of synthetic fibres in the post-war era resulted in the creation of a textile research institute in 1954, formally incorporated into the CSIR in 1964. During the 60s a requirement was identified for a field instrument capable of rapidly assessing the mean fibre diameter of wool of individual sheep prior to shearing or of fleeces after shearing. Knowledge of this fibre diameter is an important factor in wool processing.

How the local press saw the Mikronmeter development

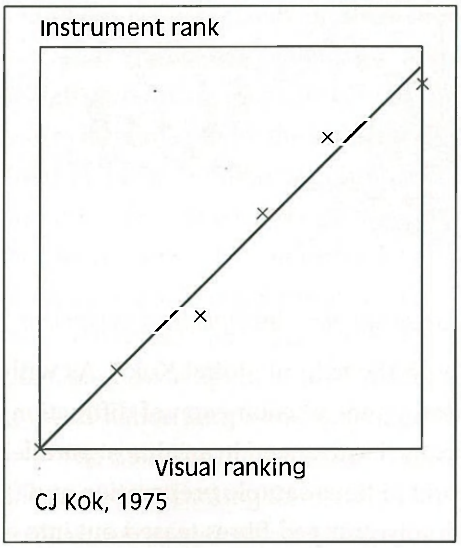
The PPM Division was approached to assist in this development and a device known as the Mikronmeter was produced by Bossie Boshoff with the help of Stoffel Kok[21]. As with previous instruments of this type, operation was based on the phenomenon of diffraction, but most previous devices had required the wool fibres to be arranged in an almost parallel fashion. The objective of the Mikronmeter was to avoid tedious sample preparation and it was used with a sample which was a bundle of randomly grouped fibres teased out into a thin film by hand. A circular diffraction pattern was obtained, which was viewed together with an illuminated reference ring.

With some practice the position of the reference ring and the first dark diffraction minimum could be reproduced fairly accurately, the adjustment being done by sliding out a tube containing an illuminated pinhole and the reference ring. The position of this tube could be calibrated for the range of 16 to 36 μm fibre diameter. Reference samples, for the operator to practice on were provided. Despite the empirical method of calibration it was found that relatively unskilled operators could determine fibre diameter with a 95% confidence level to within ± 0,8 μm.



Tinus Boshoff with an early model of the Mikronmeter testing wool samples

The Mikronmeter was to prove very popular with the local sheep farming community and some of the instruments even found their way to Australia. A later electronic version[52], more suited to synthetic fibre, was developed and during May 1975 was demonstrated to ICI in the UK, which expressed an interest in commercialisation of the device. It purchased one system but the concept was never developed further.



Correlation between trained inspector and NPRL's barré instrument

Fabric appearance monitor

Following the successful development of the Mikronmeter a major local textile manufacturer, SA Nylon Spinners, approached the NPRL for help in developing an instrument to measure barré or stripiness in knitted and woven fabrics and to look for other structural irregularities. The system developed[38,41,50] measured both the transmitted radiation as well as that reflected into an integrating sphere. This sphere was fitted with two photomultiplier detectors, green and near infrared sensitive. The detection electronics was designed so that either the green or infrared or the differential signal was amplified.

The principle of operation was based on the fact that many dyes are only effective in the visible and would absorb green light but not the infrared. The infrared thus shows structural irregularities only. The green minus infrared signal provides information on the variation of coloration detail only, as required. In practice the light was defocussed slightly so as to cover several threads and avoid the fine structural detail, which is clearly observed in the transmitted signal. The final instrument supplied to SA Nylon Spinners indicated a very good correlation between visual ranking of material by six trained inspectors and the instrument defined quality.

Spectral reflectance of diamonds

In terms of industrial studies an anecdotal story regards some work carried out in the early 1970s and published by Kok[30]. The research paper referred to measurement of reflectance and colour of small samples, without identifying the interested industrial partner, none other than world diamond market leader De Beers.

The objective was in fact to discover whether small samples in the form of individual diamonds or diamond-bearing ore from the renowned Premier and other local mines could be distinguished from worthless alluvial deposits. Apart from higher recovery of diamonds from mined ore, the method obviously also had potential in the automatic sorting and grading of gem stones according to quality and colour. The initial results obtained at the NPRL were very encouraging and indicated there were clear unequivocal differences between the spectral reflectance of gem stones and other material. The variation of this reflectance with wavelength uniquely identified the dominant stone colour. Diamonds could also be distinguished from both garnets and quartzite.

De Beers was highly interested in these preliminary results, but further developments were performed in their own laboratories. Although X-ray techniques were eventually chosen for ore sorting, work continues on new optical techniques, particularly the non-linear scattering effects obtained through the use of laser illumination. There is no doubt that photonics will be used in future for objective gem classification, removing the need for time-consuming hand sorting.

Glass filter developments

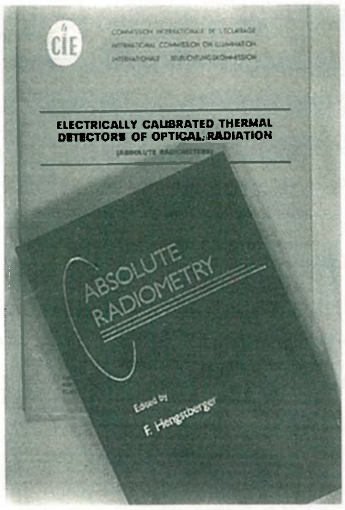
When M A Res joined the NPRL in 1971 from Eastern Europe, he brought with him extensive skills in optical glass melting. One of the areas where this was put to work was in the development of new filter glass. The initial task was to simulate one that had thwarted scientists for years, namely simulation of the V(λ) curve. Normally this could be achieved only through use of filter combinations or expensive Fabry-Perot type interference filters. This V(λ) filter was specifically required to complement the absolute radiometer and isolate the photopic spectral band. Interference filters are of course impractical for use at low temperatures and exhibit marked changes in spectral response with temperature.

The work of Res *et al*[33,34,35] has been extensively reported and single filter glasses with characteristics closely approximating the V(λ) and V'(λ) distributions were produced. Although perfect simulation of the CIE functions was not possible, agreement was surprisingly close. Secondary transmittance peaks at longer wavelengths required use of a second 'blocking' filter.

The new radiometric definition of the unit of light

The NPRL was at the forefront of the battle to convince the CIE to move away from the platinum standard for the basic unit of light, the candela. This new candle was officially adopted internationally in 1948 to replace the filament lamp based standard of the early 20th century. It still possessed numerous shortcomings, not least large differences in values of the standard in different countries.

A reference to the need for a radiometric approach for a new standard of light was contained in the NPRL Annual Report of 1960/61. It was indicated at this time that the platinum standard in common use at that time was both expensive to acquire and maintain.



International publications on absolute radiometry

As far back as 1964[22] the NPRL had anticipated a change to a radiometric standard and preliminary measurements were made on two locally constructed drift radiometers of the 1937 Guild type. The development of an absolute radiometer* was expedited following the appointment of physicist Franz Hengstberger in 1971. His doctoral thesis (submitted to the Technical University of Vienna) preempted the 1979 international adoption of the radiometric standard.

Only Australia and South Africa had performed any significant research in absolute radiometry during the 1970s, and Australia was to become the first country to place its standard on a radiometric basis. South Africa quickly followed, and the Hengstberger-designed system[48,48,59], being much more flexible and versatile was within a short period of time acquired by Argentina, Italy, Spain, the BIPM and New Zealand. A further, highly upgraded and refined version of this radiometer was delivered to Taiwan as late as the 1990s. The first NML-type radiometer was installed by IEN, Italy in 1978.

In 1984 the inventor, Dr Franz Hengstberger, was awarded a senior research fellowship by the DSIR in New Zealand to help that country establish its own light and radiometric standards, the latter including a modified, significantly more accurate version of the original instrument. In the same year his achievements were recognised by the CSIR, when he was presented with one of the first President's Merit Awards for his outstanding research work in the field of

Franz Hengstberger with the electronic control system of the absolute radiometer

*The absolute radiometer became the official national standard in September 1976. In 1979 one detector head was donated to the BIPM which then purchased the ancillary electronic equipment.

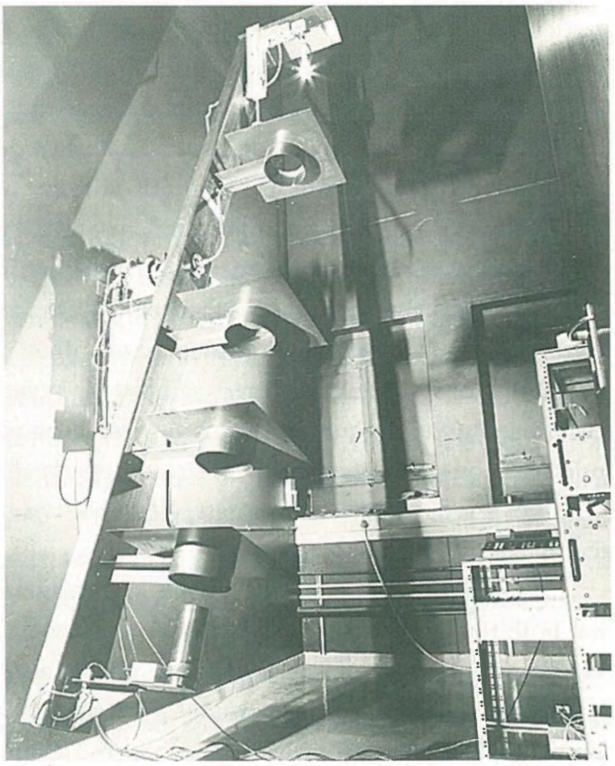
light intensity measurement. A year earlier his home country, Austria, had also recognised his achievements, presenting him with the Simon Plössl Medal for his contributions to the fields of optics and illumination engineering.

Goniophotometer development

The realisation of the new candela standard by South Africa in 1976 naturally resulted in a requirement for the ability to measure the total light output of lamps in an absolute way. While for industrial purposes luminous flux can be measured by comparison with a luminous flux standard lamp in an integrated sphere, fulfillment of an absolute standard was more problematic. The challenge was to establish a link between the unit of luminous intensity (the candela), as based on the cd definition, and the unit of luminous flux, the lumen, which is a derived unit. The relationship between luminous intensity and luminous flux is purely geometrical and can be established by moving a detector in a circular orbit around a fixed lamp, with sequential incrementing of the azimuth angle. This was the method adopted by NPRL[61,62,63,64].

The goniophotometer itself was fabricated in the NML workshop and consists of a 4,2 m long steel beam rotated about its centre. One end of this arm carries the photometer while the lamp being measured is located at the other end in a holder which provides a counter rotation (so that the lamp remains in a vertical position). The lamp to be measured can also be located on a separate stationary support which places it at the centre of rotation of the arm.

This new lumen standard has performed well since its commissioning in early 1983 and initially resulted in values being about 1,5% higher than the old lumen as represented by a set of flux standard lamps calibrated by the NPL, Teddington, in 1954.



The NML's goniophotometer

Beetle-mania

Accurate measurement of visually perceived colour has in the past two decades become of significant importance. This has been reflected in the focussed inputs to this area by Stoffel Kok, Berto Monard and more recently, François Denner. One of the more unusual studies undertaken[69,73] was the measurement of the spectral reflectance and colorimetric properties of a number of Namib beetles.

Through growing a wax bloom on their outside surface, these hardy desert insects survive in conditions untenable to their more common black counterparts. Without this bloom, measurements showed a low reflectivity normal black surface. Depending on the environmental conditions they change into a yellow/orange colour with a significantly enhanced reflectance which slows down both heat gain and water loss, allowing the beetle to survive in hot, arid conditions. This yellow/orange bloom also has a dominant wavelength almost equal to that of the surrounding sand, additionally providing camouflage from predators.

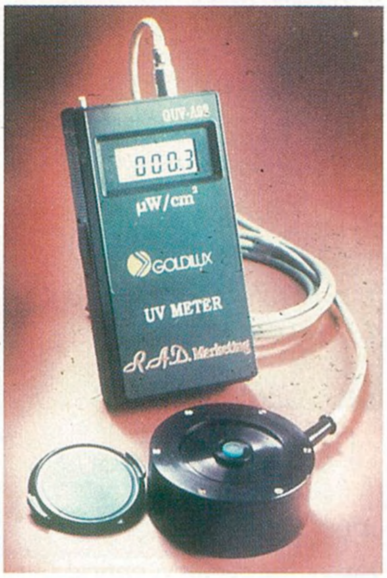
Visual displays

In recent years South African industry has become active in the field of visual displays, particularly for aircraft cockpit applications. The display types being locally developed include both conventional full colour LCD and advanced monochrome electro-luminescent types. One of these companies, Optique, recently signed an agreement with Germany's Daimler-Benz Aerospace, whereby it will act as a development house for that company in advanced display technology for both military and commercial aircraft applications. Besides local developments, many military CRT-type displays have been imported and required local verification in regard to critical specifications.

The NML was first approached in 1993 to carry out evaluation of CRT displays in terms of colour, contrast, luminance and other critical parameters. Despite the non-availability of test equipment normally used, including a PC-driven spectroradiometer, a test procedure and equipment was devised. The measurements carried out by the NML indicated non-compliance with an already overly strict specification. This was hotly denied by the overseas supplier, who refused to believe that Africa could teach them anything about spectroradiometry.

They were unfortunately unaware that radiometry is a field in which CSIR excels and that both the current head of that section, François Denner and Franz Hengstberger hold major positions in the CIE. A visit by a powerful scientific and engineering delegation to South Africa led to the acknowledgement that the most sophisticated equipment cannot compete with real radiometric excellence and South Africa and the NML are now treated with significantly more respect.

UV radiometry



Early version of the Goldilux UV meter

While the current strong interest in the ultraviolet spectral region was probably a consequence of the CFC-driven depletion of atmospheric ozone and increased levels of harmful UV-B, this shortwave radiation is finding many useful applications in the chemical and electronics industries, health care, holography and CD technology.

The CSIR's interest was driven by its local development of the Goldilux range of handheld UV radiometers (the first project undertaken by François Denner[74]). While these are now manufactured under licence by a private company, calibration is critical and CSIR was required to create the capability.

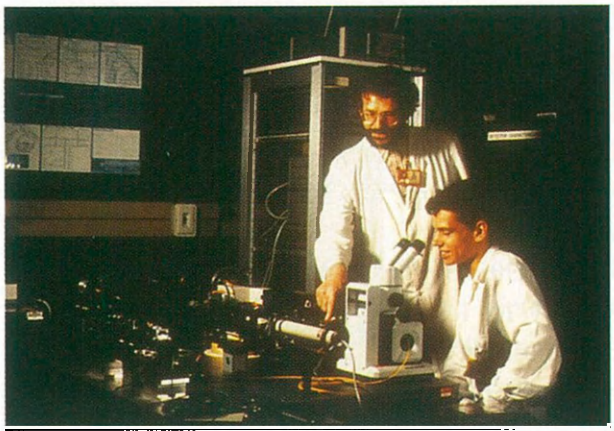
The awareness of the dangers of solar ultraviolet in South Africa is low and exposure safety requirements are poorly understood or ignored. It is expected that this will change with time, but responsibility for routine checking of ultraviolet protection factors would rest with SABS, rather than the NML. The NML would, however, be required to establish and maintain traceable standards against which test equipment could be calibrated.

Fibre optics

The South African Post Office was an early adopter of optical fibre for telecommunication purposes, one reason being its non-susceptibility to lightning strikes. As the market grew the capability for local cabling was established and it became obvious that manufacture of optical fibre was also feasible. Through a technology transfer agreement with a UK company, ATC in Brits began local manufacture of optical fibre in 1984.

Unlike many other South African companies, ATC sagely decided that it would not be restricted in terms of markets through such an agreement and immediately initiated its own R&D programme. Amongst other outcomes of this local effort is the fact that more than 65 km of single-mode fibre can now be drawn from a single preform through indigenous development of a technology designed to produce 10 km. At the same time ATC developed the techniques and processes to draw the niche-market multimode fibres.

This activity created a need for the establishment within the CSIR of a capability to measure the optical and dimensional properties of optical fibre. This initiative began in 1986 with the transfer of Indru Olivier from the National Chemical Research Laboratory of CSIR, with the specific requirement to develop relevant standards and test procedures.



François Denner and Indru Olivier doing fibre-optic measurements in the late 1980s

For a time 3 NCS laboratories at Altech Instruments, Telkom and ATC were in operation, covering such measurements as power, wavelength and attenuation. For a period, ATC has been in voluntary suspension in anticipation of the recent changes which have taken place in regard to the NCS and its strategic move into test house accreditation. After much consideration this is the path that ATC wishes to take. With the expected demands of Telkom's Vision 2000, which will provide for an additional 2 million connections by the turn of the century, optical fibre metrology is expected to be a significant area of growth. Indru Olivier was appointed in 1986 to address the radiometric aspects of optical fibre and this work is still in his capable hands.

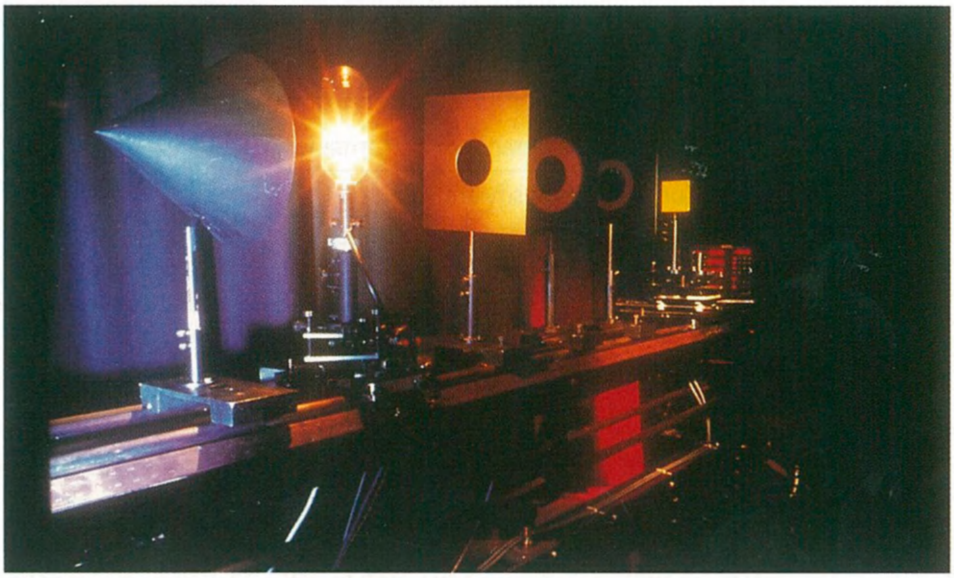
Involvement with the CIE

The CIE (Commission Internationale de l'Eclairage) is the world's ultimate authority on illumination and has defined amongst others the tristimulus functions for chromaticity and the V(λ) function. Since the early 1970s the NML and its staff, particularly Franz Hengstberger, Stoffel Kok and François Denner, have played an increasing role in the CIE's activities and have held positions with several of the CIE's Divisions, specifically 1, 2 and 6.

Franz is currently Director of Division 2 (Physical measurement of light and radiation) and François was recently appointed as Secretary of Division 1 (Colour, vision and visual ergonomics). The strong representation of South Africa on the world body's working groups is an indication of the high regard held for the expertise of the NML in the science of optical radiation and its measurement.

Future developments

While there has been a move in recent years towards cryogenic absolute radiometers rather than the room temperature systems where CSIR was at the forefront of development, François Denner believes that for commercial radiometers the room temperature approach is much more cost effective as the relative price ratio could be as high as 10:1. The NML believes that with some effort its absolute radiometer could be improved in accuracy by at least an order of magnitude. While international intercomparisons of the candela are presently focussing



Photometric bench at the NML

on National Laboratories with cryogenic systems, a room temperature versus cryogenic intercomparison is scheduled for 1997.

Photometry and radiometry activities have in the past thrived on the challenge of solving new problems with existing equipment used in a more innovative way, including development of unique electronic control systems and the writing of special software. Advances in commercially available instrumentation and more effective use of the limited human resources will, however, require acquisition of new equipment. This will include a sophisticated state-of-the-art spectroradiometer, a cryogenic radiometric standard and a high temperature black body (3 200 K) source to be used as an absolute standard for spectral irradiance. A new automated filter photometer and a sophisticated spectroradiometer were acquired in early 1997 from the world-leading US company Photo Research.

Participation in international comparisons

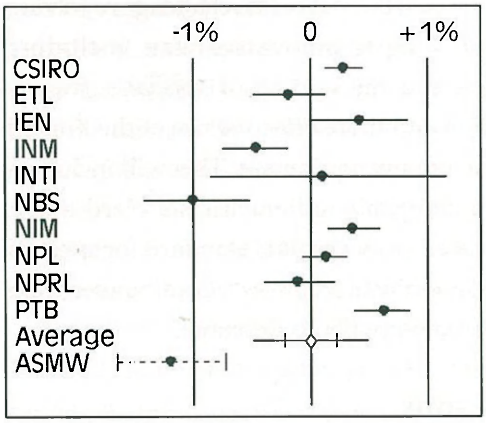
As indicated, it is in photometry and radiometry that South Africa has had the most impact internationally. The NML was actively involved in the discussions of the Consultative Committee on Photometry and Radiometry (CCPR) which led to the eventual redefinition of the candela in radiometric terms in 1979. This redefinition of the lumen and candela was first proposed by Australia in 1975, but implementation was delayed pending verification of the value of the constant K_m, which relates the photometric units to the watt at a wavelength of 555 nm. Australia independently placed its photometric scale on a radiometric base in 1975, closely followed by South Africa in 1976, the countries choosing interim values for K_m

Radiometric and photometric intercomparisons, 1980 to 1990

Year	Organiser	Purpose
1982	PTB (8 labs)	Intensity scales Lamp transfer standard performance
1984	BIPM (11 labs)	Luminous intensity and luminous flux
1886	BIPM (10 labs)	Radiant power at 488 and 633 nm
1990	BIPM	Radiant power at 1300 and 1550 nm
1990	BIPM (13 labs)	Spectral irradiance (W/m²/nm)
1990	CIE	Luminous flux, colour and relative spectral power distribution of high pressure sodium lamps

of 682 and 682,5 lm/W respectively.

By the 1977 meeting of the CCPR several new determinations had been made of K_m. The NPRL had made use of 9 standard lamps which had been calibrated by the BIPM in terms of the 1961 world mean candela, these having luminous intensities between 315 and 1 440 cd. The calculated values of K_m obtained from measurements carried out over the period 1974 and 1976 varied from 679 to 683 lm/W with the average at 681. The new international determinations of K_m, which varied from 681 to 686 were discussed at the 1977 meeting and agreement was reached on a best-estimate value of 683 lm/W which was ratified at the 1979 meeting.



Realisation of the lumen, 1984

Since that date the NML has actively participated in the many international comparisons of luminous flux (cd), luminous intensity (lm) and spectral irradiance. One of the first of these organised by the PTB between 1978 and 1979, the results being publicised in 1982 and although the intended purpose was to assess the performance of the Osram Wi 41 G lamp as a transfer standard, agreement to within ± 0,5% was observed for luminous intensity. A full comparison carried out in 1984/85 involved eleven laboratories and compared their realisation of the lumen. The NPRL's values lay very close to the mean value obtained.

Summary

With a continuing limitation in terms of both manpower and other resources during its 50 year existence, the NML had to be very selective in terms of its R&D focus. A major investment in both money and staff was placed in the areas of photometry and radiometry, where the laboratory achieved international recognition for its cutting-edge technology developments.

Acoustics

"Acoustic power measurement necessitated the creation of a new unit, the decibel. In practical use, specification of the intensity of a sound implies a comparison with that of a sound just perceptible to the human ear. A 90 dB sound is 10^9 times more intense than a barely detectable sound."

Research in acoustics was performed at the NPL right from its creation in 1946. When Halliday formed the Precise Physical Measurements Division, the capability for acoustical instrument calibration remained within the acoustics activity. Acoustics, although a physical science was, somewhat of an anachronism in its NPL location, as work such as building acoustics should more logically have formed part of the National Building Research Institute. In later years defocus also became evident from the excessive time and effort which the Division afforded the ubiquitous electrical shark cable and the experimental operation of this system at Margate, south of Durban. Although the concept was sound the efficacy was questionable, with bathers apparently being deterred more effectively than sharks!

Calibration of sound level meters

Following the promulgation of Act 76, the Acoustic Sciences Division accepted responsibility on behalf of CSIR for these standards, although the status quo continued where calibrations and maintenance of standards were secondary to other scientific research goals.

Acoustics was the last area of measurement to fall under the control of Metrology. The NPRL had maintained a separate Acoustics Division right up till its own demise in 1987. The last annual report of the NPRL (1985/86) noted that the activities of the Acoustics Division included sound propagation and intensity, building acoustics, underwater acoustics, speech and hearing and anti-shark measures. The role of developing standards of sound pressure, vibration and ultrasonic NDT was listed under the heading 'Diverse Acoustic Services'.

With the CSIR restructuring, the previous acoustics activities were distributed between the Division of Materials Technology (NDT) and Productiontek. The previous head of the division for many years, Dr Fred Anderson retired and other key members resigned to take up positions in private industry. Of the activities inherited by Productiontek, the work on the electrical shark barrier was discontinued and efforts were focussed on the development of an industry-related calibration facility for both acoustics and vibration. Of the previous staff only Peter Meffert was to remain within the metrology activities after 1988.

Today the acoustics standard (the standard for sound pressure in air) is maintained using three Brüel and Kjaer microphones. Following international practice the absolute sensitivity of these microphones is empirically determined and these values are used to calibrate industrial equipment. Confidence in the local ability to determine the sensitivity of these reference microphones is ensured through comparisons with other national laboratories, specifically the NPL, Teddington, ITRI in Taiwan and recently the NML in Australia.

The vibration standard is realised using a Brüel and Kjaer accelerometer Model 8305. This instrument is calibrated overseas in order to maintain international traceability. In turn this is then used to locally calibrate a working standard. Besides coping with a very wide range of vibration transducers, including accelerometers, calibration facilities exist for a wide range of vibration-related equipment, including machine and vibration analysers and vibration exciters and meters. A further service offered is the calibration of all types of tachometer.

An important activity is the calibration of sound measuring equipment, as required by industrial safety and other legislation. All of this equipment including sound level meters and noise dosemeters is calibrated according to the relevant IEC specification pertinent to the type and application of the instrument.

Acoustics and vibration are today the responsibility of Ian Veldman, previously involved in dimensional metrology.

Dimensional metrology

"...to demonstrate how awkward the situation can be without metrication, we note that there were, until recently, at least three different inches: British inch = 25,399965 mm, American inch = 25,400051 mm **[and the]** ***Canadian inch = 25,4 mm exactly."***

Turner and Marais, 1971.

At the birth of the NML in 1947 the standard of length was the International Metre, constructed in 1889 from platinum and iridium with an 'X' section and maintained by the BIPM in Paris. In the centennial publication of that body it was again stressed that one of the principal reasons for its creation was the unification of measures of length. Despite the availability of cadmium lamps from about 1895 which provided monochromatic lines which could be used for dimensional measurement, it was only in 1960 that the metre was redefined in terms of the orange light of the krypton 86 lamp. The NML made no attempt to obtain a copy of the metre artifact and used optical interferometry from its inception.

One of the earlier calibration tools was a 50 centimetre standard scale obtained from Hilger and Watts of London in late 1950. The original Certificate of Examination reflects the English in use in that period, with its mix of metric and imperial units:

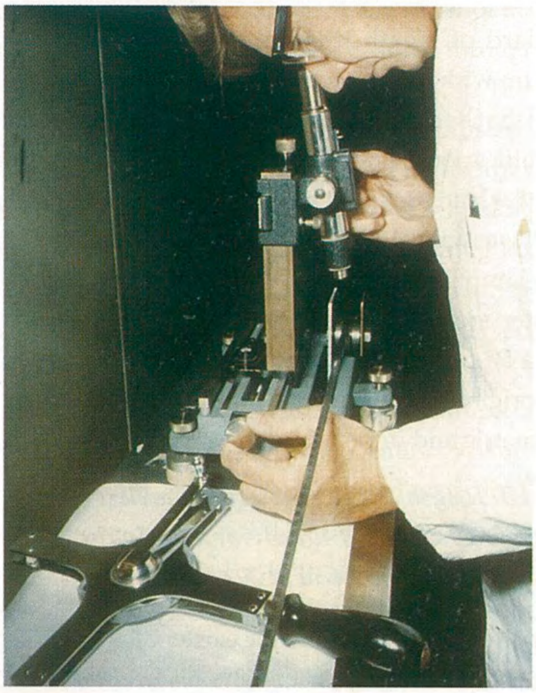
"Rectangular section 1" x 0.4"...Overall length approximately 22 inches. Graduations – The ruling is from zero to 50 c/m [cm] subdivided to single millimetres....overall length was found to be 50.000 1 c/m at 20° centigrade."

Dated 28 September 1950 this calibration was performed well before the existence of the BCS, but the certificate clearly stated that it had been checked "against a 58% Nickel Steel Line Standard, recently calibrated at the NPL (Teddington) to an accuracy of ±0,000 7 m/m".

The NPRL's tape tunnel

The tale of the tape tunnel is one of endeavour and frustration. One of the most pressing needs in regard to the measurement of length was the calibration of the metal and other tapes used by the building industry and surveyors. In the Physics of Matter section in Visagie Street this task fell to physicist Alan Morris, who together with Henry Richard (pressure), Roy Smith (mass) and Halliday comprised the entire staff complement in 1950.

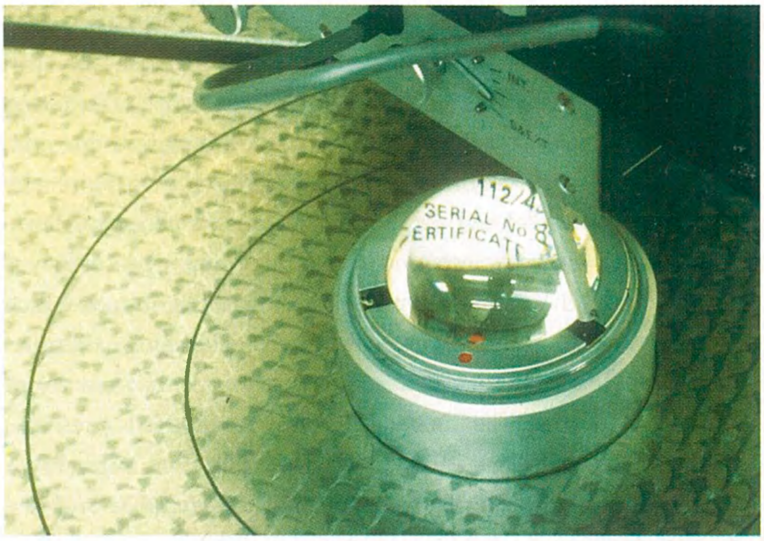
Morris began work on a novel 50 m comparator in early 1955. This was to be based on the Väisälä* 'white light' interferometer. This technique was successfully demonstrated on an experimental eight foot wall mounted on cork slabs in the Visagie Street Building in 1956. This successful experiment was followed by the re-design of the mounting system of the 166 foot (50,6 m but always referred to as 50 m) optical bench destined for the tape tunnel of the new NPRL building. The plans for this building were modified so as to incorporate a long tunnel-like room to the North of the main building and below ground level. The concept was that a 50 metre steel bar would be manufactured in the workshop and this would then be engraved with micron marks to construct a standard. The building was constructed with a 'secret' opening in the entrance staircase so that this bar could be subsequently inserted into the tunnel.



Roy Smith calibrating a tape

After the occupation of the new premises the new system based on an already installed 166 foot steel box girder was constructed. The girder had cross beams at three foot intervals which were hung at either end from specially designed spiral springs used in compression. A brick wall was first built on top of the girder and the cross beams were then screwed down on the springs. In order to avoid the possibility of distortion eight people were to be used for this task, nuts being turned in sequence, two turns at a time, from one end of the tunnel to the other. After this

*The Väisälä method although dating from the 1920s is still recognised as an important way of achieving long base-lines (up to 1 km) using interferometric techniques. Recent work (see *Metrologia*, 1994, 31, 137) has been directed at simplifying the classical, complicated set-up.



The national standard of roundness

process was completed it was later found that white light fringes could be obtained over the full 50 m length of the optical bench, indicating possible longitudinal length adjustment to better than 0,5 µm. During 1958 and 1959 the workshops at CSIR were very active producing mirror supports and other mechanical components and in the special manufacture of a 50 m stainless steel ruler. The latter was 'walked' by staff in January 1960 from the TSD workshop to the NPRL building and carefully inserted into the tunnel via the special hole referred to previously.

As soon as the optical bench was completed a routine tape (10 to 50 m) calibration service was started making use of a 50 m invar tape calibrated in 1958 at the NPL, Teddington. This tape was calibrated to "Class A accuracy (1 part in 10^6) and had a length between the 0 and 50 m marks of 49,99978 m", according to Teddington's certificate issued in July 1958. The tapes were compared using travelling microscopes, making use of two observers measuring simultaneously. The tapes themselves were supported in catenary at 10 m intervals along their length. After applying corrections to obtain the true length on a flat surface, comparisons could be made to better than one part in 10^5.

Although the tape tunnel had been planned since the inception of the NPRL and the architects had designed the facility as part of the building completed in 1957, it was only during the 1970s that it became fully operational. The final work which resulted in the two frequency laser and fringe counting techniques becoming operational was carried out by Cor van der Hoeven and Roy Smith. Work on the Väisälä method was terminated after the resignation of Morris, but a practical method had never been realised as to how to transfer the exact position of the interferometer mirror to the steel rule.

Equipment set up in the tape tunnel to measure the positioning wires for the National Accelerator Centre

Optical interferometry

Following the creation of the Precise Physical Measurements Division in 1964, work was started in earnest on the measurement of length through interferometric methods. At this time the wavelength of the orange line of the krypton lamp was the intended standard. A major problem was the short coherence length of this source which limited the length of gauge blocks being calibrated to 200 mm. It is interesting to note that as a result of CSIR's high altitude (1400 m) and low pressure, the equations which relate refractive index of air to its pressure were verified in 1970 and the agreement obtained was better than one part in a million. A new Zeiss gauge block interferometer was purchased in 1972 to replace the early Hilger instrument.

Some outstanding work was accomplished by Cor van der Hoeven and Fritz Muller in the design of Michelson and Fabry-Perot interferometer systems for use in new standards of length based on the wavelength of a laser. After Cor joined the NPRL, he and Fritz Muller designed[31] and built a system to control the scanning of a 200 mm path length Michelson interferometer. This interferometer had been specified to be able to compare wavelengths to better than 0,001 waves using a novel auxiliary Fabry-Perot interferometer. The sensitivity achieved in the published work was better than 5×10^{-5} wavelengths (633 nm). Later work[51] described a new method by which the movable mirror of the Michelson could be relocated to an accuracy of 0,3 nm using capacitor probes.

For his work on the Michelson interferometer, Fritz Muller was to obtain a PhD from the University of Natal in 1980. His thesis was entitled "Precise interferometric measurements of optical wavelengths". Details of the Michelson interferometer developed for wavelength comparison was published the same year[59].

The iodine-stabilised laser

The use of the iodine-stabilised helium laser as a wavelength standard became of international interest during the early 1970s and by 1974 several such lasers had been developed by various standards laboratories. Cor van der Hoeven had worked with Hanes of Canada's NRC on the development of the world's first such system and had specifically been responsible for building up the laser and the iodine absorption cell. As Hanes did not have access to mirrors of the required quality, the laser cavity was long and the device very unwieldy.

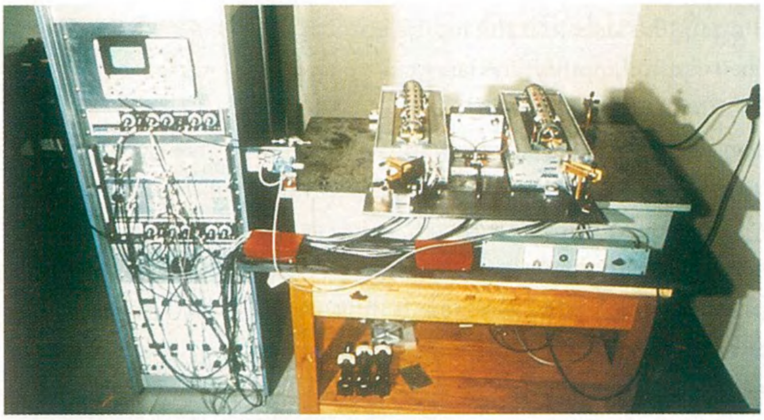
When Cor arrived from Canada, Dick Turner had not yet taken up his position and Walter Fink from the Optics Division took this opportunity to use Cor's expertise in constructing South Africa's first argon laser. The quartz-tube construction used was novel for CSIR and was one of the new technologies van der Hoeven brought with him.

Following Turner's arrival at the NPRL, Wolfgang Tuma and van der Hoeven started on a compact iodine-stabilised system, using high quality mirrors produced by Ernst Hecker and Etienne Theron of the Optics Division. Using Etienne's high reflectivity mirrors (R>99,8%) the cavity length was reduced to just 300 mm. Bob van Oorschot handled the electronics required for stabilisation and in late 1976 the first unit was completed. In 1977 Cor van der Hoeven took this laser to the NPL in Teddington, where it was compared with one of their standards. The frequency stability observed was better than 1 in 10^{12}, with a repeatability of 1 in $3X10^{10}$. The reproducibility of better than 30 kHz was for that time extremely good and CSIR's results actually compared better with the system developed by the BIPM. Following this the NPRL became the first southern hemisphere member of the exclusive 'iodine club', which at that time comprised nine first world countries.

The new laser still had several readily identifiable shortcomings and over the next period a further model was developed to overcome these. One of the major problems had been the choice of a commercially available lock-in amplifier, which had not been designed for such a demanding application. This was therefore replaced with in-house developed electronics. The piezoelectric cylinders which were used to control and modulate the position of the laser mirrors[42] were found to result in mechanical tilt and this was eliminated using a piezoelectric straightener[46]. The use of capacitor probes to position mirrors was summarised in a 1977 publication[51].

Further developments were directed around specific areas of improvement. The iodine had been found to possess a better absorption at higher temperature and a major effort was expended on the iodine cells. In regard to temperature control, expertise was provided by Roy Smith, at that time responsible for heat* standards. Two new lasers (two were needed so that the reproducibility could be measured from the beat frequency) were constructed of a design which was both more reliable and easier to use. Beating together these new lasers were found in 1978 to have a reproducibility of 2 parts in 10^{11} and a stability (over a 400 second sampling period) of 4 parts in 10^{13}. This laser, details of which were published in 1979[58] exhibited reproducibility of better than 10 kHz (less than 2 parts in 10^{11} over 200 s). This result was significantly better than that of 20 kHz obtained from an

* Heat standards are today referred to as temperature standards.



NML's stabilised lasers 'beating' together, 1978

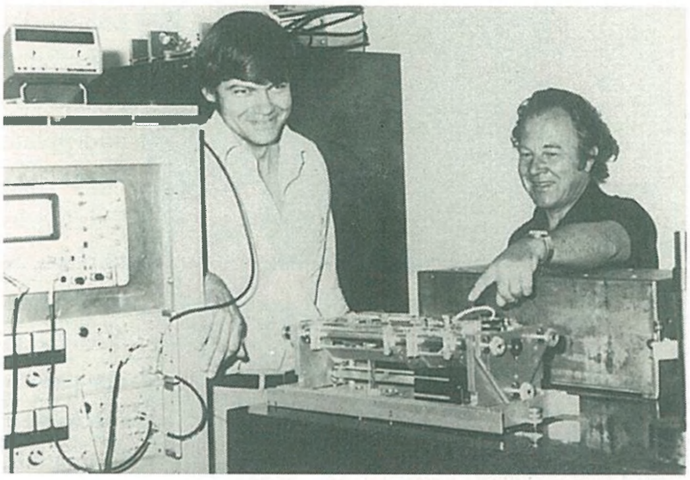
international intercomparison of other members of the iodine club during 1976. During 1979 the project development was suspended following the resignation of van Oorschot and the transfer of Cor van der Hoeven to the laser activity of the Optical Sciences Division.

Length standards at the end of the seventies

In 1978 CSIR had four measuring standards of length, which were used to calibrate a variety of other measuring instruments. The standards were a krypton lamp, a metre bar, a 50 m tape and a measured baseline. Of these the metre bar and the tape were regularly calibrated against the international standards maintained by the BIPM. During 1979 a cadmium lamp was to replace the krypton device, being much easier to use. It was not an official standard however and it was never published as such in the Government Gazette until 1994. The lamp was used together with an interferometer to calibrate end standards, including gauge blocks. The tape, in the tape tunnel, was used to calibrate surveyors' tapes.

Despite the availability of these four standards, the pressing need to traceably calibrated ring, plug and pin gauges was not catered for. Budgetary constraints necessitated careful choice of a method of calibration and use of a commercial laser interferometer was finally chosen. In order to use this as a secondary standard, the wavelength would however have to be calibrated. This was an ideal opportunity to make practical use of the recently completed iodine-stabilised laser.

The calibration procedure was simplified by the close proximity of the wavelengths, allowing direct measurement of the beat frequency caused by the difference. The measurement of the beat frequency between the NPRL's standard and the commercial Hewlett Packard laser was carried out on five consecutive days over eight hour periods. The actual wavelength in these initial measurements was determined to a precision of 10^8, an accuracy 30 times better than that quoted by the manufacturer for the interferometer as a whole[60].



Bob van Oorschot and Cor van der Hoeven with the prototype iodine-stabilised laser, 1977

While dimensional standards are well established today, few people realise that this area of metrology had been neglected. It was the impending launch of the NCS which prompted Dick into action. In a memo dated January 1980 Roy Smith was instructed to relinquish his work on temperature and other standards with immediate effect and to focus on standards for ring and plug gauges, length bars and threaded ring and plug standards. The necessary work had to be (and was) completed by the beginning of April in order to allow the launch of the NCS to proceed as planned. Calibration of threaded ring and plug standards only became possible following the acquisition of a SIP 305M in 1984.

Later stabilised laser developments

The work on the iodine-stabilised laser was resuscitated in the late 1980s under Owen Cramer and Ian Veldman. While the original laser cavity, including tube and iodine cell was used, the electronic system was completely redesigned. The cavity itself was significantly improved through the use of stacked piezoelectric rings onto which the mirrors were mounted, which improved the linear mirror movement. At the same time a major innovation was the use of carbon fibre rods (with negative expansion coefficient) to replace the original quartz ones. With stainless steel end plates the result was cavity with a zero expansion coefficient.

This laser (CSIR3) was compared with one at the BIPM in May 1991, when an offset of 10 kHz was measured. Following this a new iodine cell was acquired from the BIPM and a further model of the laser (CSIR4) was constructed during 1992. As of 1991 the laser-based system replaced the krypton lamp as the national standard for length. In 1995 the NML was invited to participate in an Asian Pacific regional intercomparison, in which eight countries participated. Results showed that the offset was only 4 kHz, with only Australia showing a smaller value.

In conclusion it can be said that standards of length developed during the 1970s onwards were based primarily on optical interferometry and laser techniques. The development of these systems and standards by the NPRL was greatly facilitated by the availability of an

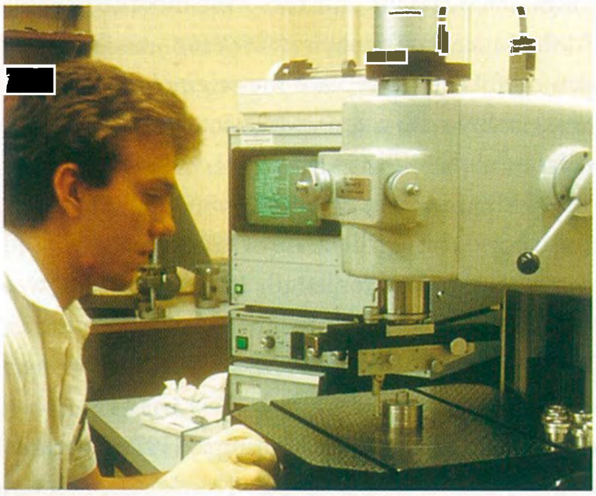
Ian Veldman with the locally developed iodine-stabilised laser

outstanding precision optical workshop in the Optical Sciences Division under Ernst Hecker. Many new materials were shaped and polished by this workshop for all the optical activities associated with metrology. This workshop also developed the expertise to restore and maintain end gauges.

Vibration-free table innovation

As previously indicated the national metrology activities were always short of money as NPRL often found 'better' uses for the government grant. One area of deprivation was the acquisition of stabilised tables such as those offered by Newport for interferometric experiments. Never to be beaten by a challenge, this was when Cor van der Hoeven first used his ingenious 'tennis-ball' approach. If you load tennis balls to about 10 kg, with them located against each other, then a granite slab (gravestone) above them is laterally and vertically stable.

Cor took this idea to the CSIR's holographic facility. Many holographers will find it hard to believe that the famous hologram of the Taung skull which appeared on the cover of National Geographic was created with laser and hologram located on separate tables. The solution was so simple that even secondhand tennis balls were used, having first been used by professionals for practice. These balls only needed to be replaced once every 12 months.



Oelof Kruger with the roundness machine

The stable capacitor – a new South African standard!

The idea for the stable capacitor had very intriguing origins. As a child Van der Hoeven had read a history of the ancient Roman city of Pompeii. Here archaeologists had found a bottle which had a ground glass top in the lava remains and it had still contained some perfume. This old discovery provided him with the idea of a very permanent enclosure.

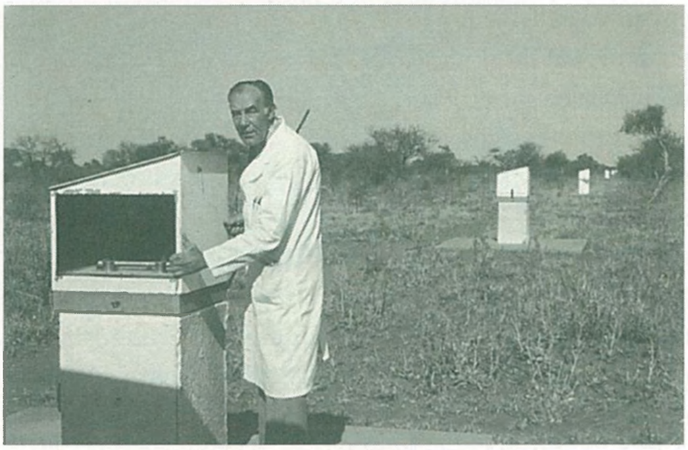
At that time the NPRL had an urgent need for stable capacitors, but funds were not available to purchase the four required. As they say in Afrikaans " 'n Boer maak 'n plan" (literally, a South African will overcome the problem) and thus local development of an ultra low expansion (ULE) capacitor was initiated. The concept was to use a metal-coated cylinder within a cylinder so if one moved at all then the capacity on one side would be less, with the other side more. The material used was titanium silicate which has practically a zero coefficient of expansion. The enclosure was sealed with a taper at either end of the cylinders with gold welds. Measurements by the NPL, Teddington resulted in very favourable results, confirming a temperature coefficient of $0{,}6X10^{-6}/K$, with a stability estimated to be $1X10^{-7}$ per month. One of these capacitors (constructed in 1973) is still used. By comparison the expansion coefficient of the best commercial capacitors at that time (mid 1970s) was $13 X 10^{-6}$.

When these capacitors were used for the primary purpose of displacement measurement, the sensitivity was such (displacement of one millionth of a tenth of a mm could be measured) that the researchers were forced to work at night and at weekends in order to remove extraneous noise caused by vibration and other movements within the building. The capacitor itself and the concept were eventually to be protected by patent and the full description of the technology has not been published. One of the best anecdotes regarding these capacitors was of an overseas visitor who was selling both high quality capacitors and measuring instrumentation. Cor brought him one of the newly developed patented capacitors which had been housed temporarily in an old 500g coffee tin. The visitor thought it was all a joke, but agreed to an intercomparison with one of his devices using his instrument. Eventually after a few days he noticed a small drift (probably attributable to his capacitor), but initially he was puzzled.

This same company shortly thereafter expressed an interest in manufacturing these capacitors under licence, but these discussions were terminated when the owner was tragically killed in an air crash. In 1975 it was reported in the NPRL's Annual Report that the possibility existed for CSIR to make a material contribution in the field of standard capacitors with this local design and preparations were in progress to patent the concept.

Kilometre baseline

In 1977 the PPM Division inherited a long length baseline standard from the National Institute of Telecommunications Research. The purpose of this was the calibration of electronic distance measuring equipment. Although referred to as the Kilometre baseline, the funding had run out when the distance reached 432 m. This had originally been set up at night by a group of scientists from the Finnish Geodetic Institute using the white light Väisälä fringe method.

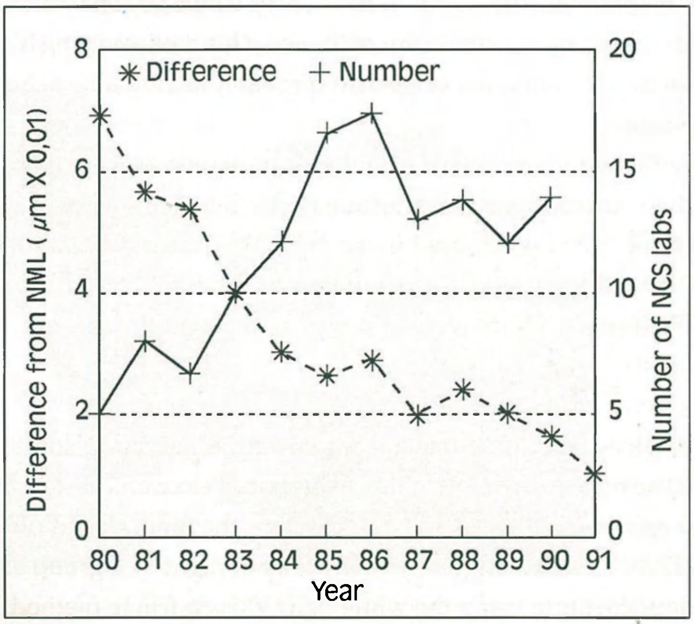


Ben van der Wagen at the long baseline in 1978

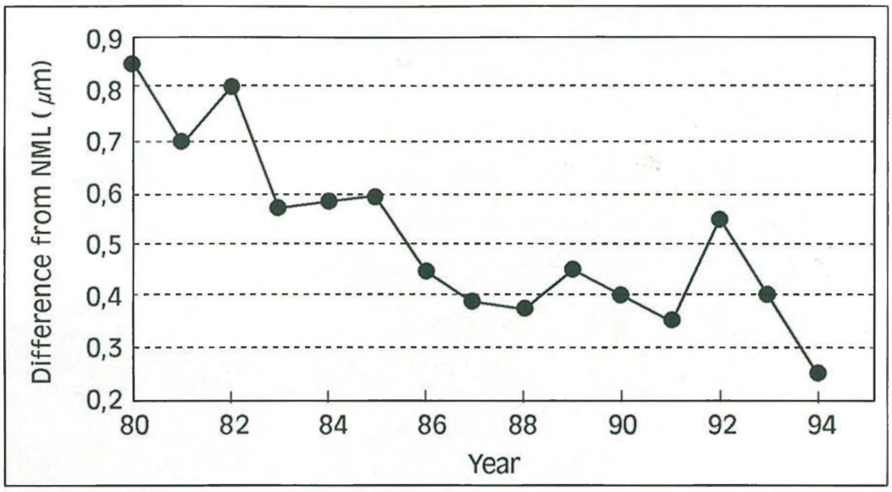
Following alignment in 1976, the provisional error was found to be less than 100 µm. Using locally manufactured infrared measuring equipment, the NITR itself extended the base length to standard measures of 864 and 1728 m. By the time it was taken over by PPM either termites or ground movement had altered the pillars and base station. Lack of finances and limited usage resulted in the eventual abandonment of the project.

Coordinate measurement capability

The capabilities of the dimensional metrology activity were significantly enhanced during 1994 with the commissioning of a SIP Co-ordinate Measuring Machine (CMM), made possible through a special capital funding allocation from DTI. This is now used for the calibration of step gauges and ball plates. Clients' step gauges are directly compared against a standard



Improvements in gauge block measurements over time



Improvement in ring/plug gauge measurements over time

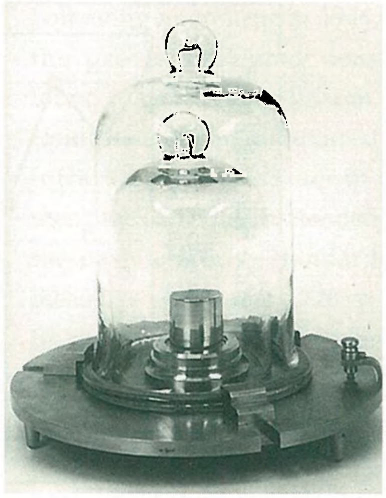
Koba gauge which is PTB-certified.

The CMM is the responsibility of John Hannaford, who has exciting new plans for the future. These include the construction of an artifact standard in the form of a light-weight metal tetrahedron fitted with precision balls in the four angled tips. The tetrahedron has been designed to have a face width of 250 mm to match standard length bars, with the centre-to-centre distance for the balls being 225 mm. This could be used to perform an international intercomparison of CMMs.

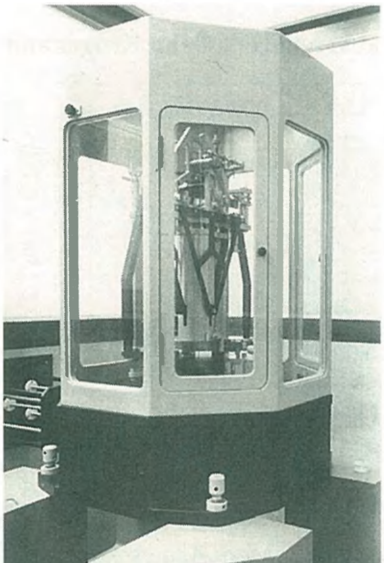
Dimensional has for the past 5 years been in the capable hands of Oelof Kruger and remains one of the more dynamic areas of metrology.

Mary Anderson who joined the CSIR in 1980, with the gauge block interferometer

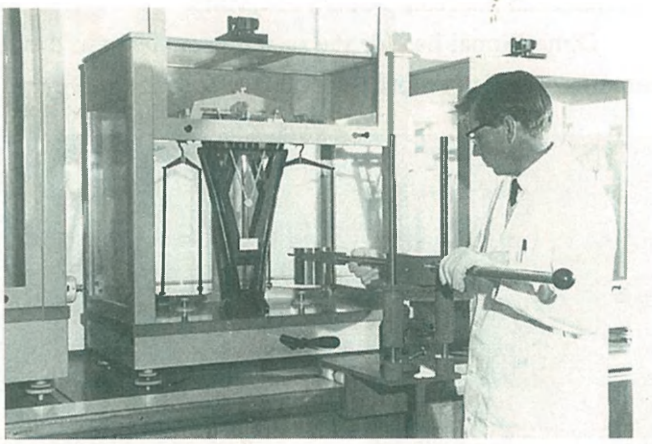
Ireen Field with a precision balance



National prototype No 56



The primary balance in its enclosure



Roy Smith in the balance room

Mass

"Notwithstanding it is provided by the Great Charter that there shall be but one Measure and one Weight throughout the Realm...yet different Weights and Measures, some larger and some less, are still in use in various places throughout the United Kingdom...which is the Cause of great Confusion and manifest Frauds."

1824 Act of Weights and Measures – Great Britain.

The international standard

Mass, in terms of the kilogram, is one of the seven primary standards in the SI unit system. While the fundamental definition of the other units/standards has changed dramatically during the twentieth century, the kilogram is still defined, as in 1889, as the mass of the international prototype kilogram as maintained by the BIPM in Paris. The original kilogram (the Kilogramme des Archives de France) dates back to 1799, but following the acceptance of the Metre Convention in 1875, three new Pt-Ir examples were constructed in 1878. These were compared to the original 1799 artifact, and one, KIII, was accepted as the new international kilogram, designated as 𝕶.

Standards of weight have suffered in the past from the ravages of fire (the historical British Imperial Standard Pound was lost in a fire in 1834 and one copy of Canada's Dominion Pound was lost in another fire in 1917). As a result, and to ensure consistent measurement, besides 𝕶, the BIPM currently maintains six official copies (Fr. témoins), two working standards and one prototype, originally allocated to the Paris Observatory, which is used occasionally. Forty prototypes (No 1 to 40) were manufactured by London's Johnson Matthey and Company in 1882 and were adjusted and polished in Paris to better than 1mg precision. In 1889 thirty four were distributed to those countries which were members of the Metre

Convention at that time, while the others became the BIPM témoins. Further national prototypes were constructed as required from 1929 onwards and South Africa was to receive No 56, which has a somewhat intriguing history as regards comparison and calibration. The method used for calibration and mass determination is one of comparing two masses and in the most exacting intercomparisons carried out occasionally by the BIPM, *all* the témoins are compared to the kilogram being evaluated in *all* possible combinations. A similar prescribed multiple-comparison procedure is used to transfer standardisation to higher or lower masses.

Mass metrology in South Africa

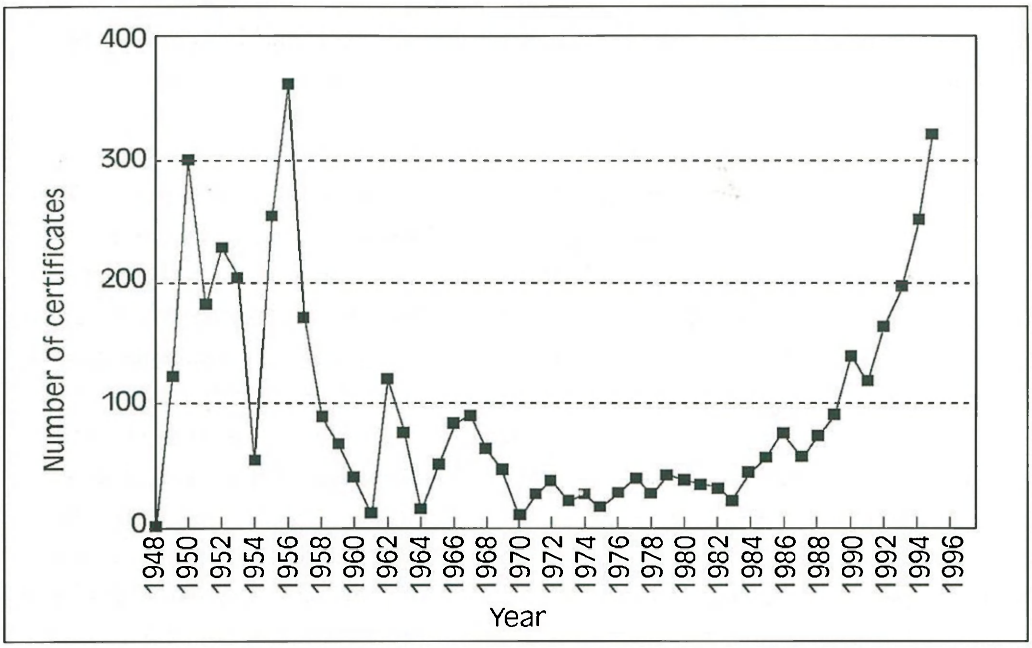
While the UK until recently maintained both an Imperial Standard Pound (constructed in 1853) and a Prototype Kilogram, as issued to it by the BIPM in 1889, the NML has maintained only metric standards of mass. Of all primary measuring standards it is mass and dimension which the general public is most aware of, most commodities being purchased today by weight (or volume) and others by length. Weighing accuracy was also very important for South Africa in the assaying of gold.

When the metrology activities were created at the NPL in 1947, mass (weight) was very visible, with every shop possessing some form of scale. In those days South Africa was still using the imperial system of measurement for trade, but it is interesting to note that despite (or perhaps because of) its colonial history the international kilogram weight was adopted as its own traceable standard right from the beginning. The following quotation dating from the 1955 Annual Report of the NPL is an intriguing anecdote, which indicates the soundness of this decision:

> ***"If the recent proposals in England and America, to define the pound legally in terms of the kilogramme (sic), are agreed to by the South African Government, the CSIR will immediately be able to supply a standardising service to the Division of Assize which will then not have to send any of its weight standards overseas for testing."***

Calibration of weights began officially in 1948, although in a letter dated 1 October that year, Dr Naudé informed a local company that although their 1/2 milligram riders could be calibrated, the mass standards department was still in the development stage and was not able to handle all tests of weights and balances as they would like to. He also indicated that he hoped this situation would improve over the next year.

The first Oertling (Orpington, England) 20 g balance was delivered to the NPL in 1949 after a full examination and calibration by the NPL, Teddington. The latter indicated in the certification that while CSIR's laboratory had not laid down specific conditions for approval,



Mass certificates issued by the NML, 1948-1996

the results served to indicate the standard of performance achieved. In any event, in the words of Ireen Field, today in charge of mass metrology at the NML, "balances in those days were hand-crafted, not just made to order."

During March 1954 a client of the NPL informed Dr Halliday that it was in fact cheaper to have his weights calibrated at the PTB in Germany. When this fact was conveyed to Dr Roux, then Director of the NPRL, he instructed that new rates should be introduced which should be just marginally cheaper than those of the PTB. After this adjustment the cost of calibrating a 1 kg weight was advertised as being £6-5-6. Following the introduction of the South African Rand (R), a later document from the PPM Division indicated a standard charge of only R3 for a 1000 g weight, for a test "to an accuracy of one part in 10^6".

The number of mass certificates issued by the NML has varied radically with time. In the 1950s the mining industry was very active and clients included assaying houses. Most weights calibrated were 1 mg to 100 g sets (as supplied with equal arm balances), as well as the 0,5 mg riders. Up to 1986 only Class A weights were calibrated (1 in 10^6). The reduction in certificates after 1960 was as a result of the introduction of electronic balances and those with built-in weights. It was also probably influenced by the lack of effective quality control measures. Towards the end of the 80s with the introduction of the ISO 9000 and the NCS, there was an increasing demand for lower-level calibration work and the NML purchased a set of electronic balances to be able to offer this service. The increase during the initial life of the NCS was affected by a policy of inserting an expiry date on certificates, often resulting in unnecessary recalibration.

The chronicle of national prototype No 56

The prototype kilogram of South Africa, No 56, has a somewhat unusual history. Ordered by the NPL in 1951, the metal was cast as an ingot by Johnson Matthey of London in 1953, then precisely adjusted to the requirements of the BIPM by L Oertling & Co. This standardising procedure is very exacting and before final polishing each BIPM prototype is distinctly marked with an assigned number. As indicated previously this kilogram was allocated the official serial number 56, even though SA was not a member state.

In any event the NPL received its kilogram, and BIPM certificate in 1955, the latter dated 7 June certifying the mass as being 1 kg + 0,183 mg. In its verification of 56 and 57, the BIPM had compared them "in all possible combinations" with a third new kilogram, designated 'C', and three others, 9, 25 and 31. 9 and 31 belonged to the BIPM and were then the prototypes d'usage, although both had been accidentally damaged. No 25 at that time belonged to the Observatory of Paris, where it was not being used and it had been proposed that it be ceded to India when that country adhered in 1957. In fact No 57 was allocated to India and 25 was acquired by the BIPM as a prototype of 'exceptional use'.

For the verification the BIPM assumed the masses of its prototypes as determined during the second international verification (1949/51) and while 9 and 31 had been used regularly since this, 25 had remained in its carrying case since 1951. During the intercomparison an unusual decrease in the difference in mass of 9 and 31 was noticed but did not cause concern. A little later, however, in 1957 No 26, the prototype of the USSR, was also measured against the same BIPM standards. The unusual difference value between 9 and 31 prompted a more detailed study and indeed a rare occasion, when 9, 25 and 31 were compared directly in September/October 1957 with the six témoins K1, 7, 8(41), 32, 43 and 47. Following this, new (elevated) values of mass were attributed to 9, 25 and 31.

A discussion between Bonhoure and C Volet, the Director of the Bureau, resulted in a decision to assume that the mass of the current prototypes of use had increased linearly with time and this was projected back proportionally to recalculate the mass of 56 and 57. A new value, some 12,2 µg higher was then provided for 56. After some prompting by the NPRL, a new certificate was issued (again prior to adherence) for the South African Standard. No 56 was to suffer a similar indignity during its 1982 intercomparison at the BIPM, the initially assigned mass being adjusted in 1983 by 0,019 mg. (Perhaps South Africa should have honoured its obligation to adhere to the Convention in 1956!). The trend over time is for all the national prototype kilograms to show an increase in mass. If 56 is compared with other artifacts manufactured after the first forty then its change has been very similar to 51, 54, 55 and 49, but very dissimilar to 50, 57 and 44 which show an increase of less than 0,5 µg per year.

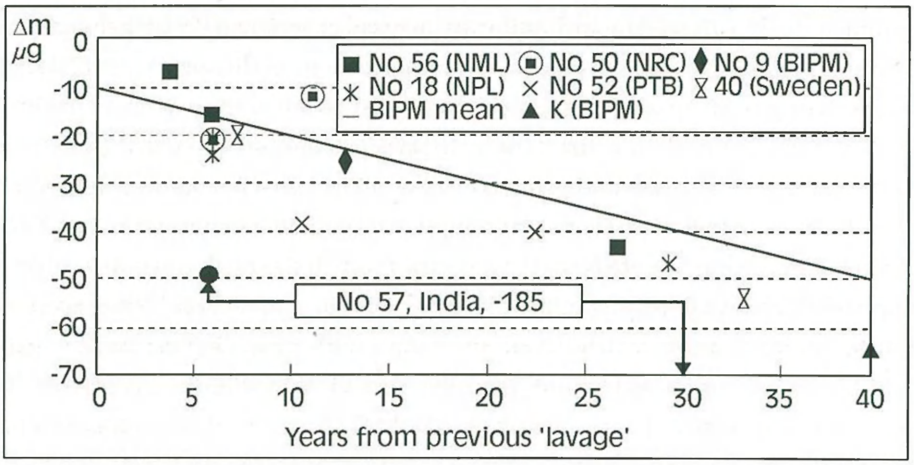
The interpretation of these changes, and the fact that one earlier prototype (23) showed an anomalous change of 95 µg over this same period must be left to the experts at the BIPM. The significance of the Verification is that South Africa's reference has changed by only some 40 parts per million over 38 years, and as stated by the BIPM "...each mass was determined with respect to the mass of the international prototype with a combined uncertainty of 2,3 µg".

What is interesting to note is that at a verification all the prototypes are subjected to a specific cleaning and washing procedure ('lavage') prior to comparison. This process removes some of the contamination which has accumulated with time. On successive cleanings at the BIPM the change on mass (Δm) of 56 agrees very closely with the average of -1 µg per year (since previous wash) determined by the BIPM. This value included measurements on such carefully kept prototypes as No 13 (95 years since 'lavage') and 𝕶 itself (42 years). This would seem to indicate that the conditions under which 56 is maintained are comparable to other major countries despite the sub-tropical climate of Pretoria. The very dissimilar behaviour of India's national prototype (No 57) should also be observed.

As the BIPM national prototypes are intended to be used only infrequently (typically every ten years), the NML also purchased four nickel-chrome 1 kg mass standards from Oertling at the same time. These were designated 1 to 4, with 1 being used for intercomparisons with the BIPM (1968 and 1984). During 1989 a further three new 1 kg stainless steel standards (5, 6 and 7) were acquired. No 5 was calibrated by the BIPM (its mass being within 3 µg of the value determined at NML), while the NML itself has compared 6 and 7 against 5, using the latter as the international intercomparison standard. The working standard 1 was itself used to maintain the rest of the NML's national mass standards down to 0,5 mg. Since 1988 mass standards have been based on a density of 8 g/cc, equal to that of the stainless steel kilograms.

Intercomparisons at CSIR using No 56 followed BIPM procedures, with the primary barometer being used to measure atmospheric pressure from which the ambient air density can be accurately calculated, essential in order to correct for the large air-buoyancy effect caused by the vastly different densities of No 56 and the Ni-Cr copies. In addition the location of the NML site in Pretoria at a height of some 1400 m above sea level, influences measurement of mass, as the density of air (1,025 kg/m^3) is significantly lower than the sea level values (1,2 kg/m^3) of most other national laboratories.

No 56 was remeasured at the BIPM in 1982, 1986 and 1993, the latter being the first time that the NML had participated in a Periodic Verification. The measurements on 56 are consistent with an increase in mass of 1,2 µg per year, similar to that observed with all prototypes and has highlighted the need for the BIPM to be able to relate mass to an atomic or fundamental constant. The merit of the Verification is illustrated by the concern expressed



Change in Δm due to cleaning and washing of some of the prototypes as a function of the number of years since previous washing and cleaning (BIPM)

in the NPRL's 1986 Annual Report, where it was reported that "[No 56] had increased in mass by 42 micrograms, a change considered as unacceptable for the custodian of South African standards". This change was attributed to instability in the mass, requiring its replacement! Roy was actually hoping that this comment would motivate the purchase of one of the new diamond-turned national prototypes.

By comparison, the Number 1 nickel-chrome working master changed by 0,516 mg over 30 years (1954 to 1984) or about 17 µg per year. While the change is accurately recorded and does not affect calibration accuracy, the new stainless steel working masters acquired during 1989 are expected to show higher stability. It is interesting to contrast the NML's regular comparison against the BIPM with the statement issued by the NRC (Canada) on 30 August 1948:

"The Dominion Standard Pound weight has recently been compared with the Imperial Standard Pound, in London, for the first time since 1874."

Prior to the acquisition of the standard kilogram, traceability was obtained using two sets of weights calibrated by the NPL, Teddington. In the very early days a set of weights (for which a calibration certificate existed) had been borrowed. A 500 g balance, with an uncertainty of 8 µg and a 20 g balance were acquired in 1950.

The primary balance

While from 1955 South Africa had its standard kilogram, the NPL could do little with it, as it did not possess a comparison balance of the required accuracy. This shortcoming was only addressed in 1959 when an order was placed on Stanton in the UK for a copy of the one in use at the NPL, Teddington since the 1930s. The cost of this piece of craftsmanship was

R6000 (roughly £3000). This NPL-type balance was referred to in 1948 (in an NRC press release) as being "perhaps the most accurate balance in the world". The BIPM at this time was still using the Rueprecht balance, which in its original form dated back to 1878 (and was in constant use until the early 1970s). This copy of the NPL's balance was one of only three made, the others going to the NRC, Canada and Australia's NSL. Stanton was to take six years to complete it and agreed to delivery in late 1966 only under pressure from CSIR.

Australia had earlier experienced some difficulties with its copy, which Halliday surmised could have been a result of the long sea passage. Taking no chances of further delays, he used his rapport with SAA, arranging for Roy Smith to travel by air to England to accept delivery. Special arrangements were made with the airline to ensure that Roy could personally oversee the stowage of the bulkier components in the aircraft hold, while three seats were assigned so that the more sensitive components could travel back to South Africa carefully strapped in beside him. The use of air travel was after this to become the norm for standards travelling overseas for intercomparison.

Roy in fact found that Stanton were struggling with the final set-up of the balance and the NPL, Teddington was not able to explain the lower than expected performance. In fact the balance was not being used as originally designed, but with some modifications, for which the CSIR accepted responsibility – this was corrected and the balance was to consistently be capable of comparing kilograms to a few parts in 10^9 up to its retirement in 1994. This 1950s masterpiece is in fact still in perfect working condition, but requires very deft human operation. It was replaced by a new automated Mettler balance.

Roy Smith eventually arrived back in Johannesburg on 22 December 1966 and as all the teething problems had been sorted out overseas, he had the device unpacked and in place (although not operational) on the following day, 23 December. The holiday almost proved to be ruinous for the prized new acquisition, as a fire was to break out in the new basement laboratories of the PPM on Christmas Day. Fortuitously Jack Whittaker had decided to do some work on this day of peace and quiet. He discovered his laboratory in flames and the rest of the corridor, with the balance room at the other end, filled with smoke. Disaster was averted following rapid reaction from the fire brigade and the balance survived! The laboratories themselves required little more than a new coat of paint.

The balance was first used to compare the four original nickel chrome copy kilograms, which were found to have lost 300 µg since their original calibration by the BIPM some ten years before. In July 1967 these measurements were repeated using copy No 1 and the final mass value obtained was 402 µg with an uncertainty of ±10 µg. Immediately afterwards No 1 was returned to the BIPM, where a value of 412 µg was measured. The NML had thus progressed to the point where the uncertainty in its mass measurements was only one part in 10^8.

Other developments

In 1961 a new low mass balance capable of weighing 2 g with an accuracy of 1 µg was acquired and the laboratory's working standards were recalibrated using this, excellent agreement being obtained with the previous 1956 calibration. During 1965 a further range of equal arm balances were acquired having head weights of 20, 10, 5 and 2 kg. All of these standard balances were mounted on a locally designed anti-vibration mount.

The expertise acquired in mass measurement technology is well illustrated by an event which occurred during 1976. A Voland balance was received from the Government Division of Weights and Measures which had received damage to its knife edge and bearing. Voland offered to re-polish these but was concerned about the ability to replace and readjust the knife and its suspension locally. Roy Smith rose to this challenge and with a new knife edge from Voland restored the balance to full operation and within the original specification (1 part in 10^7). The high standards established by Roy are carried on today by Ireen Field who as a member of the Mechanical Metrology Group is responsible for mass.

Volumetric standards

An activity on volumetric standards started in the 1970s following a request from Weights and Measures (Mr Rowland) to calibrate the then-used brass 1 litre standards. In the early 1980s glass standards were introduced and the NML calibrated sixteen regional sets (10 mℓ to 10 ℓ) for SA as well as those for Botswana and Rhodesia.

During 1988 a special 100 litre standard was developed which proved capable of calibrating a 100 litre master volumetric delivery standard used to subsequently calibrate the flow meters used in the national pipelines. Special permission was obtained to take over the responsibility for this calibration, theoretically the responsibility of the Department of Trade Metrology. The accuracy of the device developed was better than 1 in 10^5 and it was later used in the calibration of similar delivery standards built for use in Singapore.

Current status

The NML's mass activity is also responsible for the calibration of volumetric glassware by gravimetric means, such containers covering the 10 ml to 10 litre range with an accuracy of 0,05 ml. Hydrometers in the range 0,6 to 2 g/ml (maximum accuracy ±0,001 g/ml) can also be calibrated for industry. The current mass calibration service includes weights in the range of 10 g to 30 kg with an accuracy of 1 part in 10^6. From 1 mg up to 10 g the accuracy is 10 µg. These accuracies apply to good quality weights. Weights outside this range can be handled on special arrangement and the calibration of balances (mechanical and electronic) is still a service provided.

Time and frequency

"The astronomers hesitate to drop their astronomical time scales, which, even though they cannot be measured with great accuracy at any particular instant, have the over-riding advantage that they are based on a clock.... which has operated continuously throughout recorded history, and which cannot be accidentally stopped."

Jan Hers, 1967.

Early history

South Africa's national time service was for the early part of this century (1909-36) looked after by a Mr Worssell, of the Union Observatory*, who is reputed to have taken very seriously the Public Service regulations in force at that time, to the extent of personally destroying with a hammer, stop watches written off the capital register. Legend also has it that he would on occasion deliberately upset the clocks under his control, so that he would have something to do – resetting them again!

Distribution of time commenced in 1908 when an hourly signal was sent to the Johannesburg Post Office. Time was determined astronomically with an accuracy of about 0,25 seconds, but as nightly observations were impossible, the time signal (dependent on pendulum clocks) could be up to 8 seconds early or late. Three Riefler clocks were acquired over the next five years, and the signal accuracy was improved to 0,2 seconds, now limited by transit-time measurements. These clocks provided continuous service until replaced by a quartz clock in 1948. In 1912 the time service was extended to Natal, and at noon every day, the time ball on the Bluff at Durban was made to drop on a signal from Johannesburg.

*The Transvaal Observatory, founded in 1903 as a meteorological station, was renamed the Union Observatory in 1910 and the Republic in 1961, following changes to the South African constitution.

The original Transvaal Observatory building, 1944, which housed all time-keeping equipment. ZUO transmitter is the hut in the foreground

Transit time measurements ceased in 1923, when the Rugby VLF radio signal was found to be more convenient, as a single radio time signal comparison provided the same accuracy as a week of astronomical observations. Despite this, a last attempt was made by the Union to again determine time astronomically. Acquisition of a Photographic Zenith Tube was authorised in 1948, but inflation resulted in purchase being put into permanent abeyance.

During 1927 the first hour signals (a ten second dash) were sent to the then African Broadcasting Company and 1934 saw the introduction of the familiar 'six pips' signal, broadcast by the Johannesburg station, which was very seldom in error by more than 0,1 seconds. The war years and local experiments with short wave radio, resulted in the clocks being rated more accurately using the continuous signals from WWV (Washington) in 1942.

Following Worssell's retirement the task of looking after the clocks fell in rotation to the astronomers, including the renowned William Finsen who unfortunately carried out this task particularly well, especially during the skeleton-staff war years. It was he himself who was to realise that he could well be 'rewarded' by having to do this forever, and he persuaded the Union Astronomer, van den Bos (against the latter's better judgement), to appoint an electronics expert (in the guise of a physicist to avoid being accused of heresy), Jan Hers, to this position. In Finsen's own words "He (Hers) built, very quickly, a quartz clock, which was our first really reliable time instrument". In fact at this time (1945) Hers had been developing a stable oscillator for the SABC, and using the Observatory time signals had come to the conclusion that either the latter were extremely bad, or his oscillator was defying the laws of physics! This same oscillator formed the basis of the first quartz clock (known as Q1) which Finsen had referred to. It should be noted that by 1945 the new demand for accurate 'time' was coming from physicists and engineers, who were interested in its inverse, frequency, rather than period.

Finsen is on record to have remarked that during the war years the SABC was sending the blips on the hour, and the way they did this was to open the window and listen for the chimes of the Post Office clock. Years afterwards he heard that the Post Office in turn set their clock using the blips heard on the radio!

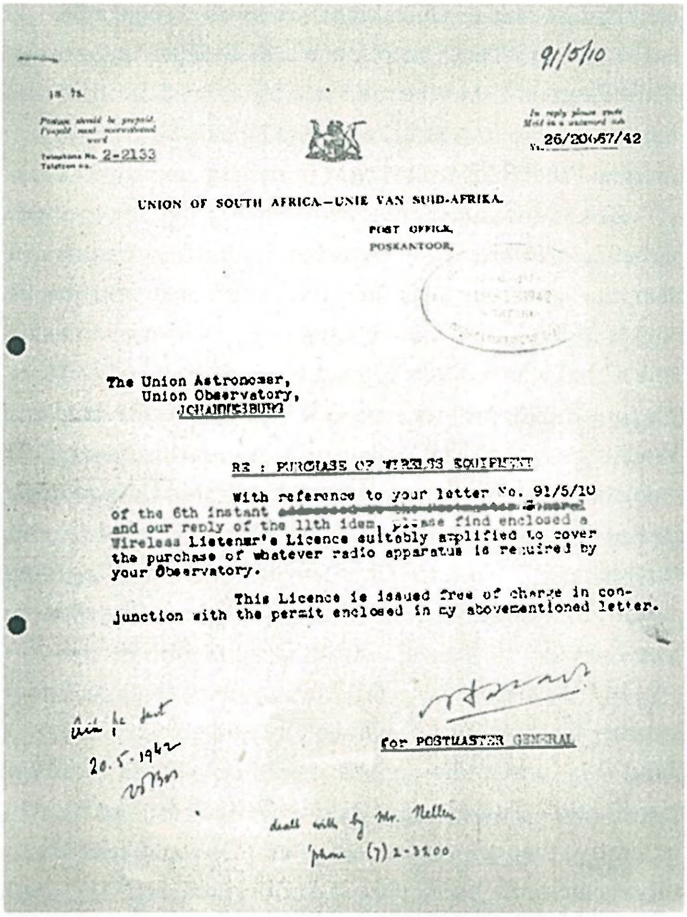
Quartz crystal technology and ZUO

"an experimental transmission of radio time signals has been started .... These signals originate at the Union Observatory, they are derived from a quartz crystal clock... Every second a pulse, consisting of 1000 c/s tone, is transmitted, except on the 59th second in each minute, when the pulse is omitted."

W H van den Bos, Union Astronomer, 19 May 1949.

Direct radio transmissions of time signals, as solicited by surveyors and geophysicists, began in May 1949 using a transmitter of the SABC, during periods where it was not in use for other broadcasts. Soon afterwards a more powerful transmitter began 24 h operation from the Observatory itself, being allocated the call sign ZUO (UO for Union Observatory). ZUO was the first station of its kind in the southern hemisphere and remained the only one in Africa. The time station was modelled on Rugby which itself only started continuous operation in 1953.

The first quartz crystal clock (Q1) was built in the observatory workshop, using an early clamped GT crystal supplied by the British Post Office (BPO), and was completed in late 1948. A second, 1950, unit (Q2) was a much more comprehensive installation based on a Western Union Frequency Standard. In November 1950, Finsen in a report to the International Astronomical Union (IAU), (emphasising concern with astronomical time) was to record "An electronic Mean Time – Sidereal Time convertor of high accuracy (one in 10^{12}) has been designed and built by Mr J Hers. Full details will be



91/5/10

Telephone No. 2-2133

No. 26/20657/42

UNION OF SOUTH AFRICA—UNIE VAN SUID-AFRIKA.

POST OFFICE,
POSKANTOOR,

The Union Astronomer,
Union Observatory,
JOHANNESBURG

RE : PURCHASE OF WIRELESS EQUIPMENT

With reference to your letter No. 91/5/10 of the 6th instant ~~addressed to the Postmaster General~~ and our reply of the 11th idem, please find enclosed a Wireless Listener's Licence suitably amplified to cover the purchase of whatever radio apparatus is required by your Observatory.

This Licence is issued free of charge in conjunction with the permit enclosed in my abovementioned letter.

for POSTMASTER GENERAL

Early open-ended wireless licence issued to the Union Observatory to allow Finsen to conduct his experiments published shortly."

The commercial oscillator had been purchased following an extensive visit by Hers to the USA and the UK during 1947. Only one unit was purchased because of the high cost ($3100) and Hers suggested that 6 additional oscillators be acquired from the BPO, then regarded as the authority on quartz clocks. Hers noted that while the BPO was unwilling to manufacture for commercial purposes, it was prepared to make an exception in the case of the Commonwealth, to whom it would supply at cost. At this time no direct comparison had been made of the American and British systems, and thus there was merit in using a 'mean clock' based on both types of oscillator.

Records duly show that the BPO later hand delivered one quartz oscillator unit W6 (a development of the original Essen-ring), and five quartz oscillators W10 to Mr Hers on 24 March 1955, the former having cost £366. A Muirhead universal signalling phonic motor (as used by Greenwich Observatory) was used to generate the time pulses. The quartz-crystal oscillator unit W6 had been specifically designed to be transportable to more distant locations. While Essen in 1954 referred to the inherent stability of these oscillators, and the satisfactory delivery of two to Australia, where he believed they were still in use, he would never have imagined that SA's unit would remain in constant operation until 1966.

ZUO transmitted time and frequency signals continuously from the 100-watt transmitter of the Union Observatory which operated on a frequency of 5 MHz. During 1957 it became clear that coverage was far from satisfactory and the Post Office began transmission at 5 MHz (4 kW), the Union changing its transmission to 10 MHz. While the duration of the time signal was initially 100 ms, this was reduced to 10 ms in 1955, and to 5 ms in 1957. At this time an attempt was made to keep the time signal within 20 ms of radio station WWV (Washington). This early attempt at standardisation by Hers was stymied by unannounced changes to the WWV time signal, attributed by him to a revised estimate of astronomical time at Washington. In a report to the IAU dated September 1957 he noted that "if such differences [in standard time] are to be avoided, ..., adjustments of phase and frequency should, if possible, be notified when they are being contemplated, instead of after they have been carried out."

In the early days of ZUO the emphasis was on frequency, which in the early 50s was accurate to 1 part in 10^9. Navigators and surveyors were satisfied with a time accuracy of about 0,1s, and radio signals were kept within these limits, but with little inter-station coordination. This changed dramatically in the late 50s when the space programme made it imperative that various tracking stations should be able to reference each other. The tracking stations in South Africa played a critical role and the Republic was requested in 1960 to join the international time coordination scheme. The ZUO signals were thus given a step adjustment on 1 December 1960, to bring them into line with the US Naval Observatory, and were thereafter kept within 1 ms of other international stations. With the introduction of the caesium standard in 1966, the ZUO carrier frequencies were derived directly from the standard and broadcast without offset. Time signals were offset from the atomic frequency as determined each year by the BIH in Paris. During late 1966 a portable caesium clock was brought to South Africa by the US Naval Observatory and the ZUO signal was phased to bring it into line.

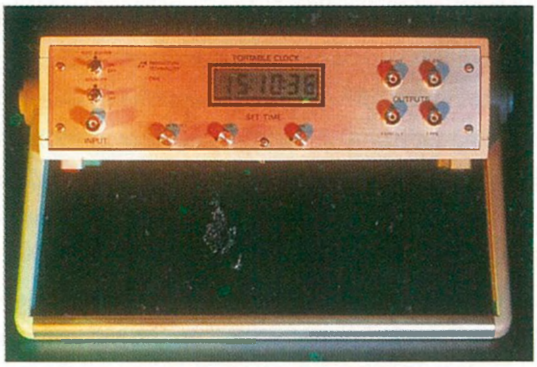
ZUO was widely used during its four decades of operation, but a most amusing story surrounds its need by the Union's own staff. At the request of the USA a grazing occultation measurement was performed in 1968 near Messina, on the border with Rhodesia. This was hardly an auspicious site to begin with, as the civil war in this state was at its peak and the spread-out observers, equipped with small telescopes were to receive several visits from suspicious border patrols who suspected more heinous deeds were in progress.

Although this was to prove to be the best observation outside of the USA, its onset was somewhat ignominious. The plan was that ZUO would provide accurate time, and each observer was armed with a portable radio and tape recorder, the moment of occultation to be marked with a voice comment superimposed over ZUO's signal. At just the crucial period reception was lost, and 'African' resourcefulness followed. A hasty telephone call ensured simultaneous recording in Johannesburg of ZUO and the 'pirate' pop station LM Radio. The observers in Messina thus recorded the occultation on a tape with the Beatles in the background, this being later tediously correlated with dubbed ZUO transmissions. The astronomers had in fact forgotten a common user complaint that within a few hundred miles of Johannesburg the ZUO signals were unreliable at night.

When the time standards were transferred to the PPM in Pretoria, the SABC accepted full responsibility for operation of ZUO and in 1976 Hers indicated that a quarter of a century after its inception it remained the only such station in Africa. It was also one of only four world stations which operated 24h, making it a major international time and frequency transmitter. Notwithstanding this Hers caustically commented that "it had the dubious distinction of being the only one of these to base all its emissions on a single caesium clock".

While altitude and temperature caused difficulties with other measurement standards, for time it was weather. The Transvaal is noted for violent summer electrical storms, which occur in the late afternoon, being referred to as 'Public Service rain' (occurring as these individuals ceased their day's work). At the Union during this period it was normal to switch off all outgoing lines at 16:00, to try and avoid lightning from knocking everything out. Hers had earlier indicated that WWV reception during the afternoon and evening was often made impossible by thunderstorms.

ZUO ceased transmissions in November 1989 for several reasons, the most significant being the fact that the transmitters were obsolete, and were becoming increasingly difficult



The NML's portable clock

to maintain, the technology itself being outdated. This was compounded by the new business-like policy of the CSIR, where the provision of 'free' services to anonymous clients could no longer be justified. The NML itself did not forego its obligation to users who could not afford other means of time dissemination such as the Television TTUs or their own atomic clocks. A new, PC-based telephone-time service (TTS) had been developed and timeously replaced ZUO. This was operated from the NML and was directly linked to the national time standard, providing subscribers with a time resetting facility to 1 ms accuracy. Using special software on an IBM-compatible PC, the TTS would be dialled automatically through a modem, the computer's internal clock being reset in typically a 2 minute connection, after transmission delays were measured and compensated for.

Ownership of time (and frequency) standards

"At the end of this month, every clock in the world should be turned back one second... South Africa will be kept "on time" by a special Time Standards Section of the CSIR.... "

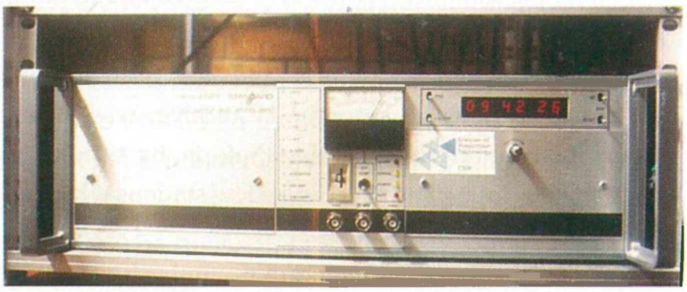
Pretoria News, June 1972, on the introduction of UTC.

The original CSIR had in fact considered the need for maintenance of a time and frequency standard as early as 1946. In a report for the NPL, Guelke concluded that as the unit of time was defined in terms of the earth's rotation, it would seem logical to locate the primary standard of time for the Union of South Africa at an Observatory where it could be checked against transit observations if necessary. He suggested that for most purposes a secondary standard would be sufficiently accurate for electrical and other calibration work, as required by CSIR at that time. Over the years there was a continued battle between scientists and astronomers for the control of time standards and the side of the latter was strengthened in 1959 by CSIR's own *Research Review*, which in an article by Mr Masson (Head of Information), was to state "As the C.S.I.R. (sic) does not operate an astronomical observatory which is an obvious prerequisite for maintaining time standards, this function is performed in South Africa....through the Union Observatory in Johannesburg".

An opportunity arose for Halliday in April 1964 when control of the Observatory (previously part of the Public Service) passed into the hands of CSIR. It is important to note that at this time Naudé was still CSIR's President and while he had been the driving force behind the establishment of the standards activity, he was equally zealous in his desire to see South Africa remain a major player in astronomy. Following the creation of the PPM Division, Halliday made a strenuous effort to have it assume responsibility for the time standards. In a memo to Dr Hewitt, dated 6 November 1964 he indicated that the present site of the Observatory was becoming increasingly unsuitable and that it would soon have to move. He concluded that "The time would now seem to be right for the centre of time measurement to be transferred to Scientia, with a stepping up of activity [frequency standards in particular] and an increase in reliability and accuracy." This skirmish continued into 1965, and although logical that the PPM division should have taken responsibility, Naude's influence probably prevailed. A final meeting (attended by Hers, Brune, Halliday and Vice of the NITR) was held in the office of CSIR's Vice President Dr Hewitt in January 1965. While the pros and cons were discussed, any decision was concluded to be premature pending the recommendations of the Long-Term Astronomy Committee. When these were available Hewitt undertook to recall the participants "in an effort to propose an integrated plan best serving the needs of the country and users in the CSIR".

This apparent discord was ultimately constructive for metrology, as the shortcomings of the facilities were highlighted. Besides discussing the relocation, an atomic standard for non-astronomical purposes was considered essential by Hewitt's committee and this led to the purchase of the first caesium clock by the Republic in 1966. Even more important was that it allowed Hers the opportunity to look for a second assistant, good fortune leading to Ron Lake's appointment. He had joined the Royal in Cape Town in 1957, being appointed to head up their Clock Room two years later. He joined Hers in July of 1965 and spent the next 27 years keeping time for CSIR.

The future for astronomy in South Africa was also resolved in the late 60s, following a proposal from Britain that the functions of the Royal and Republic should be combined. This resulted in the creation of the South African Astronomical Observatory (SAAO). A new remote site was then established for the SAAO in the Karoo and a decision was taken to transfer time standards to the PPM in Pretoria in 1972. While Hers continued to work for CSIR until his retirement in 1976, he declined to have any involvement with time, focussing on astronomical work. Danie Smuts was moved by Dick to temperature metrology and Ron thereafter assumed full responsibility for time. Danie had joined Hers in 1959, had lived on-site at the



Caesium time and frequency standard

Union and had been involved with maintaining time standards for 15 years.

Dick, having now obtained responsibility for time and frequency standards, appeared to lose interest in their further development, at least until frequency later became important to the NCS. Ron received full encouragement from George Ritter, particularly following the latter's appointment as Director of the General Physics Group of the NPRL. Thus a new caesium standard was acquired in 1980, a portable atomic clock in 1984 and one of the first of the new GPS receivers during 1986, with a second one a year later to service the new Cape time station. George also fostered development of international relations in the area of time metrology. At one time Ron thought he had finally convinced Dick of his need for a skilled assistant and located the ideal individual, Armando Costa, at one of the tracking stations. Dick allowed the appointment procedure to follow its path, only to dumbfound Ron by placing Armando in the electrical metrology activity, where he remains to this day. It was no coincidence that Dr Turner was mischievously referred to by his staff as 'Tricky Dicky'.

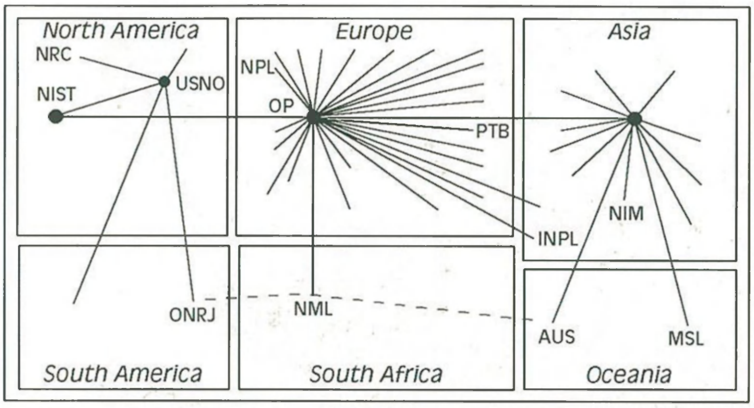
The satellite era

Commercial aviation brought with it a way to transfer time and the first international intercomparisons using a 'flying clock' were carried out by Hewlett Packard engineers in the 1960s. While limited experiments were conducted in 1964, 1965 and 1966, the most extensive took place in late 1967, with two clocks covering 100 000 km in 41 days, visiting 53 places in 18 countries. In the southern hemisphere only Australia and South Africa participated.

The results of this experiment proved highly satisfactory, with the measurements on a large number of caesium beam frequency standards showing the accuracy of the group to be within some ±5 parts in 10^{12} of the mean. Time differences were also measured during the study and the Republic was within a millisecond of the arbitrary reference used. From the 60s the US Naval Observatory was to provide a service for synchronising clocks around the world to 1 μs accuracy using portable atomic clocks.

The satellite Apollo Programmes resulted in considerable investment by the USA in the SA tracking stations. This resulted in some 15 international time checks being performed during 1966 to 1974, without cost, a fact which particularly pleased Ron Lake. A Fluke VLF receiver was purchased in 1967 and was used to continuously phase track selected international stations. A second VLF receiver was added in 1970 and UTC comparisons were maintained after the move to Pretoria. By 1976 it was clear that international interest in VLF was declining and there were few stations which provided adequate signal strength in Pretoria.

In order to allow continued future comparisons of UTC (NPRL) and UTC (BIH), it was proposed that either a portable Caesium standard be acquired, which could be compared on an annual basis with the BIH (Bureau International de l'Heure) in Paris or that a programme should be initiated to attempt time transfer between SA and Europe via satellite. A successful satellite-based experiment was conducted in 1978 when UTC standard time was compared between the NML and Teddington to within 20 ns by means of a satellite-transmitted timing pulse. This pulse was transmitted via the satellite from the UK to CSIR and back again, a novel method for that time. Following this success a decision was taken to establish a permanent satellite-based time link with Europe.



Organisation of the international GPS time links and NML links (- - -)

The advent of GPS changed time standardisation forever. The national time standard is still an atomic clock, but it is calibrated daily using GPS to a precision of some 10 ns, with frequency coordination being better than 1 part in 10^{13}. From 1988 the NML has been linked to other major national laboratories using GPS in common view mode and from the same year the BIPM coordinated clock comparisons from 50 worldwide timing centres, of which CSIR is the only one on the African continent.

SABC TV time service

"The visit to.... Prague represented the first time the flying clocks have travelled to eastern Europe. The visit was also marked by a novel* [TV] *method which was in use ... for synchronizing a distant clock."

– Hewlett Packard (HP) Journal, December 1967.

TV broadcasts in SA only began in 1976. Although ZUO was still transmitting, Ron realised TV's potential for more accurate time transfer and remembered the Eastern European work referred to by HP. Together with Hans Gaede of NITR, a time transfer system based on TV transmission was developed in 1978 and was tested by time comparisons between SABS and CSIR (caesium clocks), using the portable rubidium system. The TV transfer was in fact found to be much more stable than the latter. Following this the TTU was industrialised and small batches were manufactured for sale to NCS laboratories. This early 'commercialisation' of standards expertise was duly acknowledged by Dick as being of notable merit, the 'profits' allowing Ron freedom to fund other time-related activities.

Cyril Dodd with the TV Time Control Unit (TTCU)

The TV test pattern included a digital display and for those requiring higher accuracy the TV line scan frequency was used as a reference frequency from 1980. This service from the NML provided an accuracy better than 1 part in 10^{10} for frequency. Common signals were provided nationally using the SABC transmitters, calibrated hourly with reference to the national standard to a precision of 100 ns. Characterisation of pulses and oscilloscope calibration services are provided by the use of a reference pulse generator, itself traceable to a NAMAS accredited laboratory. With the 'new South Africa,' TV transmissions became regional, allowing local broadcasts in several languages. TV is no longer synchronised nationally and the TTCU System can only be used for laboratories in the region of the Gauteng transmitter. In the late 1980s the Cape was identified as a growth area for time services and in January 1989 Ron Lake was transferred to Cape Town to set up a local facility. By 1989 time was part of Franz Hengstberger's portfolio and he considered it essential that a second national clock should be located at a site where it would not be subject to localised power failures, providing a back-up to the CSIR's unit. Another initial objective was to make time comparisons between this now sea-level site and Pretoria, as even atomic clocks are affected by altitude.

This Cape station was operated from the old Royal Observatory premises, which by then belonged to CSIR. The time stations were tied together using GPS technology, as was a similar sub-station maintained at the Natal Technikon. When Dick regained control of all CSIR's metrology activities, he reversed Franz's decision and the Cape time station was closed.

The future

"The stage has now been reached where the rotation of the earth is no longer a standard of time, because we can make clocks which are so much more accurate.... the earth has been demoted to a short term clock."

William Finsen, unpublished interview, mid 70s.

While all metrology standards have changed radically during the 50 year history of the NML, measurement of time has probably seen the most extreme demands. While 0,1 seconds accuracy was acceptable at the time of the creation of the CSIR, today the laboratory maintains atomic time itself to some 10 nanoseconds, with frequency coordination better than 1 part in 10^{13}.

Temperature

"The National Physical Laboratory in Pretoria is able to standardize (sic) nearly all types of liquid-in-glass thermometers...If the corrections do not exceed certain limits..., the thermometer is engraved with the S.A. National Physical Laboratory monogram and the last two figures of the year in which the test was carried out."

A E Carte, The South African Industrial Chemist, March, 1954.

Dr Stan Mossop was appointed in 1947 to head up the Heat Section and after a visit to the NPL, Teddington, with the help of Ernest Carte and Mr A (Smitty) Smit he established a laboratory based closely on its model. An NPL-designed hypsometer and calibration baths as well as platinum resistance and mercury thermometers were purchased. Fixed points, including the sulphur point (444 °C) were also constructed during the 1950s in accordance with the ITS (1948) scale, with a calibration service being offered over the range -80 °C to 1700 °C.

Calibration records date back to November 1947, with detailed hand-written entries of data and comments. The clients during the first 15 years included the mining houses, other CSIR institutes, Geological Survey and SABS. The work involved calibration of both thermometers and thermocouples using the ice point.

Liquid-in-glass thermometers

The early capabilities of the NPL to calibrate liquid-in-glass thermometers was described in a 1954 publication by Ernest Carte who was a good example of the diverse skills of the early CSIR physicists, as he was to eventually become Head of the Atmospheric Sciences Division in 1981. In the 50s, like many others, he was undergoing his apprenticeship in more fundamental physics, measurement. At that time the NPL was capable of calibrating nearly all types of liquid-in-glass thermometers. The procedure first involved a physical examination, in which constructional defects were identified and care taken that no divided column existed. If the submitted thermometer had a marked 'ice point' this would be checked first, after which the device would be placed in a bath and compared to secondary standards, previously calibrated against resistance thermometers. Six or seven points would be measured and readings were taken with the aid of binoculars aligned so as to eliminate parallax error.

The disappearing filament optical pyrometer

"A function of the Heat Sub-division of the South African National Physical Laboratory is to establish primary standards of temperature in this country."
Ernest Carte, 1954.

As in other areas of standards, in the early days of the 'heat section' it was necessary to develop one's own instrumentation. ITS (1948) was attained through a number of fixed points, with interpolation between these being realised using thermocouples and resistance thermometers. Above the highest fixed point of 1063 °C (the melting point of gold) optical pyrometers were used. Ernest Carte was assigned the task of developing a local pyrometer standard and decided on the disappearing filament type.

The development of this pyrometer[3], which as with the primary barometer to be based on an earlier NPL, Teddington design, was an excellent example of multi-disciplinary team work using the available skills of the NPL. The optical system was designed by Dr E G Marais (optics), while the mechanical design and construction was the work of UK-born E J Tappere (one of the skilled instrument makers from the workshop), who also was to grind and polish the lenses. The apertures of the sector discs (used to transmit a known fraction of the radiation) were measured at the SABS.

Constant temperature bath for calibrating mercury in glass thermometers

The standard optical pyrometer was completed in 1954. For standardising other disappearing filament pyrometers (extensively used in South Africa's metallurgical industry at that time), tungsten strip lamps were calibrated in terms of current versus apparent black-body temperature. These strip lamps could then be used as sub-standards (a technique in fact used to this day). The standard itself was calibrated using the gold point, the sector discs and a black body, the laws of Planck and Wien being used to extrapolate to other temperatures.

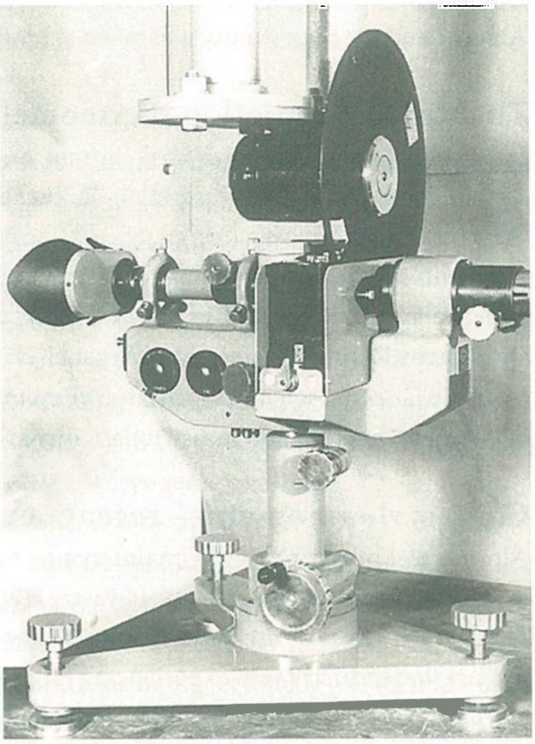
The 60s and 70s, decline and resurrection

At the beginning of the 60s, in a decision which may have been detrimental to temperature metrology, SABS was asked to take over the more routine work, with its D Marais being transferred to the section to be trained in calibration work. By 1964 Dr Mossop had resigned and moved to Australia, while Ernest Carte had transferred to the new Atmospheric Physics Group. When Roy Smith returned to the CSIR in 1964 after a 3 year absence, Marais had also resigned and had been replaced by Van der Bergh, the only remaining member of the NPRL's temperature group being A Venter who resigned shortly thereafter. Van der Bergh stayed until 1969, when all SABS staff moved to their own new laboratories in the southern suburbs of Pretoria.

Roy's first task was to implement some of the new metal (Zn and Sn) fixed points, the Annual Report of that year indicating that progress was being made in establishing the temperature scale up to the gold point and that the 'steam point' had been determined more accurately than ever before in South Africa. The gold point (1064 °C) itself was finally achieved in 1967, at which time it was indicated that the only fixed point that could not be measured to the required accuracy was oxygen.

Over the period from 1964 several people were employed in the temperature section, but their stay was short-lived until the arrival of L J Bredell in 1967. He carried out work on the calibration of the standard optical pyrometer, basically repeating much of Carte's earlier work, and he obtained an MSc in 1969. Bredell left in 1970 after it was suggested to him that he should move into the optical standards area.

By the time Dick Turner took over the PPM the temperature activities were running at a very low level, but in 1973 several events and industry requirements rekindled interest in this area. Van der Bergh had retired suddenly leaving SABS short of trained staff (increasing the calibration load of CSIR), the division received the first visit from Professor Ruffino and one of the new type of infrared pyrometers was submitted for calibration.



Disappearing filament optical pyrometer, 1950, primary standard for temperatures greater than 1063 °C

Following a serious discussion between Dick and Roy regarding the future needs of industry, the latter was sent overseas in 1974 to visit the major European temperature laboratories. On his return funding had been organised to upgrade the aging 1950s equipment and Danie Smuts from the Republic Observatory was transferred into temperature. Work immediately started on optical and infrared pyrometer calibration, with the acquisition of new equipment including optical pyrometer lamps, blackbodies and an IR pyrometer.

The old water, salt and oil baths dating from 1948 were replaced with up to date equipment, and new water triple point cells were obtained from Teddington. At the same time a complete new set of fixed point furnaces were obtained from Leeds and Northrup, and new high purity metals (Sn, Zn, Sb and Ag) were obtained, these being used for the calibration of both platinum resistance thermometers and thermocouples. By 1980 and the creation of the NCS the temperature section was fully equipped and was offering a service on a par with other National Standards Laboratories at that time.

The activity also benefited in 1982 through the appointment of Brigitte Monard who was to become an expert in the calibration of thermometers and optical pyrometers. At this time the temperature activity was also moved into the new laboratories in the basement of NPRL Annex 1 and the opportunity was taken to lay out and equip the laboratories to proper criteria.

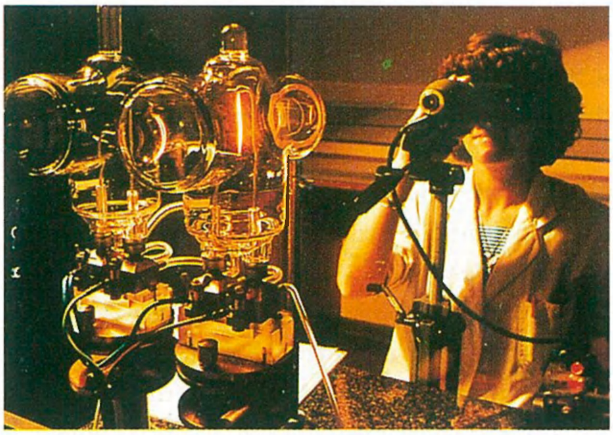
The Ruffino radiation thermometer

In 1984 Professor Giuseppe (Joe) Ruffino, an ordained Catholic priest and a researcher at the University of Rome, was persuaded to spend a period at the CSIR to build a radiation thermometer to his own design. He was an expert in this area and had advised Leeds and Northrup on the construction of their two-colour pyrometers. The plans had been sent in advance and the required lenses and filters had been constructed in the Optical Sciences Division by Dennis Chinnery and Ernst Hecker. Under his guidance and with the assistance of Mich Dumitrescu two radiation temperature standards RTS657 and RTS912 were developed[68] and are still in use today, more than a decade later.

Contact thermometry – recent developments at the NML

Almost as important as the maintenance of a reference standard is to ensure that the measuring equipment as used by industry is employed optimally, ensuring minimum errors. The first assignment[75] for Bruce Foulis, following his appointment in 1993 was prompted by the fact that industry was experiencing large errors in the use of thermocouple-type contact thermometers. Audit results in fact indicated uncertainties larger than required accuracy.

As a result a prototype thermally compensated probe was developed. This experimental device had a wound-tungsten heater element, which was dynamically adjusted through repetitive momentary contact, until the probe and the surface were at the same temperature.



Brigitte Monard in the temperature laboratory, 1988

While this proved to be an extremely accurate approach, the method of use was not practical. The follow-up was again a probe with a heater element, but with an auxiliary thermocouple junction some 2 mm away from the main sensor. An electronic system was now used to detect the point at which these thermocouple voltages were equal, indicating no temperature difference between the probe and the surface to be tested, at which point the temperature was sampled.

An audit making use of four laboratories showed excellent agreement between three, (~2 °C) and a maximum discrepancy of 7 °C compared to previous discrepancies in the region of 40 °C. The lower readings for the fourth laboratory were in fact to be expected as here the hot-plate had both a curved surface and a rough surface condition.

1985 onwards

During this period a powerful Fluke computer was acquired and the expertise of a new appointee, Wittek Bryzewski, was used to follow the example of NIST (and others) to produce calibration certificates directly from the computer's printer. Although this 'new' technology was initially strongly opposed by Dick, who preferred to remain PC-illiterate, it was readily accepted by clients and was soon to become standard practice throughout the NML.

Two Argon triple point cells were supplied by the INM in Paris during 1986, but for some reason, probably associated with changes at CSIR, these remained non-operational until 1993, when Richard Cazalet and Danie Smuts obtained the first traceable calibrations in SA down to -189 °C, greatly improving the NML's cryogenic capability.

Following Roy's retirement, Neville Robinson was appointed in 1991 to run the temperature project, assisted by Mrs Monard and Danie Smuts, the latter retiring in late 1996. With Neville's appointment a more aggressive approach was adopted in regard to intercomparisons and the increased number of NCS laboratories allowed the NML to place more focus on new standards development. Despite the aging technology of its fixed point cells the laboratory operates today according to the International Temperature Scale of 1990 (ITS90), covering a temperature range of -190 °C to 1554 °C (the Palladium fixed point). In the international TH5 WECC thermocouple audit conducted in 1991, the work of Danie Smuts in bringing the NCS up to speed was confirmed with excellent performance being observed from all South African participating laboratories. Since then the NML participated in the EAL's TH6 (resistance thermometer) audit in 1994 and will be responsible for arranging the TH9 pyrometry audit (on behalf of the European body) in 1999.

Berto Monard, whose prime expertise is in photometry and radiometry has also contributed significantly to the temperature work since 1990, taking responsibility for developments in radiation thermometry and the upgrading of the Ruffino radiation thermometers.

While the historical connection up to the 1990s was more with the NPL, Teddington, this has now been reinforced through the creation of a better working relationship with the French Institute National Metrologie (INM), where a staff member will spend up to a year in Paris working on thermocouple development, a joint venture between Russia, France and South Africa.

In 1992 temperature metrology was substantially upgraded through acquisition of two new triple-point-of-water cells from the NPL, Teddington, while a new standard platinum resistance thermometer was acquired in 1993, covering the range up to the freezing point of silver. A three-zone furnace for thermocouple calibration up to 1200 °C was also fully automated.

In 1996 several new acquisitions were made, including two standard platinum resistance thermometers (covering a range of -196 to 660 °C), a new heat pipe furnace, as well as a twin tube stirred liquid bath and a higher temperature fluidised bath. The most significant purchase was four new fixed point cells (Sn, Zn, Al and Ag) from Isotech (UK) with purities better than 99,9999%. The final acquisition was a new ASL F700 resistance bridge complementing the ASL F18 acquired during 1992. All of this new equipment should be fully operational by 1998, with the new fixed-point cells being amongst the best of their type in the world.

Humidity

The need for traceability in humidity was identified by Jan Hattingh from SABS and an activity was established in 1993 at the NML under the leadership of Andre van Tonder. In 1996 this project together with metrologist Conan Jones was transferred to temperature. At present traceability is ensured through use of an optical dewpoint hygrometer referenced to the NPL, Teddington and NIST. With the financial support of the DTI a local standard is now being established, based on a Michell humidity calibration system incorporating a precision cooled-mirror hygrometer, capable of measuring absolute values. For routine work this will be complemented with a General Eastern humidity generator with a relative humidity calibration cabinet.

The National Calibration Service (NCS)

"Measurement traceability is the life blood of a manufacturing economy, but maintenance of national standards of measurement are a scientific irrelevance if a mechanism does not exist to transfer these, with certified traceability to the factory floor, with an accuracy as necessary for specific manufactured products."

Gestation and birth of the NCS

During the early years of the NPRL, Halliday had recognised that 'a standard of physical measurement' was a meaningless phrase unless it implied a means for physical utilisation. In the 1964 brochure which described the standards activities of the laboratory, he clearly stated that after establishing a standard, the *first responsibility* of the NPRL was the comparison of standards which can be used in "other laboratories with less trouble and a somewhat lower order of accuracy". He also realised that techniques of measurement had to be disseminated, but viewed this as a *secondary responsibility*, satisfied by reports, publications, discussions, visits and interchange of personnel. Despite this apparent awareness of the needs of industry, elsewhere in the same document he was to state that "the primary interest of this laboratory lies in the field of research", and it was in this field "that the demands of measurement are most exacting".

It was only during the 70s that the NML accepted that while its fundamental legal duty was maintenance and development of the national standards, an urgent need existed to drive proper measurement practice throughout the burgeoning manufacturing industry. Much later, under Bruce Foulis, the mission of the NML would in fact be more succinctly seen as "improving accuracy and measurement techniques in order to enable industry to be both more globally effective and competitive."

Professor Wiedecke (PTB), Dick Turner, George Ritter, Roger Raab and Terry Duggen, 1985

The need for more emphasis on this aspect of the NML's activities was probably stimulated through a discussion in the mid 70s between Cyril Dodd (of NEERI's calibration lab) and Gary Weiss, at that time local representative of Fluke. Gary wanted to know how it could be established whether tests and calibrations provided by local companies were any good. Cyril told him of how the BCS (British Calibration Service) worked and following discussions with Eskom (the state electrical supply utility), Dick and the other interested parties, the NML was asked to take up the challenge.

Most historical records suggest that the NCS* was established by CSIR at the request of industry, in response to the increasing demand for calibration facilities. Dick, supported by a small core group from the electronic measuring instruments community, encouraged industry to take responsibility for its own measurement capability and to lobby the Council to facilitate this process. The NCS was a logical realisation of Act 76 of 1973, but both government and CSIR at that time were unwilling to commit themselves to further financial support.

In his mission Dick obtained staunch support from Professor Roger Raab, of the University of Natal, Pietermaritzburg. Roger had been a member of the NPRL's Advisory Committee since 1974, with special responsibility for the activities of Optical Sciences, Acoustics and the NMS&M. In 1976 a sub-committee on National Measuring Standards was created. Raab was Chairman, with the designated task of overseeing the implementation of Act 76. In his efforts Dick also received immense help from his staff, particularly Willem Marais. From the management side of the NPRL, he was to receive moral and other support from Dr George Ritter, the Director responsible for the General Physics Group.

An NCS Committee, with Professor Raab as a founder member and Dr Gorra Heymann (CSIR Vice President) as Chairman, was finally established in late 1979, the service itself becoming operational on 1 April 1980. Although officially a separate entity, the NCS was managed by Dick throughout its period of 'ownership' by CSIR which allowed him freedom

*The history of the NCS from its inception until its effective privatisation as a Section 21 company is irrevocably linked to CSIR and the NML. The realisation of the Mutual Recognition Agreements in 1993 with both the WECC and the CNLA/ITRI were due, in a large part, to the high level of competence within the NML itself, its capabilities having been extensively audited by the international bodies during the period prior to the independence of the NCS. A mutual recognition agreement establishing confidence in each other's measuring standards was signed by ITRI and CSIR in February 1991.

to access the services of the metrology staff, who also reported to him.

The first decade

The NCS was modelled on its successful British counterpart, the British Calibration Service (BCS). This had been created in 1966, originally as part of the UK Ministry of Technology, but was later moved to the NPL, Teddington in 1981, where it became responsible to the Department of Trade and Industry. The German Calibration Service (DKD) was established in 1977 and here again it was operated by the State and the PTB. The South African metrology community had a long association with both the NPL and PTB and their experiences provided vital input for similar developments in this country.

On its establishment, the NCS had thirteen officially approved* industry laboratories in the fields of electrical and dimensional metrology. These included the laboratories of the Armscor companies Atlas and Naschem, Eskom, Marconi, SAA and CSIR's Electrical Engineering Research Institute, most of which had been in existence for some time. The four inaugural members in electrical metrology drew straws to establish their registration numbers, with Eskom, Rosherville becoming Lab 101, NEERI 102, Atlas Aircraft (which had possessed a calibration lab since 1967) 103 and Marconi (now part of the Reunert Group) becoming 104. Fluke SA itself was only to be accredited in 1981 becoming Lab number 109.

In dimensional, the eight original laboratories included Yorkshire Precision Gauges as 001, SAA as 004 and Armscor's Kentron and Naschem as 003 and 005 respectively. While Eloptro in Kempton Park has the distinction of being the NCS's own 007, Volkswagen SA was shortly after to become 011.

While Dick was to use the BCS as a benchmark, South African industry differed greatly from that of the UK. Despite an impotent commitment to funding, Trade and Industry for a long time expected industry to pay for the services provided. In principle both the CSIR and the government had readily accepted the concept of the NCS, on the premise that it be self-funding through the accreditation fees. In practice, in order to encourage both membership and the development of a metrology culture, these fees were minimal, the CSIR unknowingly subsidising the NCS activities.

During this period Dick had many antagonists, but he managed to protect both himself and his vision through the creation of a strong supportive industrial lobby. Control of the NCS was in the hands of a Committee (renamed a Board as from 1988) of prominent members of industry, with CSIR's Vice President Gorra Heymann as Chairman from 1980 to 1987, followed by Maurice McDowell and then Geoff Garrett (CSIR's current President) in its last months as part of the CSIR. As a Section 21 company its first Chairman was Peter van

*Laboratories are now accredited, not approved, a subtle change in terminology.

Waldo Penzhorn (DTI) and John Wilson with some of the annual MIG trophies

Heyningen.

The carefully selected members of the NCS committee over this time included stalwarts John Wilson, Professor Roger Raab, Dr Franz Hengstberger, Professor Terry Duggan, Dennis Fulton, Waldo Penzhorn and Arthur Boettcher (the last three from DTI) and many others. Dick was to remain the driving force behind the development of the NCS from inception through to its eventual independence in 1994. As the CSIR rules and regulations at that time were not particularly friendly regarding fraternisation with industry (golf, drinks and the like), he was instrumental, together with John Wilson, in the formation of the Metrology Instrumentation Group (MIG) which provided a mechanism to circumvent some harsher CSIR edicts*.

The creation of the NCS reduced the need for CSIR's skilled metrologists to carry out routine calibrations, as the NCS accredited laboratories (which included SABS) could now supplement their internal income with calibration work carried out for subcontractors and for other independent smaller companies. In some specialised areas of metrology local demand and cost have resulted in NCS laboratories not being established and here the NML continues to provide a full calibration service. Much more important for South Africa was the visibility which the NCS created for the need for accurate measurement in industry.

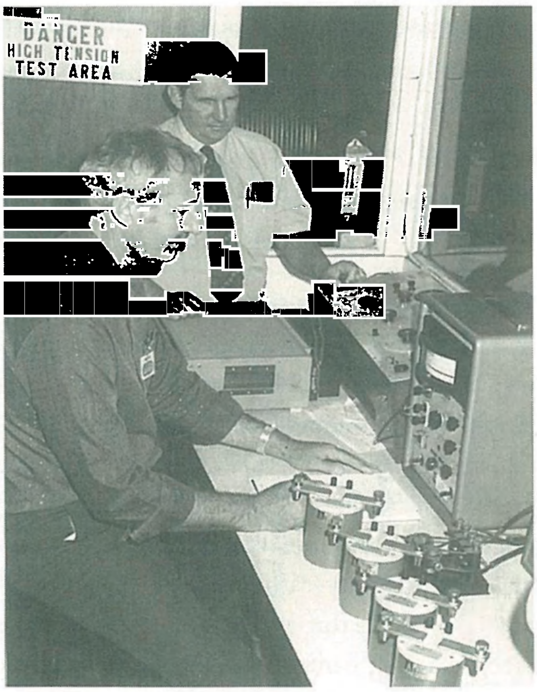
During the 80s the NCS expanded rapidly. A profound step was the establishment of an education and training system for metrologists. Here the emphasis was to ensure that the individuals were competent, rather than a focus on paper qualifications (interestingly a concept that the 'new' CSIR would adopt more generally in 1988). Regular workshops were held in areas such as electrical and dimensional metrology and a close relationship was established with the Pretoria Technikon which provided more formal courses (prepared initially by NML staff) in dimensional, temperature, time & frequency and RF. All of these involved full participation by staff members of the NML.

*The strict public service protocol of the NPRL can be illustrated by the fact that even in the 70s a summons to the office of the Director was comparable to an errant schoolboy being called to the Headmaster's study. Attendance was punctually required in proper dress (as prescribed by a CSIR edict), with no sandals or shorts allowed and preferably wearing the prescribed white lab coat (see page 22), whereafter the researcher would stand (not sit!) in front of the Director's desk to answer with due humility the questions posed.

NCS assessors were appointed from both CSIR and industry to assist in the process of new laboratory accreditations, reassessments, audits and other necessary control functions. Certificates issued by Accredited Laboratories were randomly checked for faults, often found to be typographical. From 1984 an NCS-controlled checking procedure was introduced and kept in force until PC-produced certificates eliminated this problem. Regular audits also ensured that the required standards were being maintained and best measuring capability (BMC) was revised accordingly. As the Head of the Laboratory was required to be a person approved by the NCS as competent, voluntary (temporary) suspensions of laboratories often followed staff resignations or transfers.

To assist in the administration of the NCS a system of Specialist Technical Committees (STCs) was created. Participation in these was voluntary, but well supported by the metrology community. The STC for a particular field retained responsibility for recommendations regarding laboratories, reporting directly to the NCS Manager who then presented their findings and suggestions to the full NCS Committee for approval. As the fields of activity increased, new STCs were formed from experts in these areas of metrology. In terms of new areas, photometry (Lascon Lighting) in 1986 and flow and radiation dosimetry in 1989 deserve mention. Another significant event during 1989 was the approval of the first mobile laboratory (a Transnet railway carriage).

During the CSIR control of the NCS, the objectives coalesced totally with those of the NML, the latter providing metrological skills for the former and CSIR developments being driven more directly by the requirements of industry. While CSIR was often criticised for not providing the full support to the NCS, in general this was a myopic perception. As a government-funded body, the CSIR itself was throughout most of its existence limited to the payment of salaries determined by public service regulations. Dispensations were allowed only in cases where individuals held recognised scientific and engineering qualifications, with metrology lamentably not being recognised as something special.



Willem Marais calibrating factory measuring instruments at NCS lab, Aberdare Cables, Port Elizabeth

NCS tenth anniversary

"In the days of the Franco-English war non-standardisation was desirable, as when the enemy took over your ship, their ammunition did not fit."
Rodney Buttle, Eskom, at the 1980 CSIR Conference.

In 1990 the NCS celebrated its tenth anniversary. By that time the areas covered were dimensional, electrical (AC and DC), pressure and vacuum, temperature, non-destructive testing (NDT), time and frequency, photometry, electrical (RF), force, flow, fibre optics and radiation dosimetry, this also being the historical order in which they were established. The directory at that time listed 102 laboratories, ranging from 29 in electrical to only one in such areas as photometry, fibre optics and radiation dosimetry. The standards body SABS still operated accredited laboratories in six fields including electrical, pressure, temperature, time and frequency, force and radiation dosimetry.

The 10th anniversary celebrations included a special conference held at CSIR where international speakers included Manfred Klonz (PTB), John Stoddart (NAMAS), Kai-Li Ko (ITRI) and Joe Ruffino (University of Rome). Local speakers included Maurice McDowell, Dick Turner and Rodney Buttle from Eskom. Speakers were presented with a very appropriate memento, a locally made replica of the standard kilogram, *complete with bell-jar.*

The NCS in the 90s – independence attained

"...promote quality assurance techniques, including measurement technology, and develop and manage the national measurement system."
One of the objectives of Productiontek, August 1989.

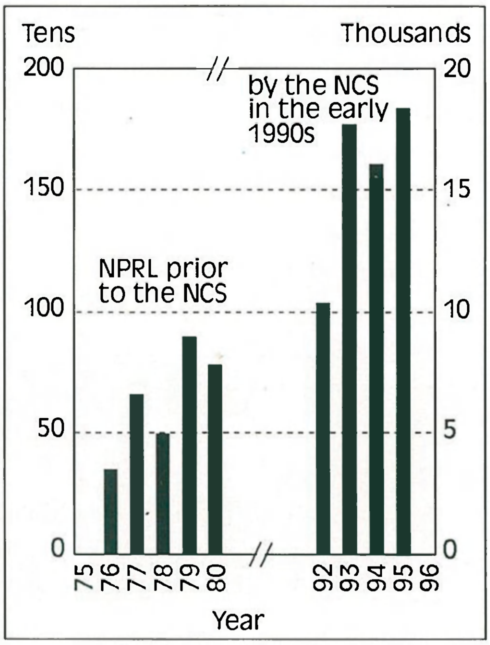
The NCS entered a new era in the late 80s and early 90s. Dick had for many years lamented that as organisations primarily intended to serve industry, the NML and NCS had not fitted well into a body (NPRL) preoccupied with academic research. The CSIR's restructuring placed both the standards activities and the NCS in the Division of Production Technology whose mission was "...the advancement of South African Industry, with special emphasis on manufacturing". The new CSIR structure was to provide more autonomy in regard to salaries, with remuneration being based (to the advantage of metrology) on individual output and responsibility, rather than just paper qualifications. While several tentative approaches had been made during the mid 1980s with a view to entering into an international mutual recognition agreement, for several reasons, including timing, and a possible lack of interest by the NPRL, no firm commitment materialised (*Scientiae* of January 1984 reported Dick as saying: "We are currently in the process of trying to get our certificates accepted in Italy, Germany and the UK"). During 1990/91 Dick once again made overtures to Taiwan (CNLA) and the Western European Calibration Cooperation (WECC). Following much work and surveillance visits, recognition agreements were signed on 6 November (CNLA) and 16 December (WECC) 1993.

The agreement with the WECC was a major coup for Dick, the NCS and the NML, as South Africa was the very first country outside of Europe to attain this prestigious status. During this period of interaction with the international bodies it became clear that local control of Accreditation and Certification bodies by the CSIR and SABS (who themselves possessed calibration, ISO accreditation and testing facilities) was not acceptable. Concern was also expressed by the WECC during the final negotiation process when the closure of Productiontek forced the transfer of the NML and NCS to Aerotek. The latter was (and still is) viewed by the international community as having primarily a defence-related mission. These concerns were to enable Dick (now nearing the age of compulsory retirement) to achieve another personal goal, the independence of the NCS, although another objective close to his heart, an autonomous metrology laboratory, was to elude him.

International events over the years had in fact resulted in major changes to the BCS, which had been the model for the NCS. A National Accreditation System (NATLAS) for test laboratories had been created during 1981 at the British NPL and for a while these two operated independently. In 1986 the two services were combined into a single body, the National Measurement Accreditation Service (NAMAS). NAMAS was later to become independent from the NPL and was finally merged with the British accreditation body for certification NACCB, today operating as UKAS.

The NCS started on the road to independence at the Board meeting held in October 1993. At this historic assembly, Geoff Garrett, CSIR's Executive Vice President was persuaded of the need for an autonomous NCS and Dick was provided with the mandate to structure a company with direct financing from DTI. (Unofficially most metrologists gave full credit to Dick for the move to independence, the story being that CSIR's Executive was exhausted by his persistent nudging and just wanted *some peace!*)

The preliminary plans were drawn up in 1993, with the concurrence of CSIR. The first AGM of the independent NCS was held in



Calibration certificates issued

Johannesburg on 16 March 1994, with a new Board of Directors being appointed. Since that date the NCS has operated as a Section 21 (not-for-profit) company, with funding being provided through an annual grant from the DTI in addition to the fees levied from the accredited laboratories. Although retired from CSIR (under a 1988 ruling which limited tenure of senior management positions to age sixty), Dick continued as CEO of the NCS until 31 March 1996, when another metrology stalwart, Mike Peet, acceded to this position. CSIR's continued support for the NCS ensured that it was granted permission to operate from the same premises that it had occupied during CSIR's control, leaving it in close proximity to the staff and facilities of the NML.

The creation of an independent laboratory accreditation body in South Africa was kept in limbo through the politicking of the main players, CSIR and SABS. The creation of the autonomous NCS in 1994 provided the DTI with a real opportunity to overcome the stalemate and it moved rapidly to put the NCS in the leadership role for this body. It is in fact ironic that during the phase of creating the privatised NCS, the name South African National Accreditation System (SANAS) had been put forward, but had not been acceptable to some of the interested parties.

Events now happened very rapidly, with the NCS being contracted during 1994 to commence work on the establishment of SANAS, which was to incorporate all aspects of accreditation, including the certification bodies, personnel and test laboratory accreditation. SABS had previously been responsible for most of these functions. It was natural that the control of SANAS, which has a critical role to play in the development and international recognition of industry in the whole of the southern African region should be in the capable hands of the NCS, which had already acquired European recognition. During late 1995 the NCS had also assumed responsibility for accreditation of testing laboratories. This led to a decision during 1996 to change the name from the NCS to the National Laboratory Accreditation Service (NLA). Following Dick's retirement in early 1996, Mike Peet was appointed Chief Executive, with Irishman Sean McCurtain as his *de facto* Deputy. While the NLA is now the officially recognised accreditation authority for laboratories, the NML remains under independent management and DTI funding, still reporting to the CSIR Board.

Mike Peet (2nd from left) receiving the 1990 SAA Award from Maurice McDowell (right)

SANAS was itself formally constituted (also as a Section 21 company) on 12 January 1996 and was officially launched by the

South African Minister of Trade and Industry, Alec Erwin at, a function later that year in the State Theatre in Pretoria. The NLA management team under Mike Peet will be used as an interim measure with the NLA itself eventually becoming one of the substructures of SANAS.

The Metrology Instrumentation Group (MIG)

"In those early days of scientific measurement, the term metrology was often to get confused with meteorology, the science of weather, which was much better understood."

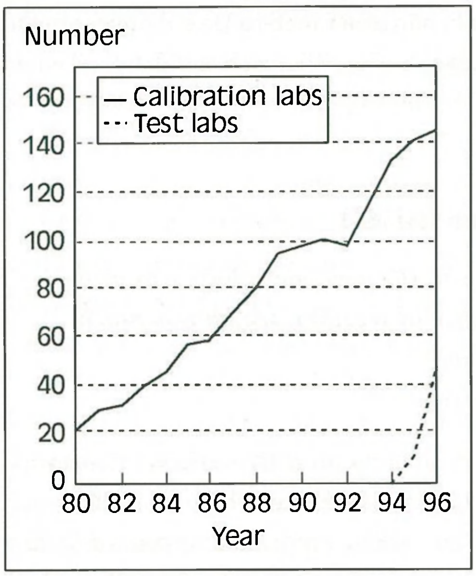
John Wilson, Spescom.

The interest of Fluke SA in metrology went further than its proactive intervention in the creation of the NCS. The lack of knowledge regarding electrical metrology was addressed at this same time by inviting John Halloran from the Fluke Corporation to run a one-day workshop soon after the launch of the NCS. The success of this initiative was followed up by Fluke in cooperation with the NML and NCS by organising a two-week workshop in the following year, again with Halloran's participation. The venue was the Sparkling Waters Resort at Rustenburg, some 100 km west of Pretoria. This was the beginning of a regular annual event on the metrology calendar, to be held at this venue, later extended from electrical to all areas of metrology. Fluke initially sponsored these workshops on its own, but in 1984 it joined forces with the other leading metrology instrumentation suppliers Protea (Tektronix) and Hewlett-Packard, to form an association to be called the Metrology Instrumentation Group (MIG).

Dick Turner entered into the spirit of these workshops with gusto and with all metrologists (from the NML, industry and instrumentation suppliers) being brought together for the first time ever, the occasions were used for intense, covert team building. After the hard work of the day the evenings were filled with social events, contests, plays and laughter. The image of scientists as remote aliens evaporated and the camaraderie of the evenings encouraged more intense interaction during the work sessions.

It should be borne in mind that during the period up to the end of the 80s, CSIR's graduate scientists and engineers were poorly rewarded salary-wise, job security and relative research freedom being viewed as adequate largesse. Metrology was not viewed by the bureaucracy as being a science, which was compounded by lack of formal paper qualifications in this area. One of the continuing functions of MIG was to organise an annual awards function in which both laboratories and individuals could be recognised for their achievements by the community they served.

John Wilson, who had been with Fluke SA since 1979, was elected as Chairman of



NLA active laboratories at year end

MIG, a position he has held ever since. In the following years MIG was to play a major facilitating role in the development of the NML, NCS and metrology in general. In those days the strict public service rules and regulations which governed CSIR forbade many otherwise normal activities such as the provision of alcoholic drinks at dinners and other functions and recognition awards. Here MIG came to the rescue and sponsored these little frills at workshops and other functions.

A request for an air-conditioned vehicle for the NCS to transport audit samples in the Reef's hot climate was also rejected outright by CSIR management. Once again this was provided through John Wilson's team, with the help of a local car manufacturer which possessed an NCS lab. (This luxury was according to legend, appropriated as personal transport for the use of the Manager, NCS.) Even NCS ties appeared long before CSIR recognised (after its 1987/88 reorganisation) that these represented a powerful means of fellowship. Besides the more covert NCS assistance, MIG contributed financially to the visits of overseas metrologists to South Africa, including Manfred Klonz and Joe Ruffino. The association was also to provide funding to certain NML developments, one of which was the portable clock which while a very sound idea was to be overtaken technologically by the advent of GPS.

In the early 1990s MIG was invited by Dennis Fulton of the DTI to help establish and facilitate the NML budget-review process. This process was the birth of the current longer-term budgeting process, driven so capably by Waldo Penzhorn and Arthur Boettcher of DTI. The original system in 1991 made use of twenty individuals representing industry to review the budget requests for metrology. Recommendations to DTI were then based on perceived priorities and local market needs.

From its creation the MIG was represented on the NCS Board by John Wilson, who was Chairman when Geoff Garrett (CSIR's Vice President) attended his first Board meeting. This historic meeting was the spark which ignited the fire for the independence of the NCS, Geoff himself asking the pertinent question as to what the NCS was doing within the NML and CSIR. It was MIG which then facilitated the NCS privatisation, contracting the attorneys to draw up the first constitution to allow the latter to operate as a Section 21 company.

The future

"Our vision of the future is to see South Africa as the centre for metrology for the whole of Southern Africa, providing services to these countries in all areas of metrology."

Dr Maurice McDowell, NCS 10th Anniversary, 1990.

The national measurement system of a country has a fundamental impact on the quality and competitiveness of its manufactured or processed goods and services. Measurement is the foundation of any quality assurance system and is required at every stage of a value-adding beneficiation chain. The South African government White Paper on Science and Technology states that "...in order to promote competitiveness in the international arena, South Africa has no choice but to remain with, or adopt, international systems of standards and conformity certification. To do otherwise would jeopardise the acceptability of our exports in world markets".

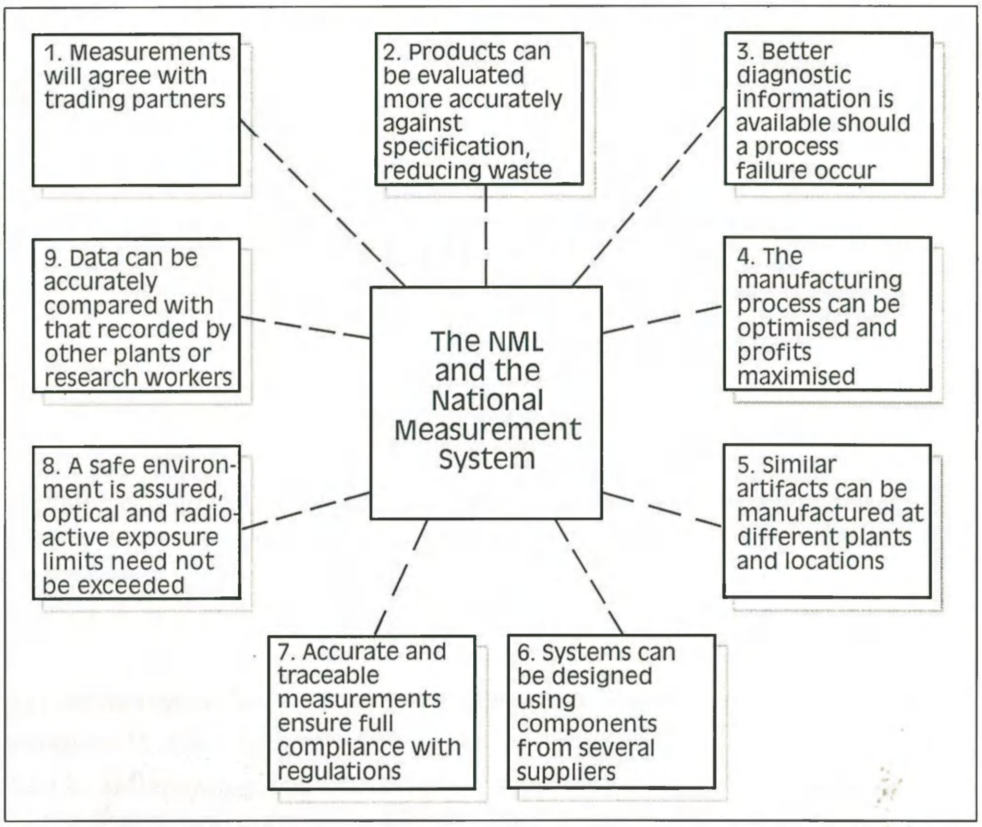
The NML and South Africa

"The CSIR's National Metrology Laboratory supports South Africa's global competitiveness through the provision of internationally traceable measuring standards and measurements."

Mission of the NML, November 1996.

While this book was conceived to mark the first 50 years of the NML, its publication has coincided closely with a number of other significant events, which when put together represent the end of one era and the beginning of another more exciting than could have been dreamed of half a century ago.

In the case of the NML itself, its restored name and international image have been



The value of a National Measurement System

consolidated with the appointment of a young and dynamic manager, who can lead the Laboratory into the 21st century, unencumbered by events and relationships of the past. A vigorous new rapport has been created with government through the DTI, also under fresh leadership through Director Eric Kruger. Under this new arrangement the NML could be operated by CSIR as a fully autonomous unit, with its own financial reporting system. The primary funding will be from DTI, supplemented by income from calibrations and other activities. As a unit it will also continue to be eligible to receive STEP funding from CSIR itself, analogous to the situation of other Divisions which are primarily funded from other government departments (eg Defence, Water Affairs and Transport).

During the 1996 and 1997 financial years the NML has benefited from a substantial injection of capital financing (more than R10 million) from DTI. This has allowed the purchase of new primary and reference standards and will allow the Laboratory to recover from many years of capital underfunding. By 1998, with further support from DTI, the Laboratory's facilities should be on a par with international standards laboratories with similar responsibilities in terms of market size and demands. From 1997 a rolling three to five-year budgeting system will be introduced, allowing for stable longer term planning in terms of both facilities and human resources. This system will follow the framework defined by the Department of Finance which will require Departments to forward plan budget requirements.

The NML itself will continue to develop human resource capabilities in the field of metrology. To this goal the existing courses in metrology will be continued and developed and further assistance will be provided to enable the Pretoria Technikon to develop both a metrology diploma and degree. Alliances will be established with other tertiary education institutions to promote education in, and understanding of, metrology and its impact on the economy.

With the support of the DTI an investigation is now in progress to see how the NML can best establish a standards facility for the mole, while other financial support will see existing standards upgraded to the latest in cryogenic, solid-state and other technologies. Another area of immediate emphasis will be to demonstrate international traceability of air pollution standards and to expand the laboratory's capabilities to other areas of environmental significance.

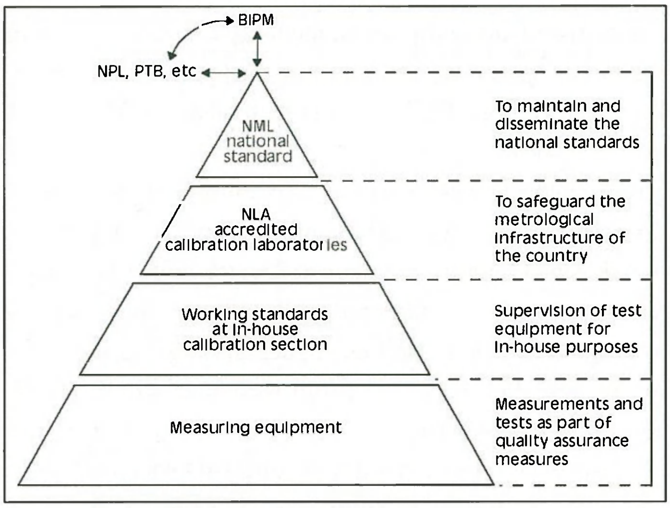
The environment

It is perhaps ironic that while Eric Halliday was the 'father' of South African metrology, he is better remembered today as the founder and head of the Air Pollution Research Group (1960). More than a quarter of a century later air pollution itself has become integral to the activities of the NML. Increased awareness of the environment has created the need for accreditation of laboratories capable of performing such measurements to international standards. In South Africa the drive came from within CSIR itself, with the Division of Earth, Marine and Atmospheric Sciences and Technology (EMATEK) requesting the NCS in 1993 to establish an accreditation capability in this area.

Funding for this purpose, in anticipation of the implementation of the international ISO 14000 series, was only obtained during 1995. Two laboratories, Eskom and EMATEK have now been accredited by the NCS. By early 1996 the NML pollution laboratory, under the management of André van Tonder was fully operational with the ability to measure NOX, SOX and hydrocarbons. The importance of this facility for a country so dependent on coal for its electrical power and liquid fuel (Sasol) needs as well as a growing ferrometals and steel industry cannot be under-emphasised.

New NCS management

While the NCS owes its development to the support of CSIR and the NML, its continued existence as part of the NML was an anachronism. The primary problem was that the control of both was in the hands of one person (apart from the period 1987 to 1993) and his staff had



The national metrology pyramid

dual responsibilities for essentially different tasks – maintenance of standards as well as calibration, auditing and other NCS-related duties. Although such a calibration service is subservient to and dependent on the national standards laboratory, the NCS itself began to claim credit (and responsibility) for the work of the NML with one Annual Report of the NCS stating: "It was very difficult to manage the NCS when project leaders in one programme (of Productiontek) had no responsibility or accountability to the Manager, NCS, for their work." In the same report it was, however, stated elsewhere that "The NCS depends critically on the support from the national measuring standards laboratories for a number of vital functions."

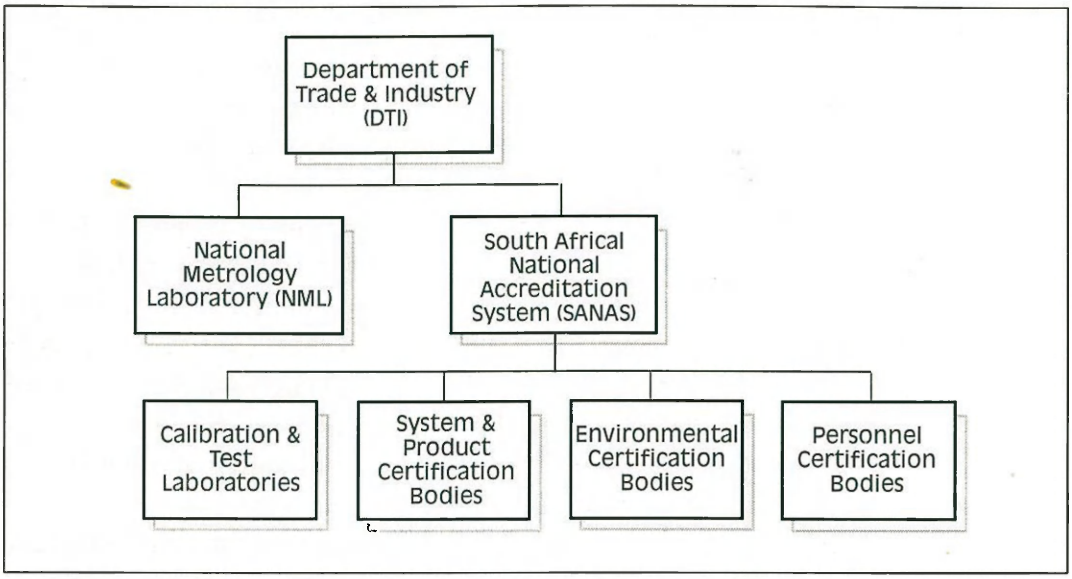
Even following its independence, the NCS under Dick Turner still appeared to believe that it was the ultimate South African authority on metrology, the CEO's 1994 report insinuating that the NCS might have to obtain its traceability from other countries, if it was to fulfil its commitment in terms of the mutual recognition agreements (MRAs) signed. The signing of the MRAs was in fact primarily as a result of the auditing of the NML itself and the finding of it to be capable of providing traceability to the certificates issued by the NCS.

This disagreement over roles between the NML and NCS was only effectively resolved following the appointment of Mike Peet as CEO of the NCS early in 1996. Coming from private industry the new CEO had no personal involvement with the staff of the NML and was able to view the situation dispassionately. As such, the internationally accepted pyramid structure with the national laboratory at the apex is now accepted by all.

SANAS

"...the NPL* [Teddington] *cannot fulfil its role as the national metrology laboratory without expending considerable effort on the development of new measuring instruments for its own use. This is mainly because commercial equipment of the type needed to audit and monitor NAMAS* [cf SANAS] *laboratories is just not available."

John Stoddart, NAMAS, 1990.



The South African Measurement System, 1997

The next major event was the creation of SANAS in 1996*, which has removed forever any doubt that may have existed regarding responsibility for measuring standards. The event was a milestone in South Africa's quality movement and placed the country amongst the leaders in the field of accreditation. SANAS will act as an independent accreditation body for laboratories, test houses, personnel and ISO 9000 and 14000 systems. As such the standards activities of SABS and the NLA will become a subset of SANAS responsibilities.

The NML itself, as the body responsible for the maintenance of the physical standards of measurement and the recognised international correspondent with the BIPM, remains independent, reporting directly to the DTI and providing SANAS and its subactivities with assistance as required. The entire accreditation and certification process is underpinned by the national measuring standards which form the basis for all traceable measurements.

The situation is now basically equivalent to that of the UK, on which metrological developments were originally based. In the UK a separate accreditation body exists, while the NPL, Teddington, with funding from DTI maintains the National Measurement System (NMS). The NML through its contribution to the NMS provides industry with a large number of benefits and competitive advantages.

*To say that the formation of SANAS was accomplished without disparity would be far from the truth, but it is interesting that a parallel was the merging of the BCS and NATLAS in the UK in 1986 to form NAMAS. Here it was reported that a "certain amount of rivalry existed", since the BCS was not perceived to be adequately concerned about paperwork, being more interested in ensuring that laboratories obtained the correct results. NATLAS on the other hand was regarded as being more interested in the paperwork, rather than results.

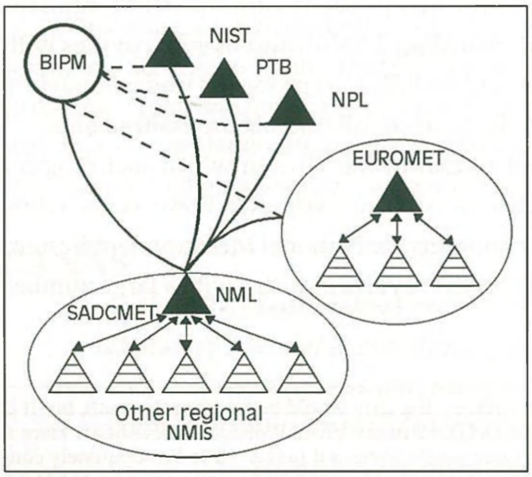
Southern African Development Community (SADC)

"The technology infrastructure in Africa, ranging from research institutions to standards and metrology bodies... is not strong, and does not help much, if at all, in raising the competitive abilities of private enterprises."

Conference of African Ministers of Industry, Gaborone, 1995.

The return of South Africa to a democracy under the leadership of President Mandela ensured the rightful participation of this country in SADC and the signing of a trade protocol in 1996 has expedited the creation of an integrated regional economy of 125 million people. As the economic powerhouse of Africa, South Africa is expected to play a leading role in this regional grouping and its economic development. In the manufacturing industry which is developing rapidly in southern Africa, traceability of measurements is imperative. Here the world authority and reference remains the BIPM in Paris, with whom the countries who are signatory to the Convention of the Metre correspond.

Whereas the original objective of the BIPM was to interact directly only with those countries which were signatories to the Convention, this is becoming increasingly impractical. The trend today is in fact towards regional-based intercomparisons. Europe led the way with the formation of Euromet as the regional authority and the mutual agreement that the various member countries of this metrology body would specialise, where feasible, in different areas of metrology, spreading costs of both new standards development and maintenance of primary standards. Other regional groupings were created in Asia and the Americas and southern Africa had been left isolated. As one of only three signatories of the Metre Convention on the African continent and the only one south of the equator it was natural that this country should take a leading role in the development of regional metrology.



International intercomparisons with regions

An event of great significance for metrology in the southern African region was the SADC Metrology Seminar and Workshop which was hosted in Pretoria by the NML in October 1996. During this event international speakers provided the background to the establishment of the new metrology communities which had been established in North America (Noramet), Europe (Euromet) and the Asia-Pacific region (APMP). The status of metrology in southern Africa was addressed by SADC member countries. Apart from Angola, which is just returning to normality after a prolonged civil war, all the member countries have an established legal metrology framework, while 50% have established a National Standards Laboratory, which in a few cases has a limited metrology capability. Amongst the states, South Africa possesses the most complete infrastructure through its National Metrology Laboratory.

At this meeting a decision was taken that for an initial period of three years the NML would act as both the link to the BIPM for international intercomparison and as the centre for regional comparisons. This is of great significance for the southern African area as the cost of establishing and maintaining a national metrology laboratory and preserving traceability is beyond the financial means of most developing countries. For this region the logical alternative was the elevation of the status of CSIR's NML to a regional authority. The choice for other countries in the region is simple. They may decide to establish a national laboratory of their own, which could be restricted to maintenance of those standards most pertinent to its industrial infrastructure or they may decide to maintain secondary standards with precision appropriate to local industrial requirements.

These laboratories will not need to be signatories to the Metre Convention or be linked to the BIPM, but could ensure international traceability through the CSIR and South Africa. The BIPM has undertaken to report on regional comparisons in the same way as it currently does for member states using *Metrologia* and its other publications. At the 82nd meeting of the CIPM in September 1993, the committee reminded those present of "the need to ensure worldwide coverage of these comparisons by taking care to include, whenever possible, one or more laboratories from the various regional metrology organisations."

A major objective of the SADC Metrology Cooperation (SADCMET) will be to promote the equivalence of measuring standards within the region and thus remove any technical barriers associated with physical measurements. The programme to achieve this goal will take many years as mere membership of SADCMET will not imply equivalence of standards. South Africa's existing Mutual Recognition Agreements with other countries could be grown over time into agreements between SADC and other international regional groupings. In addition to SADCMET, a South African Regional Accreditation Cooperation (SARAC) was formed with the objective of creating an internationally accepted resource of accredited calibration and testing laboratories. Here Mike Peet of the NLA will be the regional coordinator. SABS will play an important role in a third regional grouping, the SADC Legal Metrology Cooperation (SALMEC).

International metrology to the millennium

"Overall, the third world verification has highlighted a need for a method of linking the mass of the international prototype of the kilogram to atomic or fundamental constants."

T J Quinn, Metrologia, 1994.

What about the science of measurement itself? The prime mission of the BIPM following its creation in 1875 was to participate in the establishment of two new metric standards. The first of these was a platinum-iridium metre bar and this standard remained for 68 years until replaced by the wavelength of light of the orange line of a krypton lamp and more recently with greater precision, through use of the exact wavelength of an iodine-stabilised helium-neon laser. Despite the high precision attained, work continues in many laboratories on other stabilised lasers of different wavelengths in preparation for the next generation of length metrology.

As for mass, 𝕶 has remained to this day the international standard with copies having been circulated to all major national laboratories, including the NML. Recently considerable effort has been put into experimentation regarding the possibility of monitoring the kilogram in terms of fundamental constants such as the Avogadro Number. This in itself is a major motivation for the NML to establish a capability in the field of fundamental chemical metrology.

Time standards have this century changed from pendulum clocks to quartz crystals and finally atomic caesium clocks, while intercomparisons have taken on many forms including the flying of a standard by aircraft around the world to the simple GPS-based techniques of today. It is also interesting to note that with the accuracy of a number of primary frequency standards now approaching the level of one part in 10^{14}, certain corrections once considered insignificant must now be taken into account. Even in resistance, it appears that the day of the traditional travelling resistance artifact is over, the BIPM having constructed a transportable quantum Hall effect resistance standard with an uncertainty of a few parts in 10^{9}.

Measurement is thus a very dynamic fundamental science and as industry increases tolerance on mechanical parts and the accuracy of electronic measurements, so international standards must remain at least a step ahead. It is perhaps appropriate to end with a 1964 quotation from the pen of CSIR's first President, Stefan Meiring Naudé:

"The task* [of standardisation] *is never-ending; new developments in physics constantly make greater precision possible, and at the same time demand not only better, but also entirely new standards."

As part of its commitment to the future, the NML is now on the World Wide Web (Internet), with the following home page address which links the surfer into South Africa's metrology community: http://nml@csir.co.za

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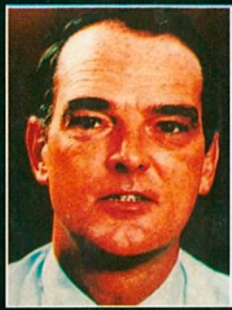

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Maurice Wilson McDowell was born in Ireland and is a graduate of the Queens University of Belfast, BSc (1st Class Honours, Physics) in 1967, and a PhD (solar ultraviolet spectroscopy) in 1971. He emigrated to South Africa with his wife, Elizabeth in October 1971, and joined the staff of the NPRL as a Research Officer, where he specialised in the field of photonics, contributing significantly to the developments in this area for the local defence industry. He became the Head of the Optical Sciences Division in 1983, later becoming the Deputy Director of the NPRL. under Dr George Ritter. In 1986 he took leave of absence from CSIR to work for American Banknote Holographics in Elmsford, New York, USA, as Manager of their extensive holographic facility. Following the 1987 restructuring of the CSIR , he was appointed as the first (and only) Director of the Division of Production Technology, and as such assumed responsibility for the metrology and standards activities.

He is now the Managing Director of Measuring Instruments Technology (Pty) Ltd, which manufactures and distributes (locally and internationally) CSIR's Goldilux range of optical radiation measuring instruments. MIT is also the Southern African agent for a large number in international electro-optical and metrology companies, including Photo Research, Oriel, Labsphere, Ealing, Oxford Instruments and GEC-Marconi Infrared. He also acts as a consulting editor for South Africa's leading technical publishing group, Technews. Maurice is the author of several hundred articles of technical and general nature which have appeared in many local and overseas publications. A particular personal interest is the writing of articles for the high-school science journal *Archimedes* whose readership is high-school students. As for history, his only previous task was to compile the story of the development of CSIR's high-density Zebra battery, a very different assignment, as unlike the near perfect records of metrology, this project was so "secret" that written records were non-existent.