

THE AUSTRALIAN METROLOGIST

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The Australian Metrologist

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Further information regarding the Metrology Society of Australia may be found on the Information Page.

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From the Editor

The change of base from Sydney to Melbourne has been responsible for the delay in TAM this year. The new national committee has been working hard sorting out future directions for the MSA, and their efforts will no doubt bear fruit in the near future. Our new President Jane Warne in her report puts many of the issues into perspective.

Much of the input for this issue has been from or initiated by the committee, and I'm sure their time is limited by work pressures.

The contents is quite varied, so there should be something for everyone this issue.

There is an addenda to last issue's article on Bayesian Statistics to sort out a few problems that crept in.

Your feedback on the TAM content is always appreciated, as it helps us focus on what you the collective membership want.

Letters to the Editor on appropriate subjects are always welcome.

- *Maurie Hooper*

2000/01 Advertising Rates for The Australian Metrologist

Space A4 page	One issue issue	Two issues issues	Three/Four issues
Full page	\$400	\$750	\$1050
1/2 page	\$225	\$425	\$600
1/3 page	\$150	\$130	\$400
1/4 page	\$115	\$215	\$290
1/8 page	\$ 60	\$110	\$150
Colour			
Full page	\$800	\$1,500	\$2,100

Closing date for copy to be received for TAM is the 15th of the month preceding publication.

Contact the TAM editor for further details.

Camera ready artwork is to be supplied. Size and specifications are available from the editor. If extra typesetting etc is required an extra charge will apply. MSA members receive a 10% discount when they place advertisements in TAM.

From the President

How to Survive Puberty

Dear Fellow Metrologists,

Here we are halfway through the year and the new committee members have their heads down and their tails up, working for you. As you will see from the CVs later in this issue of TAM there is a wide variety of people represented on the committee. People from both public and private laboratories, from both high-level research and shop floor with different metrology disciplines and from a variety of personal backgrounds. This is the strength of the MSA; a society that embraces the breadth of the profession and having some people who have developed an interest in metrology from the ground up and others who have come to it from the top down, but either way we all have a desire learn more, improve the 'science' and make it more widely accepted as a discipline.

From the inception or birth the society (at a not so small gathering of metrologists one night seven years ago) it has grown strongly through babyhood, to the childhood and a period of learning and greater discipline. To carry the analogy a little further we have been fortunate to have inherited from the previous committee a strong, health and blossoming society, verging on adolescence: a period of maturation, diversification and recognition by our 'elders' and 'peers'. However as with all teenagers there is a danger that we may crash and burn or not reach our full potential. The analogy may seem extreme to some but there is a real danger that the society could falter if we don't refocus our attention on the needs of the members and ensure that all of us are getting value from the MSA.

These concerns were the reason why earlier this year all the committee members came together for a weekend to discuss our various views on where the society is and where we want to take it. So on Friday the 15th and Saturday 16th of February the committee met to discuss our dreams for the future and more importantly how we were going to get there.

There arose a number of common issues among the committee members that this committee is now working on. Probably one of the most significant of these is TAM. As the 'face' of the MSA it is the main means of communication between members and should project a professional and vibrant image. However it is recognize that dedicated volunteer editors and a relatively small community with limited resources can only do so much. So what do we do? Firstly we have established a liaison position on the committee to improve communication between the editor and the national committee. Walter Giardini was appointed to this position. Secondly a number of subeditors have been identified to help gather

material for the magazine, since as a publication it is only as interesting as its contents. These subeditors include the state coordinators who will be expected to regularly contribute news on there state to TAM. Thirdly we are investigating getting the magazine professionally laid out, so that the format will be more readable and easy to navigate. It was also felt that there should be a balance of technical/scientific articles, industrial news and news about the society and its members.

It was also recognized that society needs a more robust National Committee structure rather than the current Melbourne/Sydney structure and not constrained by the tyranny of distance. The difficulties arise out of access to 'corporate knowledge' such as membership information. It was decided that one important and useful method of improving this structure is to make all information accessible over the internet. This is a significant task but in the long run would reduce the demand on volunteer labour and provide both individual members and state coordinator with better and more upto date information and open up a lot of other opportunities for our members to communicate.

Another issue was the number and diversity of members of the MSA. The society has for the past few years undergone 'zero population growth'. The concern is that while the states with larger memberships may be able to tolerate some decrease in membership, smaller states cannot.

While providing better service to the members through TAM and the Website it was also felt that the State coordinators' roles needs a rework to help them better understand their responsibilities.

One of my personal issues is the continued diversification of the membership. Without this the society will rapidly get to the situation where we are 'preaching to the converted'. I will give an example of what I mean. When the society started Chemists as such were initially considered to be outside the strict definition of 'metrologist'. After some discussion it was agreed that anyone who measured something should be termed a metrologist. It has taken a number of years but the number of chemists in the membership of the MSA is slowly rising, but more importantly there is a lot that the physics/engineering metrologist can learn from the chemists and vice versa. For example while the chemists are now coming to terms with uncertainty of measurement and how it applies to their discipline, they are well ahead of the average physicist when it comes to method validation. I am sure that adding biologists, medical metrologists etc will bring other dimensions to our 'community' and help us understand metrology in a more complete way. To this end we are intending to establish official contacts within a variety of organizations and institutions to encourage the flow of information and diversification of the society.

There were many other issues raised and in later issues of TAM they will be discussed but as I see it these were the big ones. Who are we? What do we want to achieve? Where do we see ourselves going in the next 3 to 5 years? From the committee's perspective however there is one issue we cannot attack directly and that is each individual's commitment to the society. We can grow the infrastructure from the great base we inherited, we

can encourage the communication even further but we need each of us to commit. It might mean attending the next function organized by your state committee, it might mean writing an article for TAM or a letter to the editor. When it comes down to it this is all our society and as they say "You only get out what you put in." I look forward to seeing you at the next meeting....

Dr Jane Warne

DON'T YOU JUST HATE THE TERM "UNCERTAINTY of MEASUREMENT"

NATA's manager for proficiency testing David Hayles says measurement uncertainty is not enough. Only comparisons between laboratories, nationally and globally can give real confidence in our measurements, ... or can they?

Firstly I would like you to consider confidence in measurement rather than the uncertainty of measurement.

As such how confident are we in the measurements we make. The standards we work to tell us that we should ensure we are 95% confident in our measurements, or there is a one in twenty chance that the true value will fall outside of the limits we have determined.

To achieve this perception of confidence, we spend time taking many measurements, we consider the historical calibration data of an instrument, we control our temperature, and analyse statistically all these and other components of the measurement chain with the hope and blind faith that the final result from this analysis will come close to what our gut feeling tells us.

Extract from the GUM

3.4.8 *Although this Guide provides a framework for assessing uncertainty, it cannot substitute for critical thinking, intellectual honesty, and professional skill.*

The evaluation of uncertainty is neither a routine task nor a purely mathematical one; it depends on detailed knowledge of the nature of the measurand and of the measurement.

The quality and utility of the uncertainty quoted for the result of a measurement therefore ultimately depend on the understanding, critical analysis, and integrity of those who contribute to the assignment of its value.

Confidence in measurement is normally defined as a percentage, whilst the limits of this confidence is the uncertainty of our measurement. Generally the term uncertainty seems to conjure up the thought of a complex statistical calculation process, designed to create a high degree of confusion with all that attempt to understand it. To try to reduce this apparent complexity let us consider confidence with limits.

Firstly in any analysis of our measurements the focus must be on the components that may effect the final result. This will be irrespective of the type of measurement, as all our measurements will have an associated uncertainty. These measurements could be physical, chemical or biological. Associated with these measurements there will be limits, outside of which, we are less than 95% confident that the true value lies. It must also be remembered that is important that all components should be tabulated and considered, not just those we consider the more significant. If this is not done there is a very real chance that a component that may have a significant effect could be missed.

We have a tendency to concentrate on the final result in any analysis of our assessment of uncertainty. However, if in the first step of the process, we focus on the components of our uncertainty, we can be far more critical in the analysis of our measurement system. Consequently, areas of our measurement process that can benefit from a small change will be far easier to detect. For example, the introduction of a quite subtle change to our method, or a change in the selection of measuring or reference equipment could result in a significant improvement in our confidence in the final result.

Each of these components will have an uncertainty associated them. The value chosen may be the result of a calculation from measurement data, or from a calibration report, a pre-characterisation, or estimation based on experience. The source of these uncertainties will determine how they are treated mathematically. The appropriate treatment of these values is well documented in the ISO GUM or in the NATA guide.

For convenience, the tabulation of the components and the final calculations are best done in a spreadsheet.

We have now calculated the limits for our confidence. Or if you like the *uncertainty of measurement*.

How meaningful is our result?

For example: we have measured a length standard with a nominal length of 150 mm and found it to be 149.999 8 mm with an uncertainty of $\pm 0.000\ 5$ mm at a confidence level of 95% (and with a calculated coverage factor of 1.98).

On the surface this is a fairly impressive measurement. However let us look a little more closely at these results.

We have a sophisticated laser length measurement system, which has a known measurement capability of better than 1 ppm in ideal conditions. However, it does rely on the ambient conditions and component temperature to be known to a high degree of accuracy. These must be taken into consideration during the measurement process. Additionally these conditions must be stable with no airflow turbulence. The temperature and atmospheric pressure measuring instruments all have their own uncertainties and limits of accuracy to be considered.

As this is a contact measurement system the interface between the components and other possible geometric errors must be considered and critically analysed.

There may also be operator heat, short-term drift of the instrument to be considered as well as compression corrections to be calculated and included.

With all these source components to be accurately assessed can we be sure we have not introduced a bias in our measurements. Our measurements may well be consistent and our calculated uncertainty realistic, yet the only true way of confirming our result may be by comparison with an independently validated artefact with similar characteristics.

Yet even then the validation of this measurement may not show a possible bias as the uncertainty of the reference artefact could in fact mask the true result.

How then can we be confident of our result?

Let's consider the results from a *National* interlaboratory comparison (ILC) amongst peer laboratories using an artefact with proven stable characteristics. After we

analyse the results it will then be possible for us to either decide on a consensus reference value, or a reference value and uncertainty with a consensus agreement. The consensus agreement on the uncertainty does of course rely on knowledge of the methods and equipment used by each participating laboratory.

The variations of each of the laboratories from the agreed reference value will not only highlight possible areas requiring further investigation, it will also give a far more accurate indication of the true uncertainty of measurement that each participant achieved in the programme.

Therefore: Perhaps our conclusion should be; the only true way confidence in measurement can be validated is by a well-designed proficiency testing program with interlaboratory comparisons. This is where the real validation of the reference value and the real uncertainty of your measurements will be realised.

Australia is an island, with us tending to view our measurement system as self regulating and self sufficient with our shores defining the edge of the measurement world. We however, must be aware *we are but a spoke in a wheel* (to use an old adage), and as such, true and accurate measurements rely on us all measuring the same globally as well as nationally. Validation of methods employed in the calibration of high accuracy reference standards with very small uncertainties of measurement should be by global interlaboratory comparisons with laboratories of similar capabilities. If global intercomparisons are not undertaken then there is a real danger of harbouring an incestuous national measurement system without true international traceability.

In Australia our National Measurement Laboratory is continuously involved in interlaboratory comparisons with its National Measurement Institute partners.

- David Hayles

Memories of a "METROLOGIST"

Metrology has been practised since the dawn of man, in many different contexts and environments, MSA member Brian Phillips recalls his early days as a metrologist in outback Australia in the early 60's.

Our memory is a marvellous thing designed to enhance our past; it exaggerates fact and romanticises recollection. With this in mind I make no apology if some of the recollections I relate deviate slightly from the truth as the intention is not deceit but merely a storytellers licence.

The complete failure of the English education system to fire my interest in Latin, French, Economics, The British Empire or Ancient British History did on the other hand

leave me with a passion for Maths, Physics and all things Scientific for which I am eternally grateful. I left Grammar School with the mind of a child who had to know "Why", the hands of craftsman who had to tinker to find out "How", and most important of all, the ability to admit ignorance when I do not understand.

My first encounter with metrology was as a trainee Fitter and Turner, (this grandiose title being merely a disguise for cheap labour), followed by a short stay as an instrument mechanic in the RAF. These experiences introduced me to "inspection", started my eventual career in instrumentation and were responsible for my migration to Australia way back in 1964.

A short stint with the National Instrument Company in Melbourne, was enough to convince me that the weather

there was never going to be much better, and so I moved on to Brisbane where I was introduced to the NATA system with "Instrument Engineering" (as this company had only just obtained accreditation in Temperature and Pressure) and later with a company called Watson Victor. That is where my relationship with "outback" metrology really started. I took up a territory servicing microscopes and balances, over an area that now makes me shudder, spanning many thousands of kilometres and taking me on the road for 20 weeks of the year. This was the coastal route from Grafton in NSW to Mossman in North Queensland, inland from Brisbane to Mt. Isa via Longreach or from Townsville to Mt. Isa via Charters Towers. On the trip back from Cairns to Brisbane, I would go inland from Mackay to Moranbah to service the coal mines, then continue down through Mt Morgan, Biloela, Kingaroy and back to Brisbane. All travelled by car. I also serviced in the Northern Territory, by road and air travel from Alice Springs to Darwin, by road from Darwin to Jabiru and flying between Cairns, Weipa, Groote Island, and Kununurra in Western Australia.

Planning was always a problem while on the road as it was difficult to estimate where I would be at the end of a working day. Travelling down to Brisbane I would service equipment at the CSIRO Mundubbera and no matter how I planned the trip it would always be late in the day when I finished. In the early days there was little accommodation in Mundubbera so I would travel on to Gayndah, hoping that the caravan park had a vacancy. Quite often when the caravan park was full, I slept in my car on the forecourt of a garage in Gayndah so as to be able to use the shower in the morning. Ingham was another place of dread to be caught late in the afternoon as the only place to stay was at a hotel and I remember the first and last stay in the Hotel Ingham, as I had to take a room with no door. (In defence of the Hotel it was the only room available and not usually in use). Another old Hotel in Bundaberg had limited town water supply only to the bathroom. To have a shower you had to book in advance – not easy when you arrive late, leave early and do not have a mobile phone!

Early days of servicing at a Main Roads Laboratory at Splitters Creek just outside Bundaberg was done in a building with earth floors and wooden duckboards to walk on. I can also recall that Sugar Mills of the same era, an all-male "frontier" environment, had no facilities for Ladies, only a problem when my wife managed to travel with me. Going in to Groote Eylandt was also a rare experience. I would fly in from Cairns late on Tuesday afternoon with about 8 hours work to do. The next flight out was the same aircraft the next morning. But on my first visit, not knowing the procedure, the company had booked me out on Thursday, which meant I had hours to spend with nothing to do. Talking to a fellow passenger I learnt of the routine adopted by most contractors, fly in and out on the same aircraft. This route had only male stewards and I asked if he could

arrange for me to fly out the next morning, this he promised to try. Not hearing from him again, I left the aircraft feeling rather depressed, but a hand on my shoulder was about to change my mood. It was the pilot, and after confirming my request to fly out the next morning he said "You turn up tomorrow morning and I will fly you out even if I have you on my lap". He had been stranded himself on the Island and was not prepared to see me suffer. The accommodation arranged for me from that time on was a camp bed in the toilet block. I would finish work about three in the morning and grab a few hours sleep before being whisked off to catch my plane.

One flight I will never forget went from Cairns to Darwin. It was a regular charter flight by Til-Air in a De Havilland Dove going from Groote Island to Katherine via Nhulunbuy, Victoria River Research Station, then on to a place on the Daly River near Elizabeth Downs. On this particular flight it rained all the way and every time we landed or took off a thick red/brown mud covered the windows. In the minds of most passengers, it was an even chance of surviving the next take off or landing. We arrived in Katherine after dark and got into Darwin after travelling for nine hours.

Sleeping arrangements were another source of adventure. I had similar arrangements with the CSIRO station at Kununurra in West Australia as with Gemco on Groote Eylandt. It was a research facility to serve the Ord River Scheme and there was about 12 hours work involved. My first visit to Weipa was almost a disaster as once again with no previous experience to guide me, I failed to make the correct bookings. I flew in from Cairns, was taken to the laboratory and worked on until about five o'clock when the lab manager told me it was time for dinner. He took me in his very old VW beetle to the canteen and on the way asked me where my bedding was. Of course I knew nothing of any bedding and found out I was supposed to arrange for a "donga" and bedding before arrival. The "donga" was a tin hut with the bare minimum of comfort, allocated to contractors who stayed overnight. The correct term was "dinga-donga" and I was told it was an aboriginal description of "a dry river bed where animals slept". Luckily for me the lab manager let me stay at his place and lent me his old VW to get back to his place when I had finished work. After dinner I toiled on and finished the task. With relief I got in to the old car, started the motor, and then turned on the headlights, NO LIGHTS at all. I had to drive about a kilometre across the mine site with my head out of the side window to see properly and when I brought the subject up to my host he replied "I meant to tell you about that".

- Brian Phillips

XVII IMEKO World Congress Dubrovnik, Croatia 22-27 June 2003

The International Measurement Confederation - IMEKO and the Croatian Metrology Society are organizing the XVII IMEKO World Congress in the city of Dubrovnik, Croatia, 22-27 June 2003.

The IMEKO World Congresses are the only expert world congresses in the field of measurement. The long history and experience of organisation of the IMEKO congresses (from the year 1958) guarantee interesting and beneficial meetings with colleagues from all around the world. I invite you to take part in the XVII IMEKO World Congress: you will have a chance to present your knowledge and ideas, as well as to share your expertise with the outstanding and responsible people of the same area of research.

The structure of the Congress offers many possibilities. During the Congress different events will occur: carefully selected papers from scientific and industrial resources; outstanding metrologists will present invited lectures; seminars and round table discussions on topics of mutual interest; presentations of regional and international metrology organisations; exhibition of measuring equipment. The Congress will be an open forum for dissemination of knowledge in the field of measurement, for better international professional cooperation, for

lobbying for metrology, and for improving confidence and making friends among metrologists.

Important Dates:

September 2, 2002 Submission of Extended Abstracts

November 15, 2002 Notification of Acceptance and Full Paper Instructions

February 10, 2003 Submission of Full Papers for Proceedings

February 25, 2003 Exhibitors Applications

XVII IMEKO World Congress June 22-27, 2003.

The Congress will take part in the city of Dubrovnik, Croatia, the jewel of the Adriatic Coast. During his history from 6th century, Dubrovnik has preserved the beauty of a medieval town. Its outstanding cultural and historical monuments have earned it a place on UNESCO's World Heritage List.

The First Announcement and Call for Papers including among other the information about extended abstract preparation and forms for electronic registration are on the website: <http://www.imeko.org> or <http://www.bmd.hr/imeko>.

Metrology Program Demonstrates Benefit from Strong Industry/University Collaboration

As anticipated at the outset, the Graduate Certificate program in Metrology and Quality, offered by the Industrial Research Institute Swinburne (IRIS), is proving to be of significant benefit to students and their employers - largely due to the decision to maintain maximum involvement of expert industry practitioners in its development and operation.

The impetus for this program came from the Metrology Society of Australia (MSA) who had been searching for a suitable program - with little success. The difficulties encountered by MSA included:

- the inability to bring together a viable number of potential students in one location
- a general decline in the interest being shown in metrology by much of the education sector over a significant period
- the somewhat disparate educational backgrounds of potential students.

Fortunately, through discussion and negotiation with IRIS, a program was outlined which overcame these difficulties - and the program is now operating its third

year. A small group of students have completed their studies and will graduate later in 2002.

Whilst IRIS, as part of Swinburne University, is responsible for the formal aspects of the program such as accreditation, enrolment and student administration, every effort has been made to make maximum use of expert industry practitioners. Under IRIS supervision, a dynamic team of practitioners has developed each of the units and provide the essential learning services to students.

Although most students undertaking the program to date do not have a first degree, entry to the program can be gained by virtue of a combination of formal qualifications, workplace learning and relevant industry experience. Indeed, for the majority of students in the program, a significant factor affecting their decision to take the program is to gain formal recognition of their prior learning. When coupled with the broadening and deepening of knowledge gained through the program, it is anticipated that graduates will have significantly enhanced career prospects. Their fuller understanding of metrology, and a more systemic view of its

relationships to industry, is seen as vital in assisting them to assume more responsible positions and be more proactive in addressing the needs of their employer companies.

As is common with most Graduate Certificate programs, students undertake 4 units - each of one semester duration. A major feature of the program is that these units are completed in "distance" mode. At the start of each semester, students receive a "learning package" containing learning material, reference sources and a learning guide. They work through the defined program

and complete assessment tasks with the support of assigned mentors - industry practitioners with whom they communicate regularly (typically by email). An important consequence of this methodology is that students may be physically located anywhere - and the current cohort are spread across Australia and even internationally.

Further information on this program may be obtained from the program convenor, Brian Costello, at IRIS. Ph: (03) 9214 8005 <bcostello@groupwise.swin.edu.au>

NATA AND METROLOGY

- Ian Bentley

The science of measurement - metrology - has a special place in NATA's firmament of testing fields. In this article, Ian Bentley, the manager of its metrology field, fills us in on a few facts of special significance to our community.

The Metrology field was the first field established by NATA, but despite its name it does not cover all areas of measurement and calibration. A significant proportion of calibration activities are actually covered under NATA's other fields such as Acoustic & Vibration Measurement, Electrical Testing, Heat & Temperature Measurement, Optics & Radiometry and Chemistry fields (gas analysers). People sometimes ask why this is, would it be more sensible to group all calibration activities together? Well, the reason for having the calibration activities under different fields is to ensure that the most appropriate technical committee (each field has an

Accreditation Advisory Committee) is involved in setting criteria and reviewing the assessment activities. To help the smooth integration of the calibration activities in such diverse technical areas, NATA has a Calibration Liaison Officer, Ms Mary Ryan, whose task is to review the consistency of technical criteria between fields. There are however occasions when the Chairmen and staff of these fields will meet to resolve significant cross-field issues. -One area where this has occurred in recent times is the implementation of the new uncertainty formalism.

The following table gives an breakdown of the main areas only (areas of calibration involving less than 5 laboratories have not been listed) currently covered by NATA's Metrology field and the corresponding number of laboratories:-

Area of calibration	No. of laboratories
Mass, balances, weighing	48
Length	27
Flow, large volume measurement	26
Force, hardness, impact	25
Pressure	24
Torque	13
Standard measures, pipettes, hydrometers	7

LEDs, Transport Signals and Metrology

Steve Jenkins, Optical and Photometric Technology Pty Ltd.

1. Introduction

There has been a burgeoning use of LEDs as light sources in a wide range of signalling devices including traffic signals, rear-turn combination signals in vehicles, variable message signs, railway signals etc. This has been driven by major advances in the manufacturing technology of LEDs which have produced light sources which are more efficient than the usual incandescent sources. LEDs have many advantages and they have some disadvantages especially for those metrologists who are trying to characterise their performance.

In this paper, a brief description of their operation and performance is given and some of the advantages and disadvantages of their use in traffic signal devices are described.

2. LED Operation

LEDs are solid-state semiconductor devices that convert electrical energy directly into light. They consist of a p-n junction, so that when a forward voltage is applied the electrons in the conduction band combine with the holes in the valence band and the resulting energy is released as a photon with an energy slightly less than the difference in energy between the conduction band and the valence band. With careful selection of materials and doping, the emitted photons can be made to have energies that lie within the visible spectrum.

Because the energy band gap can be closely defined, the energies of the emitted photons are also tightly grouped so that the radiation lies within a narrow wavelength range usually between 10 nm and 50 nm. It is now possible to obtain an LED that can have a peak wavelength positioned anywhere across the visible spectrum. Some typical examples are shown in Fig 1 below including some infrared LEDs.

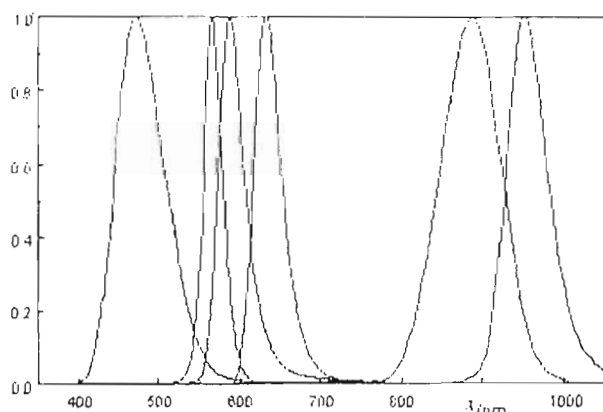


Figure 1 Examples of relative spectral power distributions of some typical LEDs and infrared LEDs. (Taken from CIE 1997)

LEDs which lie within the red/orange region are phosphides, namely (Al, Ga, In)P

LEDs which lie within the blue/green region are nitrides, namely (Ga, In)N

It is also possible to now get white LEDs, either by grouping a blue, green and red chip together in one unit, or by using a blue LED with a yellow-green phosphor.

3. Characterisation of Individual LEDs

There are really three major problems for metrologists when measuring individual LEDs. The first is that the luminous intensity of an LED is temperature dependent with the intensity decreasing with increasing temperature. This increase in temperature comes from the current passing through the LED and this will stabilise after a minute or so, and from the ambient temperature. Thus an LED will give a smaller intensity at an ambient temperature of 55°C than it will at 20°C all other things being equal.

The second is that the light emitted from an LED is quasi-monochromatic, i.e. it emits light over a fairly narrow range of wavelength. This places severe constraints on the instruments used to measure the LED intensity and colour.

Photometry and colorimetry is concerned with measuring the effect that radiation has on the human eye. The eye is not equally responsive to all wavelengths of optical radiation, it only responds over the wavelength range 380 nm to 780 nm with its peak responsivity at 555 nm for normal daytime viewing. This responsivity curve is called the photopic response curve or the $V(\lambda)$ curve and is shown in Figure 2. As the level of light dims, the spectral response of the eye changes gradually until it becomes completely dark-adapted when its spectral response becomes the scotopic spectral response curve or $V'(\lambda)$ with its peak moved towards the blue at 507 nm. The reason why there is a gradual change is that there is a change of the types of detectors in the eye. At daytime brightness levels, the active detectors are the three types of cones that give rise to our perception of brightness and colour. When we are completely dark-adapted (a very rare occurrence), the rod detectors are the only ones active. The $V(\lambda)$ curve is the spectral response of the three cones combined and the $V'(\lambda)$ curve is the spectral response of the rods. In between the two extremes, both of them operate to some extent and this is called mesopic vision. We commonly use mesopic vision when we are driving at night.

Practically all photodetectors have spectral responses that are close to this $V(\lambda)$ curve. When they are measuring the, say, illuminance from a broad-band source such as

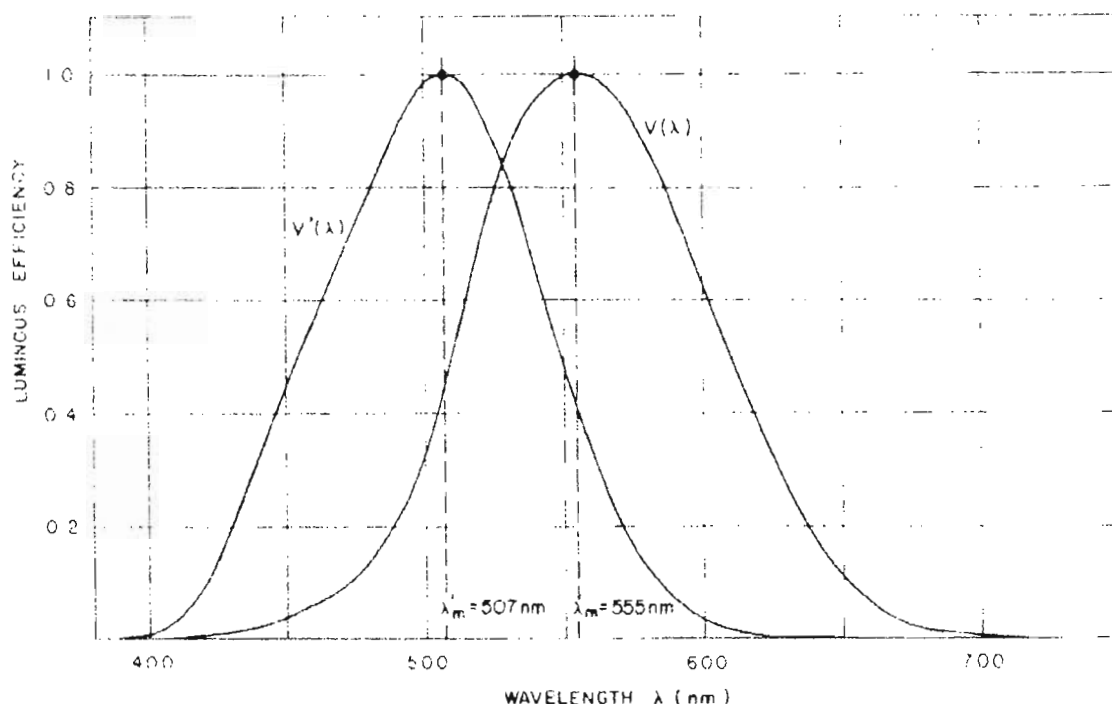


Figure 2. Graph of the Photopic [$V(\lambda)$] and scotopic [$V'(\lambda)$] curves both normalised to one at their peak. (taken from Wyszecki, G. and Stiles, W.S.S. (1982) Color Science)

an incandescent lamp or a street lamp, then the match to the $V(\lambda)$ curve can be reasonable without incurring any significant inaccuracies. However, when a quasi-monochromatic source has to be measured then the $V(\lambda)$ correction must be very much better with a consequent increase in the cost of the photodetector.

It may be that the match to the $V(\lambda)$ curve is very good over much of the spectral range but may be out by as 25% in the region close to the peak of the light emitted by an LED. This is particularly a problem near the ends of the spectrum where matching is more difficult and the $V(\lambda)$ curve has low values.

The third problem for metrologists is that while LEDs have a high luminous efficacy (lumens/Watt), they give out small amounts of flux (lumens). The brightness of LEDs is characterised by their luminous intensity. The luminous intensity is attributed to "point sources" only i.e. when viewed they have no apparent area, and is the amount of flux emitted in an elemental solid angle in a given direction. In practice, the detector has to be placed close (100 mm to 300 mm) to the LED to achieve a reasonable signal. The detector then subtends much larger than an elemental solid angle and "luminous intensity" is not what is measured. This gave rise to problems in manufacturers specifying the LED intensity as it would depend critically on their geometric conditions. The CIE resolved the matter in Publication No.127 by recommending the test distance(s) and the detector diameter and defining the measurand as the "Averaged LED Intensity".

4. LED Clusters in Traffic Signals

We have now gone some way to solving the problems associated with the measurement of individual LEDs. However, there is a different set of measurement problems when we have LED clusters such as for Traffic Signal Lanterns. The types of Lantern in use include vehicular signals, pedestrian symbols, vehicular symbols (arrows, U-turns and crosses), and bicycle symbols. Symbols, e.g. the walking and standing man for pedestrians, may be filled or may be in outline. In the majority of cases that we have measured so far, the LED clusters have been manufactured from clear LEDs with a clear protective cover.

Australia was the first country to develop a Standard for traffic signals based on research work carried out at Melbourne University and the University of New South Wales. The Standard has been reviewed several times to encompass new technology as it arose, e.g. aluminium reflectors, quartz halogen lamps.

The problems that arise now when trying to apply the current Standard to LED lanterns are:

- (i) Should the levels of intensity that should be specified for LEDs be the same as those already set for incandescent signals?
- (ii) The measurement of luminance and luminance uniformity for filled symbols or symbols in outline. Luminance is the physical measure of the sense of brightness and is applied to the brightness of area sources

such as ceilings, walls, sky, sun etc. It becomes a problem of definition when we want to apply it to a source that has an area but is composed of point sources.

(iii) Sun-phantom can occur with traffic signals. When the sun is low and shines directly into the traffic signals, the sunlight is reflected back as the same colour as the signal and it can appear as though the signal is on. For the majority of LED signals we have seen, the reflectance from the sun is white and consideration needs to be given as to whether a white signal generates confusion in a driver. This white reflection is called a veiling reflection as it tends to mask out the true signal.

(iv) The colour of yellow LEDs sometimes falls outside the allowed colour boundaries.

(v) The temperature sensitivity of the LED cluster.

(vi) The electrical requirements for photometric and colorimetric testing.

4.1 LED Traffic Signal Intensity Distribution

The Australian Standard specifies the performance of traffic signals in terms of their intensity (cd) distribution. This is because, at the distances at which they need to be seen with certainty by drivers, they appear as point sources. The intensities that are specified for the red, yellow and green signals have been well-established now over decades and work well. There is essentially no difference between incandescent filtered light and LED light as far as the eye is concerned. However, the Standards committee adopted higher minimum intensities for LED traffic signals on the basis of their extraordinary longevity and their well-characterised degradation over time. The road authorities expect some 100,000 hours of life from the signals and over this time their intensities will gradually decrease. In order that the signals should remain effective over the 100,000 hours, the Standard required that they should have "as new" intensities somewhat higher than the incandescent lamps.

4.2 Luminance of Symbols

The symbols that are used in traffic signals (U-turn, bicycle, arrows) and pedestrian signals are, of course, area sources as the eye has to discern their shape. When made up of LEDs they can be in outline or as filled symbols. These symbols are currently all specified in terms of their luminance distribution and luminance uniformity. Rather than wrestle with the problem of defining luminance (cd/m^2) for a cluster of discrete point sources, a more "engineering" approach was taken. When the observer is sufficiently far from the symbol and the individual LEDs are sufficiently bright, then the symbol appears continuous either as a filled symbol or as a continuous outline.

Consequently, it is then possible to measure the total luminous intensity of the symbol from a distance long enough that the symbol approximates a point source and

to divide the total intensity by the total area of the symbol or total area of the outline.

4.3 Veiling Reflection Intensity from the Sun

There is likely to be two adverse effects when the sun shines directly onto an LED signal. As the most common arrangement is for the LEDs to be clear and the protective cover over them to be clear, then the colour of any reflected sunlight will be white. If this reflection is strong, then the driver will be faced with possible, two apparent white signals and one other signal that is ON but quite desaturated i.e. washed out.

Clearly some limits had to be set to ensure the veiling reflection intensity was not too great. It was decided that one limiting requirement would be that the colour of the signal should remain within the specified colour boundaries even when the sun shines on the LED signal. This turns out to be a very tough requirement and as yet we have not tested a signal that will comply. The solution for manufacturers is possibly to use a coloured protective cover so that any reflected light is the same colour as the signal itself. Then the signal has to pass the sun-phantom requirements which have proved to be possible.

4.4 Colorimetry of LEDs

Colorimetry is three-dimensional and we perceive colour through the different responses that the three cone types have to the optical radiation entering our eyes. The CIE have defined three spectral response functions (not equivalent to the spectral responses of the cone types) and the convolution of these with the spectral power distribution from the source allows a set of numerical values to be given to the source colour. One of these three defined spectral response functions is the $V(\lambda)$ function we mentioned earlier.

One possible way of measuring colour is then to have a photocell which can view the source radiation in turn through three filters which are matched to the three CIE defined spectral response functions. Then the colour can be specified by forming ratios between each measurement to the sum of all three measurements. This works well for broad-band sources and for instruments that have very good matching to the CIE functions.

Unfortunately, matching to the CIE functions is difficult to do well. The matching is even more critical when we come to measure LEDs which are quasi-monochromatic for exactly the same reason as it was for the measurement of photometric quantities with photocells matched to the $V(\lambda)$ function. Consequently, the measurement of LEDs with these types of colorimeter is not recommended unless the instrument is exceptionally well matched to the three CIE defined functions and this implies a very expensive instrument.

The alternative is to use a spectroradiometer which will measure the spectral power distribution of the source. It is then a matter of calculation to determine numerical

specification of the source colour. There are still some stringent requirements that have to be met by the spectroradiometer to achieve low uncertainties. The spectral resolution should be better than 3 nm, wavelength accuracy better than 0.5 nm, stray light rejection should be three to four orders of magnitude, the detector should be linear and the accompanying electronics should have a dynamic range of three to four orders of magnitude.

The measurement of the LED signal colour is carried out once the intensity has stabilised. The colour of LEDs changes slightly with temperature, the reds and yellows moving towards the red as temperature increases and the greens and blues moving towards the blue as temperature increases. At present, the colour of yellow LEDs is more variable than other colours and some batches can fall outside the colour region allowed by the Australian Standard. It is expected that this problem will disappear as the LED technology improves

4.5 The Temperature Sensitivity of the LED Traffic Signal

As we mentioned previously, the intensity of LEDs decreases with an increase in temperature. When we have a large LED cluster as in a traffic signal, with, for example, around 100 LEDs in the red signal and 250 LEDs in the yellow signal, all sealed in a traffic signal lantern, then the effect is magnified. As soon as the signal is activated, the initial intensity starts to drop and will come to equilibrium after about one hour. The magnitude of drop in intensity depends on the type of LEDs, i.e. on their colour. The red and yellow clusters can drop to 65% of their initial intensity, whereas green LEDs exhibit hardly any change.

Of course, the measurements have to be carried out when the unit has stabilised but this would then give an unnecessarily adverse measurement of the performance of the signal as they are generally only on for a few minutes and the yellow only on for seconds. Consequently, the measured intensity values have to be

corrected back to the values they had one minute after activation.

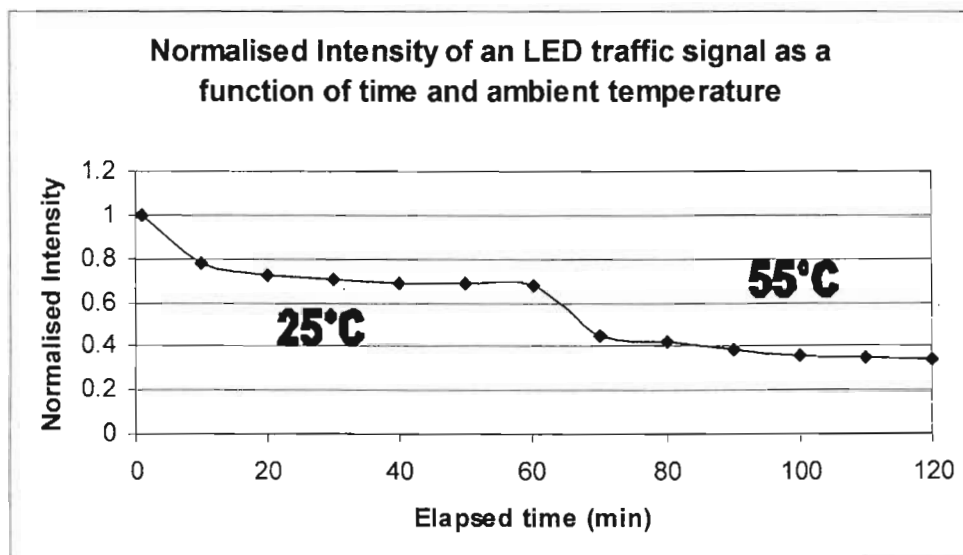
Road authorities are also concerned that the signal should remain effective in summer under hot conditions. So the magnitude of the drop in intensity has to be measured when the ambient temperature changes from 25°C to 55°C.

A typical temperature/time curve for a red traffic signal is shown in Figure 3. The lantern is placed in an enclosure with a glass front and a thermostat. The signal is allowed to stabilise at an ambient temperature of 25°C and then hot air is blown into the enclosure maintaining an air temperature of 55°C. The intensity of the signal (which is still on) is then monitored until it reaches a stable value. This then allows the ratio of the intensities at 55°C and at 25°C to be calculated. The ratio (which is less than one) is then applied to the one minute corrected intensities to give the final intensity distribution which is compared to the requirements of the Standard.

4.6 Electrical Input Requirements.

The intensity of an LED depends on the current that is passed through it and so it is crucial that the electrical input is carefully controlled. Now all traffic signal lanterns have to accept power from the mains at 240 V AC and so they must condition this to supply the LEDs. LEDs operate on DC and the 100,000 hours lifetime that is specified by the manufacturers is for a current of 20 mA. This is for a certain type of LED which is commonly used in signals. The development of LEDs is rapid and there are now LEDs that operate at several hundred mA but they are not as yet generally used for signals. If the current is raised above 20 mA then the intensity will increase and the lifetime will decrease. To maintain a level playing field, the Standard requires the testing to be carried out with 20 mA DC passing through each LED (on average).

At this early stage of development, several manufacturers have opted to pulse the LEDs at high current for a short



time maintaining an equivalence to 20 mA DC. However, it is not yet clear what affect this high current pulsing has on the longevity of the LED, remembering that the intensity levels in the Standard were predicated on a lifetime of 100,000 hours. The instruments needed to measure high frequency pulsed current sources to give true rms values are expensive.

The circuit design of the LEDs also have to be provided by the manufacturers. Obviously all the LEDs should not be connected in series as one failure will be catastrophic for the whole signal. Generally they are wired in chains of four, six or eight so that if one chain goes down only a small decrease in signal intensity eventuates. The provision of the circuit design is essential for the metrologist as it is only possible to measure the total

DC current into the board. In order to calculate the average current per LED the number of chains and number of LEDs per chain is required.

5. Summary

The extraordinary developments in LED technology over the last ten years are now having a major impact on their use in transport signalling. Even greater efforts and resources are placed into developing a white LED that will challenge incandescent and fluorescent lighting for indoor use.

The benefits are clear, low energy and long lifetimes. The disadvantages are the measurement problems that they bring up for metrologists. As the proverb says, every silver lining has a cloud.

NEWS FROM AUSTRALIA'S NATIONAL MEASUREMENT LABORATORY (NML): APRIL 2002

The CSIRO National Measurement Laboratory (NML) National Facility is the holder of Australia's physical standards of measurement and the source of traceability for calibration, testing and measurement services in Australia. Following on from the Retrospective of NML's activities provided in TAM Feb 01, the following report reviews the highlights over the year 2001, together with news of current activities and initiatives.

NML represents Australia in International Metrology activities:

NML continues its ongoing commitment to provide an effective international interface for Australia's measurement activities, with NML scientists representing Australia at peak international meetings in the various specialist metrology disciplines. During 2001, senior NML scientists represented Australia at meetings (including Working Group Meetings) of the CIPM (International Committee of Weights and Measures) Consultative Committees (CCs) for:

- ☐ Acoustics, Ultrasound and Vibration (CCAUV)
- ☐ Amount of Substance (CCQM)
- ☐ Length (CCL)
- ☐ Photometry and Radiometry (CCPR)
- ☐ Temperature (CCT), and
- ☐ Time & Frequency (CCTF)

[NML experts also represent Australia on the CCs for Electricity & Magnetism (CEM) and Mass (CCM), although these Committees did not meet in 2001.] These meetings provide regular opportunities for experts from the major National Metrology Institutes (NMIs) around the world to join with the International Bureau of Weights and Measures (BIPM) to discuss relevant technical activities in each specialist metrology area.

NML's Director, Dr Barry Inglis, represents Australia at the annual Meeting of Directors of NMIs convened by the Director of the BIPM in Paris, which was held in February 2001, and also at the annual General Conference on Weights and Measures (CGPM), held in October 2001.

NML scientists also participate in a number of international technical meetings. In 2001, these included working group meetings of the International Electrotechnical Committee (IEC), the International Conference on Large High Voltage Electric Systems (CIGRE), the Asia Pacific Radio Science Conference, and the International Special Committee on Radio Interference (CISPR), among others.

Asia Pacific Activities:

NML plays a strong role in the Asia-Pacific Metrology Programme (APMP), the Regional Metrology Organisation that promotes collaboration between 25 NMIs in the Asia Pacific. NML experts attended the annual APMP General Assembly and associated Technical Committee meetings in Japan in November 2001. At the November meetings, the APMP Technical Committee on Quality Systems (TCQS) was established, with Dr Rohana Ediriweera, NML's Quality Manager, being elected as the inaugural Chair. The work of the TCQS will largely be directed at assisting APMP member NMIs establish quality systems that meet the requirements of the global Mutual Recognition Arrangement (MRA) between NMIs.

In his capacity as TCQS Chair, Dr Ediriweera attended the EUROMET Initiation Workshop for NMIs on "Solving Practical Problems when Implementing a Quality System based upon ISO/IEC 17025", held in the Netherlands on December 13-14 2001. He presented a plenary lecture titled "Status of Quality Systems of NMIs in the APMP Region" which described the APMP criteria for accepting calibration and measurement certificates issued by signatories to the CIPM MRA and reviewed the various approaches taken by APMP member laboratories. The basic APMP criterion that needs to be satisfied is the implementation of a quality system complying with ISO/IEC 17025. Dr Ediriweera presented data from twenty APMP member laboratories. Thirteen of these laboratories already have ISO/IEC 17025 based quality systems in place, while the other seven are in the process of doing so.

Over a number of years, NML's activities in the Asia Pacific have been greatly facilitated by the generous support of the Australian government, through its Department of Industry, Science and Resources (ISR) and the Australian Agency for International Development (AusAID). In addition, in 2001, NML was project coordinator for two projects funded by the Asia Pacific Economic Cooperation (APEC) and concluded a World Bank-funded bilateral program with Indonesia. In all, activities undertaken by NML in 2001 include:

- chairing of the APMP MRA (Mutual Recognition Arrangement) Advisory Committee by NML's Director, with support from DISR. The MRA Advisory Committee's role is to assist APMP NMIs participate in the global MRA between NMIs;
- commencement of an AusAID-funded bilateral program with the National Institute of Metrology (NIM), China, to undertake collaboration in the areas of high voltage and dimensional measurement;
- coordination of an APEC-funded project on the development of Quality Systems in Asia Pacific NMIs;
- undertaking an APEC-funded project to develop international recognition of measurement capability in the area of AC-DC transfer standards in four Asia Pacific economies, specifically the NMIs in Philippines, Thailand, Vietnam and Indonesia;
- conclusion of a multi-year World Bank-funded project with Indonesia's NMI; and
- conclusion of a complementary multi-year DISR-funded project with Indonesia's NMI.

Awards, Fellowships, Secondments

Awards and Fellowships

Over 2001, the work of NML scientists has been recognised in a number of fora. As reported in the September 2001 issue of TAM:

- the paper "Precision Digital Filters for High Voltage Impulse Measurement Systems" written by NML staff members Dr Yi Li and Dr Juris Rungis received the IEEE Power Engineering Society's Power System Instrumentation and Measurement Committee's Prize Paper Award for 2000;
- CIGRE presented NML staff member Dr Vic Morgan with an Award of Merit for prolonged meritorious service to the electricity industry;
- Dr Ilya Budovsky, NML's Project Leader in AC-DC Transfer Standards, was awarded a prestigious three-month Japanese Fellowship to undertake joint research with counterparts at the National Metrology Institute of Japan (NMIJ);
- NML's Dr Esa Jaatinen was awarded the inaugural IIZUKA Prize, together with Cheong Tak Leong of PSB (Singapore Productivity & Standards Board). The Prize is awarded to individuals aged 35 years or under in recognition of their outstanding contribution to research activity related to metrology standards in the Asia Pacific region.

Most recently, Mr Bruce Meldrum, NML's expert in Acoustics measurement, was awarded a prize for the best paper at the Australian Acoustical Society conference in Canberra in November, continuing a proud tradition for NML at this conference. (In previous years the same award has been won by NML's Dr Suzanne Thwaites and Mr Norm Clark.)

Secondments:

New Director of the AGAL National Analytical Reference Laboratory

The Australian Government Analytical Laboratories (AGAL) has appointed Dr Laurie Besley as the Director of its National Analytical Reference Laboratory (NARL). The appointment is a period of three years, with Dr Besley taking up the position on 1 February 2002.

NARL is an operating division within AGAL and has primary responsibility for developing an Australian chemical measurement infrastructure. Working in the areas of inorganic and organic chemistry, NARL:

- Develops primary methods for quantitative chemical measurement;
- Develops and disseminates chemical reference materials; and

- Represents Australia at international chemical metrology forums.

For the period of his appointment as Director - NARL, Dr Besley will be seconded from his current position at the CSIRO National Measurement Laboratory (NML). He will be based at the AGAL laboratory in Pymble, Sydney, NSW (the location of the NARL headquarters).

While the NARL directorship will occupy most of Dr Besley's time, he will continue in a part-time capacity at CSIRO. During this time, Dr Besley will lead NML's Metrology in Chemistry Project. This project has responsibility for Australia's composition standards for gases and gas mixtures.

NARL was inaugurated four years ago with Dr Bernard King as its Director. Under his leadership NARL has made a significant scientific contribution by supporting and fostering Australian and international initiatives in the sphere of metrology in chemistry.

One measure of the extent of the NARL/NML achievements during the last four years is the recent admission of Australia as a member of the CIPM's Consultative Committee on Amount of Substance (CCQM). This international recognition is testament to Australia's national capability in metrology in chemistry. Additionally, the admission to the CCQM recognises Australia's ability to contribute to international developments in this area.

For further information on Dr Besley's appointment or for additional information on NARL contact Dr Sandra Hart, General Manager/Australian Government Analyst, AGAL. Telephone 02 6213 6075 Fax 02 6213 6815 or e-mail info@agal.gov.au

Two other NML staff are currently undertaking or shortly to begin secondments with sister organisations:

- *Dr John Miles, head of NML Melbourne Branch's Dimensional Metrology unit, began a two-year secondment at the National Research Council (NRC) of Canada in July 2001. Dr Miles is working on the measurement of the form of objects at nanometre accuracy during this period.*
- *In February 2002, Dr Angela Samuel, NML's Project Leader of International Metrology, commenced a 12-month secondment at the BIPM, in order to establish the Secretariat for the JCRB (Joint Committee of Regional Metrology Organisations and the BIPM).*

Accreditation of NML's Calibration Services

NML's calibration services are covered by a quality system satisfying ISO/IEC 17025, the major portion of which is accredited through NATA. Eight of the eleven metrology areas are accredited (Mass & Related Quantities, Optical Radiometry, Temperature, Length,

Power Systems Technology, Time & Frequency, Resistance & Voltage, and Low Frequency Standards), two areas have been assessed but not yet accredited (Acoustics & Vibration and Radio Frequency & Microwave) and the remaining area (Impedance) will be assessed early in 2002.

Assessments were carried out using international assessors drawn from other NMIs to ensure international credibility.

New Research at NML - NML Pressure Standards

NML's Melbourne Branch has instigated a novel partnership arrangement with Rosebank Engineering to develop higher-accuracy pressure standards in Australia. Using a design and specification prepared by Mr Walter Giardini and Dr John Miles at NML Melbourne, Rosebank has produced a state of the art piston-cylinder for use in hydraulic deadweight pressure standards. NML now can undertake fundamental work on the dimensional characterisation and distortions under pressure of piston-cylinders and on the behaviour of the hydraulic fluids used in these devices. Ultimately these studies should provide a definitive characterisation of the uncertainty of measurement in this type of pressure standard. The project has four main benefits:

- The findings of this study should contribute to a resolution of differences between National Metrology Institutes (NMIs) and better international standardisation.
- Australia will obtain a state-of-the-art deadweight pressure standard, and will do so with greater confidence and less cost than purchasing market devices.
- Rosebank Engineering will obtain authenticated dimensional characterisation of the piston-cylinder that will attest to their skill in manufacturing devices at this level of dimensional accuracy.
- There is a reasonable market in retro-fitting existing deadweight pressure standards to raise their level of accuracy at low cost.

NML Opens New Facility Providing Traceability to Low-Frequency EMC Tests

Recently, several international and Australian Standards have been introduced that specify limits of low-frequency Electromagnetic Compatibility (EMC) parameters such as harmonics of current up to 16 A, voltage fluctuations and flicker. To enable low-frequency EMC tests to be performed traceably throughout Australia, NML has developed a Facility for the calibration of power analysers that are designed for such tests. The development is funded, in part, by a grant from the Department of Communications, Information Technology and Arts.

The new facility can generate and accurately measure through precision current shunts and a digital acquisition

system three-phase current and voltage signals containing any combination of powerline harmonics up to 99th. Voltages with precisely known fluctuation and flicker can also be generated.

One of the unique features of the NML facility is that its digital measurement system is fully traceable to Australian national standards of alternating voltage and current. Such traceability has been achieved through an independent evaluation based on a high-frequency thermal power comparator of NML design. Results of the measurement of harmonic amplitudes from 0.01 to 20% performed using the two different techniques agree to better than 10^{-5} of the fundamental.

Natural Gas Industry Seminar

With the development of NML's Reference Gas Mixture facility, funded by the Australian government Department

of Industry, Science & Resources, a seminar was held in December 2001 involving 22 representatives from the gas industry and other interested bodies. The objective was to inform industry on gas mixture developments at NML, to demonstrate the new gas mixture facility, and to seek industry input on future needs and requirements.

Calibration Services for Australian industry

Within Australia, NML continues to provide a range of services to the Australian measurement community. Calibration services are provided to NATA-accredited calibration laboratories, and directly to industry in cases where services are unavailable through NATA-accredited laboratories. [Year 2002 details are available from Ms Darien Northcote (ph: (02) 9413 7180)].

TRAINING COURSES AT NML

NML provides formal training courses and tailor-made tutorials to help metrologists better understand their measurements and the errors involved, make informed calculation of uncertainties and, generally, to increase the reliability of their measurements. Tutorials are aimed at satisfying the particular needs of any one company or organisation (or group of similar laboratories) and may be created from a variety of topics, such as:

acoustics	dead-weight testers	dc voltage
CMM	DMM calibration	EDM
force	frequency	gas flow
humidity	high voltage	Wh meters
LIDAR systems	mass	photometry
pressure	resistance	temperature
RF	UV radiometry	time

the ISO Guide to uncertainty & its application to any field.

Mass & Balance Calibration

A two-day intensive course was held in March 2002. The scope included the calibration of balances and weighing machines, weights (mass standards) upon which these balance measurements depend, mass traceability, the effects of buoyancy, true and conventional mass and the estimation of uncertainties at all levels using the ISO Guide (*see below*). This course will be offered in subsequent years, and potential participants are welcome to register their interest (contact: Robin Bentley ph: (02) 9413 7764 or email: robin.bentley@csiro.au).

Other formal courses planned for the coming year are:

Temperature Measurement (October 2002)

A three-day course on the theory and practice of temperature measurement, with emphasis placed on the traditional techniques involving thermocouples and thermometers based on resistance, radiation and liquid expansion (mercury, etc). Given particular attention will be the errors that occur during measurement and how to calculate resultant uncertainties (using the ISO Guide, below).

The ISO Guide to Uncertainty (on a regular basis).

One- and three-day courses are conducted on the ISO Guide to the Expression of Uncertainty in Measurement. The 1-day course is appropriate for staff requiring only a general knowledge of the Guide or as an introduction to it. The 3-day course is suitable for technical and scientific staff required to make formal estimates of measurement uncertainty. In both courses, the participants will be required to work through a series of graded examples in applying different aspects of the Guide.

Participants at NML's courses receive comprehensive texts (books or monographs), which are available separately. For more information, brochures & registration forms for the above courses or details on the monographs available from NML, contact Robin Bentley (phone: +61 2 9413 7764 or e-mail: robin.bentley@csiro.au).

Calibration of Measuring Equipment

Lee Coleman of Testing & Certification Australia

Lee Coleman of Testing & Certification Australia gave this talk at a recent meeting of the NSW branch. We reproduce it for other MSA members in TAM, as a useful and concise introduction to the main aspects of calibration practice.

With Quality Accreditation the control of measuring equipment has become an important process for organisations. AS/NZS ISO 9001:2000 requires organisations to carry out measurements in a manner that provides evidence of the conformity of product and that, where necessary, measuring equipment shall be calibrated periodically against standards traceable to national standards and that the results of calibration be maintained.

Quality auditors, when assessing an organisation to ISO 9001, expect to find that measuring equipment is within its calibration interval and that the performance of the equipment is suitable for its application. Auditors also expect to see records of calibration and a process to assess previous measurement results when equipment is found not to conform to requirements.

Calibration

Calibration is the comparison of measurements performed by an instrument to those made by a reference instrument or standard, for the purpose of reporting errors in the instrument being calibrated. When sending measuring equipment to a calibration laboratory it is important to specify any functions, ranges and points which are of importance to the user.

Measurements performed during calibration must be traceable and this is achieved when each reference instrument or standard used in a calibration is traceable by a chain of inter-comparisons to national standards. The growing global acceptance of the ISO 9001 quality standard has led to a general increase in commercial requirements for the traceable calibration of test and measurement equipment. The purpose, with a view to product safety and fitness for use, is to ensure that the products manufactured in one country will be acceptable in another.

Reporting

Two forms of reporting are usually offered by calibration laboratories; a full calibration report or certificate of conformance.

Calibration Report

A calibration report usually provides a set of results that show the performance of the instrument being calibrated in comparison to a reference instrument or standard. Measurements are recorded for each function, range,

and points tested and the uncertainty of each measurement is reported. The report enables users to be aware of the errors of their instrument, and if necessary, apply corrections based on the results given in the report. Depending on the magnitude of errors the client may wish to have the instrument adjusted.

Calibration Certificate

A calibration certificate usually states the compliance of an instrument with the manufacturer's specification. Measurements made by the instrument being calibrated are compared to the manufacturer's specification. If the instrument is within specification, a statement that the instrument meets manufacturer's specification at the points tested is made in the conformance certificate. Any points that are outside specification, or not able to be determined, are reported as exceptions. Assessment of meeting manufacturer's specification takes into account the measurement uncertainty.

A statement of conformance to manufacturer's specification may also be given in calibration reports.

Uncertainty of measurement

There is uncertainty associated with every measurement and factors such as the accuracy of the reference instrument(s) or standard(s), characteristics of the instrument under calibration and influences on the measurement system contribute to uncertainty. The way in which calibration laboratories are expected to deal with uncertainties is set out in the ISO Document "Guide to the Expression of Uncertainty in Measurement". The NATA publication "Assessment of Uncertainties of Measurement" is a good reference on measurement uncertainties and very useful in understanding the requirements of the guide.

Measurement uncertainty in calibration reports is normally quoted as a range about the measured value with a certain confidence level and coverage factor. The interpretation of uncertainty stated this way is that the true value lies within the range stated with a certain level of confidence. Calibration laboratories have standardised on 95% confidence level and this means that there is a 95% probability of the true value being within the range stated.

Coverage factor is usually quoted as 2, or close to 2, and relates to the shape of the distribution associated with the measured value. Coverage factor is provided in calibration reports to allow uncertainty calculations associated with the use of the instrument to be made.

Uncertainty is stated in a calibration report as an expanded uncertainty, and this means that the confidence

level and coverage factor have been taken into account in the calculation of uncertainty.

Calibration Intervals

A question that is often asked of a calibration house is 'How often do I need my instrument calibrated?'

The answer is not straightforward and depends on factors such as: the impact of the instrument on quality, the environment and the way in which the instrument is used, periodic checking against other instruments and recorded history of the instrument.

Calibration laboratories operate under AS ISO/IEC 17025 (General requirements for the competence of testing and calibration laboratories) and the supplementary requirements for accreditation by NATA to ISO 17025 is a useful guide in determining calibration intervals. The NATA document sets out the requirements for the frequency of recalibration of test equipment used by testing and calibration laboratories. For digital instruments the required recalibration interval is a maximum of 12 months and this interval is frequently used for instrument calibration.

ISO 17025 requires that a calibration report or label shall not contain any recommendation on the calibration interval except where this has been agreed with the client. There are three ways in which calibration intervals are commonly reported on a calibration report:

Client Agreed – This is when the calibration interval has been agreed between the client and the calibration laboratory and 12 months is typical. This is reported as '*Calibration Interval* - '.

Client Specified – At times the client will specify the calibration interval required for a particular instrument and this will be based on the clients understanding of the use, performance and history of the instrument. This is reported as '*Client Specified Calibration Interval* - '.

Manufacturer's Recommended - Manufacturers often recommend calibration intervals for their instruments. These recommendations are based on their knowledge of the design of the instrument and the performance history of a significant number of the same instruments over a period of time. Generally manufacturers recommend an extended calibration interval once they have gained confidence in the instrument's performance. This is reported as '*Manufacturer's Recommended Calibration Interval* - '.

NATA's supplementary requirements give maximum checking intervals for test equipment and for digital instruments this is 3 to 6 months. Periodic checking of the performance of an instrument in relation to another instrument(s) is recommended in helping to ensure that performance is maintained between calibrations.

MSA in SA April 2002

Our first meeting for the year was a commercial presentation from local member, Mark Histed who represents Trio Electrix. Trio are agents for Fluke, and Fluke recently took over Hart Scientific, manufacturers of temperature calibration equipment. The takeover suits Mark well, because his background is in temperature calibration. So we received an enthusiastic address on Hart equipment, and a demonstration of some of it.

Our next meeting will have a commercial bent as well, with a visit to Ellex Laser Systems before our usual meal-and-chat. I am not sure what Ellex do, but we have been assured that it is interesting.

Les Felix, our South Australian events organiser, reluctantly agreed to act in that capacity again in the absence of a volunteer replacement, and has now hit his straps for the year. Les, like our former president Jim, is a muzzle-loading rifle enthusiast, and we have been invited to witness a demonstration of old military stuff, including muskets, flintlocks and pistols. This should be an interesting distraction from our hum-drum, explosion-free lives.

Les is planning ahead this year, and has a regular program of meetings at about two-month intervals for the rest of the year. More on that later.

- Jeffrey Tapping

Obituary - Malcolm McGregor

It is with regret that we note the death of Malcolm McGregor (Mac) who died suddenly on 16 November 2001 aged 83 years. He was a long time member of CSIRO National Measurement Laboratory and a strong supporter of NATA.

At NML he was a key member of the Electrical Impedance Group for many years. He worked with Mel Thompson as a member of the team that developed the first Thompson-Lampard Calculable Capacitor and realised the SI ohm at NML. This expertise and technology made NML the reference point for standardisation of the ohm for more than 20 years.

On the basis of his Australian work, Mac was also seconded to the National Bureau of Standards (now NIST) in the USA to work with the team that built the American version of the Calculable Capacitor.

Mac made many far-reaching contributions to NML's electrical impedance standards and was the primary contact for the impedance calibration service for many years. Mac continued to work at NML on a voluntary basis after retirement, and was in the laboratory as recently as a few weeks prior to his death. His cheerful face and good humour will be sorely missed.

Reprinted from NATA News

THE NATIONAL COMMITTEE OF THE MSA

Jane Warne (President) has a background in both Physics and Chemistry. She completed her PhD in Chemistry from Monash University in 1989 and went onto work in the Physics department in the area of spectrometer design. In 1991 she joined the Bureau of Meteorology as a metrologist, specifically working in the areas of temperature, pressure, humidity, rainfall and wind measurement. She has been involved with the MSA as a National Committee member for five years and Vice president for one. Her current roles on the committee are sheepherder and web site liaison. Jane is married with two children, Jaimon 6 and Samantha 3, enjoys playing a 12 string guitar in a church music group, photography (I'm always the one behind the lens not in front), drawing and drinking the odd glass of good red! Jane wants to see the MSA develop into a mature, vibrant and diverse community, serving the educational and social needs of its members. In particular she would like to see a greater cross fertilisation of ideas between the disciplines included under the umbrella of Metrology, because this is where she sees the greatest benefit to the general metrology community can be achieved.



Walter Giardini (Vice President) works with the National Measurement Laboratory in physical (pressure) metrology. His primary committee work is with the sub-editorial committee for TAM, and his number one goal is to see the MSA develop a vibrant program of regular meetings and seminars on metrology science and technology.



Ilya Budovsky (Honorary Secretary) is leader of Low-Frequency Electrical Standards Group at the National Measurement Laboratory, with the responsibility for the development and dissemination of Australian standards for direct and alternating voltage, current, ac-dc transfer,



electrical energy, magnetic field and magnetic flux. He is a member of NATA Advisory Committee on Electrical Measurements. Ilya serves on the membership subcommittee of the MSA, and would like to see the Society deliver maximum benefits to its members.

Marian Haire (Treasurer) is currently employed by the National Standards Commission in the role of Training Officer. Her priority wish in the MSA is to see TAM becoming a journal that metrologists see as essential reading.



Jim Gardner (Past President) has recently retired after a number of years as leader of the Optical Radiometry group at NML. His role included representation of the laboratory in matters radiometric at the International Bureau of Weights and Measures and within APMP. He keeps his hand in as a CSIRO fellow, working on tracing uncertainties in a rigorous way from primary spectral standards to various parameters in photometry and colorimetry. Currently spending a stint at NIST USA working on similar matters.



Tony Jackson runs a two man Calibration Laboratory for TestSafe Australia, part of Work-Cover NSW. He was one of the early members of the MSA in NSW which he says has given him a great insight into the world of Metrology. His committee work is in the role of States' Liaison coordinator.



Steve Jenkins is Technical Manager at Optical and Photometric Technology Pty Ltd. His main committee work is with the TAM sub-editorial committee.

Jim Miles. After emigrating from the UK, Jim worked at CSR Vinyl Flooring for over 10 years where he was responsible for Quality. He is currently a TAFE teacher in the area of Manufacturing and Quality.



Neville Owen joined the Gas and Fuel Corporation in 1977 after graduating in Applied Physics from RMIT and has since been involved in a variety of measurement projects in the fields of pressure, temperature, noise and vibration, displacement and force. He has been involved in gas industry projects to manufacture and implement new measurement equipment and techniques to assess thermal hazard and automate gas meter calibration on a large scale. He has been a NATA signatory since 1980 (metrology for pressure measurement and flow) a NATA assessor since the late 1980s and he established the first verifying authority appointment by the National Standards Commission for gas volume in 1994. He is presently employed by Gas Technology Services in charge of a small team conducting specialized measurement projects and general calibrations in gas and liquid flow for the gas and wider industry.



Brian Phillips started his working life as a Fitter and Turner in UK after an inglorious education at grammar school. A short spell in the Royal Air Force saw him trained as an Instrument Fitter and completely changed his career direction. Working as an Instrument Maker after leaving the Royal Air Force, he migrated with his young family to Australia in 1964. He has been occupied as an Instrument Service and Calibration Technician since 1965, for most of that time in NATA accredited laboratories.



Dennis Sexton is a Senior member of the American Society for Quality, a Certified Quality Engineer, and a Certified Six Sigma Black Belt. He is employed by Delphi Automotive systems as an Advanced Process Quality Engineer. Starting life as an



apprentice and tradesman machinist on the shop floor, he is also a registered Professional Engineer (I.Eng) with the Engineering Council of the United Kingdom, and a member of the American Society of Mechanical Engineers (ASME).

Involved with Six Sigma projects in a manufacturing environment, Dennis also has his own consulting business (DGS Quality Assurance) where he works mostly for academic institutions. Current projects include the design, development, and mentoring of the "Graduate Certificate in Metrology and Quality" for IRIS at Swinburne. Previously Dennis has designed short courses for TAFE in QS 9000 and Statistical Applications for manufacturing, as well as providing Metrology training for business on a part time basis. Dennis's committee work is primarily in the education subcommittee with responsibilities for liaison with Swinburne for the Metrology program.

Jeffrey Tapping worked for 30 years for the CSIRO National Measurement Laboratory. For the first 23 of these years he was in the Temperature Group, where he mainly worked on high temperature measurement standards. For the remaining 7 years he was Officer-in-Charge of the Adelaide Branch of NML where he managed a group which provided a variety of services including electrical, mass, density and temperature calibrations, and thermal conductivity measurements. While with CSIRO Jeffrey was a lecturer and demonstrator for the renowned biennial Temperature Measurement Course which was attended by more than a thousand participants during this time.



Jeffrey is a NATA assessor, and for many years was a member of NATA's Proficiency Testing Advisory Committee. He is a foundation member of The Metrology Society of Australia.

As a youngster he was a passionate hockey player. He has had a broad range of hobbies and interests, but especially electronics, photography and native plants.

Jeffrey now works as a private consultant in Adelaide under the trading name of Quality Answers. He retains an interest in disseminating information on measurement, and has presented his own one-day courses in uncertainties and temperature measurement, mostly in Adelaide.

Report on IMEKO Workshop and Symposium on "Tools for Education in Measurement"

Walter Giardini

The International MEasurement (C/K)Onfederation has about 20 technical committees (TCs) in all areas of metrology from measurement of "flow" to "human functions". Whilst active internationally, the current centre of gravity is around northern Europe and the MSA is the Australian member and representative of IMEKO. Late last year, I attended the first "virtual/real" workshop and symposium organized by TC-1 "Education and Training in Measurement and Instrumentation", with the theme of "Tools for Education in Measurement". The MSA as part of its commitment to supporting its relationship with IMEKO offered some financial support to attend the conference, and asked me to represent the Society and to report back on the symposium.

The format of the event was that a "virtual" workshop was held over two weeks in mid June 2001. Participant's papers were put on the TC-1 web site, together with links to any software or "virtual" instrumentation tools stored at the authors' own web sites which could be downloaded. Over the two weeks, participants read, discussed, downloaded and used the various software tools. The amount of activity was not huge, but there were extended "open" discussions between several of the participants. The workshop was then followed by a real life face-to-face symposium at Enschede in the The Netherlands in early September 2001, at which authors presented extended and separately submitted papers in the usual way. One of the advantages of this format was that by the time of the symposium there had already been significant interaction and exchange between participants, and so the level and depth of interaction was greater.

The 30 or so participants, mostly tertiary educators from University Engineering Faculties (particularly electrical and control) took part. I was the only participant from an NMI and similarly there were few industrial participants. Of course this may well be pretty much as it should be, after all education and training is primarily the business of the educational sector. On the other hand I think it is desirable, and no doubt probable, that this will evolve towards a more balanced mix of educators, industry and professional metrologists.

It was pleasing to hear Australia's well known and highly regarded role in this field through IMEKO's association with the metrological community centred around the University of South Australia's Centre for Test and Evaluation and Prof. Peter Sydenham's significant texts on fundamental metrology theory and practice.

About 12 papers and "tools" were presented, and these are still able to be accessed on the web at <http://imeko.mit.tut.fi/>. Many of the papers deal with the use of "LabView" and similar software tools by which students can interact with a computer generated instrument on a screen, complete with dials, knobs, switches, display meters and so on. The instruments look, behave and "feel" like their real counterparts, and are extremely effective in

delivering high grade simulations of real working hardware very economically.

Prof. Martin Halaj from Slovakia talked about a major project (COMET) backed by EU funding under their "society of knowledge" program, to create and deploy a multimedia metrology training package. He and his colleagues have already written a substantial textbook which has been migrated to CD and the Web, with the intention of using it as platform to develop and deploy a package of interactive modules – about 10 European universities are involved in this project.

Dr. Peter Bode spoke about the need for University training and research institutions to take on the concepts and methodologies of "quality systems" and differentiated between negative results of hypothesis testing, (a valid research outcome) and inadequate or poor methodology, which is a matter of competence and poor quality management.

Prof. Dietrich Hoffman's talk was strongly focussed on the need to make metrology practical and useful at the "business" or user end, and he made a dramatic point of the need for real world relevance by standing on a table and unrolling his special collection of measuring tapes he collected over many years and in many different countries, all 1.5 m in nominal length, and yet clearly varying by up to 20-30 cm! (see photo). A strong underlying view emerged at the symposium, particularly by Prof. Hoffman who is a significant figure in this field, and supported and taken up by others that the distinction between "virtual" and "real" instruments is somewhat arbitrary, a view which I felt requires more critical debate.



The rest of the papers dealt with specific systems designed to simulate metrological systems, instrumentation or metrologies in a software environment as teaching aids. Prof. Takayama from Japan presented a paper on an automated navigation control system, and its use in teaching a systematic metrological approach to measurement and sensing problems.

A meeting of the TC-1 board was also held, at which it was decided to run the workshop again in 2002, (see the web site). Tours of the universities' engineering department displayed work in automatic flow measurements (using ultrasonic upstream and downstream signals), automatic imaging systems which can detect and recognize parts, or follow the movement of 3D objects in space.

I came away with the view that "metrology" for universities and industry primarily means creating systems

which can measure a quantity of interest, so the focus is on the value of the result. Metrology for NMI's and NATA metrology laboratories means understanding and controlling the measurement process to ensure valid measurements, so the focus is on the uncertainty of the value – a subtle, but important difference.

Myth: Establishing Traceability for My Standards Is the Responsibility of the Lab That Calibrated Them

By Ron Ainsworth, Hart Scientific Calibration Laboratory Team Leader

(This article is reprinted by permission from Hart Scientific "occasional publication" Number 8, Winter 2002. Hart are represented in Australia by Trio Electrix).

With the 2002 Winter Olympic Games approaching a flame will soon be passed from torch to torch in an unbroken chain from Athens Greece to Salt Lake City. Similarly you can imagine a value from a standard at a national laboratory transferred in an unbroken chain of comparisons from one reference standard to another until the value from the national standard has been transferred to a device in your own laboratory.

Traceability is defined as the "property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties." (Quite a mouthful for some of us!) For purposes of addressing our myth we point out two critical parts of this definition: "an unbroken chain of comparisons" (as illustrated by the Olympic flame) and "having stated uncertainties."

The ISO Guide to the Expression of Uncertainty in Measurement (the GUM) gives general rules for expressing uncertainties and says that any documentation supporting a claim of traceability for a measurement result should include explicitly stated uncertainties. Therefore claims of traceability and uncertainty calculations are inseparable.

But be aware: it is the responsibility of the person or lab making the claim of traceability to be able to support that claim. It's not the responsibility of the national lab. Traceability cannot be achieved simply by following a particular procedure or by using a certain piece of equipment. Nor does sending equipment to a national or accredited lab guarantee traceability.

NIST for example says "Although the measurement results in a calibration or measurement certificate can be considered to be 'certified' by NIST to be traceable to NIST reference standards *at the time the measurements were performed* NIST cannot 'certify' that those measurement results are valid *after an instrument or artifact or reference material has left NIST*" (from NIST web site, emphasis added). NIST clearly makes the point that the

responsibility of verifying the continuing validity of a result of a measurement belongs to the user of that result.

So how do you "verify continuing validity" and ensure traceability? NIST recommends establishing your own measurement assurance program or "MAP." A MAP involves characterizing the transfer instrument standard or system for which traceability is desired and establishing measurement assurance charts (indicating associated values and uncertainties.)

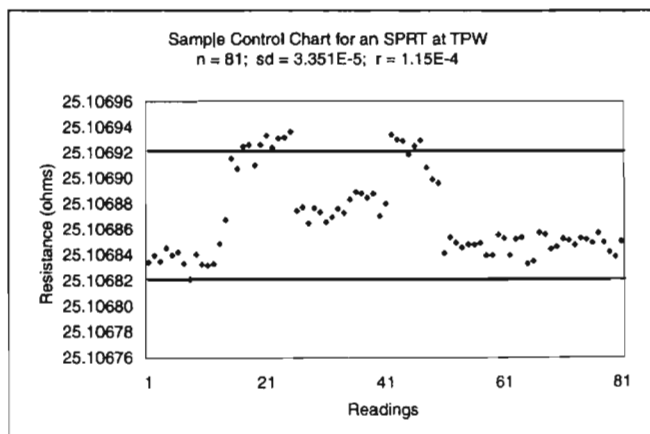
Take the example of a system in which calibrations of PRTs are performed in a bath using an SPRT (standard platinum resistance thermometer), as the reference thermometer. The SPRT might be characterized by monitoring its triple point of water value before and after each use. Using this data you can establish a measurement assurance chart that would allow trends to be analysed and any changes in the characteristics of the reference to be captured.

At the same time incorporate a check standard into the measurement process. A measurement assurance chart characterizing the measurement system would allow the tracking of any changes in the system and the quantification of uncertainties in the system.

With this MAP in place and the system and transfer standard both characterized you are now in a position to send your reference out for calibration. When it returns with its new calibration certificate you are able to quantifiably verify the integrity of your calibration and measurement system by continuing your MAP. This provides support to your claim of traceable measurement results. (After all how can you claim traceability if you can't prove that your standard is behaving the same now as it was at the time it was calibrated?)

Your analysis of the data collected in a MAP should include an evaluation of the uncertainty associated with your measurement results and any changes that may have occurred to the transfer standard during use.

For traceability to exist many believe that a transfer instrument standard or system must continually produce results that demonstrate a consistently quantifiable uncertainty. A measurement assurance program is the tool for the job. It may seem like a large investment of time and resources but the investment is small compared to the cost of a recall or the loss of a customer.



Bayesian Statistics - addenda

In the last issue of TAM there were some problems with the article commencing page 25 on "Bayesian Statistics".

Two paragraphs were omitted, together with two graphs, and these are printed here together with a further note from Bob Frenkel regarding a mistake in the original article.

Bob writes:

In the article on Bayesian statistics in the previous issue of TAM, I made a mistake in the first two medical-diagnosis examples. I assumed the probability of a false-positive test result to be the same as the probability of a false-negative test result, but of course this need not be so. I am indebted to Greig Small for pointing this out, and hope that not too many readers were led astray.

A diagnostic test for a disease can be described by two parameters: its specificity and its sensitivity. High specificity implies a low probability of a false positive, and high sensitivity implies a low probability of a false negative. Ensuring high specificity is (I understand) a more complex and error-prone diagnostic process than ensuring high sensitivity, so the probability of a false positive will usually exceed that of a false negative.

Fortunately, the conclusions stated in the article are not significantly affected. In the first example, if the probability of a false positive is kept at 1% but that of a false negative is taken as (say) 0.5% (rather than also 1%), then $P(\text{disease}|\text{positive})$ is still about 1 in 20. If we raise the probability of a false positive to 5% and the probability of a false negative to 1%, the patient's chances are even better, since $P(\text{disease}|\text{positive})$ is now only about 1 in 100.

In the second example, if the probability of a false negative is kept at 1% but that of a false positive at (say) 5% (rather than also 1%), then $P(\text{disease}|\text{negative})$ is still very low at about 1 in 200000.

Two paragraphs were missing from the article (and are printed in the next column), but their gist can be quickly summarised as follows. In the first medical example, the prior probability of the disease was 1 in 2000. The positive test on the patient, using a test with a 1% probability of a false positive, yielded a posterior probability of disease of about 1 in 20. The leap by a factor of 100 is related to the 1% probability of a false positive, but 1 in 20 is still low, since that is our standard metrological confidence level!

Two graphs were missing, and are reproduced here. The first shows the performance of a voltage standard artefact as conventionally measured, and the second shows the

same results subjected to a Bayesian analysis as described in the article.

Bob Frenkel
National Measurement Laboratory

The text omitted from page 30 of TAM 26 is given in italics:

.....A case in point occurred in the US some years ago during the trial of a high-profile public figure.

In the above three examples, we converted from prior probabilities to posterior probabilities, using new evidence as it became available. Thus in the first medical example, the prior probability of the disease was 1 in 2000. However, the positive test on the patient yielded a posterior probability of 1 in 20 of the disease. The leap by a factor of 100 is of course related to the 99% reliability of the test. So in this case the posterior probability of having the disease is much higher than the prior probability – yet is still low, since 1 in 20 amounts to 95% confidence in the absence of the disease, and this is our standard metrological confidence level!

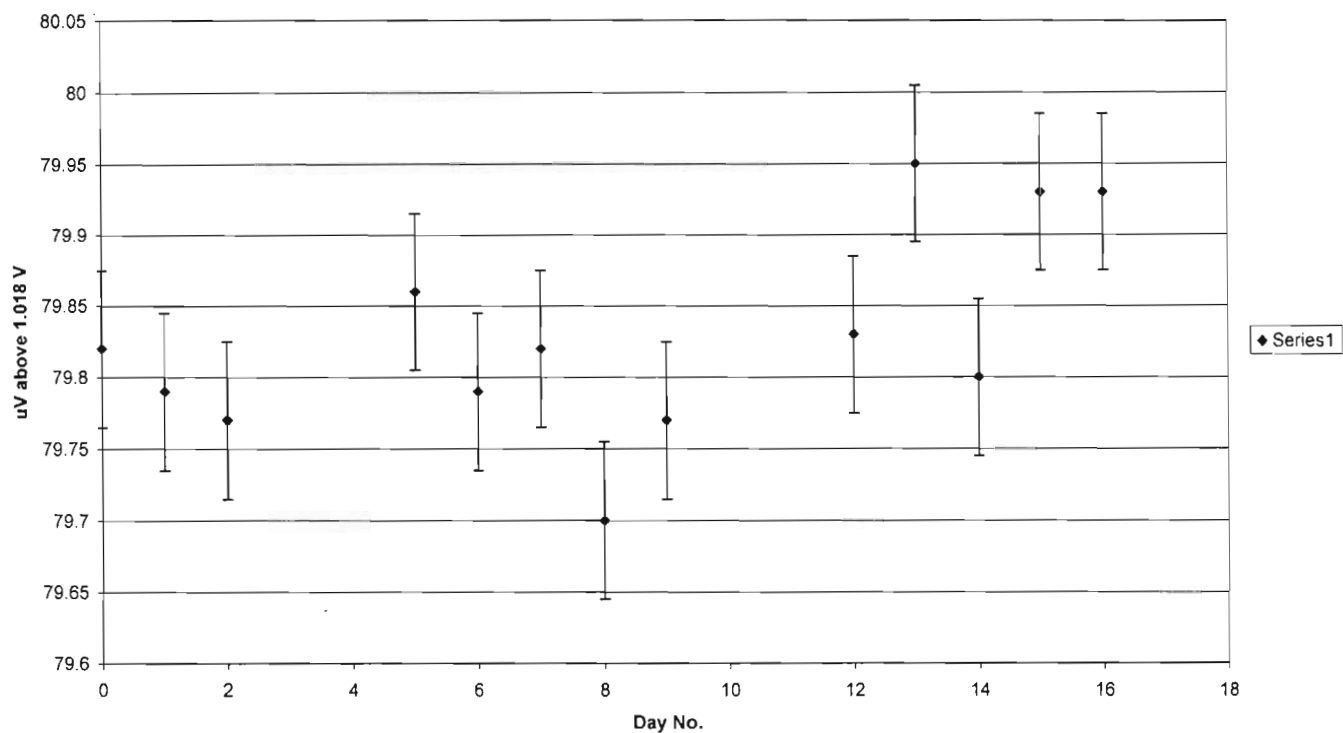
Similarly in the case of the DNA test. The prior probability of innocence is less than 1 (certainty) by only one part in two million. Yet after the DNA match evidence the posterior probability of innocence is not near-certainty but 2/3 – and yet this is still odds-on in favour of innocence.

Bayes' Theorem with Probability Distributions

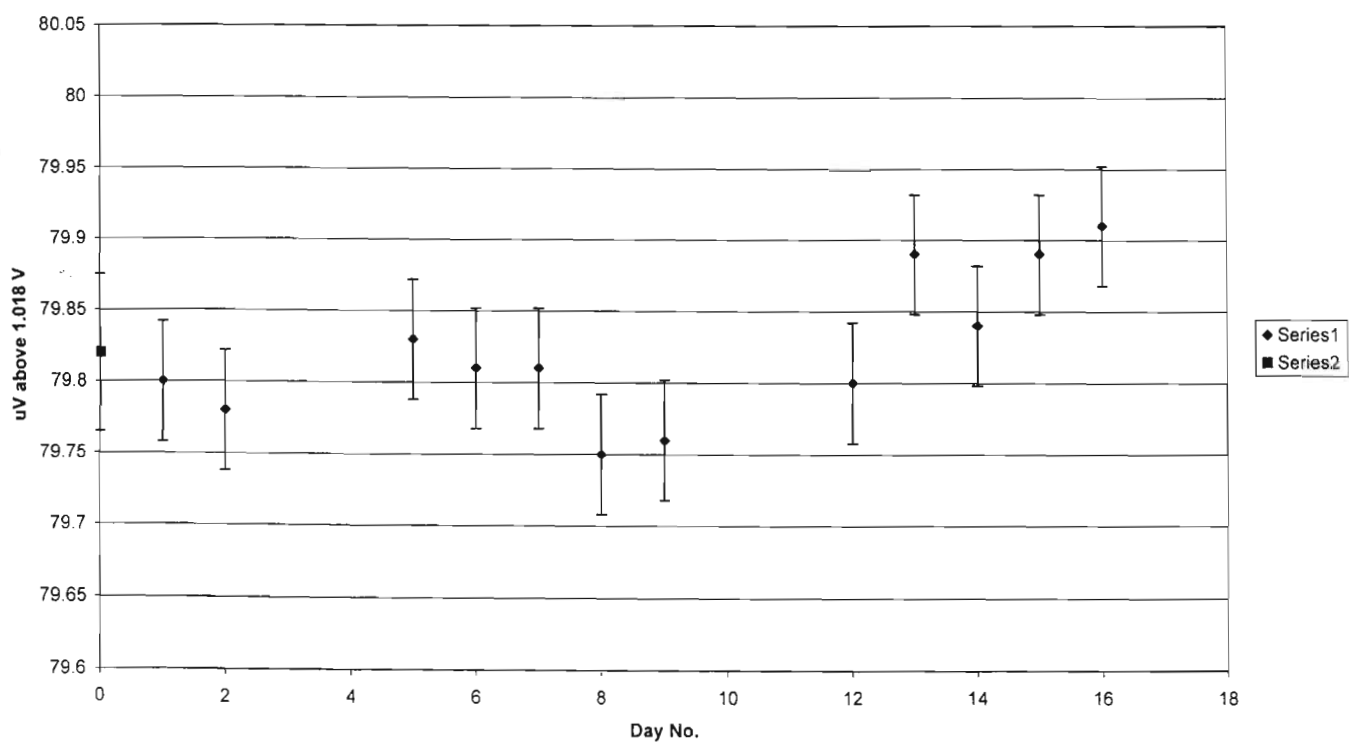
Equ. (4) is readily adapted to the very common case in metrology, or indeed in any branch of science....

The two graphs are given on the next page.

Volt Standard Original Measurements



Volt Standard Bayesian analysis, using previous-measurement priors and 0.049 uV rms scatter



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