

## Strategic action plan for Danish metrology<sup>1</sup>

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### *Abstract:*

This report summarises action plans for the ten EUROMET subject fields. Each of them describes the field in an international context, the Danish needs and resources at the NMI-level, and finally it proposes specific actions. The costs and financing of the proposals are enumerated for 2005 and for a "Strategy year" that describes the situation after implementation of the proposals. Also the income form related NMI-services are given. The characterisation according to their merits within INNOVATION, QUALITY OF LIFE, and SCIENCE, proposed in the iMERA project is discussed and are presented in 8 out of ten subject fields.

### *Dansk resumé:*

Denne rapport sammenfatter handlingsplaner for EUROMETs 10 hovedområder. Hver plan beskriver området i international sammenhæng, danske behov og ressourcer på NMI niveau, og endeligt giver den konkrete forslag. Omkostningerne og deres finansiering er opgjort for 2005 og for et strategiar, som beskriver situationen, efter at ændringerne er indført. De tilhørende indtægter for det pågældende NMI er også givet. En karakterisering af forslagene i forbindelse med INNOVATION, VELFÆRD og VIDEN, som er foreslået i iMERA projektet, diskuteres, og den præsenteres for 8 ud 10 hovedområder..

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## TABLE OF CONTENTS

1	Dansk resumé .....	3
2	Executive Summary.....	7
3	Introduction .....	11
4	iMERA categorisation of foresight and prioritisation.....	13
5	Subject field action plans.....	15
5.1	Mass.....	15
5.2	Electricity .....	18
5.3	Length .....	23
5.4	Time and frequency .....	28
5.5	Thermometry.....	31
5.6	Ionising radiation and radioactivity.....	35
5.7	Photometry and radiometry.....	37
5.8	Flow .....	41
5.9	Acoustics.....	45
5.10	Amount of substance .....	49
6	Summary and conclusions .....	52
7	Appendixes .....	56
7.1	Methods used in foresight .....	56
7.2	Proposal for iMERA grading .....	59
7.3	List of acronyms.....	60

## 1 Dansk resumé

Formålet med denne rapport er at sammenfatte og opdatere 17 års strategisk planlægning af dansk fundamental metrologi og at give et bud på dens udvikling. Formålet er dels at give dokumentation for de forslag, der er fremsendt til regeringen med henblik på at forberede den danske metrologiorganisation på fremtidige behov, og dels at give et bidrag til diskussionen om en fælles europæisk holdning til fremsyn og prioritering, som for tiden foregår i projektet iMERA.

I perioden er der udarbejdet i alt 23 handlingsplaner for de ti tekniske områder, som metrologien internationalt opdeles i. Planerne tager deres udgangspunkt i danske behov, og de foreslår løsninger, der ud fra teknologiske og praktiske overvejelser kan lade sig realisere i Danmark. Et vigtigt element i planernes prioritering er det strategiske hensyn til nærhed i såvel leveringen af kalibreringer som vigtigheden af tilgangen til den tilhørende viden. Hvor der ikke er et strategisk hensyn til nærhed, er løsningen ofte at sørge for adgang til udenlandske faciliteter.

Danske virksomheder skal have ubesværet adgang til internationalt anerkendte målinger, hvor dette er væsentligt for deres innovative muligheder på et globalt marked; og danske borgere skal for eksempel have sikkerhed for at de medicinske analyser, de udsættes for, er i overensstemmelse med EU's krav om sporbarhed ved, at der er adgang til den tilhørende tekniske kompetence.<sup>2</sup> For at tilfredsstille disse behov er der etableret en decentral og åben dansk metrologiorganisation DANIAMet, der besidder de mest nødvendige kompetencer, og som er i indgreb med det internationale system; men størstedelen af behovene for sporbarhed, - mellem 80 og 90 % - henvises for tiden til udlandet.

Dansk deltagelse i den globale videndeling er endvidere en forudsætning for, at især mindre danske virksomheder får adgang til de udenlandske faciliteter. Dette sker ved, at DANIAMet og nogle få danske forskningsinstitutioner deltager i udvalgte forskningsprojekter, hvor både den danske nytteværdi og muligheden for et synligt dansk bidrag til de internationale forskningsresultater er særlig stor. For tiden forberedes der med dansk deltagelse – i det omtalte iMERA projekt - et egentligt europæisk forskningsprogram for metrologi under EU's 7. rammeprogram.

Nærværende rapport sammenfatter og opdaterer handlingsplanerne. Konklusionerne er, som det er angivet i "Dansk metrologi 2006+3 – en handlingsplan", at dansk metrologi er sakket bagud, og at der derfor er behov for en saltvandsindsprøjtning i form af øgede midler til både drift og investeringer. Handlingsplanerne opgør de samlede timebaserede omkostninger til 48,7 millioner kr. om året til at drive en prioriteret men tidssvarende metrologiorganisation i Danmark, hvortil kommer et engangsbetøb til udskiftning af nedslidt udstyr på 40,4 millioner kr.

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<sup>2</sup> In vitro diagnostic medical devices (98/79/EC)

Denne rapport bedømmer, at behovet for resultatkontraktmidler er omkring 26 millioner kr. til dækning af de timebaserede omkostninger, og at udstyret bør finansieres over en særskilt infrastrukturel pulje. Det bemærkes, at handlingsplanerne har foretaget en prioritering inden for de respektive fagområder; men en prioritering fagområderne imellem er der ikke foretaget.

Herudover er der et behov for en tværfaglig aktivitet, blandt andet til at holde sammen på den decentrale organisation, og der er behov for at Danmarks deltagelse i den ny europæiske videndeling gennem iME-RA projektet hjælpes i gang med den nødvendige medfinansiering.

For at foretage den nødvendige prioritering mellem de ti hovedområder foreslås det, at de metrologiske områder opdeles i tre grupper: Indsatsområder, opgraderingsområder og nedprioriterede områder:

*Indsatsområder: Etablering af fire "Centres of Excellence".*

I overensstemmelse med "En strategisk vision for dansk metrologi" (2004) foreslås følgende større indsatsområder i form af Centres of Excellence:

1. *Dansk primærlaboratorium for Elektrokemi.* Elektrokemi er en af de få kemiske discipliner, der anvendes inden for mange industrielle sektorer og offentlige kontrollaboratorier. For eksempel er pH-målinger den hyppigste kemiske analyse, og ledningsevne målinger anvendes af medicinalindustrien, kraftværker, på hospitaler og i elektronikindustrien. På basis af det eksisterende samarbejde mellem Radiometer og DFM, er det formålet at etablere et primærlaboratorium for elektrokemi, der hører til blandt de fem bedste i verden. Opbygningen vil ske i samarbejde med de øvrige ledende laboratorier i Europa. Centret vil støtte væsentlige danske erhvervssektorer, og vil betjene det internationale marked. Det vil desuden give international synlighed til dansk metrologi. Omkostningerne ved at etablere centret er opgjort til 1,7 millioner kr. om året i perioden 2007-2009. Hertil kommer 0,5 millioner kr. i engangsinvesteringer.
2. *Center for optisk metrologi.* Optisk kommunikation er atter i kraftig vækst, og dermed opstår en række nye krav til karakterisering af materialer, komponenter og systemer. Formålet med centret er at tilfredsstille det mangefacetterede behov gennem en fælles nordisk indsats, der går ud på at udnytte de nye muligheder, som lasere og optiske fibre giver inden for moderne metrologi og sensorteknologi. Fra dansk metrologi deltager en række danske virksomheder og DFM, og DFM indgår i det foreslåede nordiske samarbejde med udvikling af bølglængdereferencer i det fiberoptiske område (800 –1700 nm), måling af MFD (mode field diameter), NA (numerical aperture) og ulineære egenskaber. Optiske teknikker vil også blive anvendt inden for partikeltælling og bestemmelse af partikelstørrelse, hvor der er et akut behov for sporbare målinger, både inden for industrielle rene rum, i stalde med intensivt dyrehold og med hensyn til karakterisering af farlige nanopartikler. Omkostningerne ved at etablere centret er opgjort til 5,1 millioner kr. om året i perioden 2007-2009. Hertil kommer 9,4 millioner kr. i engangsinvesteringer.

3. *Primærlaboratorium for akustisk metrologi.* Akustik er et af de områder, hvor dansk industri og metrologi er gået op i en højere enhed, hvor det hidtidige primærlaboratorium har opnået status blandt de fem bedste i verden; men der er behov for et generationsskifte, idet det hidtidige samarbejde mellem DTU og Brüel & Kjær skal omlægges, så DFM kan indgå i stedet for DTU. Danske virksomheders succes inden for lyd er velkendt. Oticon og B&O er flagskibene, men der er en bred vifte af virksomheder, der er stærkt knyttet til viden om lyd. Industrien støttes af forskning især på DTU og Aalborg Universitet. Udover fortsat at lede udviklingen inden for mikrofoner og vibrationsmåleudstyr skal centret beskæftige sig med "det kunstige øre", som er en fælles europæisk indsats, og i forlængelse af vibrationsforskningen skal dynamiske målinger tages op i nordisk regi. Omkostningerne ved at etablere centret er opgjort til 3,7 millioner kr. om året i perioden 2007-2009.
4. *Center for Flow-målinger.* Sigtet er her at skabe et stærkt dansk metrologicenter inden for måling og beregning af strømninger med vand, andre væsker end vand, luft, gasser og varmeenergi inden i rør og rundt om konstruktioner. Centret tager sit udgangspunkt i de eksisterende kompetencer på TI og FORCE; hvor der er behov for en øgning af den teoretiske forståelse af komplekse strømninger. Det skal styrke danske producenter af måleudstyr, procesindustrier, distributionsselskaber, myndigheder og andre både via samspil og ved at skabe resultater, som kan anerkendes internationalt. Det skal dække såvel mikrostrømninger med relevans for medicoteknik og avancerede processer, som makrostrømninger med betydning for proces- og kraftværksindustrien, for energi- og forsyningssystemer og for miljøet. Perspektivet er et flowcenter, der via sit brede virke og via synergi kan skabe resultater, som gør en forskel. Omkostningerne ved at etablere centret er opgjort til 8,1 millioner kr. om året i perioden 2007-2009. Hertil kommer 10,2 millioner kr. i engangsinvesteringer.

*Opgraderingsområder: Opgradering af fire hovedområder.*

I overensstemmelse med handlingsplanerne for alle ti områder, er der ud over de fire indsatsområder behov for væsentlige opgraderinger. Det drejer sig om:

1. *Masse.* Området har på nogle felter været i en kraftig udvikling i de senere år, dels ved at opbygge DFM's evne til at veje på højeste niveau, og dels ved FORCEs udvidelse af både kraft og tryk, hvorimod udviklingen indenfor volumen og densitet har været mindre. Disse målinger er af den art, som det danske erhvervsliv forventer at have adgang til med kort leveringstid, som mere eller mindre standardydelse. Samtidigt er DFM's nye aktivitet, nemlig at benytte avancerede matematiske metoder inden for metrologi, opbygget med særlig henblik på massebestemmelser. Feltet kræver kontinuert udvikling og der er behov for nogle udvidelser såvel som to større udstyrskaffelser for at bringe instrumentparken op på internationalt niveau.

2. *Elektricitet.* Elektrisk kalibrering er uhyre vigtigt, eftersom alle målinger via sensorer omsættes til elektriske signaler. Området er dog inde i en periode, hvor der ikke er behov for en stor forskningsindsats, men derimod en overførsel af kompetence fra DFM's forskningsmiljø til Arepa's mere praktiske miljø. Samtidigt skal det meget snævre udbud udbygges for at tilfredsstille danske behov.
3. *Længde* minder om de to ovenstående områder, bortset fra at de fleste behov inden for nanoteknologi ligger inden for dimensionsmålinger. Her skal der etableres et nyt samarbejde mellem DTU, Teknologisk og DFM, hvor den gryende danske nanoindustri skal betjenes, både når nano handler om overflader, IT og bio. Og så skal DFM's lasere anvendes meget bredere til at understøtte nøjagtige målinger, end det hidtil har været tilfældet.
4. *Temperatur.* Temperatur- og fugtighedsmålinger griber ind i næsten alle områder af arbejds- og privatliv. Procesindustrien og energisektoren er to store erhverv, hvor temperaturen spiller direkte ind; men også inden for farmaceutisk, kemisk og keramisk industri er temperatur en vigtig influensparameter. Samtidigt indgår temperaturmålinger som et lovpligtigt element ved afregning af fjernvarme. Laboratorierne på Dansk Teknologisk, DELTA og Risø besidder i dag komplekse kompetencer inden for området, men udstyret er for en del udtjent og dækker for lidt af behovet.

Handlingsplanernes samlede omkostninger til de fire opgraderingsområder er 21,1 millioner kr. Hertil kommer 16,6 millioner kr. i engangsinvesteringer.

*Nedprioriterede områder:* To handlingsplaner er ikke prioriteret; det drejer sig Tid og Frekvens samt Ioniserende stråling og Radioaktivitet og Dosimetri. Førstnævnte er et område, hvor internationale normaler i form af radiosignaler sendes ud til alle med en dertil indrettet modtager, og der er derfor ikke behov for en statslig facilitet. Det andet område, der blandt andet vedrører radioaktiv stråling til medicinsk diagnostik og behandling, er et eksempel på hvad der sker, hvis metrologien ikke følger med tidens krav. Her er der nemlig tale om et institut, der godt nok opererer som referencelaboratorium for sundhedsministeriet, men som ikke lever op til kravene til optagelse i CIPM-MRA, og som derfor ikke længere kan sikre international sporbarhed på et sundhedsmæssigt særdeles vigtigt område. Det ligger derfor udenfor denne rapport at prioritere området.

Endvidere er handlingsplanen for kemi nedprioriteret for så vidt angår andre områder end elektrokemi. Dette gælder for eksempel laboratoriemedicin og fødevarer kemi, som hører under andre ministerier, og hvor der er et åbenlyst behov for metrologi, men hvor det for tiden ikke er lykkedes at skabe en ramme for disse områder, der er forenelig med DANIAMet.

*Tværfaglige aktiviteter.* Udover de ovenfor nævnte fagspecifikke planers prioriteringer, er der en række tværfaglige aktiviteter, som kræver finansiering. Det drejer sig om deltagelse i det generelle internati-

onale arbejde, udvikling af undervisningstilbud og de specielle omkostninger til koordinering af den decentrale organisation, idet de anselige gevinster, der er ved denne, har sin pris i form af en mangel på fælles holdninger til begrebet metrologi og et behov for at skabe et fælles ansigt udadtil; disse forhold er beskrevet i "Dansk metrologi 2006+3 – en handlingsplan". Hertil kommer medfinansiering af eventuel dansk deltagelse i det kommende EMRP (European Metrology Research Programme).

## 2 Executive Summary

The purpose of this report is to summarize and to give an update on 17 years of strategic planning of Danish fundamental metrology as well as predict its development. The aim is partly to document the proposal that has been forwarded to the Danish government with the aim of preparing the Danish metrology organisation for future demands, and partly to contribute to the discussion, on a common European attitude to foresight and prioritising that is currently going on within the iMERA project.

During the 17 years a total of 23 plans of action, covering the ten technical fields into which international metrology are divided have been prepared. The plans of action are focussing on the Danish demand and they suggest solutions that, taking into account technological and practical considerations, can be realised within Denmark. An important element in the prioritisation in the plans of action is the strategic consideration towards closeness in delivery of calibrations as well as the importance of access to the related knowledge. In cases where taking consideration to closeness is not necessary, a solution is often to seek access to foreign facilities.

Danish industry should have easy access to international accepted measurements where these are important for the industry's innovative capabilities in the global market. Danish citizens should be secured that the medical analysis they are subjected to are in agreement with the EU regulations on traceability, by having access to the associated technical competence<sup>3</sup>. In order to satisfy these needs a decentralised and open Danish metrology organisation, DANImet, has been established. DANIAMet holds the most needed competences and has excellent connections to the international metrology system. However, approximately 80% of the needs for traceable measurements in Denmark are referred to foreign countries.

Danish participation in the global knowledge transfer is a prerequisite for providing access for Danish companies, particular SME's, to foreign facilities. This is happening by the participation of DANIAMet and a few other Danish research institutions in selected research projects where both the value of the Danish input and the possibility of a Danish contribution of high visibility to international research results are particularly large. At present, preparations are made for Danish participation in the iMERA project, which is a European research programme for metrology within EU's 7<sup>th</sup> framework programme.

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<sup>3</sup> In vitro diagnostic medical devices (98/79/EC)

This report summarizes and updates the plans of action. The conclusions are, as described in "Dansk metrologi 2006+3 – en handlingsplan"<sup>4</sup>, that Danish metrology has fallen behind and that there is a need for additional funding for both running costs and investments. The total annual need has been estimated at 38 MDKK in addition to the current annual performance contract of 13.3 MDKK between the Ministry of Science, Technology and Innovation and the involved GTS institutes.

However, it is suggested by prioritising within the ten plans of action that the most important proposals can be realised by a total performance contract for metrology of 26 MDKK as described below. To this end the plans of actions divided into three groups: Focus areas; Areas requiring upgrading and Downgraded areas:

*Focus areas: Establishment of four "Centres of excellence".*

In agreement with the report "En strategisk vision for dansk metrologi"<sup>5</sup> (2004) the following focus areas are proposed in the form of Centres of Excellence:

1. *Danish primary laboratory for electrochemistry.* Electrochemistry is one of a few disciplines in chemistry that is used in many industrial sectors and public laboratories. The measurement of pH for example is one of the most common chemical analyses and the measurement of conductivity is used in the medical industry, power plants, hospitals and in the electronics industry. On the basis of the existing collaboration between Radiometer and DFM it is the goal to establish a primary laboratory for electrochemistry, which will position itself among the five best in the world. The establishment will be made in collaboration with the other leading laboratories in Europe. The centre will support important Danish industry sectors and will provide services for the international market. In addition, it will provide visibility for Danish metrology. The expense in establishing such a centre is estimated at 1,7 MDKK annually during the period 2007-2009. To this should be added 0.5 MDKK in capital investments.
2. *Centre for optical metrology.* Optical communication is again growing, leading to new demands for characterising materials, components and systems. The centre should satisfy the large variety of needs through a common Nordic institute that will explore the new possibilities provided by lasers and optical fibres in modern metrology and sensor technology. A series of Danish companies together with DFM are participating and DFM is part of the proposed Nordic collaboration concentrating on the development of wavelength references (800-1700 nm), MFD, NA and non-linear measurements. Optical techniques will also be used in connection with particle counting and particle size determination, and area in which there is an increasing demand for traceable measurements. This area includes industrial clean rooms, farm environment and toxic nanoparticles. The expense in establishing such a centre is

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<sup>4</sup> English translation: "Danish Metrology 2006+3 – a plan of action"

<sup>5</sup> English translation: "A strategic vision for Danish metrology"

estimated at 5.1 MDKK annually during the period 2007-2009. To this should be added 9,4 MDKK in capital investments.

3. *Primary laboratory for acoustic metrology.* Acoustics is one of the subject fields where Danish industry and metrology has been working closely together and where the primary laboratory has reached the status of being among the top five laboratories in the world. However, there is need for a generation change since until recent collaboration between DTU and Brüel & Kjær has to be re-structured and DFM will take the role that DTU had. The successes of Danish companies in the subject field of acoustics are well established. Oticon and Bang & Olufsen are the flagships, however, there is a broad range of companies that constitute the Danish knowledge base within sound. The industry is strongly supported by research at DTU and Aalborg University. In addition to continued focus on further developments of microphones and vibration measurement equipment, the centre will work with the development of an "artificial ear", which is a common European focus area. Research in vibrations will be a focus area within the Nordic region. The expense of establishing such a centre is estimated at 3.7 MDKK annually during the period 2007-2009.
4. *Centre for flow measurements.* The aim is to create a strong Danish metrology centre for measurements and calculation of flow in water, other liquids than water, air, gases and heat energy in pipes and around constructions. The centre will be based on the existing competences at TI and FORCE where a need for an increased theoretical understanding of complex flow is needed. This will strengthen Danish producers of measurement equipment, the process industry, distribution companies, authorities and others both via cooperation and by generating results that will be internationally recognised. The centre shall cover both micro flow relevant in medico technique and advanced processes as well as macro flow that is important for the process and power plant industry for energy and supply systems and for the environment. The perspective is that the flow centre via its broad range of capabilities and via synergy can create results that will make a difference. The expense of establishing such a centre is estimated at 8.1 MDKK annually during the period 2007-2009. To this should be added 10.2 MDKK in capital investments.

*Areas requiring upgrading: Upgrading in four subject fields*

In agreement with the plans of action for the ten subject fields there is a need for important upgrading outside of the four focus areas. The concerned subject fields are:

1. *Mass.* The field has seen a considerable development in some sub fields in recent years, partly by establishing DFM's capabilities of weighing at the highest level and partly by FORCE's expansion in both force and pressure, whereas developments in volume and density has been smaller. Such measurements are of the sort that Danish industry expects to have access to, including short delivery time, and consider being standard services. In addition, one of the newly established fields, advanced mathematical methods for metrology, is built on the

basis of the determination of mass. The field is functioning well, but there is a need for some expansion as well as replacement of outdated equipment in order to bring the laboratories up to international standard.

2. *Electricity*. Electrical calibration is extremely important since all measurements using sensors are transferred to electrical signals. The field is in a period of time where there is little or no need for research efforts, but rather a transfer of competences from DFM's research environment to Arepa's more practical laboratories. In addition, it is required that the very limited services be expanded to satisfy the Danish demand.
3. *Length*. The situation in length is very similar to the two above mentioned subject fields, except that most of the needs within nanotechnology is related to dimensional measurements. It is necessary to establish a new collaboration between DTU, TI and DFM where the upcoming Danish nanoindustry can obtain services, both when it is a question of nano measurements relating to surfaces, of information technology and of biotechnology. DFM's park of lasers will be applied to a much broader range of fields to support accurate measurements.
4. *Temperature*. Temperature and humidity measurements are relevant to almost all parts of working and private life. The process industry and the energy sector are two large industries where temperature plays a direct role, but also in the pharmaceutical, chemical and ceramic industries is temperature and important influence parameter. Temperature measurements are part of the legal requirements for providing district heating. The laboratories at TI, Delta and Risø today possess the complex competences in this subject field; however, some of their equipment is outdated and does not cover all the needs.

The total expenses proposed by the plans of action in the four areas requiring updating are estimated at 21 MDKK annually. To this should be added 16,6 MDKK in capital investments.

*Downgraded subject fields*: Two of the plans of action are not prioritised. These are Time and Frequency and Ionising radiation and Radioactivity and Dosimetry. The former is a subject field where international standards in the form of radio signals are transmitted to all parties that possess an appropriate receiver. Therefore, there is no need for government-funded facility. The other subject field, which among other things include the sub field radioactive radiation for medical diagnostics and treatment, is an example of what happens in the case of too little funding for metrology. The services of a previously well-recognised institute have declined and it can no longer secure international traceability in a field of great importance for health.

Further, the action plan for chemistry has been downgraded regarding the other fields than electrochemistry. This concerns for instance laboratory medicine and food chemistry, since it is currently not feasible to treat these fields in a way that is compatible with DANIAMet.

*Interdisciplinary activities*. Beside the above-mentioned specific prioritisation by subject field, there is a number of interdisciplinary activi-

ties that require financing. This includes participation in general international work, development of courses and financing for coordination of the decentralised Danish metrology organisation is needed, since, despite the considerable value of this organisation, it has its price in terms of lack of common attitude towards metrology and a need for creating a Danish metrology organisation with a common face; this subject is treated in the action plan: "Dansk metrologi 2006+3 – en handlingsplan".<sup>4</sup> In addition, initial co-financing of the possible Danish participation in EMRP (European Metrology Research Programme) has to be found.

### 3 Introduction

The purpose of this report is to summarise and update 17 years of strategic planning for Danish fundamental metrology and to give a suggestion for its development. The motivation is twofold: Firstly, this provides the background for the suggested actions by Danish government in order to prepare the Danish metrology situation for future needs; and secondly, it provides a unique input to the ongoing discussion in the project IMERA about best practices in foresight analysis and prioritisation.

Since 1989 DFM has prepared topical action plans for the 10 technical EUROMET subject fields (i.e. excluding interdisciplinary metrology and quality); and this has served as guidelines for the development of Danish metrology within the decentralised Danish metrology organisation DANIAMet. The work has been performed in contract with the Danish Accreditation and Metrology Fund DANAK that has the political responsibility for metrology in Denmark, as delegated from the Danish Safety Technology Authority of the Ministry of Economics and Enterprise. Hence the action plans serve as the planning tool for Danish metrology.

The plans have an element of foresight as well as an element of prioritisation in them. They start with a technical description of the subject field in question, including a subdivision into sub fields. Then the needs are described and projected over a five-year period (the foresight part) with focus on Danish needs in the following sectors: Industrial applications, Legal and other regulatory applications, Calibration and Testing, Research, and Other applications. Thirdly, the available resources to address current and future needs are enumerated before a gap analysis is performed in order to make recommendations for future developments (the prioritisation part); this takes into account both the possibility of setting up facilities in Denmark or of deferring the needs to other EUROMET partners. Special attention is given to the proposal of establishing new national metrology institutes for new sub fields. Finally, economical estimates of the costs associated with the proposed initiatives are given.

Technical people representing the stakeholders of the subject field in question write the action plans. Sometimes the authorship has been broad so that all relevant viewpoints were represented; sometimes a small group of authors have drafted a report, which has then been circulated to a wider audience.

Whereas the format of each action plan has been fixed during the 18 years, several other aspects have changed. This is only natural, as the focus of metrology has developed significantly during the period. For instance, what was seen in the strict national scope some years ago is today seen in the light of globalisation. Of practical significance is that subject fields have developed internationally, but there is only partly coincidence between the subdivisions of subject fields in DANIAMet, EUROMET, and the meter convention as well as in European Accreditation EA. The driving force for the formation of sub fields in Denmark is that they must represent a significant national need; and they should form a sound technical basis for the formation of an NMI. A national metrology institute (or designated institute in the terminology of the meter convention) is namely appointed by DANAK for one sub-field, although in some cases several organisations collaborate to cover the competences of an as-defined sub-field.

The present report combines and updates the 23 action plans that have been written so far. Further, it brings them into the context of the iMERA project. This project has formulated the work of relevance to the Danish action plans in iMERA work packages WP1 "Systematic Exchange of Information and Best Practice". In particular, it addresses issues related to the questionnaires that have been circulated for WP1.1: National programme landscaping, WP1.2: Overview of national foresight processes, WP1.3: Overview of national prioritisation processes, WP1.4: Knowledge transfer activities, and WP1.7: Training opportunities and exchange of personnel. However, the main interest for this report is focused on the WP1.2 " Overview national foresight processes".

The work package WP1.2 of the iMERA project collects the different methods used to carry out foresight studies by the iMERA partners. The information is qualitatively and quantitatively assessed as part of the work package WP2.1 "Assessing existing foresight information". Finally, the output is a report that establishes an appropriate mechanism to maintain and update foresight studies into the iMERA partners. The present report is part of the work package WP3.1: "Joint foresight studies" and have given input to the report "European Metrology Foresight 2007". The needs and trends described have links with the nine topics of the Seven Framework Programme and they are common interest among different iMERA partners.

Each summary estimates the staff involved in the operation of the involved National Metrology Institutes (NMI's), as well as the key economic figures. These are the costs of operating the specific NMI for the 2005 and for the "strategy year" where investments have been implemented and services established. The strategic investments are also enumerated. The corresponding proposed performance contract are given. Finally client income from calibrations directly related to the function as an NMI is given.

Staff is given in units of person years (full time equivalent per year) and costs are given in Danish kr. (DKK). 1 € is approximately 7,5 DKK.

#### 4 IMERA categorisation of foresight and prioritisation

Within the context of IMERA, different ways of doing foresight have been classified (See section 7.1). According to this terminology the Danish action plans are based on limited environmental scanning, issue surveys and trend extrapolation as it is described below.

The environmental scanning method is carried out by a group of experts who are working in various fields of metrology such as legal metrology, industry, accreditation, and research. They are responsible for finding stakeholders in each metrology subject. Stakeholders are requested to feed back the needs and trends in the society where metrology can be applied.

The issues surveys have been used for asking to the stakeholders regarding needs and trends that can be solved by applying metrology, e.g. surveys used for "Expert Opinions" as part of Delphi method. However, the process has been slow and sometimes the feedback received by the stakeholders is not clear or sufficient. This issue could be minimized or avoided by means of the personal interviews. During the interview, the stakeholders have the opportunity to clarify their feedback immediately.

The trend extrapolation method gives by its nature a linear projection into the future, because the historical data analysed with this method are the same one considered in the past. It is therefore important that this method is supplemented by non-extrapolatory methods to catch novel needs.

The brainstorming method offers such an approach in foresight studies. It is seen as an implicit method within all the methods, because the stakeholders may contribute with novel ideas and viewpoints as well as creativity.

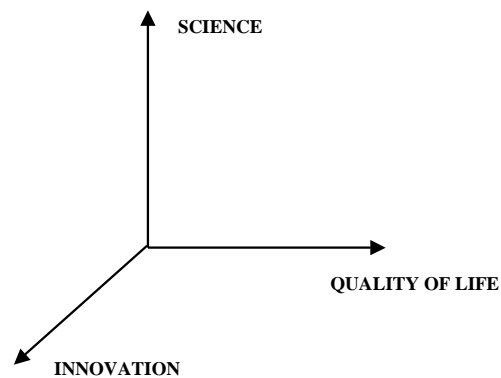
The Expert opinions are important, and they have an element of "Delphi", since the stakeholder hearings are repeated to the same or similar audiences each time an action plan for a specific subject field is repeated.

Hence, the stakeholders have an important role into foresight studies. They identify and analyse the needs and trends in the society. The stakeholders should have a vision oriented towards social-economic aspects as well as technical aspects. The stakeholders with a social-economic background have a broader vision regarding quality of life and innovation than the stakeholders with a technical background. An example has been the collaboration with a consultant with experience in foresight studies. During 1999, several interviews were performed in order to know why metrology is important for the Danish society as well as how metrology could meet its needs and trends. The consultant carried out the interviews with various stakeholders. The interviews were carried out by means of the telephone. The stakeholders were people with different backgrounds. The result detected needs and trends unknown by the experts group (who have always realised foresight studies in Danish metrology). One of the "unknown" need was regarding "soft" metrology (measurement of human perception).

Also, the methods used for carrying out foresight studies have been useful in order to have a broader vision in the long term regarding the needs and trends in the society, as well as how they could be addressed by means of metrology. These methods could also be combined in order to strengthen the foresight studies, e.g., by introducing methods as SWOT analysis, the simulation modelling, and the technology road mapping. In addition, the identification of "good" stakeholders is a key piece and starting point into foresight studies.

Whereas the needs should be formulated by people who have a broader vision than often found within metrology experts, the solutions to those needs should be primarily formulated by specialists in metrology, in order to ensure a professional approach to future metrology.

In prioritisation, high value is always given to national demands. This includes the special attention to the fact that sectors where Danish industry is either strong or has a great potential should be given preference. But it may also include societal needs related to quality of life. The second item on the prioritisation agenda is the ability to establish the necessary competence, often through collaboration with others in order to set up a new facility or service. It also includes consideration of relying on foreign contacts solely so as to avoid unnecessary duplication of effort and an unhealthy competition on services. Finally, a project must contribute to the international visibility of Danish metrology; this is particularly important for developments with a strong scientific content.



When looking upon metrology as a support for the development in society, three axes have been conceived as sketched above. There is the current dominating axis of INNOVATION, where the competitiveness of particularly industry is supported by the ability to do measurements properly. The other basic axis reflects the emerging for QUALITY OF LIFE, where the challenge of measuring intangible parameters such as well-being, pleasure and satisfaction are treated in metrology terms. Finally, there is the axis of SCIENCE reflecting that metrology also contributes to the furtherance of scientific knowledge; here a new definition of the kilogram related to natural constants currently provokes the researchers, and the CIPM has set up the ambitious goal of redefining the SI in 2011.<sup>6</sup> Below we have adopted this new iMERA

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<sup>6</sup> CIPM recommendation 2005

classification when characterising the proposals in the action plans. Subcategories and their respective weights are given on section 7.2.

## 5 Subject field action plans

### 5.1 Mass

This subject field was treated in action plans in 1989 and 1997. It has resulted in the appointment of a primary laboratory for Mass measurements (DFM) and two national reference laboratories (FORCE Technology) for Force and pressure as well as for volume respectively. The latter includes density, where collaboration with DFM has been established.

#### 5.1.1 The subject field and its sub fields

DANIAMet sub-fields	EUROMET sub-fields	CIPM working groups
Mass measurements	Mass	Mass standards
Force and pressure	Force	Force
	Pressure	High pressure
		Medium pressure
Volume and density		Low pressure
		Density
		Avogadro constant
		Hardness
		Gravimetry
		Viscosity

The subdivision of the subject field for DANIAMet and the three major international organisations are given in the table below. As is seen, the Danish division is easy to map onto the international ones, except for the specialised working groups of the CIPM that reflects special work at the BIPM.

#### 5.1.2 Needs

The needs as expressed by the sectors defined cover the following parameters:

*Industrial applications:* Mass is a convenient quantity for the quantification of solid bodies, powders, and liquids for the use in trade and process control; there is a growing need for the calibration of balances in the process industry as a result of increased focus on quality control. Force is needed in building, machine and shipbuilding industries. Torque is increasingly needed in the same sectors plus entertainment and medical sectors. Pressure is of important for the process and off-shore industry. Finally, volume is important when quantifying liquids and when measuring big containers. After the action plan from 1997,

density has emerged as an important parameter in connection with the calculation of gas density, and viscosity also appears to be needed more than anticipated. Finally, low-pressure facilities are needed.

*Legal and other regulatory applications:* Legal metrology, as administered by DANAK demands calibration of weights, balances, and volume standards for gas and liquids. For weighbridges, calibration and testing of load cells by force measurements with high accuracy are needed. Recent developments are that the recommendation OIML R111 requires that weights of  $E_1$  and  $E_2$  have their density determined, and that the EU directive on measuring instruments (2004/22/EC) "MID" will require substantial changes in the verification of instruments.

*Calibration and testing:* There are currently 28 calibration accreditations within the subject field of Mass, covering all parameters mentioned above, and largely satisfying Danish needs. This includes the three NMI's. For the well-established measurements, there are no reports of significant problems in achieving the necessary traceability to internationally accepted primary standards, although the majority of primary calibrations are performed abroad. This of course includes the calibration of the national standards of the national reference laboratories. There are 9 testing accreditations within physical and mechanical testing; also here there are no reports of unsatisfied traceability needs. It is noteworthy that the number of calibration and testing accreditations in 1997 were 18 and 25 respectively, which signifies both an increase in the needs as well as a tendency of merging accreditations into bigger and more sustainable ones.

*Research and Other applications:* Dynamic measurements and calibrations is a new field that will be increasingly needed. After the action plan, mathematical methods and software have been recognised as a generic metrology tool.

### 5.1.3 Resources

The personnel at the three NMI's under the subject of mass amounts to about 12 person-years, and the equipment largely satisfies the current needs. Mass measurements can be performed traceable to the Danish prototype K48 in the range from 1 mg to 20 kg, which allows calibration laboratories go to 150 tons with adequate uncertainty.

Force and pressure calibrations are performed with traceability to the Danish national standards with somewhat restricted ranges and uncertainties and the demand for accuracy has increased. In consequence, a number of Danish users send their standards for calibration abroad.

Volume and density of fluids can be calibrated with sufficient accuracy in Denmark either by direct measurement or indirectly by weighing and dimensional measurements. For solids, which is particular relevant for weights of class  $E_1$  and  $E_2$ , a density facility has been set up for a limited range of weights.

#### 5.1.4 Recommendations (gap analysis) and follow up.

Below is an updated summary of the recommendations 1997 plan of action are as follows:

*Focus on dynamical measurements, in particular for mass, force and torque.* This is unlikely to be pursued in Denmark at this stage of research, but links should be made to for instance SP, where active research is ongoing.

*The establishment of a 500 kN deadweight tester for force and pressure.* FORCE Technology has established a deadweight tester in the range between 0.5 and 100 kN. It should be supported by a semi deadweight facility up to 2 MN in order to cover the growing demands for better accuracy in this area. Later, needs for *Low pressure* became clear, so calibrations at the level of  $10^{-5}$  Pa should be established.

*MID Metrology Clubs.* FORCE has been one of the founders in setting up CLM, which is the forum for the discussions on the implementation of MID in Denmark. Also, specific needs for dynamic calibrations are foreseen. This need became clear after the plan of action was made; but it is similar in nature to the proposal for setting up metrology clubs further to the clubs of FVM, DANIAmet, and EUROLAB. This made DFM start a series of user-groups. The one on mass measurements was not sustainable.

*The establishment of a reference facility for volume, and density determination for weights.* Here, a national reference laboratory has been set up by FORCE Technology. Its facility should be improved with respect to the accuracy of gas density. A partial facility for density of masses has been set up in collaboration with DFM. Since 1997, *Viscosity* has appeared to deserve similar recommendations, and the present reference laboratory for volume should extend its scope to cover this parameter. The EUROMET TC-M addresses viscosity.

*Focus on optimisation of calibration intervals for all subject fields, including knowledge transfer.* This was pursued in a special project and has been reported, both in writing and at conferences.<sup>7</sup> This has later evolved into a separate discipline at DFM, namely *Mathematics in metrology*

*Extension of on-site calibrations.* Several laboratories now offer on-site calibrations.

*Primary Mass Laboratory:* After the action plan a need for upgrading of the primary mass comparator at DFM has occurred. This is a must for the maintenance of the high level of weighing competence in Denmark.

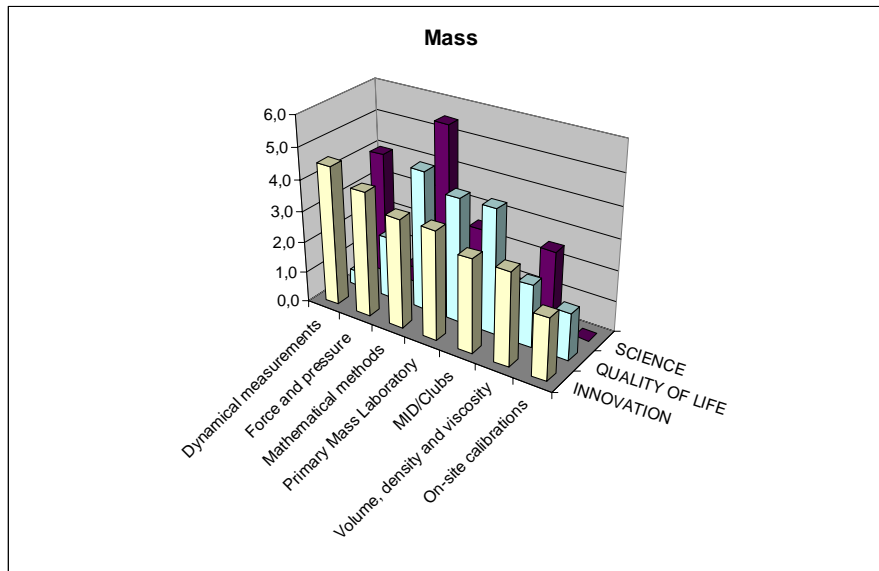
Hence, a number of the prioritised recommendations as well as the newly emerged needs have been dealt with within current budgets; but satisfactory contacts to the Swedish research in dynamical measurements, low pressure facilities, force calibration facilities, viscosity, as well as a substantial effort within mathematical methods have not been funded.

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<sup>7</sup> DFM report DFM-96-R19

No changes were proposed in the NMI structure, and the existing NMI's have taken up all the recommended initiatives that have been proposed.

### 5.1.5 iMERA classification



**Figure 1. Classification of the seven recommendations mentioned in 5.1.4 , using the grading scheme from 7.2 and order according to innovative grading. The highest scores are given to the two most novel recommendations of dynamical measurements and mathematical methods; Force and pressure, which is an extending of existing capabilities, is the second most innovative recommendation.**

### 5.1.6 Costs and financing

The economic key figures for the subject fields are as follows:

MASS	2005 STRATEGY	
Costs	3,7	6,6
VTU contract	2,8	5,5
Investment		11,4
Clients	7,9	8,9

## 5.2 Electricity

The latest action plan within this subject field was published in 2002. The following is a condensate of this action plan updated with current knowledge of this subject field. The turnover of the Danish electronics industry was 67 billion DKK in 2005 (61 bDKK in 2001) of which 6.1 bDKK is from the manufacturing of electronic measurement equipment. There are currently (in 2005) 17 accreditations within calibration, hereof 2 belonging to the Danish Primary Laboratory for Electricity, DPLE. Two laboratories are accredited for testing yielding all together 19 accreditations. The turnovers of accredited electrical calibra-

tion and testing were of the order of 85 MDKK and 74 MDKK, respectively, in 2001. The DPLE covers only a small corner of the required traceability at the primary and reference level. The remainder is provided by national laboratories abroad.

### 5.2.1 The subject field and its sub fields

DANIAmet sub-fields	EUROMET sub-fields	CIPM working groups
DC	DC and Quantum Metrology	WGKG (kilogram)
AC	AC-LF	WGLF (low freq. quantities) WGACQHR (quantum hall AC resistance)
HF	RF and microwave	WGRF (radiofreq. quantities)
		WGRMO (Regional Metrology Organisation coordination) WGSP (strategic planning)

The subdivision of the subject field for DANIAMet and the two major international organisations are given in the table below. The Danish division is readily mapped onto the international ones whereas the two non-technical working groups under the Consultative Committee for Electricity and Magnetism (CCEM) of CIPM do not map well to EUROMET and DANIAMet.

### 5.2.2 Needs

*Industrial applications:* Electrical measurements (AC and DC voltage, current, resistance and power, radiation and EMC) are required in a large variety of industrial areas in Denmark: energy distribution, manufacturers of consumer devices, testing equipment, telecommunication equipment, antennas, and of electrical production equipment. In particular the significant activities in development (and production) of mobile phones and medical equipment are demanding electrical metrology services and insight to and representation in standardisation working groups. There is also a yet uncovered demand for electrical and magnetic characterisation of materials (in particular metals) in traditional production areas, e.g. of iron and steel used in ship manufacturing. Many companies have outsourced their metrology functions, and therefore have a need for external consultancy and training, since the in-house expertise vanishes over time.

*Legal and other regulatory applications:* There are numerable regulated applications of electrical metrology; many based on EU directives including the directives for telecom equipment and consumption measurement and the low-voltage- the EMC- and the MID (2004/22/EF) directives. The directives deal with both functions, safety and environmental issues. In addition there is a long list of national specifications, regulations and written standards both in Den-

mark and abroad. The accredited laboratories cover the legal and industrial requirements to traceability.

*Calibration and testing:* Testing is performed as part of quality control and type approval, often under regulatory circumstances (see above). Testing generally serves to prove that devices operate safely and according to specifications under extreme conditions. Calibration is performed under well-characterised environmental and operating conditions. The testing laboratories acquire traceability from the accredited laboratories, which again get traceability from the Danish primary laboratory and in most cases from foreign national laboratories. The industrial needs for measurements are reflected (directly or indirectly) in needs for calibration and testing. Current uncovered needs include (see details under Recommendations and gab Analysis): DC: extension of DC resistance, calibration of magnetic field probes; AC: AC resistance standards, AC/DC transfer up to 1 GHz, better measurement capability and extension of measurement ranges for voltage current and power; HF: General development of written standards and of standards for attenuation, noise, impedance etc., and an accredited facility for calibration of reference antennas and field probes.

*Research and Other applications:* In principle the needs are the same as for industry; however, traditionally calibration has not played a big role in university research. But as the path from research laboratory to final product gets shorter and shorter with innovative high technology products the need for quality control of measurements at the scientific level is increasing. Recently Danish measurement technology has been drawing international attention with the magnetometers developed at DTU for space applications and the micro/nano four point probe surface resistivity analyser developed by CAPRES A/S and DTU. At the national level research in electrical metrology will support innovation by increasing the general understanding of traceability. Internationally high profiled research projects will place Denmark as an equal amongst partners in the international metrology community.

### 5.2.3 Resources

There is of the order of 100 engineers, technicians and other personnel involved in accredited calibration and testing within electricity. The Danish Primary Laboratory for Electricity, DPLE, (consisting of Danish Fundamental Metrology Ltd and Arepa Test and Calibration Ltd now part of the Trescal group) has about 5 person years allocated for maintenance of standards, international work, research, and calibration for clients. DPLE holds the national primary standards for DC voltage and AC/DC transfer and the national reference standards for DC resistance, microwave -power, -attenuation and -reflection. Several of the accredited laboratories also hold standards. Presently only DFM receives public funding (through performance contracts) for maintenance of standards, international comparisons, and work in the CCEM and EUROMET. DFM spends about 500 person-hours on maintenance, comparisons and work in committees. Since 2003 the research efforts have been limited (less than 500 person-hours/year).

#### 5.2.4 Recommendations (gap analysis) and follow up

##### General:

*Maintenance of standards and participation in comparisons and international committees.* In all sub-fields maintenance in the form of internal calibrations, participation (and occasional coordination) of international comparisons and participation in the RUOMET and CIPM committees is continuously required.

*Establishment of a Danish Primary Laboratory For Electrical metrology (DPLE) in order to join competences at the two primary and reference laboratories.* DPLE was formed by DFM and Arepa Test and Calibration A/S in 2005. The joint efforts so far have been limited and requires strengthening in order to exploit the full potential of the collaboration.

*Private companies should be given the same possibilities for public funding as the traditional GTS institutes for the maintenance of national standards including participation in international comparisons.* The law for Technology and Innovation (2002) allows private companies to receive funding but the implementation of the law is still under development. It is unknown to what extent metrology services will be subject to such limited tenders.

*Assessment of the extent at which Danish accredited laboratories obtain traceability from foreign metrology laboratories.* The aim was to supplement the traceability map between national metrology institutes (NMI) prepared in 2003 with the traceability provided to Danish accredited laboratories directly from NMIs abroad. This opportunity was missed.

*Dissemination of knowledge within the fields of calibration and testing directed towards companies (who have outsourced their metrology function), e.g. training courses, publications.* Arepa Test and Calibration A/S, Danish Technological Institute and DFM provide courses and consultancy in calibration, testing and uncertainty analysis. At present no further demands have been identified.

*Strengthening of participation in standardisation work within testing including telecommunication protocols.* The trend is that industry is actively participating in order to influence coming standards and to get advance knowledge so their products will live up to standards. In the areas under development (where industry is not yet producing) public attention is relevant. Presently no specific topics are identified.

##### DC:

*Facility for magnetic field and susceptibility sensor calibration* The demand for magnetic field testing has increased since the publication of the most recent action plan for electricity in 2002. A facility for magnetic field and susceptibility sensor calibration is suggested. Presently Arepa is working to establish a calibration facility for magnetic field probes. This work is closely associated with research at Århus University on a new principle for a primary standard for magnetic field strength.

*DC resistance extension to 1 mΩ and 1 GΩ and improvement of measurement capability to international level using improved scaling*

*techniques and later by use of a cryogenic current comparator (CCC). A better uncertainty has been obtained and the range has been extended to  $1\Omega$  to  $1M\Omega$ . The Quantized Hall Resistance has been abandoned and the CCC was given in up 2005 due to technical problems since the maintenance and development can not be justified by the current demand for enhanced accuracy for resistance calibrations in Denmark. The extension of the range of resistance at the reference level to  $1m\Omega$  to  $1G\Omega$  remains relevant, with traceability to primary standards in e.g. Sweden or United Kingdom.*

*New applications and extension of measurement ranges for the existing Josephson Voltage Standard and for quantized Hall effect, e.g. for calibration of digital multimeters and calibrators. Calibration of calibrators and multimeters using the Josephson Standard has been demonstrated in a joint Arepa/DFM project, but there is yet no demand for the improved accuracy. Internationally another route is being followed which requires much larger investments. When the demand arises DPLE will be able to establish the relevant ties to a facility within Europe.*

#### AC:

*Development of standards for AC resistance including shunts for AC current and of equipment for scaling of AC resistance. Use of AC quantum Hall standard for traceability of capacitance and inductance with the final aim of calibrating LCR meters. The quantum Hall standard has been abandoned and links to other European facilities will be established as need arise. So far the development of AC resistance standards has been pursued in DPLE in connection with specific applications, e.g. electrochemistry, but should be extended to other fields of use, e.g. temperature, low-noise sensors and electro-acoustics.*

*The primary level for AC/DC transfer should be extended to higher frequencies (1GHz) as electronics and time domain testing instruments become faster. Only little has been done at DFM and Arepa since the termination of the centre contract in 2002. This area is important not only for the establishment of traceability for state-of-the-art instrumentation, but is an important area of research and collaboration in the European metrology community.*

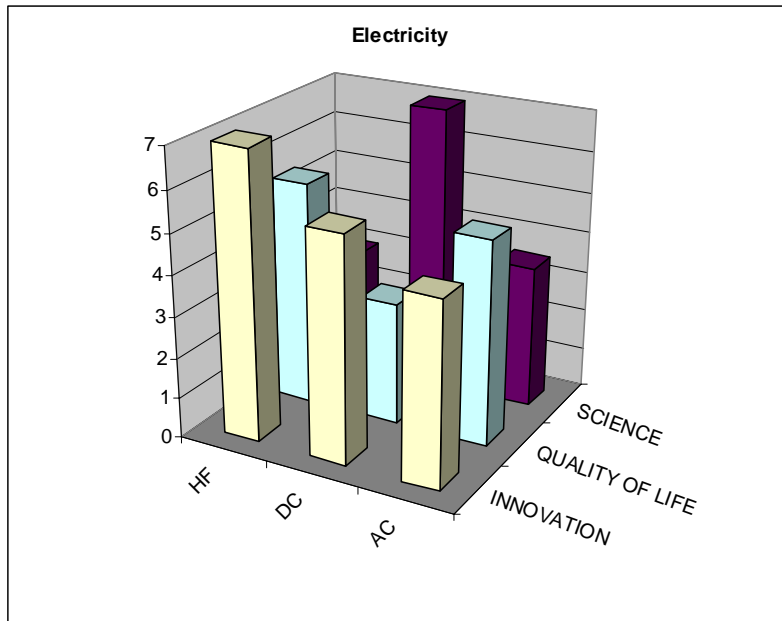
*Extension and improvement of measurement of AC voltage ( $< 100mV$ ,  $1-50MHz$ ), AC current ( $< 1mA$ ,  $> 20A$ ), AC power to  $50kW$ , flicker, harmonic distortion, general impedance. Only little has been done since 2002 (at Arepa). Some development efforts is required, but will mainly be driven by customer demands.*

#### HF:

*Establishment of an accredited laboratory for calibration of field probes and EMC testing. In the 2002 action plan it was suggested to establish a primary laboratory starting from Centre for Person Communication at the University of Ålborg. There has been no further assessment or work in this direction. The laboratory at the University of Ålborg has served as de facto reference laboratory and the set-up has been copied by some companies and universities. Currently Arepa is developing a calibration service for electrical field probes in the frequency range  $20MHz - 3GHz$ , which partly addresses the demand.*

*Development of reference standards within attenuation, noise, impedance and equipment for measurement of complex reflection, noise temperature and phase noise. Only little has been done since 2002 (at Arepa). Some development efforts is required, but will mainly be driven by customer demands.*

### 5.2.5 iMERA classification



**Figure 2. Classification of the recommendations of the three subfields mentioned in 5.2.4 , using the grading scheme from 7.2 and order according to innovative grading. HF is the most innovative because of its direct relation to telecommunication, whereas DC has the greatest scientific potential, because of its connection to quantum phenomena.**

### 5.2.6 Costs and financing

The economic key figures for the subject fields are as follows:

ELECTRICITY	2005 STRATEGY	
Costs	1,0	2,8
Contract	0,5	1,2
Investment		0,0
Clients	3,5	3,7

## 5.3 Length

The subject field was treated in action plans in 1989 and 1998. In Denmark the field of length is subdivided into the sub-fields length

measurement and dimensional metrology. Danish Fundamental Metrology (DFM) is nominated as primary laboratory for length measurements. NGM, established as collaboration between Department of Manufacturing Engineering and Management at the Technical University of Denmark and Danish Technological Institute, is nominated as primary laboratory for dimensional metrology. Current plans call for a merger of DFM and NGM into a Danish Primary Laboratory for Length (DPLL).

### 5.3.1 The subject field and its sub-fields

DANIAmet sub-fields	EUROMET sub-fields	CIPM working groups
Length measurement		WGMeP Joint CCL/CCTF WG
Dimensional metrology		WGDM Nano-metrology

The subdivision of the subject field for DANIAMet and the three major international organisations are given in the table below. Internationally, the field of length is not subdivided, and the distinction between length measurement and dimensional metrology reflects the Danish situation. Three working groups are established under the CIPM consultative committee for length CCL: WGMeP on the Mise en Pratique for the metre definition, WGDM on Dimensional Metrology, and the Joint Working Group CCL/CCTF on Secondary Representations of the Second and the Metre. In addition several discussion groups are established, Denmark being a member of the discussion group on nano-metrology.

The sub-field of length measurement covers those aspects of length that are related to realizing the metre definition, and to providing traceability at the highest level of accuracy through optical interferometry. This sub-field will also cover work on frequency standards which, following the 1983 redefinition of the metre, are identical to wavelength standards.

The sub-field of dimensional metrology covers those aspects of length that relate to the characterisation of dimensions, form and surface properties of material objects. For practical reasons nano-metrology will in the following be singled out from the sub-field of dimensional metrology, and treated separately. Also the upcoming establishment of DPLL, which covers the entire subject field, will be treated separately.

### 5.3.2 Needs

*Industrial applications:* The most recent plan of action for length issued in 1998 called for development of standards and methods for establishment of traceability through non-contact techniques. This is currently being pursued through interferometry with particular emphasis on the nano range. Another suggested initiative was the development of interferometric methods for characterization of form errors in gauge blocks. With current upgrading of equipment such characteri-

zations are now possible, but the demand from industry has been small. A final recommendation concerning research in wavelength standards based on atomic and molecular spectra has been implemented under the field of radiometry.

Needs in dimensional metrology as foreseen in the 1998 plan of action to a large extent focused on coordinate measurement technology, and the intermediate period has seen a steady improvement in competence and instrumentation in this area. A major trend has been in the direction of smaller dimensions with characterisation of surface properties on the nano-scale, and the relation between surface properties and functionality. Also the characterisation of object dimensions on the scale of micrometer and nanometer, as well as the characterization of free form surfaces of small objects attract increasing interest.

*Legal and other regulatory applications:* There are no applications of length metrology within the field of legal metrology.

*Calibration and testing:* Four Danish calibration laboratories have a need for length calibration at the highest level of accuracy. These laboratories subsequently provide traceability to the vast majority of traceable length measurements performed by Danish industry. Calibrations in dimensional metrology relating to coordinate measuring machines are performed for about 50 Danish clients, and a similar number ask for related services which are not in the form of accredited calibrations. Demand for calibration in nano-metrology is still scarce but increasing.

*Research and Other applications:*

Research activities mainly relate to optical techniques, and to the field of nano-metrology where traceable length measurements and surface characterization are at the cutting edge of technology.

With recent developments in the measurement of optical frequencies, the link to the metre definition will in the near future be established through frequency measurements of the current length primary standards with traceability to atomic clocks. Although this will formally change the status of length primary standards to transfer standards, it will have no implications for the practical establishment of traceability in length.

Overall, the present needs of industry are satisfied. However, emerging needs, to a large extent relating to the micrometer and nanometer range, will require upgrading of current equipment both in atomic force microscopy and in optical techniques.

### **5.3.3 Resources**

The resources given below refer to the combined resources of the three institutes involved in the field of length at the primary level, i.e. Danish Fundamental Metrology, Department of Manufacturing Engineering and Management at the Technical University of Denmark, and Danish Technological Institute.

The combined resources allocated to the field of length amount to approximately 13 person years, running costs of about 0.34 MDKK/year and investments of about 0.5 MDKK/year. The instrumentation and

laboratory facilities of the institutes have been continually upgraded, and satisfy present needs. A renewal of DFM's standard for nano measurements is foreseen in the near future, and is taken into account in DFM's planned investments.

#### 5.3.4 Recommendations and follow-up

In the following is given a summary of recommendations in the 1998 plan, followed by updated recommendations

##### **Length measurements:**

*Development of methods for interferometric characterization of form errors of gauge blocks.* Implemented but of decreasing relevance.

*Research in wavelength standards based on atomic or molecular references.* Implemented (in part under the field of radiometry), and continuing.

##### **Dimensional metrology:**

*Developing industrial competence in GPS (Geometrical Product Specifications) and uncertainty analysis.* Has been largely implemented by DFM, NGM, and DS (Dansk Standard), and should be continued.

*Accredited testing through coordinate measurement techniques.* Fully implemented.

*Development of uncertainty budget for coordinate measurement.* Partly implemented and continued.

*Development of standards and methods for 3-D surface characterization.* Fully implemented

*Development of standards and methods for roundness, cylindricity, etc.* No specific industrial needs. Low priority.

*Rationalization of surface roughness characterization parameters for 2-D and 3-D characterization.* In progress and increasingly relevant.

*Development of standards and methods for non-contacting measurements in production environment.* In progress, and increasingly relevant.

There is a strong trend towards smaller dimensions in the micrometer and nanometre range, characterization of free-form surfaces, characterisation of surface properties on the nano-scale, and towards research in the relation between surface properties and functionality. Also, the issue of bringing metrology closer to the workshop floor remains important. Techniques still need to be developed, and traceability problems in the presence of very heavy environmental influences need to be solved. In combination, this leads to the following updated recommendations

##### **Length measurements:**

*Continued research in optical frequency/wavelength standards and interferometry with particular emphasis on traceability in nanometrology*

##### **Dimensional metrology:**

*Development of optical methods for characterization of objects in the cm to  $\mu\text{m}$  range*

*Increased focus on techniques for form and surface characterization.* This includes new and improved stylus instruments for surface characterization, as well as interference microscopy and other optical techniques for form measurements.

*Continued focus on development of standards and methods for non-contacting measurements in production environment*

#### **Nano-metrology:**

*Atomic force microscopy with nano-positioning capability.* This will extend the operating range of current AFMs and hence provide a very significant extension of the range of objects that can be characterized by this technique. At the same time such equipment has a potential for measurements, which do not traditionally belong to the length field. This includes the mechanical properties of thin coatings important in biotechnology (e.g. implants), surface electrical conductivity and surface-chemical effects relevant for catalysis, and spectroscopy on nano-structures, which has widespread application. All together this offers a significant interdisciplinary potential.

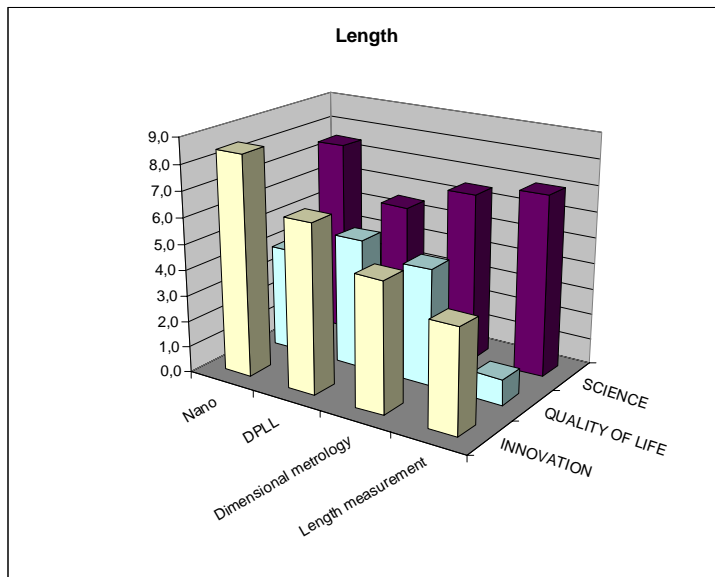
*Research in traceability for scanning electron microscopy and other imaging techniques*

*Continued strong focus on optical techniques for non-contact measurements in production environment.'*

#### **Danish Primary Laboratory for Length (DPLL):**

*The establishment of a primary laboratory covering the entire subject field. All sub-fields will benefit from a rationalization of the structure in Denmark. There will significant synergy in establishing such a coordinated approach.*

#### **5.3.5 iMERA classification**



**Figure 3. Classification of the four recommendations mentioned in 5.3.4 , using the grading from 7.2 and order according to innovative grading. Length is characterised by a high scientific content, with nano as the most innovative.**

### 5.3.6 Costs and financing

The economic key figures for the subject fields are as follows:

LENGTH	2005 STRATEGY	
Costs	6,6	8,7
VTU contract	1,9	2,8
Investment		1,8
Clients	6,0	6,8

### 5.4 Time and frequency

This subject field was treated in actions plans in 1992 and 2000. The action plans have had a low influence on the field. Only the recommendations on increasing activities related to optical frequency calibrations (i.e. wavelength calibration) have been realized. However, these activities are also part of length and optical (e.g. photometry and radiometry) metrology.

#### 5.4.1 The subject field and its sub-fields.

DANIAmet sub-fields	EUROMET sub-fields	CIPM working groups
		TAI (International Atomic Time) GNSS Time Transfer Standards Two-Way Satellite Time and Frequency Transfer Uncertainties in Primary Frequency Standards Secondary Representations of the Second Joint Working Group, Secondary Representations of the Second and the Mise en Pratique of the Metre Consequences of the CIPM MRA

There are no activities in the field at the NMI-level in Denmark, except for the optical frequency standards. There are no primary or reference laboratories for Time and Frequency. The subject field and its sub fields

The subject field is not subdivided in DANIAMet and EUROMET. The subdivision within CIPM is given in the table above.

#### 5.4.2 Needs

The needs within the optical frequency range are included in the radiometry and photometry section. The needs as expressed by the sectors defined cover the following parameters:

*Industrial applications (<1 THz):* Counters and frequency generators are used in all kinds of electronic measurement equipment. The required accuracy is relatively low and calibrations can be made at Danish calibration laboratories for electrical equipment.

Within telecommunication and in data transmission networks, higher accuracy is needed for synchronisation of signals. This is available via commercial primary time standards (Cs-clocks) and GPS-based clocks. These activities take place on commercial terms and do not require NMI activities.

Time is needed in computer networks for providing time stamps for files, email, bank transactions etc. The availability of such a service is usually considered to be the responsibility of the authorities. However, in Denmark this service is currently provided on a private basis. Other countries are taking initiatives to establish official time stamping facilities for digital documents with traceability to time standards at NMI level. This will become increasingly important with e-commerce, e-auctions, digital signatures etc.

*Legal and other regulatory applications:* The official time in Denmark is defined from the mean solar time in an old law from 1893. This law was outdated long time ago, and in practice UTC-time is used as in the rest of the world. Legal requirements exist for radio and tele terminal equipment.

*Calibration and testing:* There are currently 6 calibration accreditations with time and/or frequency within their scope (below 1 THz). Traceability is obtained from the DCF77 signal. Some laboratories would like to use GPS-based standards, but concerns with respect to integrity and traceability have so far prevented this. In other countries this is obtained by comparing GPS signals to the national time standard. Another problem is the short-term stability of reference standards used in calibration. The use of the DCF77 signal requires long averaging time (about 24 hours), but in most calibrations the laboratories use much shorter averaging time. The laboratories rely on specifications since traceable calibration/characterization is not available within Denmark due to the lack of primary time standards.

*Research and other applications:* Research within time and frequency is limited to the optical frequency standards as described in the radiometry and photometry section.

### **5.4.3 Resources**

A few old Cs primary standards exist at calibration laboratories, but they are no longer in service. TDC runs a few Cs primary standards together with GPS receivers for their synchronisation net.

The accredited calibration laboratories meet the needs for calibration of time and frequency in the electrical domain (below 1 THz). Less than 20 persons work with accredited time/frequency calibrations, and these calibrations constitute only a small fraction of their overall work.

Resources related to optical frequency standards are included in the length and radiometry & photometry sections.

### **5.4.4 Recommendations (gap analysis) and follow up.**

Updated summaries of the recommendations of the 2000 plan of action are as follows:

*Implementation of UTC – new law on time.* The law has not been changed.

*Optical frequency standards.* It was suggested to establish an accredited laboratory, which can meet the industrial needs. The extension suggested in 2000 will be available at DFM in 2006. Further requirements are described in the radiometry and photometry section.

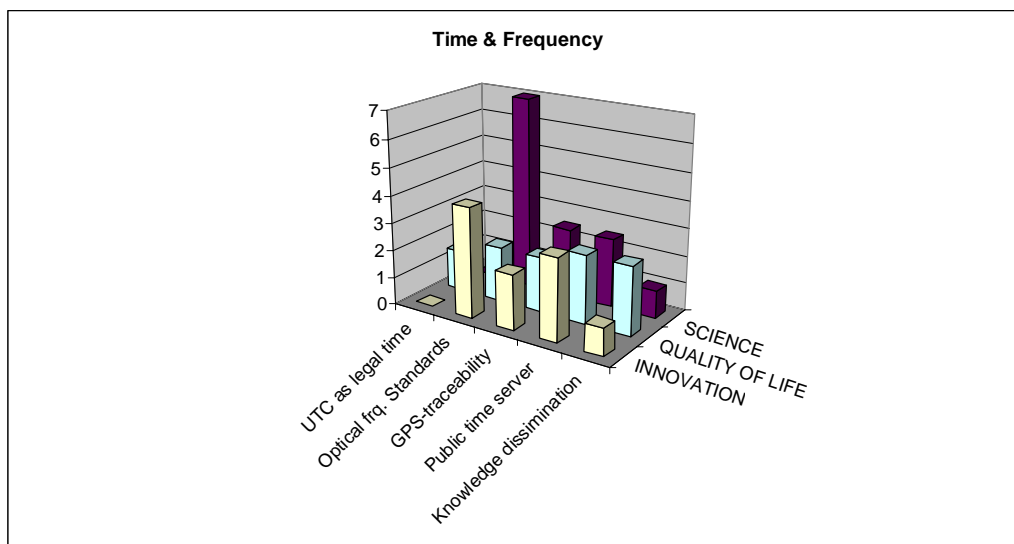
*Accredited calibration based on GPS time references.* The calibration laboratories would (still) like to use GPS time as a reference in calibrations. Possible solutions to integrity and traceability of the GPS time have not been found due to lack of resources.

*Public timeserver.* It was recommended to follow the development within e-commerce and evaluate the needs for a public timeserver. This was suggested as a task for e.g. *IT-sikkerhedsrådet* or for an established "centre" for collection and dissemination of knowledge within the time and frequency field. Other European countries have initiated investigations or work on a traceable public timeserver, but so far no initiatives have taken place in Denmark.

*Strengthened expertise and dissemination of knowledge within time and frequency.* The plan of action revealed a significant lack of knowledge within time and frequency metrology. It was suggested to compensate for this by establishing a "centre" for collection and dissemination of time & frequency knowledge. This has not been realized.

The situation in the time & frequency field has not changed since the 2000 plan of actions, except for the optical frequency standards covered by optical metrology (radiometry & photometry).

#### 5.4.5 iMERA classification



**Figure 4, Classification of the five recommendations mentioned in 5.4.4 , using the grading scheme from 7.2. It appears that optical frequency standards are the most interesting; and this is indeed taken up under photometry in 5.7.**

### 5.4.6 Costs and financing

The economic key figures for the subject fields are as follows:<sup>8</sup>

TIME & FREQUENCY	2005 STRATEGY	
Costs	0,0	1,0
VTU contract	0,0	0,6
Investment		0,0
Clients	0,0	0,5

## 5.5 Thermometry

This subject field was treated in action plans in 1992 (thermometry), 1996 (humidity) and 2000 (thermometry and humidity). Technological Institute is appointed as national reference laboratory in Temperature Measurement by contact, RISØ is appointed as national reference laboratory for Non-contact temperature measurement and DELTA as national reference laboratory for humidity.

### 5.5.1 The subject field and its sub fields

DANIAmet sub-fields	EUROMET sub-fields	CIPM working groups
Temperature measurement by contact	Thermometry	Defining fixed points and interpolating instruments Secondary fixed points and techniques of approximation to the ITS-90 Thermodynamic temperature determinations and extension of the ITS-90 to lower temperatures
Non-contact measurement		Radiation thermometry
Humidity	Humidity	Humidity measurements Thermophysical properties

The subdivision of the subject field for DANIAmet and the three major international organisations are given in the table below. As is seen, the Danish division is easy to map onto the international ones, except for the specialised working groups of the CIPM that reflects special work at the BIPM.

The sub-field Humidity was part of the subject field Mass; but it has later been transferred to Thermometry.

The subject field is composed of the following most important parameters:

*Temperature measurement by contact:* Fixed points, resistance thermometers, thermocouples etc

*Non contact temperature measurement:* Blackbodies, Pyrometres etc

<sup>8</sup> The "VTU contract" in the strategy budget has not been included in Table 5-5 of the report "Dansk metrologi 2006+3 – en handlingsplan"

*Humidity:* Gravimetric hygrometers, Psykrometers, resistive and capacitive sensors.

### 5.5.2 Needs

The needs as expressed by the sectors defined cover the following parameters:

*Industrial applications:* Temperature measurements at a high level are needed in many industrial sectors for instance pharmaceutical, medico, food, chemical, ceramic, process industry, and energy. As demands for more efficient production is growing and the temperature measurements increasingly becomes part of the quality control of products among others within food and pharmaceutical industry, the needs for more accurate calibrations in a wide range are following.

The same applies for humidity and the demand here are spread to new areas. (Electronics, paint etc). Better humidity measurements are also needs in connection with actions against global warming

*Legal and other regulatory applications:* Temperature measurements are part of the legal requirements in connection with energy measurement (heat meters used in district heating systems), transport of food and clinical thermometers. There are also legal requirements mentioned in various directives from governmental bodies.

*Calibration and testing:* There are currently 10 calibration accreditations, which among their primary activities perform calibrations within the subject field of temperature and humidity.. This includes the three national reference laboratories. For the well-established measurements, there are no reports of significant problems in achieving the necessary traceability to internationally accepted primary standards. Temperature is an important factor in connection with practically all testing and calibration activities. There is a need for better accuracy for temperature measurements below -40 °C and above 660 °C.

*Research and Other applications:* Research is in Denmark made in connection with sensor development and radiation, and there are several Danish companies manufacturing measurement equipment in this field and they need access to knowledge. Research within thermometry and humidity is driven by better measurements needed for finding solutions to societal challenges related to environment, energy efficiency and transport. One example of an evolving need here is the measurement of the pure saturated water (ice) vapour pressure below – 40°C. Further the approach used for such measurements can be modified to make measurements of enhancement factors possible. Enhancement factors for other gasses than atmospheric air are of increasing interest in the future – especially in the area of hydrogen fuel cells where knowledge about partial water pressure is important. The future need for thermometry in research seen in a European Context is described in the EUROMET Thermometry and Humidity Roadmaps that is an outcome of the iMERA project.

### 5.5.3 Resources

The personnel at the three NMI's under the subject of temperature amounts to about 7 person years., The equipment however is for a large part quite old and need replacement and updating (i.e. the central equipment which forms the basis of the national reference laboratory for contact thermometry is 30 years old or more.

The national laboratories currently covers the following parameters and ranges:

#### The national laboratory for contact thermometry

- Calibration of contact thermometers at the highest level (primary) by means of fixed points in the range -39 °C to 660 °C
- Calibration of contact thermometers by comparison (secondary level) to reference thermometers in thermostats (liquid bathes and furnaces) in the range: -40 °C to 1200 °C
- Calibration of contact thermometers in air in the range: +10 °C to +90 °C

#### The national laboratory for non-contact thermometry

- Calibration of blackbody radiators by comparison in the range: -80 °C to 1600 °C
- Calibration of IR thermometers such as pyrometers by comparison in the range: – 80 to 1600C.

#### The national laboratory for humidity

- Calibration of dew point hygrometer by comparison to a reference dew point hygrometer in the range -75 °C to +82 °C.
- Calibration of relative humidity hygrometers in the range: 15 %rh to 96%rh.

- The personnel at the three NMI's under the subject of mass amounts to about 7 persons, and the equipment largely satisfies the current needs.

Temperature measurements by contacts can be performed at temperatures between -150 to 1600 C and non-contact from – 80 to 1600C.

Humidity measurements are measured as water content from 1 mg/kg to 20 kg dry air or as dew point –80 °C to +82 °C or as relative humidity from 15% to 96%.

### 5.5.4 Recommendations (gap analysis) and follow-up

Below is an updated summary of the recommendations from the year 2000 plan and new demands (2006 input).

*Appointment of a national laboratory for non-contact temperature measurements.* Risø has been appointed.

*Establishment of blackbody fixed point with ITS-90.* This is still under consideration (funding is lacking). Need in order to fulfil industry demand for better accuracy

*Establishment of non contact calibration facilities in the range from -50 °C to 300 °C.* These facilities are now available.

*Upgrading of the national laboratory for contact measurement to primary level.* This has not been possible due to lack of funds (i.e. is additional fixed points and state-of-the-art equipment needed).

*Extension of the contact measurement area upwards from 660 °C to 961 °C at primary level.* It has not been able to find funding for this and the demands from users are now extending to new areas.

*Extension of the contact measurement area downwards from -39 °C to -189 °C at primary level.* This is still under consideration (funding is lacking). ). Growing demands for higher accuracy.

*Establishment of contact calibration facilities in the range -190 °C to -40 °C.* This is still under consideration (funding is lacking Needed in order to fulfil higher demands in developing new industries

*Establishment of consultancy and courses in the field (non contact temperature and humidity).* A course on non-contact temperature have been established in cooperation between RISØ and Danish Technological Institute. A humidity course has not been established but a workshop for humidity is planned to take place in the later part of 2006.

Hence a number of the prioritised recommendation have been dealt with within the current budgets, but upgrading to primary level , establishment of additional fixed points for both contact and non contact, extension of the national laboratories ranges to need the new demands of industry, elaboration of new methods and providing more training, education and workshops are necessary. In general industry demand for higher accuracy is growing and internationally traceability at higher and higher level is needed.

#### **5.5.5 IMERA classification**

The IMERA classification has not been performed for the subject field of temperature.

#### **5.5.6 Costs and financing**

The economic key figures for the subject fields are as follows:

TEMPERATURE	2005 STRATEGY	
Costs	1,1	3,0
VTU contract	0,3	1,8
Investment		3,4
Clients	3,6	4,6

## 5.6 Ionising radiation and radioactivity

This subject field was treated in action plans in 1992 and 2000. It has not resulted in the appointment of any reference laboratory. There are two operators in the field, namely the high dose reference laboratory HDRL (is accredited by DANAK) at Risø National Laboratory and the National Institute for Radiation Hygiene SIS (serves as a secondary standards Dose laboratory SSDL under the IAEA). Only SIS is considered a candidate for NMI status.

### 5.6.1 The subject field and its sub fields

DANIAMet sub-fields	EUROMET sub-fields	CIPM working groups
Absorbed dose – industrial applications	Photon dosimetry	Photon dosimetry
Absorbed dose – medical applications		
Radiation Protection		
	Neutron measurements	Neutron measurements
Radioactivity	Radioactivity	Radioactivity

The subdivision of the subject field for DANIAMet and the two major international organisations are given in the table below. As is seen, the Danish division is not immediate to map onto the international ones.

### 5.6.2 Needs

Industrial needs are becoming prominent in all applications of radioactivity and ionising radiation because of the introduction of quality assurance and because of requirements from EU-directives. However, from an industrial point of view the need for the establishment of a Danish NMI is not essential, and hence the traceability to NPL for the HDRL is satisfactory, as long as the quality is assured through an accreditation.<sup>9</sup>

In medicine there is a pressing need for both documented traceability as well as a NMI that can provide a link to the global community and provide a knowledge base for this important field in both diagnostics and radiotherapy.

### 5.6.3 Resources

The metrology activities at SIS are staffed by about one person per year.

### 5.6.4 Recommendations (gap analysis) and follow-up

The recommendations are summarised as follows:

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<sup>9</sup> Very recently, Risø has pointed out the need for an NMI activity within industrial applications of radioactivity and ionising radiation. This needs further investigations.

*Absorbed dose – industrial applications:* Requirements for quality assurance are increasing in connection with the internal market and EU-directives; and HDRL is prepared to meet these demands.

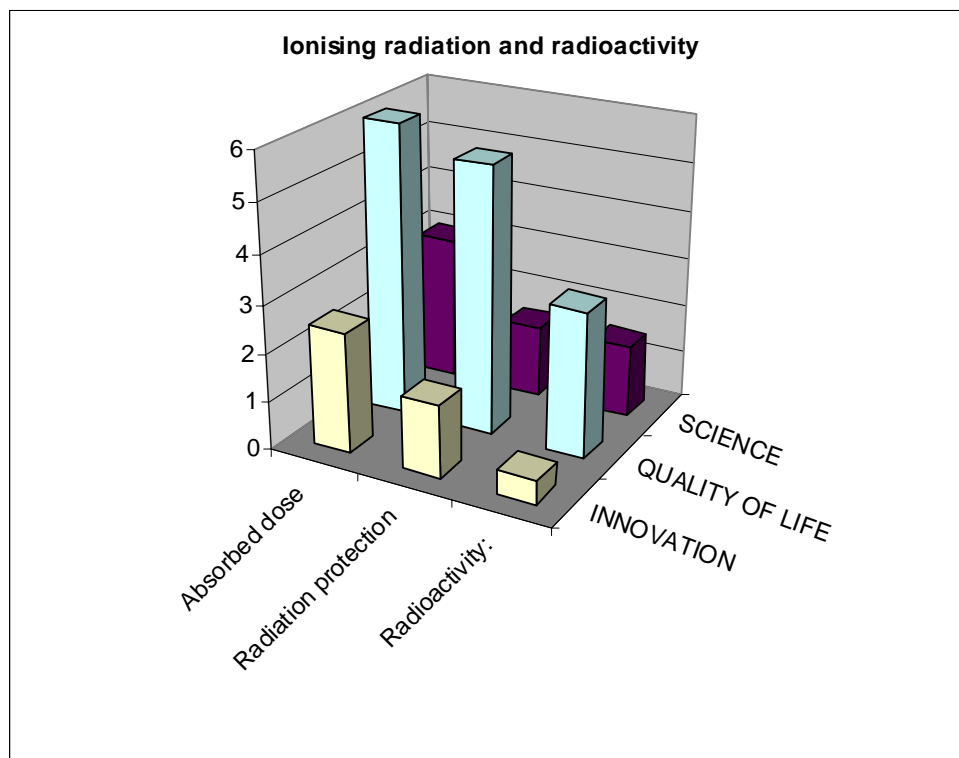
*–medical applications:* For many years SSDL has performed calibrations for hospitals, and has contributed to a high standard dosimetry in radiation therapy. It is recommended to bring SIS to a state, where it meets the criteria for national reference laboratories, in order to ensure international recognition.

*Radiation protection:* When recognised as an NMI, SIS should broaden its scope to testing and calibration of industrial instruments for the monitoring of radiation. Here Denmark has a significant industry.

*Radioactivity:* The need for absolute calibration of radioactive sources is limited and can be satisfied by SIS by its present capabilities.

The most important recommendation, to upgrade SIS to a NMI within the DANIAMet scheme, was followed up by an international evaluation of SIS. This unfortunately gave a negative result, so that no progress can be reported.

#### 5.6.5 iMERA classification



**Figure 5. Classification of the three recommendations mentioned in 5.6.4 , using the grading scheme from 7.2 and order according to innovative grading. The order of importance is the same for both science, quality of life, and innovation.**

### 5.6.6 Costs and financing

The economic key figures for the subject fields are as follows:<sup>10</sup>

IONISING RADIATION AND DOSIMETRY	2005 STRATEGY	
Costs	1,0	2,0
VTU contract	0,0	0,0
Investment		0,0
Clients	0,0	0,0

### 5.7 Photometry and radiometry

This subject field was treated in action plans in 1990, 1996 and 2004. It has resulted in the appointment of a primary laboratory for Optical Radiometry (DFM).

#### 5.7.1 The subject field and its sub fields

DANIAMet sub-fields	EUROMET sub-fields	CIPM working groups
Radiometry	Photometry and Radiometry	
Photometry		
Colorimetry		
Fibre Optics		

The subdivision of the subject field for DANIAMet and the two major international organisations are given in the table below. As is seen, the Danish division is easy to map onto the international ones.

#### 5.7.2 Needs

The needs as expressed by the sectors defined cover the following parameters:

*Industrial applications:* Radiometric measurements are used in many industrial areas (subjects): building construction (transmission and reflection), graphics (radians), telecom (power) and instrument manufacturing (radians). Radiometric measurements are used to characterise optical detectors, filters, components, sunglasses, laser goggles, welding glasses, displays and LED's. Laser power measurements is needed in connection with lasers used in the manufacturing industry, in medical applications and the increased use of UV sources in manufacturing technology. Turbidity measurements are increasingly used to verify the quality beer, wine and other drinks. Particle measurements to establish correct clean room facilities. Photometric measurements

<sup>10</sup> Note that only figures for the proposed NMI (SIS) have been included and that SIS offers calibration for free.

are mainly used in the lighting industry, work place control, street lighting, light transmission of windows, reflections from streets and safety clothing. Fibre optic measurements are mainly used by the telecom industry. However, optical fibres are increasingly used in many areas to transmit light.

*Legal and other regulatory applications:* The focus on laser safety has increased during recent years and it is therefore required to certify and categorise instruments in connection with sales. The international standard for classification of lasers (IEC 60825-1) has to be followed. Optical methods are used for determining the quality of water. Regulations exist on allowable number of particles in clean rooms in particular in the pharmaceutical industry. Optical measurements are used to determine this number. There are regulations for accepting automobile lights, signal lights, lanterns and reflecting materials. Photometric measurements are used in these measurements.

*Calibration and testing:* There are currently 3 calibration accreditations within the subject field of photometry and radiometry. An increase in the number of calibrations is expected as companies become certified according to ISO 9000. In addition it is expected safety regulations and type acceptance of radiation sources will require traceable measurements. For the health sector it is expected that a coming demand for increased quality of optical measurements will require calibrations.

*Research and Other applications:* There is considerable effort in developing new quantum detectors for use in the infrared and ultraviolet regions as well as for improving response time. This effort requires radiometric measurements. In the fibre optic field there is considerable activity in Denmark in the development of special fibres as well as new fibre optic instrumentation, which require fibre optic measurements. There is generally considerable effort in fibre based photonics research.

### **5.7.3 Resources**

DFM's primary laboratory for optical radiometry is staffed by 4 person years.

The personnel at the three Danish DANAK accredited laboratories under the subject of radiometry and photometry consist in total of seven; four engineers and three technicians. There is a large equipment park that satisfies most the current needs. Optical power measurements can be performed traceable to the Danish primary standard. Photometric measurements are performed using reference standards traceable to either NPL or PTB.

Optical wavelength calibrations are traceable to molecular transitions. Molecules are used as reference materials due to their fixed frequency transitions.

Colorimetric measurements are performed using reference standards traceable to NPL.

#### 5.7.4 Recommendations (gap analysis) and follow up

Updated summaries of the recommendations of the 2004 plan of action are as follows:

##### Radiometry:

*Establishment of a calibration facility for power measurements in the UV-A and UV-B wavelength regions.* It is expected that a UV-B calibration facility using discrete laser wavelengths will be finalised at DFM by the end of 2006. A similar facility for the UV-A region is needed for the calibration of medical and meteorological instruments.

*Establishment of a calibration facility for the measurement of energy and pulse width of pulsed lasers.* Pulsed lasers are increasingly used in manufacturing processes, medicine and research. There has been an increasing demand for measuring the two mentioned parameters since measuring an average power is not always sufficient.

*Establishment of a calibration facility for the measurement of optical power in the infrared spectral region from 2,5 to 20  $\mu\text{m}$ .* An increasing demand is foreseen for calibration in this region in particular in connection with lasers used for material

*Study of the needs for measurements of turbidity, particle counting and certification of lasers.* There is currently some need for turbidity measurements in the pharmaceutical industry; however, it is proposed to put the issue on hold until a larger interest is expressed. There has been a steady increase in demand for calibration of particle counters used in clean rooms by pharmaceutical companies and wafer manufactures. It is recommended that a facility be established. DFM is in the process of developing a laser safety course.

*Development of stable frequency standards for the optical communication wavelength regions.* DFM has established a reference based on a fibre laser for the 1550 nm region. References are required for the 1310 nm region and for the proposed 1625 network surveillance region.

##### Colorimetry:

*Facility for transmittance measurements.* There has been a growing need from Danish industry for traceable transmittance calibration. Such a facility can by relative small means be incorporated into an existing facility for spectral reflectance.

##### Fibre Optics:

*Establishment of a Nordic virtual institute for fibre measurements.* An institute has been established. It remains that DFM as part of this institute establishes facilities for measurement of numerical aperture and mode field diameter of fibres.

*Establishment of an OTDR calibration facility within the virtual institute.* SP has agreed to establish this facility.

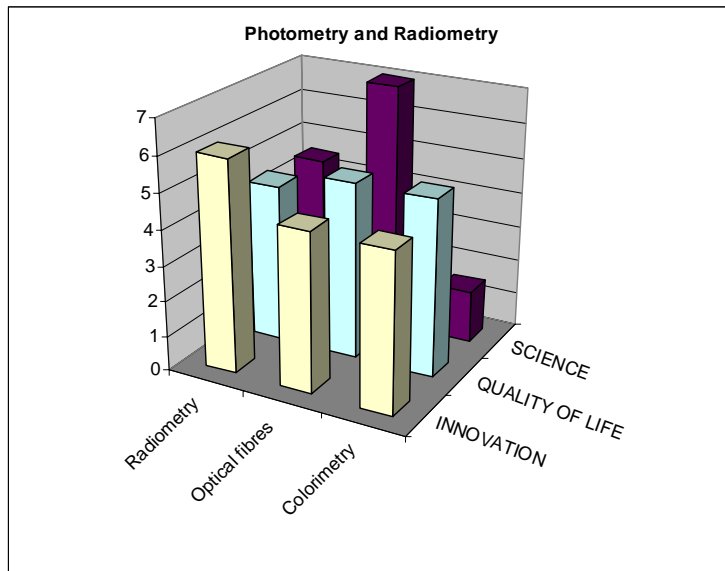
*Extension of the dynamical power measurement at 1310, 1550 and 1625 nm.* This has been done for the 1550 nm region. It remains to extend the power ranger for the 1310 nm region to 500  $\mu\text{W}$ , while in the 1625 region 100  $\mu\text{W}$  is sufficient.

*Characterisation and verification of light sources and detectors.* The expected demand for such service has not been seen. It is proposed to postpone the establishment of such a facility.

*Establishment of a facility for LED characterisation.* This was not recommended in the plan of action. Due to demand from amongst others the toy industry DFM is currently establishing such a facility.

Several of the prioritised recommendations as well as the newly emerged needs have been dealt with within current budgets. Many of the Danish needs within fibre optic measurements can be honoured by the Nordic virtual fibre optic institute.

### 5.7.5 iMERA classification



**Figure 6. Classification of the three subfields mentioned in 5.7.4 , using the grading scheme from 7.2 and order according to innovative grading. In Denmark, radiometry is considered to contribute the most to innovation whereas optical fibres have the greatest scientific potential.**

### 5.7.6 Costs and financing

The economic key figures for the subject fields are as follows:

PHOTOMETRY AND RADIOMETRY	2005 STRATEGY	
Costs	3,8	5,1
VTU contract	2,4	4,0
Investment		9,4
Clients	0,1	0,5

## 5.8 Flow

This subject field was treated in action plans in 1990 and 1999. It has resulted in the appointment of a primary laboratory for water flow and national reference laboratories for gas flow and flow other liquids than water and anemometry.

A summary of the field in terms of the IMERA three-axis classification is given below. Out of the foresight eight prioritised development are chosen, and they are rated on a scale from 0 to 10 for each of the axes innovation, quality of life, and science. The results are shown graphically below.

### 5.8.1 The subject field and its sub fields

DANIAmet sub-fields	EUROMET sub-fields	CIPM working groups
Gas flow	Low pressure Gas flow High pressure gas flow	Fluid Flow (under CIPM-CCM)
Water flow	Water flow	
Flow other liquids than water	Flow other liquids than water	
Anemometry	Anemometry	

The subdivision of the subject field for DANIAMet and the three major international organisations are given in the table below. As is seen, the Danish division is easy to map onto the international ones, except for the specialised working groups of the CIPM that reflects special work at the BIPM.

Not included in the list is the working group of the CIPM CCM, on key comparisons (included in the sub-fields of DANIAMet and EUROMET).

The subject field is composed of the following most important parameters:

*Gasflow:* The field includes volume meters, flow meters and mass flow meters and the measured media are combustible as well as non-combustible (gas, air, nitrogen etc). Calibrations are performed by piston provers (low flows 1 – 50.000 ml/min.), bell provers and PDmeters (25 l/h – 400 m<sup>3</sup>/h) and turbine meters for the higher flow rate ranges.

*Water flow (volume, mass, and heat):* All forms of water, potable water, sewage water, water used as process water, cold and hot water. Measurement of heatflow is normally consisting of a volume flow-metering and two temperature measurements. Calibration of energy meters are done by comparison between references for volume flow, temperature and internationally accepted tables for heat capacity. Traceability is obtained through mass or via volume and density or by use of master meters. For on site calibration of water and district heating meters clamp on meters and LDV methods are being used.

*Flow other liquids than water:* The most common fluids measured are oil, and other hydrocarbons. Meters used are PD meters, piston provers, volume flow meters and massflow meters. The traceability of

volume meters come from volume standards, which are calibrated with water and traceable to mass and density.

*Anemometry:* Speed of air in open channels is measured by a combination of pressure, temperature, relative humidity, length and time. Windtunnels and pitot tubes and towing tanks are being used.

Other challenges regarding flow measurements are multiphase flow, flow simulation (CFD, Computational Fluid Dynamics) and use of laser based methods comprising Laser Doppler Velocimetry (LDV) and Particle Image Velocimetry (PIV).

### 5.8.2 Needs

The needs as expressed by the sectors defined cover the following parameters:

*Industrial applications:* Flow measurements are needed in practically all industrial process installations from the medico industry with very small flows to large meters at e. g. salt and sugar producing companies, at sewage treatment plants etc. Airflow and velocity measurements are also of importance in relation to indoor climate, which is coming more and more in focus. Likewise exact measurements of wind speeds are important for evaluating the efficiency of wind turbines. The various flow meters are used to control the processes. In Denmark further exists relatively many industries producing flow meters, valves, heat exchangers, pumps etc., where measuring flow is of considerable importance.

*Legal and other regulatory applications:* There are legal requirements for gas meters, for hot and cold water meters, for heat meters, for allocation meters in buildings and for meters for other liquids than water. In total approximately 2 million meters are under legal control. The activities covers type testing, pattern approvals, verification and reverification. In Denmark there are many supply companies for gas, water, district heating etc. and also several manufactures of meters exists. The MID will increase the need for consultation.

*Calibration and testing:* There are 26 accredited laboratories in this field and also laboratories doing testing in connection with type approval. We have in Denmark many producers of flow measuring equipment and they also need access to testing facilities and consultation.

*Research and Other applications:* There are a need for research in connection with development of new measuring equipment, new testing methods in new areas (f. inst. flow around windmills and nano flows). Research is done at the accredited laboratories at the producers and at the technical universities in Copenhagen and Aalborg.

### 5.8.3 Resources

In the field of flow the following NMI's have been appointed:

Gas flow at FORCE Technology (National Reference Laboratory) comprising of piston provers (low flows 1 – 50.000 ml/min.), bell provers and Positive Displacement meters (25 l/h – 400 m<sup>3</sup>/h) and turbine

meters for the higher flow rate ranges. Further primary facilities up to 10 m<sup>3</sup>/h and 12 national reference standards up to 4000 m<sup>3</sup>/h exist.

Water flow at Danish Technological Institute (Primary Laboratory). The facilities comprising 3 test rigs covering water flows from 1,5 l/h up to 400 (500) m<sup>3</sup>/h and with possible temperature variations from 12 to 85 C. The flow references are either weighing tanks and measurement of time, or calibrated reference meters. Heat meters can be calibrated by combination of a volume flow metering and two temperature measurements. The laboratory further uses LDV partly for measuring flow profiles in combination with calibrations, partly for on site calibrations. The laboratory is thus accredited to make on site calibrations of large water and district heating meters up to DN 1000 and several research projects related to the use of LDV have been carried out.

Flow in other liquids than water at FORCE Technology: The facilities comprises of piston provers, master meters, volume standards etc. Most common fuels measured are oil and other hydrocarbons, but also various other liquids like milk. Meters used are PD meters, piston provers, volume flow meters and mass flow meters. The traceability of volume meters comes from volume standards, which are calibrated with water and traceable to mass and density. The flow rate is up to 600 m<sup>3</sup>/h and 800 kg/h.

The appointed laboratories are regularly participating in relevant key comparisons and have several accepted CMC's

In the field of anemometry Danish Technological Institute have accredited calibration facilities for air velocity in the range of 0 m/s to 27 m/s and for air flow in the range of 1,5 – 33 l/min. The laboratory has a follow-up on the LDV activities related to water flow also started research related to the use of LDV for anemometry; actually the laboratory participate in the key comparison EUROMET M.FF-K3. Likewise in the field of anemometry FORCE Technology has established facilities for accredited calibration of cup anemometers in the velocity range of 4 m/s to 16 m/s.

The personnel at the four NMI's in the field amounts to around 20 persons. There are growing demands for calibration in all areas and the knowledge level in then scientific area has to be enhanced.

#### **5.8.4 Recommendations (gap analysis)**

Below is an updated summary of the recommendations from the year 1999 plan and new demands.

*Extensions and improvements of the facilities and competences of the national reference laboratories:* FORCE Technology has established facilities for calibration of gas flow meters up to 50 bar pressure and higher flow at 50 bar and flow rates up to 6.500 m<sup>3</sup>/h and up to 10.000 m<sup>3</sup>/h for pressure lower than 35 bar, but there are still need for better traceability (primary level) with natural gas. Upgrading to primary level will give access to the European unit for gas flow and give possibility for participation in international developments projects.

Technological Institute have in the period increased the capacity of their accredited testing facilities for water and heat flow up to 400 m<sup>3</sup>/h and in the field of using LDV for flow measurements many research activities have been carried out.

Possibilities for measuring air speed should be improved 0,002 – 2 m/s (growing demands from industry) and facilities for calibration of meters for liquids other than water should be extended. (Higher flow rates). There should also be established facilities for low liquid flows. The last two requirements are due to demands for higher accuracy to fulfil legal requirements, when performing in-situ calibrations and industry demands.

National reference laboratories for anemometry and flow (other liquids than water) should be established. This has been carried out.

*Use of CFD, LDV, PIV should be improved:* In the field of LDV Technological Institute has carried out several research projects mostly related to use of LDV for on site calibration of large meters but also in relation to improving knowledge about flow disturbances and their influence on measurement uncertainties. Some of the projects have been carried out in cooperation with engineering high schools and universities as part of exam projects as well as Ph. D.s and post doc studies ( The Engineering College of Aarhus and Aarhus University) As a result of these projects an accreditation for on site calibration of water flow meters up to DN 1000 and a flow rate of 16900 m<sup>3</sup>/h has been obtained. Only limited progress has been made in the other fields due to lack of funds. In the field of CFD FORCE Technology has established a department which supply CFD analyses of flow- and combustion processes to power- and production industries.

*Research and establishment of facilities in the field of multiphase flow:* This has not been possible due to lack of funds. There are industry demands in this area.

*Calibration facilities for low flow (air and other gasses down to 0,1 l/min):* FORCE Technology has established facilities to 1 ml/min.

*Facilities for calibration of big energy meters (from 500 m<sup>3</sup>/h to 2.000 m<sup>3</sup>/h):* This has not been established due to lack of funding. The demand is coming from industry

*Facilities for calibration of big mass flow meters (up to 400 t/h):* Now covered by existing facilities.

*Development of in-situ calibration and research related to better knowledge about flow inlets and disturbances:* Except the results related to on site calibration with use of LDV only limited progress in this field, e. g. use of clamp on meters, due to lack of funds. Demand for more areas and higher accuracy, as industries need to become more and more efficient

*New developments.* Flow is of considerable importance in Denmark with both many industrial and legal interests. The flow facilities are - despite the above mentioned lacks - of relatively high international level comprising large and very new facilities for gas flow and relatively large facilities for hot water flow; further the research activities in using LDV are on a relatively high level. The flow facilities are

placed at two independent institutes, however, it has been found that establishing a virtual Danish Flow centre covering the facilities at both the institutes can improve the national as well as the international strength in the flow area. Such a centre will have better possibilities for fulfilling the needs described above and will assure easier access to up-to-date knowledge, arrange courses, collect information, establish web-based knowledge platforms etc. Primary and national reference laboratories. The centre will secure an efficient development of the abovementioned defined needs by combining the knowledge from the existing operators.

### 5.8.5 iMERA classification

The iMERA classification has not been performed for the subject field of temperature.

### 5.8.6 Costs and financing

The economic key figures for the subject fields are as follows:

FLOW	2005 STRATEGY	
Costs	3,7	8,1
VTU contract	1,7	5,9
Investment		10,2
Clients	14,7	16,8

## 5.9 Acoustics

This subject field has been treated in action plans in 1992 and 2000. The Danish Primary Laboratory of Acoustics was created in 1991 as cooperation between Brüel & Kjær A/S, B&K, and the Acoustics Laboratory of the Technical University of Denmark, DTU. Recently, DFM has taken over DTU's role in the DPLA scheme and calibration equipment has been moved to DFM.

### 5.9.1 The subject field and its sub fields

DANIAmet sub-fields	EUROMET sub-fields	CIPM working groups
Air-borne acoustics	Sound in air	
Vibration in solids	Acceleration and vibration	
Acoustics in liquids	Underwater acoustics	
Not covered	Ultrasound	

Acoustics includes a number of quantities that are related to the elastic oscillations in fluids (gasses and liquids) and solids. It is customary to divide the subject of acoustic metrology into three sub-fields:

Different techniques are used for measurements in the sub-fields. Each sub-field can be divided further after frequency range (infrasound, sound, and ultrasound) and/or application (technical or medical ultrasound), etc..

The most important quantities are pressure, velocity and intensity and their derived units. None of these quantities are realised in the form of reference artefacts, but through calibrated transducers. The traceability of such quantities is then linked to length, mass and AC/DC voltage standards.

The subdivision of the subject field for DANIAmet and the three major international organisations are given in the table below. The Danish division is easy to map onto the international ones. However, there is not any particular working group instituted within the Consultative Committee in Acoustics Ultrasound and Vibration (CCAUUV) of the CIPM and all issues of the subject field are treated under the Committee itself. Sound in liquids and ultrasound is not covered by DANIAmet, and there are no laboratories in Denmark accredited for such quantities .

### 5.9.2 Needs

The needs as expressed by the sectors defined cover the following parameters:

*Industrial applications:* There is a continuous demand for instrumentation and equipment for the measurement of acoustical parameters of a diverse variety, for example, instrumentation for acoustic measurements, audio-logical instrumentation, hearing aids, loudspeakers, etc. Normally, the instrumentation needed for characterising such a variety of devices should be calibrated. Furthermore, the requirements set for noise-making machinery and household devices have a double impact: a) it requires that the manufacturers measure the intensity using calibrated and traceable instrumentation, and b) it demands advanced measurement methods. This can be applied in the case of air-borne sound, vibration and sound in liquids. Acoustic measurements in different frequency areas are becoming an important issue, especially air-borne sound and vibration at low frequencies.

*Legal and other regulatory applications:* Although there are no legal requirements with respect to acoustics, there are specific requirements of maximum noise levels at working stations, from noise sources to their surroundings, etc. There are also specifications with respect to the maximum noise emitted by vehicles, building codes about the allowed transmission between dwellings through building elements. The requirements for the traceability of the instrumentation used in the measurements are the same as for the industrial applications.

*Calibration and testing:* Currently, there are 11 accredited laboratories in the subject field of acoustics. This includes a Primary Laboratory that calibrates microphones and accelerometers. There are laboratories accredited for the calibration of measuring instrumentation, measurement of sound in field applications, measurement of acoustic characteristics of building blocks. There are also two laboratories accredited in acoustics in water. There is no laboratory accredited at the reference level because the differences between the level offered by a primary laboratory and the requirements of the customers are very small.

*Research and other applications:* Basic research on microphone calibration techniques in different sound fields is needed in the light of the extensive standardisation activities and the development of new transducers. The same is the case in vibration. Research and development of mini-hydrophones and its calibration is also required.

### 5.9.3 Resources

The personnel at DPLA under the sub field of air born acoustics amount to about 3-4 engineers/scientists/technicians. The instrumentation available satisfies the current needs for pressure and free-field calibration of microphones and for the determination of some audiometric quantities and accelerometer calibration as well.

In the sub-field of sound in water and ultrasound the two institutions involved employ about 2 engineers per year divided among several people. The instrumentation and facilities needed for this purpose are available as a part of their internal R&D activities.

### 5.9.4 Recommendations (gap analysis) and follow-up

Below is an updated summary of the recommendations of the action plan for the subject area in 2000:

*Fundamental work in the subject area:* The subject area is characterised by the fact that the calibration techniques are based on the actual primary standards, while the transducers (microphones, accelerometers, hydrophones, etc.) can be considered as transfer standards. Hence, the properties of the transducers and their dependence on external parameters are an important factor when disseminating its accuracy. Therefore estimations of such dependencies are required, as well as the effect of various sound fields.

*New transducers, new calibration techniques:* With the coming of new micro mechanical transducers there is a need for developing new calibration techniques.

*Vibration calibration:* Measurement methods for measuring intensity of vibrations in solids are under development, leading to new calibration techniques. It is also necessary to develop laser based calibration techniques for torsional vibration, shock and dynamic force transducers. Since the action plan was finished, the proposal has been made to adopt a Danish activity in dynamical measurements into studies of vibration, so that a Danish-Swedish combined effort could be established.

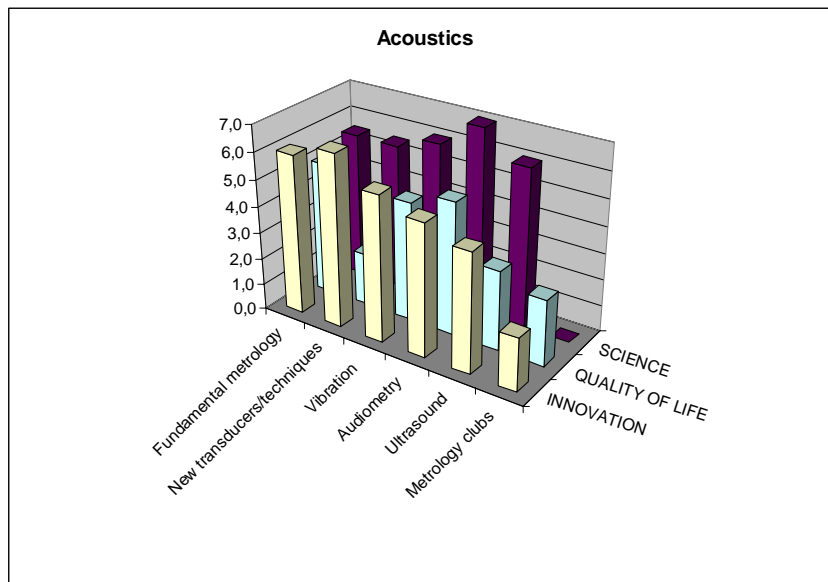
*Audiometry:* In the audiometric area there is the need for better estimation of the reference quantities and for calibration methods based on head-torso simulators. The accredited calibration of ear-simulators and artificial mastoids cannot be performed at this time and should be developed.

*Ultrasound:* It is foreseen that the frequency range of the existing calibration should be expanded for applications of medical ultrasound. In the long term this calibration services should be taken to a primary level; a possibility would be within DPLA.

*International collaboration:* A very important activity of any primary laboratory is its participation in the international network in Europe and Worldwide. Nowadays, Danish laboratories participate actively in the international arena through EUROMET; CCAUV and through working groups in IEC and ISO.

*Formation of metrology clubs:* It is recommendable to develop awareness in users of acoustical calibrations and other services of the requirements and possibilities of the services they receive. The primary laboratory supported by an accredited laboratory should take such a task of an awareness club/campaign.

### 5.9.5 iMERA classification



**Figure 7. Classification of the six recommendations mentioned in 5.9.4 , using the grading scheme from 7.2 and order according to innovative grading. Note that vibrations and audiometry have the greatest contributions to quality of life, whereas the other recommendations have very similar impact; except metrology clubs.**

### 5.9.6 Costs and financing

The economic key figures for the subject fields are as follows:

ACOUSTICS	2005 STRATEGY	
Costs	3,5	3,7
VTU contract	0,6	3,0
Investment		0,0
Clients	1,1	1,8

## 5.10 Amount of substance

This subject field was treated in action plans in 1992, 1995 and 2004.

A summary of the field in terms of the IMERA three-axis classification is given above. Out of the foresight 3 prioritised developments are chosen, and they are rated on a scale from 0 to 10 for each of the axes innovation, quality of life, and science. The results are shown graphically above. From this it appears that the subject field amount of substance in Denmark contributes equally to innovation and quality of life.

### 5.10.1 The subject field and its sub fields

DANIAmet sub-fields	EUROMET sub-fields	CIPM working groups
Electrochemistry	Electrochemistry	Electrochemical Analysis
Product and Materials	Inorganic	Inorganic Analysis Surface Analysis
Environmental Chemistry	Gas	Gas Analysis
Food Chemistry	Organic	Organic Analysis
Pharmaceutical Chemistry		
Laboratory Medicine		Bio Analytical Analysis

Amount of substance/metrology in chemistry encompasses a very wide range of sub-fields, quantities and measurement methods. The subdivision used in the latest action plan and the two major international organisations are given in the table below. There is only to a limited extent a direct correspondence between the subdivisions used in the Danish action plan and the international working groups.

### 5.10.2 Needs

Metrology in chemistry relies to a very large extent on the availability of and access to certified reference materials (CRMs). Traceability for the property values of CRMs must be documented, and depending on the required comparability (local, national, global) traceable to appropriate higher order CRMs or standards. Internationally recognised primary and reference methods exist which provide traceability for a few primary CRMs to SI.

The needs as expressed by the sectors defined cover the following parameters:

*Industrial applications:* Most production processes require precise control of composition and quality of materials and chemicals. Metrology needs arise from process control, specification of products and documentation of regulatory requirements. A few examples are specification of nutritional value of food, active ingredients in pharmaceuticals, smoke stack air emissions and heavy metals in waste products. Access to standardised analysis methods, reference laboratories and certified

reference materials is crucial for the ability to place products on the market, fulfil export and other regulatory requirements.

*Legal and other regulatory applications:* Within many of the sub-fields e.g. food, pharmaceuticals, laboratory medicine and environmental analysis there is a large body of regulatory requirements, ranging from European Directives to local legislation. The EU Drinking Water Directive is just one example. Some Directives presuppose the existence of designated bodies monitoring various technical aspects, requiring metrology facilities. Some international bodies provide technical documents specifying reference methods, detection limits and reference materials. E.g. within the food sector, the Codex Alimentarius Commission develop written standards, in the field of pharmaceuticals technical specifications are published in the European Pharmacopoeia.

*Calibration and testing:* There are currently 63 accredited chemical analysis laboratories, mainly in the fields of food and environmental analysis, laboratory medicine and construction materials. There are two producers of certified reference materials, Eurofins A/S (water and solid matrices) and DFM (electrochemistry). Efforts are made, e.g. through the European Coordinating Centre for Reference Materials (VIRM), to coordinate the access to CRMs. Chemical analysis laboratories also rely heavily on traceability of physical measurements in e.g. mass, electricity, flow and temperature.

*Research and Other applications:* Development of well-characterised reference materials is crucial for the furthering of traceable measurements in chemistry. It will also be beneficial to investigate the possible widening of applicability of CRMs, e.g. properties in one matrix versus another. More robust scientific methods of estimating uncertainty due to sampling are needed.

### **5.10.3 Resources**

Within DANIAMet, Radiometer Medical and DFM have activities with the chemical subject field, namely electrochemistry; and they have a staff of about 2 persons.

Further, there are 15 laboratories (2004) appointed by various Danish Ministries as reference laboratories with varying responsibilities, mostly in order to fulfil requirements for the national infrastructure in connection with European Directives. For the 3 institutions that have taken part in making the action plans the staffing is estimated to be 6 persons.

There are 63 accredited laboratories (2004) within the field of metrology in chemistry, covering all the sub-fields described in the action plan.

There is only limited contact and hardly any coordination between laboratories from different subfields of metrology in chemistry. There is no participation in the working groups of EUROMET and the Metre Convention, apart from the field of electrochemistry. There is only limited participation in EUROMET and CIPM comparisons. Hence metrology in chemistry in Denmark is not represented in the CIPM MRA.

#### 5.10.4 Recommendations (gap analysis) and follow up

Updated summaries of the recommendations of the 2004 plan of action are as follows:

##### Electrochemistry:

*Establishment of a primary laboratory for electrochemistry.* Radiometer Medical has decided not to continue the maintenance of its pH primary standard. The standard has been offered to DFM, and the transfer is planned for the summer 2006. The combined facility has been evaluated by an international assessment team and is ready to be appointed as national primary laboratory as soon pH is covered by the DFM accreditation.

##### Environmental Chemistry:

*Establishment of a coordinating centre for environmental chemistry.* Presently there are four reference laboratories active in the sub-field, covering chemical measurands in water and soil, air emissions and ambient air quality. A formal collaboration between these laboratories would improve the development efforts and would increase international influence. The centre could coordinate research and development efforts into certified reference materials and their applications, and strategies for estimating uncertainty due to sampling.

*Development of certified reference materials.* To fulfil the requirements in the Drinking Water Directive reference materials for organic micro pollutants are necessary.

*Air-emissions test centre and proficiency testing schemes.* There is an increasing demand for calibration of on-line air monitoring equipment as well as proficiency testing activities and interlaboratory comparisons in the field. It is recommended that an air-emissions test centre be established to provide these services.

##### Food Chemistry:

*Resources for the development and production of reference materials.* Existing reference materials and proficiency testing schemes only cover parts of the requirements in the field. It is recommended to strengthen the network of European reference laboratories and further access to reference materials, proficiency testing schemes and information from this network.

##### Pharmaceutical Chemistry:

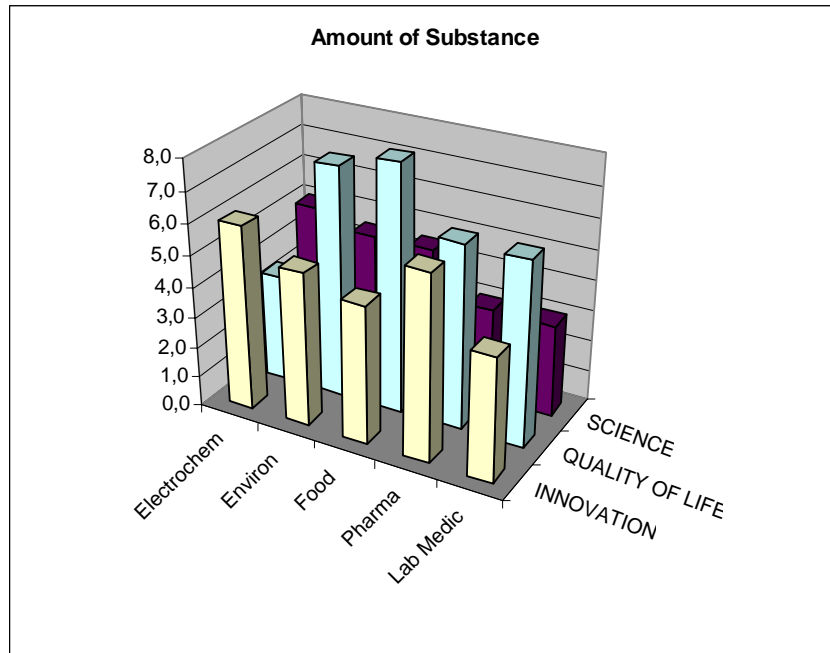
*Mutual recognition of reference materials.* Certified reference materials for active pharmaceutical ingredients are produced by the regional pharmacopoeias commissions. The certified values are provided without an uncertainty statement. There is a need for quantitative comparability between the reference materials among and within pharmacopoeias or establishment of global certified reference materials. This will require policy changes from the pharmacopoeial expert groups.

##### Laboratory medicine:

*Coordination of reference laboratories.* There exist several laboratories within the laboratory medicine sub-fields with the relevant competences to serve as national reference laboratories each with narrow scope. Some of these already serve as e.g. WHO or Danish Ministry

reference laboratories. However, they may not individually have the proper quality management systems in place and would benefit from a central coordination.

#### 5.10.5 iMERA classification



**Figure 8. Classification of the five subfields mentioned in 5.10.4 , using the grading scheme from 7.2 and order according to innovative grading. They have very similar impact, except for environment and food that is estimated to have the greatest influence on quality of life.**

#### 5.10.6 Costs and financing

The economic key figures for the subject fields are as follows:

METROLOGY IN CHEMISTRY	2005 STRATEGY	
Costs	7,7	7,7
VTU contract	1,1	1,5
Investment		4,0
Clients	0,8	1,0

## 6 Summary and conclusions

Most of the summary and conclusions are given in the executive summary, and here we only summarise the points that need amplification. These are the following:

*The decentralised metrology organisation DANIAmet*

The Danish decentralised metrology organisation DANIAMet consists of some 9 partners covering a wide range of different metrology issues that would be have been possible to address in a single dedicated institution at the current level of funding. Only DFM is fully dedicated whereas the others have metrology as an attachment to their core business. This brings the customer in focus and it defrays costs; and currently the performance contract from the Ministry for Science, Technology and Innovation covers 35% of the operational costs related the development and maintenance of measurement standards and the associated knowledge.

However the decentralised organisation also has its costs. The cohesive force towards metrology as an international scientific discipline with generally accepted practices tend to appear marginal to the DANIAMet partners at large, and the task of presenting DANIAMet as one coherent organisation has proven to be a non-trivial one. Therefore some of the significant savings of the organisation must be "paid back" into coordination and promotion.

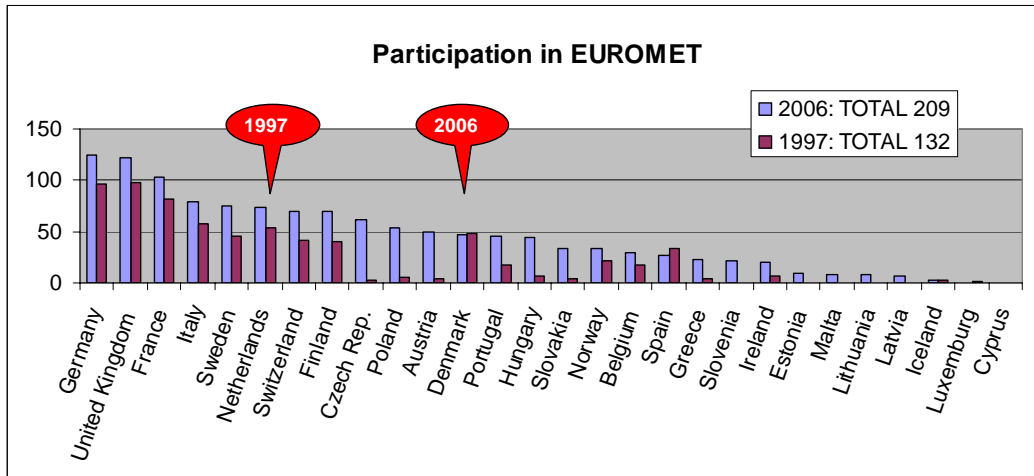
*The current Danish coverage of Danish needs.*

Currently, DANIAMet is active in 8 out the 10 EUROMET subject fields, but in all of them the participation is limited to a fraction of the total work of the groups. There are two ways of quantifying national participation. One is the count the number of registered calibration measurement capabilities CMC that are registered in the Key Comparison Data Base KCDB (appendix C); and here Denmark has registered some 200 to be compared with the number of 1000 that the big countries have registered. Assuming that the broad based Danish industry and society needs measurement traceability for essential all parameters and contemplating that the big countries presently look after all needs, one arrives at the Danish coverage as being 20%. Another way is to count the Danish participation in comparisons (KCDB appendix B) amounts to 10% of the total number of key and supplementary comparisons.

Hence, DANIAMet's participation in international metrology covers 10 – 20% of the national needs for traceable measurements. For the time being, this level allows all other needs for traceability to be deferred to foreign laboratories; and this is possible as long as the foreign partners acknowledge that Denmark is contributing with its share to the "metrology balance of payment" by producing its share of knowledge, research and development and making this available to the international community.

However, the mere access to traceable calibrations is not enough for the development of a society that is going to be a winner in the combat for knowledge-based innovation in the future. The critical knowledge, necessary for the development of new products and services, will only be available to those who contribute to that knowledge themselves. Therefore, increased focus on the availability on measurement knowledge within Denmark is becoming an issue, so that Denmark will not be deferred to a second ranking in metrology.

*The decline of Danish participation in international metrology*



EUROMET was established in 1987 to foster an increased European collaboration on measurement standards, and it has successfully evolved into an all round forum for scientific and industrial metrology. A measure of national participation is therefore the number of collaborative EUROMET projects that a country participates in.

DANIAMet takes part in 47 of 209 projects that EUROMET operates at present. This puts Denmark as the 12<sup>th</sup> most active country in metrology knowledge sharing in EU and EFTA, as is shown in the figure above. This is a significant decline from 1997, when Denmark was chairing EUROMET, was leading the Nordic countries in project participation, and ranked 6<sup>th</sup> on the European scale. This decline is attributed to a lack of political attention to international participation of DANIAMet in EUROMET and in the Meter Convention, as well as the lack of funding of DANIAMet members to join the European technical collaboration.

#### *The need for upgrading of Danish metrology*

In its recent report the Globalisation Council has set ambitious goals for Denmark in order to pave the way for continual prosperity for Danes. 17 targets have been set, focussed on education, research and innovation, which will make it possible for the country to stay competitive in the global economy.

Simultaneously, the Danish government has published plans to increase the public funding of research to 1% of GNP. This is done to fulfil the Barcelona accord on Europe's dedication to knowledge-based innovation.

Also the Council for Technology and Innovation has announced its plans for implementing the Globalisation Council's objectives and it has set the following targets for the Approved Technology Service (to which metrology belongs):

- The GTS service should be more open
- There should be a closer connection between the GTS system and the research institutes, including universities.
- The GTS-system should be internationally evaluated.

Metrology offers the following solutions to these targets. It provides a knowledge infrastructure, which is essential for the transfer of scientific research to innovation; because only when inventions have been quantitatively characterised, will they be innovative and commercially viable. "One cannot produce better than one can measure" is truer than ever in the global economy.

The traditional rationale behind metrology, to protect the consumers against fraud, for instance by ensuring that the weight and volume of pre-packaged goods are in accordance with the declaration label, is still a valid one; and it assures a great deal of comfort that weights and measures can be trusted in a society. However, it is often neglected that nowadays the content of goods is nowadays submitted to very advanced measurements before they are safe to consume. And societies that do not master such measurements are the societies where illegal goods are sold.

Measurements of the health and safety of citizens become more and more essential for the well-being of a population. Also these measurements nowadays require specialised knowledge and instrumentation. But currently such measurements rarely comply with current best practices for metrology, and that leads to significant losses for society. For instance the Danish savings in bringing laboratory medicine up to modern standards would save some 300 million Danish kr. annually.

Much of metrology knowledge is generic in nature, meaning that metrology is a general-purpose infrastructure with many different – and apparently diffuse – applications. It is therefore interesting to follow how up-to-date metrology may be applied to novel problems. As an example it may be noticed that indeed metrology is relevant to one of the key public concerns, public safety and fight against terror. Indeed in an innovation consortium, one of the private partners manufactures holograms for identification cards, and the optical and nanometrology that DANIAMet has developed in international projects is helping to make the cards more reliable – and thereby making the society safer.

The Danish metrology organisation DANIAMet addresses all these issues of modern metrology. It is decentralised and open; it consists of four GTS-institutes, three private enterprises, as well as the Danish Technical University and Risø National Laboratory, with DFM as the core institute. DANIAMet participates in European organisation EUROMET and within the Meter Convention, and hence provides the necessary links to the global knowledge base of measurements.

However, Danish metrology, which has always been characterised by low public funding, is lacking behind international developments as well as losing ground with respect to the countries that Denmark will be competing with in the global economy. In order to continue to serve Danish interests by providing the most essential metrology know-how and services within the country and by providing access to the global knowledge base by contributing to research and development, there is a need for a significant increase in the government funding.

## 7 Appendixes

### 7.1 Methods used in foresight

**Environmental Scanning** - Systematic analysis of documentary sources: media, journals, reports, conference proceedings, web-sites, etc. Bibliometric approaches and Patent analysis may be used too.

**SWOT analysis** - Analysis of Strengths, Weaknesses, Opportunities, and Threats (SWOT), that is of significant internal and external factors influencing an organisation's or territory's strategies and its possible futures. It is portrayed as a 2x2 matrix, which presents overview of major issues to be taken into account.

**Issue Survey** - Used to consult, by post or email or telephone interviews, a wide range of expert opinions to find out what they consider to be important developments in their areas. The survey may be fairly open-ended, in which the experts are allowed to elaborate on the issues in their own style, often supplying relevant documentation.

**Trend Extrapolation** – A trend refers to historical data. Extrapolation means that these data are projected forward, by mathematical or statistical equation-fitting. In order to assume that a trend will continue to evolve into the future, it is needed to identify which forces are driving a trend.

**Simulation Modelling** – A computer simulation model represents a system in terms of its key components and relationships. It can be used to project how the system will operate over time, or as a result of specific interventions, and allows to deal with a very large number of variables simultaneously.

**Genius Forecasting** - Term used to describe the generation of a vision of the future through the insights of a gifted and respected individual (academic, researcher, expert,...). Some individuals can provide fresh thinking to foresight, and can take up perspectives that may otherwise be neglected in the work of committees and panels.

**Delphi** - Involves a survey of expert opinion. What makes Delphi different from other opinion surveys is the way in which this is accomplished. The survey is circulated, to the same set of respondents, at least twice. Together with the same set of questions, the respondents in later rounds receive feedback on the structure of responses from previous rounds and have the chance to modify their judgements in its light. This allows people to see how far their forecasts and expectations correspond to those of a wider pool of respondents. The anonymity of the survey is intended to reduce the dominance of discussions and the exercise of influence by the loudest or most senior figures. The researchers should receive information on why judgements were made; all respondents should thus be able to have access to special information that only a few possess, but which can inform judgements that diverge from the average.

**Brainstorming** – Aims to reduce inhibitions about generating "wild" ideas, and thus to stimulate creativity and novel viewpoints. The term is applied loosely to any free-ranging discussion, but the 'classical'

definition involves two main steps: 1) A period of freethinking, which is used to articulate and capture ideas, with no critical comments (as a group or alone activity); 2) The idea-generation is followed by more rigorous discussion of these ideas. This typically involves clustering them through a process of group discussion and prioritising the most important themes. Brainstorming should not normally be expected to generate output that can be directly used in reports, etc. It may be a useful technique to use in establishing the future work of expert panels.

**Expert Panels** - Open up the Foresight process to potentially hundreds of individuals and are ideal forums for in-depth discussions and debate. Each Panel comes in many shapes and sizes, normally consists of 12-15 individuals and is mandated to use its collective expertise in addressing a particular problem or set of issues. Experts meet face-to-face, normally in private session, at intervals. During this time they use their judgement in interpreting available evidence. In many cases, Panels produce their own published reports.

With some foresight methods, panels are a near necessity for the generation of inputs, the interpretation of outputs, and/or the overall conduct of the method.

**Cross-impact Analysis** - Like Delphi, it is an expert-based method producing quantitative results, through a more complicated statistical processing of the data. The approach is to ask the experts to rate the likelihood of various events occurring and furthermore, to rate the likelihood of each event occurring if each of the others does or does not occur, forcing attention to chains of causality: x affects y; y affects z. This creates a matrix of conditional possibilities. This matrix can be subject to mathematical analysis to assign probabilities of occurrence to each of the possible Scenarios resulting from the combinations of events.

**Scenarios** - Consist of visions of future states and courses of development, organised in a systematic way as texts, charts, etc. They may be used more as an element of the Foresight process: as inputs to start discussion and idea generation in panels, as tools for working groups to marshal their arguments and test the robustness of policies and/or as presentational devices that can communicate Foresight results to wider publics. The ways of producing scenarios vary immensely: from the outputs of simulation models, through the work of small expert teams, to the undertakings of workshops and the delineation of different views in even wider samples of expertise. Scenarios provide planners with one point estimates of innumerable possibilities of what the future holds, helping participants to radically alter the way they think about the future.

**Critical (or Key) Technologies** - A particularly useful approach for assessing various technologies (or research directions) when selection of priorities is the major task. The method is based on four steps. First, to select a cohort of experts for consultation. Secondly, an initial list of technologies is generated - this can be produced starting from existing lists (e.g. from, previous Foresight studies), or the list can be produced by a combination of brainstorming and bibliography searches. In other cases, panels of experts are used in combination

with patent analyses, bibliometrics and other studies. The third step involves clustering and prioritising the list of technologies. This is typically done through discussion and often voting procedures. The fourth step is to assemble the final list of critical technologies.

**Technology Roadmapping (TRM)** - Used widely in industry to support technology strategy and planning. Increasingly, the approach is being applied in foresight studies focused upon particular industrial sectors. Roadmaps are comprised of multi-layered time-based graphical charts that enable technology developments to be aligned with market trends and other drivers. In this way, research and other development directions can be established and actions determined in a goal-oriented manner.

## 7.2 Proposal for iMERA grading

The iMERA project proposes to categorise research along three axes, namely:

- Innovation
- Quality of Life
- Science

Here innovation is the most commonly used success-criteria for metrology, and the "innovation quality" may be subdivided into the following categories:

Sub categories of Innovation	Max points
Support to national strong industry sector	2
Support to national promising industry sector	2
Support to SME's	2
Supports several industry sectors	2
Gives international recognition (incl. Patents, standardisation)	2
SUM	10

Recently the quality of life aspect of research has been in focus, and the proposed sub categories are the following:

Sub categories of Quality of Life	Max points
Support to consumer protection	2
Support to health and the environment	3
Support to public safety	1
Support to "soft" metrology	2
Support to Knowledge transfer (incl. Training)	2
SUM	10

Finally, in any research, scientific value is a merit in itself, with the following subcategories:

Sub categories of Science	Max points
Publications	2
Scientific impact factor	2
Contributions to conferences	2
Contributions to graduate studies	2
International recognition (incl. EUROMET, CIPM-CC)	2
SUM	10

### 7.3 List of acronyms

BIPM	Bureau International des Poids et Mesures, France
CC---	Consultative Committee under the CIPM
CFD	Computational Fluid Dynamics
CIPM	Comité International des Poids et Mesures
CIPM MRA	CIPM-Mutual Recognition Agreement
CMC	Calibration Measurement Capabilities (in CIPM-MRA)
CRM	Certified reference materials
DANAK	Danish Accreditation and Metrology Fund
DANIamet	Danish Metrology Organisation (of NMIs)
DPLL	Danish Primary Laboratory for Length (proposed)
DTU	Danish Technical University
EA	European Accreditation
EMRP	European Metrology Research Programme
EUROLAB-DK	Danish Branch of the European Laboratory Organisations
EUROMET	European collaboration between NMI
FVM	Foreningen af værkstedsmetrologer
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
iMERA	Implementing the Metrology Research European Area
ISO	International Standards Organisation
KCDB	Key Comparison Data Base of the CIPM-MRA
LDV	Laser Doppler Velocimetry
MID	Measurement Instrument Directive
NGM	National Primary Laboratory for Geometrical Metrology
NMI	National Metrology Institute
PIV	Particle Image Velocimetry
SI	International System of Units
SIS	Statens Institut for Strålingshygiejne
SSDL	Secondary Standards Dosimetry Laboratory (IAEA)
SWOT	Strengths, weaknesses, Opportunities and Threads
TC---	Technical Committee under EUROMET