

**Report on the
BIPM Workshop on *Metrology at the Nanoscale*
18-19 February 2010, BIPM, Sèvres.**

Letter from the chairman

Extract from the KCDB Newsletter of June 2010

Acknowledging the importance of measurement science and metrology in emerging areas of technology, the BIPM organized and hosted a Workshop on Metrology at the Nanoscale, bringing together scientists from the NMIs and industry with experts from the regulatory and standards development community. The two day Workshop, held on 18-19 February 2010, was attended by more than 100 delegates and approached the very broad topic of nanotechnology with thematic lectures and round-table discussions in eight topical areas:

- Toxicological testing;
- Nanobiology;
- Aerosols;
- Microscopy;
- Surface analysis;
- Thin films and coatings;
- Mechanical metrology; and
- Electrical and magnetic applications and measurements.

The program was very lively, and the presentations were uniformly excellent, allowing the attendees to address the focal question of the meeting: “What activities are required to establish an effective international infrastructure for metrology at the nanoscale”

The full report, which will be released this summer, includes a comprehensive summary of the discussions on this question, including the drivers to work on the topic, technical issues and barriers to progress, status and needs for traceability to the SI, as well as the anticipated use and need for reference materials and documentary standards. Briefly, however, it can be said that the principal drivers for international involvement are in environment, health and safety, in supporting and defining an appropriate regulatory framework, in encouraging and fostering industrial and therefore economic advantage. While the element of curiosity to explore new areas was an overarching theme, one principal barrier to progress was the long lead time required to develop research into innovation. Although there is a varied level of maturity in metrology and standardization, it was acknowledged that there is growing awareness and a high level of anticipation for results.

The current and potential applications of nanotechnology are vast, and there is a great deal of work required to advance the state of the science to ensure the safe and responsible introduction of these new technologies. Perhaps the most rewarding element of the Workshop was the opportunity to meet and establish connections outside of our normal communities: this sentiment was echoed with equal enthusiasm by participants from the world of metrology, by the industrial delegations, and by the attendees from international standards and policy development. We were presented with a very broad spectrum of measurement techniques and instrumentation, of new and very challenging measurands, and of the need to act across

traditional organization- and discipline-based boundaries to ensure that these pressing needs are met.

“I was very pleased with the level of engagement over the two hectic days, and with the superlative efforts of the Session Chairs and Discussion Hosts who each gave a summary of the work done in the breakout sessions. The BIPM was an ideal venue for such a cross-cutting Workshop, and I know that I speak for everyone who participated when I offer my sincere thanks for the chance to participate and express my desire to attend another productive meeting at some point in the future!”

(By Dr A.G. Steele, NRC, Canada, Chairman of the Workshop)

Summary report

1. Rationale of the workshop

Nanotechnologies are developing rapidly, and associated documentary standards and regulations are being adopted at the national and international levels. There is increasing pressure on metrologists to develop reliable and accurate measurement techniques and methods to underpin this. To meet this expectation, international coordination among National Metrology Institutes (NMIs) is required, with new approaches to overcome the complexity of this area caused by its highly multidisciplinary nature. The BIPM therefore organized a Workshop on Metrology at the Nanoscale, which took place at the BIPM on 18-19 February 2010.

This event was aimed at bringing together representatives from the NMIs with other stakeholders, such as nanomaterial manufacturers, regulatory authorities and standardization bodies involved in nanotechnologies, to answer the following question:

“What activities are required to establish an effective international infrastructure for metrology at the nanoscale?”

2. Workshop programme

The programme is available on the [workshop page](#)¹ of the BIPM website, and reproduced at the end of this document.

The first two hours were devoted to introducing the workshop and its objectives. Three talks focused on major issues of metrology to be studied in greater detail during the scientific thematic sessions: standardization (P. Hatto), traceability (M. Tanaka) and reference materials (H. Emmons).

The remainder of the workshop was designed to have one introductory talk per session (total of 4 sessions per day) in plenary, before dividing the audience in 4 groups for the discussion sessions.

The eight (4 per day on 2 days) scientific thematic sessions were:

- Methods and Technologies for Toxicological Testing of Nanoscale Materials
- Nanobiotechnologies
- Aerosols (nanoparticles in the air)
- Microscopy
- Mechanical metrology
- Nanomagnetism
- Surface Analysis
- Thin films and coatings

Each of the sessions started with a brief introductory talk, mainly by NMI representatives, with the aim of describing the current situation in NMIs with respect to the subject of the workshop. A minimum of two hours was devoted to discussions within the breakout sessions led by a chair, chosen preferably from steering committee members. Major questions had been prepared within the steering committee and distributed to session chairs before the

¹ <http://www.bipm.org/en/events/nanoscale/>

meeting. This template was used to gather the answers from the audience, and at the end of each day, chairs presented a short summary of their session's findings to the whole audience. The workshop chairman, Dr Alan Steele, presented a report at the end of the workshop.

3. Attendance

A total of 105 participants were registered for the Workshop, including 73 attendees, 21 speakers and 12 BIPM staff members. There were representatives from 47 different institutes (or companies). Most of them were working in National Metrology Institutes (NMIs), and were also active in Technical Committees or Working Groups of International Committees or Institutions such as ISO and OECD. There were also 6 representatives from industry (Bayer, Intel, IBM, Intertox, Ionbond, and JEOL), all of whom were speakers during the workshop. There was one speaker from a university (UC Dublin).

4. Main conclusions of the workshop

A summary of the conclusions on the seven main questions, prepared by the steering committee for the participants, is presented below. A compilation of the session reports is also provided as annex to this document.

4.1. What are the drivers (e.g. commercial, research, application, legislation, trade) in this area?

The two main drivers which emerged from the participants' comments are industry (which drives innovation and Research and Development) and EHS (Environment, Health and Safety) issues. While industry in general has been increasingly using nanotechnologies for a large range of applications (such as in electronics, electromagnetics, mechanical devices, opto-electronics, cosmetics, medical devices, etc.), public concerns about the toxicity of nanoparticles has also increased. Many countries and intergovernmental organizations (such as the OECD and EU) are already well engaged in toxicity testing of nanoparticles and legislation is being implemented, in particular for airborne nanoparticles. Attitudes towards the metrology community could also be classified as follows: while industry recognizes the need of metrology when quality control aspects come into play (commercialization stage), EHS issues require a deep knowledge of nanoparticles and their interaction with the environment. This requires a large range of measurements for which metrological quality is still not satisfactory in many cases.

4.2. Technical issues to be faced by the metrology in this area?

Participants highlighted a variety of technical issues which arise from the characteristics of nanoparticles. Firstly, it was noticed that the measurand is often difficult to define, and that measurement techniques which claim to perform the same measurement can give different results because they actually measure different properties. This is particularly the case for size measurements, where it is increasingly acknowledged that the term "size" is not precise enough and may not be relevant for nanoparticles. Secondly, almost all sessions observed that the reactivity of nanoparticles, their interaction with their environment, and the necessity to perform in-situ measurements, complicates the measurements. Matrix effects can be important, stability issues arise, and it might be necessary to consider time-dependant properties. Finally, the use of models and calculations in some measurement techniques were recognized as being a potential additional source of measurement biases and uncertainties (especially for "size" measurements).

4.3. Traceability to the SI: do researchers/users think about traceability to the SI or other stated references? Would traceability help solve some problems? How possible is traceability to the SI? How should method-defined measurements be dealt with? Give examples.

The discussions on the traceability to the SI indicated very different levels of comprehension of this term. It was seen as a too high a goal and difficult to achieve in nanobiotechnologies but it is the subject of studies, with already existing solutions, in surface analysis, aerosols or microscopy. It was mentioned in several groups that there is a need for a more general discussion with industry on metrological terms and on traceability in particular. The requirement for calibrations, which come with the traceability, was becoming more urgent, as products containing nanoparticles reach the commercialization stage. Regarding the traceability to SI units, many efforts were mentioned in measurements related to particle size and to particle concentration. However, the difficulty of the task was frequently expressed and it was agreed that in some cases, method defined approaches and standard procedures constitute an acceptable solution.

4.4. Reference materials: what is the role of reference materials and artefacts? Are there reference materials available? Are they equivalent? Is there a need for comparisons? When? Where are the most urgent needs for reference materials development?

Generally speaking, most of the discussion groups acknowledged an important need for reference materials. More precisely, it was seen as a priority in the field of aerosols, surface analysis and nanobiotechnologies in general and toxicity testing in particular. It was also a priority in mechanical metrology but less so in microscopy and electricity. Some reference materials are already available, and the database hosted by BAM² was mentioned. However, a significant amount of work is required on the existing materials to prove their reliability and even more so on the development of other reference materials.

4.5. Written standards: what documentary standards are required and when? Are there regulatory/legislative implications/requirements? If yes, is the “measurement dimension” included? Involvement of NMIs in documentary standards (national and international level)?

As stated in the rationale of the workshop, EHS issues are an important driver for the development of written standards to underpin existing and future legislation regarding nanoparticles and all products containing nanomaterials. The amount of work required to bring the necessary scientific bases to a written standard remains significant. This was confirmed by many participants, who emphasized the important role of the metrology community in this process, via participation in appropriate ISO technical committees, IEC/TC 113, as well as in the activities of VAMAS³. NMIs members are already involved in ISO TCs dealing with measurement techniques which are used in nanotechnologies, such as ISO/TC 201 (Surface Chemical Analysis), ISO/TC 202 (Microbeam Analysis), ISO/TC 213 (Dimensional and geometrical product specifications and verification) and ISO/TC 24 (Particle characterization including sieving). However an enforced participation in ISO/TC 229 (Nanotechnologies) was strongly encouraged and a role for the liaison between ISO/TC 229 and the BIPM was seen in helping this process. In particular, it was noted that “the Study Group on Metrology of ISO/TC 229 is a vehicle for NMI participation and awareness of the documentary standards activities”.

² <http://www.nano-refmat.bam.de/en/>

³ Versailles Project on Advanced Materials and Standards (<http://www.vamas.org/>)

4.6. International coordination: are the activities covered (or potentially covered) by a particular CC, several, or none of them? What are the barriers? Is the interdisciplinary nature of nanotechnology a problem? Could several NMIs working on a common problem help provide the right mix of expertise? What kind of forum/activity is most urgent (technical workshop with exchange of knowledge, CC working group to set up KCs, international survey of users)?

Due to the interdisciplinary nature of nanotechnologies, related activities in the NMIs are covered by several consultative committees: CCQM (Consultative Committee for Amount of Substance) has many relevant activities in its Working Group on Surface Analysis, but also in Gas Analysis (Aerosols); CCL (Consultative Committee for Length) has a working group on Dimensional Nanometrology (WG-N), and the CCEM (Consultative Committee for Electricity and Magnetism) has a Task Group on Materials which could potentially cover electrical measurements at the nanoscale. During the workshop, all discussion groups called for more communication between the CCs, a task which could be facilitated by the CIPM and the BIPM. As for the appropriate forum, there is a need for more workshops such as this one, as well as more focused workshops with more participation from other communities, or satellite workshops during conferences. In addition, regional programmes, such as CO-NANOMET in Europe, as well as participation in the pre-normative activities of VAMAS were also seen as appropriate ways forward.

4.7. Recommendations: do you have any recommendation? To whom? Who should take action?

There was a general feeling that the challenges of measurements at the nanoscale are significant, and that the metrology community should get involved as much as possible. In particular, the following recommendations emerged from the audience:

- Better communication between the CCs should take place, with the help of the CIPM and the BIPM;
- NMIs should increase their participation in standardization activities, in particular in ISO/TC 229 and its Study Group on Metrology;
- Workshops involving the metrology community with other experts should be organized;

Authors

This report was prepared by the chairman of the workshop, Dr Alan Steele (NRC-INMS) and the scientific secretary, Dr Joële Viallon (BIPM), with the help of the discussions sessions chairs: Dr Peter Hatto (chair of ISO/TC 229), Dr J.T. Janssen (NPL), Dr Alex Knight (NPL), Dr Laurie Locascio (NIST), Dr John Miles (NMIA), Dr Valérie Morazzani (LNE), Dr Sara Prins (NMISA), and Dr Wolfgang Unger (BAM).

Annex - Compilation of Discussion Sessions Reports

This annex is produced from the discussion session reports written by the chairperson for the plenary session. It contains reactions from the participants recorded by designated secretaries. It is not intended to be a comprehensive report, although it includes valuable information provided by participants, which could not be incorporated into the main report.

1. What are the drivers (e.g. commercial, research, application, legislation, trade) in this area?

1.1. Session 1 – Toxicity testing

- Regulation, Legislation and Trade are all important.
- Industry wants answers, to decide which products to develop and where to invest.
- Public confidence and fear of regulation without scientific input.
- Motivation is for the development of improved materials.

1.2. Session 2 – Aerosols

- The main drivers are related to the potential risks induced by the use of nano-particles on both human health and the environment
- A primary concern, mainly by the producers of aerosols, was occupational health (Production, Utilization, Accidents).
- A second concern was the release of potentially toxic particles into the environment.
- Linked to the previous point is EU regulation, specifically in the case of Vehicle emissions.
- Aerosols have to be controlled, because of toxicity concerns.
- A final concern was is the determination of atmospheric particles relevant to climate change.

1.3. Session 3 - Microscopy

- NPL: microscopy drivers are from people developing structured surfaces, broad industrial applications; no existing methods for measuring over large areas, e.g. in photonics, automotive, aerospace for coatings or patterns; use of structured surfaces to affect function; reduced friction might lead to energy efficiency (5 or 6 support votes).
- INRiM: ITRS semiconductor road map with specific targets for dimensions of devices (large number of votes); current needs from Intel are already at the 32 nm feature size, so microscopy is required; 3-D imaging (at atomic scale) is a corresponding driver.
- NIST: is there a distinction between needs of microscopy and metrological microscopy? Intel: yes, both – but more metrology in the future since it is difficult to know whether the correct structure is being interpreted.
- NMIA: will electron microscopy remain relevant? Intel: yes, in part because it is unknown which alternative will work.
- NIST: ITRS is an important driver, especially the metrology chapter, in large part because it is a clear statement of needs and a clear identification of appropriate measurands: SUGGESTION: Can the BIPM help coordinate industry workshops to produce metrology roadmaps of equivalent clarity?
- INRiM/EMRP on Magnetics: lots of properties beyond dimensional are of interest, such as quantitative magnetic measurements. At a small scale this is difficult and there are no reference standards; driver is memory demand and hard drives, although producers are not in Europe but are based largely in Asia-Pacific; Europe has a stronger activity in functional materials as piezoelectrics etc.
- LNE: in France, demand comes from research laboratories to compare different microscopic techniques, with reference materials and standard methods, with an emphasis on thermal properties.
- NRC: in Canada, EHS is a strong driver, especially given size-related toxicity (about half agreed) so metrology of sizing from microscopy is an enabler for legislation, regulation etc for

human nano-medicines and others; NMIA (and about half of the participants) agreed that nanoparticles for a variety of applications (including medicine) are a strong driver.

1.4. Session 4 – Surface Analysis

- Particles – nanostructures (on surfaces)
 - All technical applications, e.g. sensors and catalysts
 - Bio-medical applications
 - Understanding toxicology and environmental effects based on known starting materials
- Technology
 - Trade
 - Commerce – need to have nano-objects and other nanomaterials with clearly specified and reproducible surface chemistry
- EHS
 - Legal authorities

1.5. Session 5 – Nanobiotechnology

- Medical
 - Same as in non-nano: quality
 - Intellectual Driver: Achieve greater efficiency than “molecular drugs” – a new way to think about therapy
 - More efficacious, more accurate, and less invasive treatments
- Research and Innovation
 - Curiosity driven, new possibilities and ways to enhance quality of life
- Trade
 - Lack of nanometrology in this area may be a barrier to trade

1.6. Session 6 – Electricity

- Beyond CMOS, extend the end of Moore’s law.
- Closure of the quantum electrical triangle at or below 10^{-7} .
- Magnetic storage media (patterned,...)
- Magnetic drug delivery.
- Health and safety.
- Need to understand phenomena at quantum level.
- New materials: graphene, CNTs.
- Comparability of research results between institutes.
- More reliable measurement techniques for small electrical and magnetic signals.
- More sensitive techniques for small signals.

1.7. Session 7 – Mechanical metrology

The input from organizations considering entering nanotechnology was:

- Singapore: Nanoindentation is important, the driver is an internal department (mechanical metrology).
- Thailand: External drivers, external research institutes with a broad range of measurement needs. Cosmetics, food etc..
- Russia: Need for new methods and calibrations in gravimetry.
- Italy: Biological characterization of (DNA) scaffolds, geometry, Young’s Modulus, need help with mechanical measurements. No European Metrology Research Programme (EMRP) call for nano at the moment but some drive from Health.
- Australia: The silo breaking capabilities of nanometrology are an internal driver within NMIA. Confirmed by NRC and others. NIST not necessarily driven by this, but US generally beginning to look at joint programmes.
- UK: Materials development is an important driver generally. Polymer and biomaterials are driving NPL.

- US: National laboratory recently approached NIST regarding a MEMS device it wanted to sell. They anticipated needing traceability on each individual device. The process of Research to Innovation to Commercialization needs traceability in the US.
- US: There is continual commercial and near commercial pressure for nanometrology from multinational companies (semiconductors, chemical companies) often seeking to use metrology to move to deterministic design. This was also true in the UK.
- Russia: Raised the question of how far the nanomechanical measurements are from the quantum limit? Comment from meeting; a factor of about 5 only.

1.8. Session 8 – Thin films and coatings

- Commercial.
- List of applications:
 - Electronic
 - Electromagnetic
 - Electrical – conductors, batteries, fuel cells
 - Opto-electronic – PV, PC, ...
 - EM radiation – waveguides, x-ray mirrors,...
 - Mechanical
 - Biological
 - Chemical barrier
 - Sensor
- Mechanical – requirement for increased performance in sustainable tooling, better fuel efficiency in internal combustion engines. Functionality derives from nanoscale structures.
- Different methods in different companies – comparability.
- Devices are still largely proprietary.
- Time and cost constraints on depositing films. Define the important parameter – density, thickness, uniformity.
- Research.
- Properties in 2D.
- Need for 3D structural analysis if nanostructures are present inside a thin film.
- Legislation/Regulation.
- Climate change and environmental issues – e.g. photovoltaic potential, photocatalysis - Mainly policy related rather than strict legislation.
- Food-packaging: nanolayers to improve shelf life. Trade.
- Trade: WTO-TBT (Technical Barriers to Trade).

2. Technical issues to be faced by the metrology in this area?

2.1. Session 1 – Toxicity testing

- 1) Materials physicochemical characterization should continue in a big way
- 2) In biological assays:
 - Reducing variability in the biological experiment.
 - Establishing comparability in the biological assay.
 - - Classical toxicology may not be most appropriate so advances are needed in toxicological measurement.
 - Establishing a closer dialogue between physical metrologists, biological metrologists and toxicologists.
 - Defining clinically or biologically relevant measurement methods.
 - Bringing awareness of uncertainty evaluations and possibly experimental design to toxicology community.
 - Fundamental metrologically sound research can help the biological sciences to mature as it has with other fields.
- 3) Production of nanomaterials
 - See also:
 - 4th Trilateral Workshop <http://download.isiglobal.ca/inms/enter.html>.

- National Nanotechnology Initiative (NNI), USA:
<http://www.nano.gov/html/society/EHS.html>.
- What are the most important technical issues faced by metrology in this area? (and how can the NMIs contribute)?

2.2. Session 2 – Aerosols

- The parameters to be measured are :
 - Sizes of particles.
 - Quantity/concentrations.
=> Distribution of quantities as a function of size.
- Difficulties for measurements of the size are:
 - Calibration of size, specifically in the case of poly-disperse aerosols.
 - Influence of the chemical properties of the material that can modify dimensional characteristics.
 - The fact that measurement of size is not direct, but deduced via an algorithm : determination of the uncertainties is difficult.
 - None availability of aerosols canisters.

2.3. Session 3 – Microscopy

- NPL: surface features, linear scales (x,y,z) and angular tolerance may be under control, but there is no automatic transfer to 3-D complex surfaces; understanding the instrument transfer function is vital but non-trivial; terminology is sometimes misleading, for example “roughness” is used when “form” is being measured; NMIA likens this to the state of maturity of CMMs 15 years ago, since calibrating the scales and inferring a form are distinct.
- INTI: no current requirement to publish calibration information and thus microscopy without calibration is intrinsically non-comparable across laboratories and publications; a marketplace driver is “resolution” but there is no assurance of the quality of service.
- NRC: probe compensation methods may exist, but continuously changing probe shape during use may be an intractable problem (8-10 agree); PTB: methods to address this issue include a fully automated semiconductor industrial system that re-measures the tip shape in a monitoring mode, although this might be a “circular” solution; NPL experience is that 90% of tip wear occurs in 10% of use, although that does not address tip contamination.
- NIST: alternative imaging modes (magnetic, capacitance, etc.) which are integrated into an AFM, but then the image is a convolution of the topography with the additional measurement mode; the de-convolution problem is a significant technical challenge.
- NIST: lots of pressure, not on traceability or calibration, but on selection of microscopy mode (eg: what technique would be suitable to measure problem xxx); matching the information sought against the selection of measurement modality or the creation of a new one; NPL notes that there is not a true 3-D probe, although it is possible to combine 2-D (AFM in plane) and 1-D (optical in z-axis): where is the tomography and geometry? Is the expertise in the NMIs?
- NRC: Consistency among measurements with different microscopes is low compared to resolution and uncertainty; a technical issue is understanding the differences in measurand being probed by the different techniques to expose the underlying “true” concept (overwhelming agreement).
- INDUSTRY: opportunities for development of new techniques are strong, but bringing experts together for instrument development is a barrier to progress (Possible BIPM coordination role).
- INRiM: use of different techniques simultaneously is valuable, but there are no (?) metrological methods for calibrating two or more measurands at the same time; major point to address is that artefacts are not available, and the cost of assembly is prohibitive (there was not 100% agreement that this is not happening, but everyone agreed that expense and technical challenges for making artefacts in a deterministic fashion remain significant).
- NIST: apart from DNA, it is expensive to build large numbers of anything at the nanoscale; there seems to be a gap in NMI capability in this type of nano-manufacturing, but a technical issue is related to overcoming the cost and/or identifying appropriate self-assembling structures – intrinsic and/or natural standards are a goal here.

2.4. Session 4 – Surface Analysis

- Tools to characterize the surface.
- Medical applications - metrology for quantification of active surfaces in bio/med.
- Medical application -: NMR contrasts: Magnetic particle for tumour therapy; How to determine magnetism of NP? Application driven.
- Characterization with regard to the matrix in which nanoparticle is incorporated, e.g. sunscreen.
- Not only size should be considered, it should be holistic/comprehensive and include chemistry and other properties where applicable (of the particle or material system as a whole).
- Range of techniques – access to well defined ways of doing things that go beyond the experience of an individual researcher or research teams.
- Depositing films with NPs – need to measure and characterize surface before the next layer is deposited.
- Need to understand individual objects in detail and to be able to appropriately characterize large quantities of material.
- Need to recognize that nanostructured materials are more sensitive to environmental conditions, probe damage and time than many other types of materials. Places a priority on *in situ* measurements.
- Because some properties are not well defined, identified or physically understood (size, surface coverage) there is a major challenge in consistency with a variety of measurement methods and procedures.

2.5. Session 5 – Nanobiotechnology

- Measurement problems in ‘traditional’ nano and bio.
- Unique problems at the interface of nano/bio.
- In nano/bio there is a need for innovation in metrology: quantifying and characterizing biological materials at the bio/nano interface; quantifying nanomaterials in biological systems (*in vitro* or *in vivo*).
- Adapting metrology tools to work in the relevant biological environment.
- Adapting biochemistry tools to work in nanoparticle environments. For example, is it possible to measure 3D structure of proteins in corona?
- Need to have a sweeping vision and ambition – this will be a revolutionary field, similar to microelectronics.
- Need for measurement tools and methods for:
 - Fundamental chemical-physical characteristics of materials.
 - Characteristics of modified materials.
 - Characterization of materials in cells and in the body.
 - Fundamental underpinning standards for instrumentation (fluorescence imaging etc).
 - Possibilities for the creative development of new standards – e.g. much needed positive controls for nanotoxicology.
 - Communication between the two communities.

2.6. Session 6 – Electricity

- Making and characterizing contacts, at dc and rf.
- Fabricate CNTs and other nanostructures reproducibly.
- Characteristic impedances very different on macro and nano scale.
- Most accurate sensors require cryogenic temperatures.
- Elimination of background signals.
- Stability of nanostructures.
- Conductivity of CAFM-tip (conductive atomic force microscope).
- Theory linking properties at the nano- and the macro-scale.

2.7. Session 7 – Mechanical metrology

- Designing artefacts that are useable e.g. Identifying and locating positions on a cantilever when used by laboratories.

- Tip characterization for nano indentation - for pushing and pulling it is necessary to know the shape.
- Issues are not necessarily technical, they can be linked to funding for research.
- Scalability to industrial use of research techniques. AFM (like electron microscopy) will never become a metrological tool in workshops..
- Mechanical nanoscale devices and instruments are players in process development but not process operation.
- There is a significant need to measure time dependent properties at the nanoscale. Viscous elastic properties. Velocity dependent properties. What is modulus as a function of frequency.

2.8. Session 8 – Thin films and coatings

- Principally property determination – thickness, structure, chemical, mechanical, electrical, optical and magnetic, characterization of biological and chemical interactions, determination of “system” behaviour, e.g. adhesion, etc.
- Thickness: Proper traceability statement requires reference to the method? Often density dependent.
- Where does it start? Where does it end? What is defined as the interface. Define what to measure (measurand). Technique-dependence of interface definition. Even more difficult for functionally graded materials.
- Composition and chemical functionality (groups, optical properties, density).
- Uniformity.
- *In-situ* measurement during deposition and use – challenge to perform, and to characterize structure and composition. Environment for the analysis – represents working conditions, techniques often do not.
- Mechanical properties: Residual stress/strain. Other mechanical properties on a small scale is a challenge. Results will clearly depend on sample homogeneity.
- Porosity and functionality in porous films.
- Density profiling.
- Deposition conditions (critical for most thin film techniques) – frequently affects performance by influencing film stoichiometry, crystallography and properties.
- Quality control, process control – metrology control probably more useful for the latter and not so much the film.
- Contamination and defects.
- Post-production/ageing.
- Interactions with the ‘real world’.
- Reference materials needed especially for organic and functional surfaces.
- Scale factor – information needed for small amount or large amount.
- Anisotropy issues.

3. Traceability to the SI

3.1. Session 1 – Toxicity testing

- Difficult for now and method-defined approach is most likely.
- Possibly the physicochemical characterization aspects are the most likely area for traceability in the shorter term.

3.2. Session 2 – Aerosols

- Traceability to number concentration is warranted.
- BUT : Size determination is a problem.
 - Comparisons of different techniques, using different physical principles of measurements are required.
- Some labs are studying other techniques.
 - Techniques with a traceability to mass is being studied.

3.3. Session 3 – Microscopy

- BEV: most industrial users do not even consider traceability to be relevant at the microscale (reasonable support for this); difficult to influence industry to acknowledge since “instruments are already calibrated”; NPL had experience with poor performance in an industrial proficiency test and it was revealed that in-house calibration was non-existent.
- INDUSTRY: unless you have traceability, it is an industrial challenge to change materials, since recipe-based solutions are not portable.
- CMS-Taiwan: Users feel that the only reason to have a calibration report is to satisfy accreditation or audit requirements; little or no experience (poll) in industry making use of the uncertainty provided to customers of NMIs; the awareness may be inadequate on what these certificates are good for (BIPM Role in education?); NPL agrees especially at the R&D stage, but sees hope when production and quality control issues take priority (i.e. after the research stage).
- NMC-Singapore: user awareness session on traceability and uncertainty and calibration support were successful (organic photovoltaics example cited), particularly where the research had consistency and quality control issues.
- NIST: positive pressure from US-based instrument manufacturers trying to gain foreign market access; traceability allows “comparison shopping”, but at present there is often a lack of trust since manufacturers do not always have the luxury of demonstrating compliance to a standard.
- JEOL: development costs are very high, instrument costs are high, but adding in a traceability element might not add too much incrementally since these programmes are already very large.
- VSL: when it is available directly from OEMs it is mature, important for trade; reproducibility is the first requirement, not traceability.
- BIPM: is there a need for additional comparisons (yes!) and in what areas (in length already, in surface analysis); there are sometimes problems in nano-comparisons in part because the system for organizing these is overwhelmed (?); PTB: there is regular work to compare among NMIs outside of the nano work, and these are time consuming; NPL: it is necessary to get the dimensional capabilities under control, before moving to functionalized material comparisons.

3.4. Session 4 – Surface Analysis

- Do researchers/users think about traceability to the SI or other stated references?
 - Mole and length (and other SI depending the application).
 - Convention parameters, e.g. electron mean free path or optical path length.
- Would traceability help solve some problems?
 - Yes. There is not have full traceability to the SI for most techniques.
- How possible is traceability to the SI?
 - In some cases SI traceability will apply, but there will be cases where it will be method defined or convention parameters.
- How should method-defined measurements be dealt with? Give examples.
 - Convention methods/approaches (when not trace back to SI).
 - Ensure comparativeness / comparability between techniques for method defined measurements, especially when using convention parameters; Agreed parameters as determined through comparisons.
 - Incorporate all possible methods to not favour specific method above others.
 - Acknowledge there might be range of methods initially for certain measurands.

3.5. Session 5 – Nanobiotechnology

- In summary – participants are still at the stage of problem definition – not ready to talk about traceability yet.

3.6. Session 6 – Electricity

- Traceability for magnetic quantities needed (susceptibility, magnetization) to allow comparison of measurements.
- Dangerous to rely on a particular local standard (loss, damage etc.).
- In general, electrical quantities can be scaled over a large range.
- How to measure new quantum properties (entanglement).
- Process of measurement can influence measurement result.

3.7. Session 7 – Mechanical metrology

- Traceability was seen as a means of producing repeatability and reproducibility.
- There was not an overwhelming call for traceability.
- There was some confusion about what traceability means?
- Standard cantilevers with known stiffness are required.
- Traceability to base units (length, mass) first then to derived units (stiffness, elastic modulus etc.).
- There were vague requests for “standards” and “traceability” from industry. It will be necessary to clarify what industry requires.
- AFM much more than repeatability. Interoperability is more important. Traceability as a means to an industrial end.

3.8. Session 8 – Thin films and coatings

- Conceptual issue – but areal density is often more important – expressed as (mass per unit area). Composition should also be defined.
- Roughness - broadly relevant to most applications. Changes in refractive index will affect results when using optical techniques for looking at different materials.
- Traceability not so known in industry, but consistency is of critical importance. Need to ensure metrology terminology is understood by industry.
- Method defined: Nano-hardness. Nano-Indentation behavior.

4. Reference materials

4.1. Session 1 – Toxicity testing

- Reference materials or artefact standards targeted for microscopy e.g. for microscope scale or resolution calibration.
- Need to consider varying levels of standards - study materials and reference materials.
- Positive and negative controls are critical.
- Materials in matrices (EU is developing well defined food materials with embedded nanomaterials).
- Standard biological media.
- Study materials are likely to be appropriate in many cases, but may need some very well characterized materials to determine structure-function relationships and predictive toxicology.
- Need to educate researchers that they should not trust what is “written on the bottle” when it comes to materials because materials change; also need to educate them to use standards to calibrate instruments.

4.2. Session 2 – Aerosols

- Reference material: PSL
 - Gold particles standards of respectively 10, 30 and 60 nm are available from NIST.
- Some other materials exist:
 - TiO₂.
 - Single nano tube of carbon.
- Keeping material in suspension presents some problems
 - Stability of PSL.
 - For mono-disperse standards, problems of coating and surfactant are crucial.

- The control of the charge of the standards is required.
- There is also a need for poly-disperse standards.

4.3. Session 3 – Microscopy

- Two roles: calibration and transfer artefacts; traditional in analytical chemistry, novel for instrument calibration.
- Need is not always the driver; sometimes the reference materials are produced based on ‘what we can do’; e.g. dimensional artefacts abound, but this is not identified as the only desired application.
- Small investments sometimes limit progress; EURO project to make microwave and magnetic reference materials for use at nanoscale; NIST work to make force references, distinct from use of intrinsic molecular properties without SI characterization.
- Since particle size measurement is a key area, standards for, e.g., dynamic light scattering would advance that technique; this could be the start of thinking about 3-D reference artefacts; could consider these as a 3-D analogue of gauge blocks; some of the existing artefacts are not suitable for the measurement techniques – e.g. grids and gratings and steps are not the same as size measurement.
- An evolving need in microscopy, although it is uncertain what form it will take.

4.4. Session 4 – Surface Analysis

- What is the role of reference materials and artefacts?
 - Traceability.
 - Comparability.
 - Verification/validation of new analytical approaches.
- Are there reference materials available? Are the reference materials equivalent? Is there a need for comparisons? When?
 - Almost none.
- Where are the most urgent needs for reference materials development?
 - Coated nanoparticle with known core shell composition – interpreting results e.g. XPS (and compared to a flat surface of same composition and thickness as nanoparticle).
 - Functionalized nanoparticle, e.g. a nanotube (can be linked to a verified recipe to make the reference material) – Coverage (mole/m²) and Functionality.
 - Nano-structures to define shape, topography, etc.
 - A material to determine contamination.
 - Contamination of buried layers.
 - Bio-applications: to enhance contrast in NMR scans.
 - Drug doping / drug delivery systems.
 - Need to test materials (and methods) to establish reliability of sample handling and testing competency of groups making tests on thickness and surface functionality.

4.5. Session 5 – Nanobiotechnology

- Fluorescence standards, e.g. quantum dots or particular fluorophores?
- Standards for microscopy and other imaging tools could also be important.
- Working on reference “corona” – using NIST gold as a reference. Requirement for positive controls is highly significant.
- Reference materials for counting cells expressing markers, or for differentiation of cells on a scaffold.
- Homogeneous materials, rather than reference materials, may be what is needed (e.g. gold nanoparticles as a study material).
- Rather than supplying an end product, e.g. a functionalized surface, need to have a standard protocol for producing them.
- For nanomedicine, the important measurand is dose and there is a need for reference materials to support those measurements.

4.6. Session 6 – Electricity

- For electrical measurement, no reference materials needed, because quantum standards exist.
- Magnetic nanoparticles for medical applications require reference materials: magnetization, crystal structure, distribution of diameter and shape, surface condition.
- Graphene and CNT could be used as reference materials, but dependant on substrate, preparation etc. stability is also limited.

4.7. Session 7 – Mechanical metrology

- There is a need for nanoindentation standards (only fused silica at present).
- The marketplace has a need for reference materials but there is insufficient investment and imagination.
- May need to engineer new materials.
- There are already reference materials for dimension and stiffness.
- DNA is now a consensus standard as well as the proteins biotin and avidin.
- Gold bond rupture standard would be useful.
- Link to computational community? Need to establish a strong link to computational community above the level of the gold bond.
- Porosity reference standards are needed.

4.8. Session 8 – Thin films and coatings

- BAM hosts a database of nanoscale reference materials (RMs) (developed with support of PTB and ISO/TC 229): <http://www.nano-refmat.bam.de/en/>.
- (note: database is all current RMs, not only certified RMs).
- The available film thickness RMs from the list cover the full nanoscale range.
- No CRM for periodic steps.
- Some materials are sold as non-certified RMs, which can be sent to a calibration laboratory for measuring and certifying for the desired property value.
- Most urgent needs:
 - There is a need for more reference materials for:
 - Chemical composition.
 - Ultra-thin films - chemical composition distribution.
 - 2D reference materials.
 - Polymer and organic films (thickness/uniformity).

5. Documentary standards

5.1. Session 1 – Toxicity testing

- NMIs need to emphasize participation in ISO TC 229 as a priority.
- How can the metrology community help documentary standards bodies to interact?

5.2. Session 2 – Aerosols

- Some NMI are involved in documentary standards and associated committees:
 - ISO24 SE4 CPC Calibration.
 - TC264 Standard for particle size and total number concentration in ambient air.
 - SAE 31 mass and number of non-volatile particles, draft protocol for sampling.
 - ISO TC229.

5.3. Session 3 – Microscopy

- ISO 201 develops standards for calibrating microscope axes, but other areas, e.g. roughness, are open territory; method definition might be an appropriate starting point; ISO 202 has only very few standards under development for SEM and TEM, including an important one on scale calibration; standards in progress for optical interferometry; there is disagreement on the maturity of the science, so it may be premature to write a documentary standard.

- Most participants indicated that they currently use ISO or other international standards in their work; many were unsatisfied with what they had access to..
- It is a problem to capture the appropriate meta-data, the information about how you capture data and perform the measurement; automatic storage of instrument set-up and condition in the data file is a bonus..
- Regulators are willing to regulate, but the scientific community is still defining the measurands; this community will become a driver for producing documentary standards for compliance; it may be necessary to ask the right questions about risk, but it is not always possible to make the appropriate measurements to provide the answers.
- Documentary standards for consistency are a necessary first step: algorithm for selecting edge location gives tighter grouping in comparisons; standard sample preparation techniques remove one variable from the equation e.g. how many particles is it necessary to count so that statistical uncertainty is adequate; often these fall into the category of “technical specifications” rather than “standards”
- About one third of our participants from NMIs were involved in drafting, reviewing, refereeing standards.
- The established ISO TCs (201, 202, 213) have a strong linkage to NMIs and thus a trustworthy metrological foundation; as a new TC, there are challenges faced by TC229 since this is a new area and many NMIs do not have a formalized structure for handling nanotechnology as a distinct discipline; smaller NMIs may find it difficult to bring their metrological expertise to bear in an area where they do not have a presence.
- BIPM should investigate whether it is appropriate to encourage and / or coordinate the NMI involvement; their role as liaison to ISO TC229 might be used as a vehicle for informing and engaging NMIs, particularly the smaller ones that are not formally part of the standardization infrastructure in their country.

5.4. Session 4 – Surface Analysis

- What documentary standards are required and when? Are there regulatory/legislative implications/requirements?
 - There are guidelines and recommendations, not enough information yet to have standards. Standards can be referred to in legislation or can be used to implement legislation. Research and comparisons are needed to get input for the legislation stage.
 - For EHS there is a need for legislative requirements before nano-objects can be used in the body.
 - There may be a need to establish best practices when standards are not yet appropriate.
 - Standards that ensure chemical purity of nanoparticles in solutions – need to ensure it is clarified.
- Involvement of NMIs in documentary standards (national and international level)?
 - NMIs active in TC201 and TC229, there are also appropriate activities within national bodies.

5.5. Session 5 – Nanobiotechnology

- It may be too soon for documentary standards in most areas of nano-bio.
- Many standards in the medical device sector – it may be possible to extend these standards to devices containing nanomaterials, although this may require some additional material, e.g. around risk assessment (e.g. ISO 194).
- ISO TC 229 does not deal with nano-bio currently – is there a role here? It does deal with nanotox (under WG3), which is a subset of nano-bio. Specific measurements could fall under WG2.
- Liaison between the different TCs is very important, and also with other committees, e.g. IUPAC.

5.6. Session 6 – Electricity

- Standardization needed for measurement procedures, sample preparation of nanoparticles.
- Measurement of low level signals (targeted at non-specialists outside electrical metrology).

- Documentary standards needed for medical applications (e.g. Magnetic particles for internal heating against hypothermia) but more research needed first.
- IEC TC113 starts to become active in the nano-field.

5.7. Session 7 – Mechanical metrology

- List of a number in progress. Work is on-going.
- Documentary standards required for methods.
- Most NMIs with current activity already involved through ISO, VAMAS and ASTM.
- Standards activities are a way of gaining access to international and national knowledge and developing and fostering collaborations. Sometimes there are barriers to involvement from within countries.
- Depends on Standards body. NPL has positive results. So does NMIA, NIST and NRC.

5.8. Session 8 – Thin films and coatings

- Names involved in ISO TC 229, 201. and more.
- Work items for measurement standards should be adopted only after inter-laboratory comparisons, which have to resolve technical issues; e.g. Depth profiling - Sputter rate and thickness.
- There is a need to differentiate between what NMIs/metrology do/deliver and written standards that meet industry needs.
- VAMAS activities support standards development.
- Are measurement standards really needed in the presence of effective metrological tools.
- General needs:
 - Standards for sputtering techniques to determine thickness in industrial applications e.g. GD-OES – thickness of oxides, C60 sputtering of organics.
 - Nano-tribology and a general lack of standards in mechanical area for thin films and coatings.
 - Optical properties – typically dealt with by IEC.
 - Technical specifications versus ISs on measurement methods for thin films.
 - Thicker coatings with nano-structures, e.g. TBC's.

6. NMI coordination

6.1. Session 1 – Toxicity testing

- Some work is ongoing but more so in all the technical areas listed.
- More communication on measurement issues and measurement uncertainties.
- Workshop to develop global programme - Global issue – need a large programme to support innovation and metrology.
- European metrology research programme (EMRP).

6.2. Session 2 – Aerosols

- Activities related to gases, and thus aerosols
 - Activities are linked to CCQM, as well as the TC of EURAMET associated with chemistry.
 - Some workshops on airborne nanoparticles.
 - Common work and projects are in progress (for example on the behalf of VAMAS).
 - There are no obvious links with the dimension researchers..
- No common point of view from dimensional and chemistry TC could be agreed.

6.3. Session 3 – Microscopy

- The ISO TC229 Study Group on Metrology is a vehicle for NMI participation and awareness of the documentary standards activities.
- CCL has a Working Group on nanoscale dimensional metrology.

- CCQM has a coordination role, e.g. in a surface analysis and microscopy studies; the comparison revealed areas for improvement.
- CCEM established a Task Group on Materials, which has some linkage to nanoscale electrical and magnetic issues, although little has happened so far beyond the results of the CIPM Survey on Materials Metrology; better scheduling may help. It may not be the right time to carry out a survey on Metrology at the Nanoscale beyond what is happening at this and similar Workshops.
- Regional programmes, such as CO-NANOMET in Europe, work outside the single-CC model as a means to handle the multidisciplinary nature of this problem; CIPM may wish to examine how inter-CC issues should be examined within their structure.

6.4. Session 4 – Surface Analysis

- Are the activities covered (or potentially covered) by a particular CC, several, or none of them?
 - Partially by CCQM (SAWG), also partially by CCL.
 - VAMAS as pre-normative body.
- What are the barriers? Is the interdisciplinary nature of nanotechnology a problem?
 - Time, money.
 - Interactions and communication between CCs and other bodies are not optimized, terminology differs.
 - There is a strong need for interlaboratory comparison of data. It is difficult to get funding agencies to support such activities.
- Could several NMIs working on a common problem help provide the right mix of expertise?
 - Yes
 - Often the efforts of the standards and metrology community are focused on metrology organizations or industry. There is a great need in this area in academia, but a major effort will be required to reach them (with cost as a concern).
- What kind of forum/activity is most urgent (technical workshop with exchange of knowledge, CC working group to set up KCs, international survey of users)?
 - Communication between CCs.
 - Exchange of knowledge.
 - Get all role players involved – beyond the NMI community, involve other experts.
 - Establish preliminary reference materials and set up inter-laboratory comparison studies to determine status of reproducibility.
 - Satellite meetings at big conferences in material science.

6.5. Session 5 – Nanobiotechnology

- Joint meeting of BAWG and SAWG in Brazil as a start – is this the right model, rather than a new grouping?
- Intercomparison study suggestion: Albumin or DNA on surfaces?
- More round robins would be a useful learning experience.
- Tiered approach, moving from simpler to more complex systems.
- Workshop to get the medical and environmental communities together.
- A workshop on positive and negative controls would also be useful.
- ISO could organize a conference where all relevant TCs, ASTM and IEC committees could share information.
- ISO TC 201 could be a place for these standards.

6.6. Session 6 – Electricity

- Interdisciplinary nature requires collaboration between NMIs.
- Barriers are time and money.
- Nanoelectrical measurements at present not covered by CCEM, but TG on materials metrology has recently been formed.
- Coordinate horizontal activities between CCs, coordinate information exchange in field of materials metrology and metrology at the nanoscale (task for CIPM, BIPM).
- BIPM database for measurement capabilities on nanostructures.

6.7. Session 7 – Mechanical metrology

- BIPM does not see a short term role in arranging exchanges but already many good activities occurring.
- Statement from NPL: BIPM has had a huge role in developing low force standards and it would be a shame to see that stop. BIPM would be open to suggestions for such work.
- No need for BIPM to do anything extra as NMIs already interacting well.

6.8. Session 8 – Thin films and coatings

- Are the activities covered (or potentially covered) by a particular CC, several, or none of them?
 - Good international coordination exists.
 - Film thickness – where does it belong? CCQM versus CCL. Need to communicate between the CCs. Nano likely to be covered by more than one CC. Mechanism needed to ensure communication between the CCs.
- What are the barriers? Is the interdisciplinary nature of nanotechnology a problem?
 - Coordination is critical to overcome the problems associated with the interdisciplinary nature of nanotechnology and the associated standardization activities
 - Some technology areas not acknowledging nano in their industries e.g. food.
- Could several NMIs working on a common problem help provide the right mix of expertise?
 - Active participation of NMIs in the development and review of standards documents is strongly encouraged to help ensure technical and linguistic accuracy.
- What kind of forum/activity is most urgent (technical workshop with exchange of knowledge, CC working group to set up KCs, international survey of users)?
 - Workshops, bringing together different expertise, e.g. Metrologists + Toxicologists.

7. Recommendations

7.1. Session 2 – Aerosols

- One point to overcome:
 - No traceability for bigger particles : PMT 2.5 and 10.
- Some other properties and measurements have to be linked to the size distribution:
 - Chemical properties have to be analyzed.
 - Surface area measurements.

7.2. Session 3 – Microscopy

- Get involved!

7.3. Session 4 – Surface Analysis

- Make metrology lucrative.
- Developing reference materials to move towards to CRMs.
- Involve the larger community (possibly through new means of communication – going beyond the usual standards or metrology community).
- NMIs engage with industry to raise metrology awareness.
- Proper evaluations of existing roadmaps before initiating further activity.

7.4. Session 8 – Thin films and coatings

- Communication between CCs (CCQM and CCL about thickness).
- NMIs: increased participation in standardization, e.g. TC229 and its metrology group (ref. the production of its metrology checklist).
- NMIs: engage with industry to raise metrology awareness.
- EHS concerns about nanotechnology – standards awareness drive/campaign aimed at societal stakeholders.
- All relevant parties: proper evaluations of existing roadmaps and surveys before initiating further activity.

Day 1 – Thursday 18 February 2010 Chair Dr Alan Steele, NRC-INMS co-chairs Prof. Andrew Wallard, BIPM director & Prof. Dr Michael Kühne, BIPM deputy director				
8:30	Registration			
9:00	Welcome and expression of interest on the part of the CIPM on this topic Prof. Andrew Wallard, BIPM Director			
9:15	Objectives of the workshop Dr Alan Steele, Director, Metrology, NRC-INMS, Ottawa, Canada			
9:30	Expectations from the ISO TC 229 - Nanotechnologies Dr Peter Hatto, Chair, ISO TC 229			
9:50	The concept of traceability in nanometrology Dr Mitsuru Tanaka, Research Coordinator/AIST, Tsukuba, Japan			
10:10	Reference materials for nanometrology Prof. Hendrik Emons, Head of Reference Materials Unit, IRMM, Belgium			
10:40	Coffee			
11:00	Session 1 Methods and Technologies for Toxicological Testing of Nanoscale Materials Introductory talk: <i>"The OECD sponsorship programme on nanomaterials"</i> by Dr Peter Kearns, OECD			
11:30	Session 2 Aerosols Introductory talk: <i>"Needs of standards related to emission, transfer and containment of airborne nanoparticles"</i> by Dr François Gensdarmes, IRSN, Physics Laboratory and Metrology of Aerosols			
12:00	Session 3 Microscopy Introductory talk: <i>"Reliability of "nanoscopes" nowadays - with example of AFM"</i> by Dr Masashi Iwatsuki, Japan Electron Optics Laboratory, JEOL			
12:30	Session 4 Surface Analysis Introductory talk: <i>"Need we metrologically underpinned standards for surface- and nanoanalytic ? Yes and No !"</i> by Dr Matthias Voetz, Bayer			
13:00	Lunch			
14:00	Session 1 - Methods and Technologies for Toxicological Testing of Nanoscale Materials Chaired by Dr Alex Knight, NPL	Session 2 - Aerosols Chaired by Dr Valérie Morazzani, LNE	Session 3 - Microscopy Chaired by Dr John Miles, NMIA	Session 4 - Surface Analysis Chaired by Dr Wolfgang Unger, BAM
14:30	Introduction to the discussion <i>(final title to be defined)</i> by Dr Richard Pleus, Intertox discussion	Particle number concentration and particle size measurement Dr Hanspeter Andres, METAS discussion	Microscopy for characterization of nanostructures: trends and challenges Dr Harald Bosse PTB discussion	Chemical analysis of nanosized objects and nanostructured surfaces: current practice, common misconceptions and metrological needs Dr Ronald R. Baer, PNNL discussion
15:30	Coffee			
16:00	discussion	discussion	discussion	discussion
17:00	Reports from the discussions : each chair to give a 10 minute summary			
18:00	Reception			

Day 2 – Friday 19 February 2010 Chair Dr Alan Steele, NRC-INMS co-chairs Prof. Andrew Wallard, BIPM director & Prof. Dr Michael Kühne, BIPM deputy director				
9:00	Session 5 Nanobiotechnology <i>"NanoBiotechnology: metrology for nanoparticles in situ in biological systems"</i> by Prof. Kenneth Dawson, UC Dublin			
9:30	Session 6 Electricity and Magnetism Introductory talk <i>"Some microscopy challenges in nano-electronics"</i> by Dr Juan J Perez-Camacho, INTEL			
10:00	Session 7 Mechanical Metrology Introductory talk: <i>"Mechanical metrology at the scale where top-down meets bottom-up manufacturing"</i> by Dr Jon Pratt, NIST			
10:30	Session 8 Thin Films and coatings Introductory talk: <i>"Materials Characterization Challenges in Next Generation CMOS Devices"</i> by Dr John Bruley, IBM T.J. Watson Research Center			
11:00	Coffee			
11:30	Session 5: Nanobiotechnology Chaired by Dr Laurie Locascio, NIST <i>Measuring nano-bio interactions - a foundation for effective risk management, standards and regulation</i> Dr Richard Moore, Institute of Nanotechnology	Session 6: Electricity and Magnetism Chaired by Dr JT Janssen, NPL <i>Quantum electrical metrology on the nanoscale</i> Dr JT Janssen, NPL	Session 7: Mechanical Metrology Chaired by Dr Alan Steele, NRC-INMS <i>Nanoscale mechanical properties of materials</i> Dr Mark McDermott, NRC-NINT	Session 8: Thin Films and coatings Chaired by Dr Peter Hatto, ISO TC 229 <i>Metrology issues in thin film process for next-generation semiconductor</i> Dr Kyung Joong Kim, KRISS
12:00	discussion	discussion	discussion	discussion
13:00	Lunch			
14:00	discussion	discussion	discussion	discussion
15:30	Coffee			
16:00	Reports from the discussions : each chair to give a 10 minute summary			
17:00	Summary of findings and recommendations Dr Alan Steele, NRC			