

**Scoping Paper on Requirements  
for Future European Infrastructural  
Integration and Development**



## **Scoping paper on the Requirements for future European infrastructures for innovation, education and research in nanometrology**

This scoping paper is elaborated after the discussions at the

Co-Nanomet workshop “Future European infrastructure in Nanometrology”  
Lyngby, 23<sup>rd</sup>/24<sup>th</sup> of September 2010

and in the

Co-Nanomet Task 4.2 Group “Future European infrastructure in Nanometrology”

Kai Dirscherl<sup>1</sup>, Kim Carneiro<sup>1</sup>, Leslie Pendrill<sup>2</sup> and Ludger Koenders<sup>3</sup>,

<sup>1</sup>Danish Fundamental Metrology, Denmark

<sup>2</sup>SP Sveriges tekniska forskningsinstitut, Sweden

<sup>3</sup>Physikalisch-Technische Bundesanstalt, Germany

## Table of Contents

1	Introduction to Infrastructures for Innovation, Education & Research in Europe .....	4
1.1	Infrastructures: Towards a Strategic Nanotechnology Action Plan .....	4
1.2	Funding options for infrastructures.....	10
1.3	European nanometrology facilities .....	13
1.4	Other infrastructures related to nanometrology.....	16
2	General approach to nanometrology infrastructures.....	17
2.1	The strategy for the future infrastructure.....	17
2.2	Impact evaluation.....	18
3	Infrastructures in nanometrology .....	21
3.1	Database of metrological services .....	21
3.2	Objectives of a nanometrological infrastructure .....	22
3.3	Infrastructure needs .....	23
4	Registered services in nanometrology.....	25
4.1	Dimensional Nanometrology .....	25
4.2	Chemical and Thin Film Nanometrology .....	27
4.3	Mechanical Nanometrology.....	28
4.4	Nanometrology for Structured Materials .....	29
4.5	Biological Nanometrology .....	30
5	Capabilities and control of the infrastructure.....	31
5.1	Action Points: Building of a distributed infrastructure in nanometrology .....	31
5.2	Communication and public engagement.....	33
5.3	Education and training .....	34
5.4	SWOT Analysis.....	35
6	References.....	36

# 1 Introduction to Infrastructures for Innovation, Education & Research in Europe

## 1.1 Infrastructures: Towards a Strategic Nanotechnology Action Plan

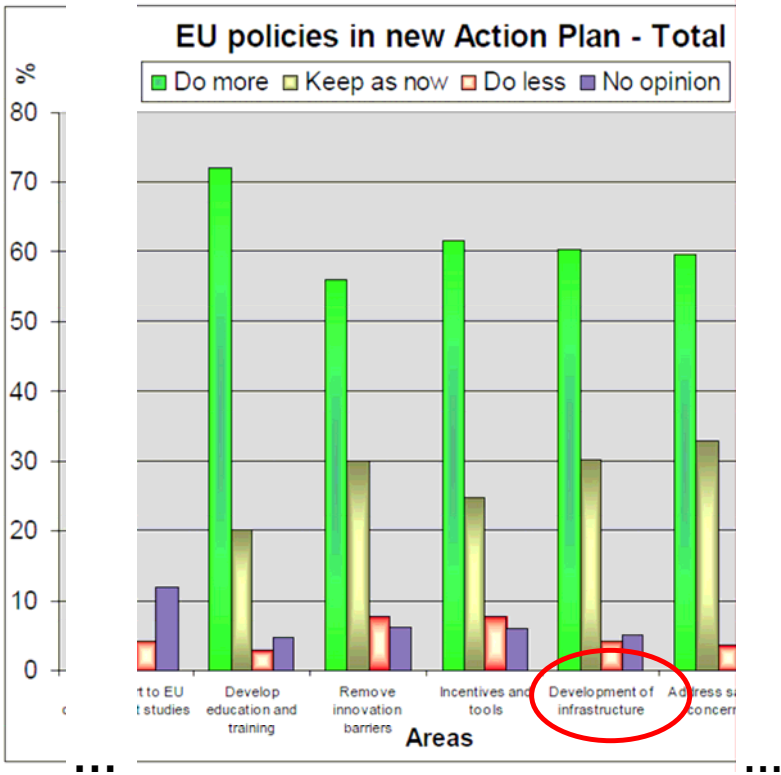


Figure 1: Extract of the results of the EC public online consultation “Towards a Strategic Nanotechnology Action Plan (SNAP) 2010-2015” [1]: 60% of the respondents request an increased development of infrastructures. Only the relevant central part of the original diagram is shown, along with the relevant axes.

Both experts and the general public see many benefits in nanotechnologies, as well as potential risks. More than 80% of respondents to a recent public consultation “Towards a Strategic Nanotechnology Action Plan (SNAP) 2010-2015” [1] have either high or reasonable expectations of nanotechnologies in general. Finally there is a perceived need to strengthen action in all areas of nanotechnology strategy pursued until now, from research and innovation to safety and outreach. Of the EU policies related to the new Action Points, the development of infrastructures in innovation, education and research are particularly emphasized, see figure 1. The same study emphasised the need for EU policies in the new Action Plan to do more in particularly: (a) developing education & training (b) developing better tools; (c) active communication and (d) international cooperation.

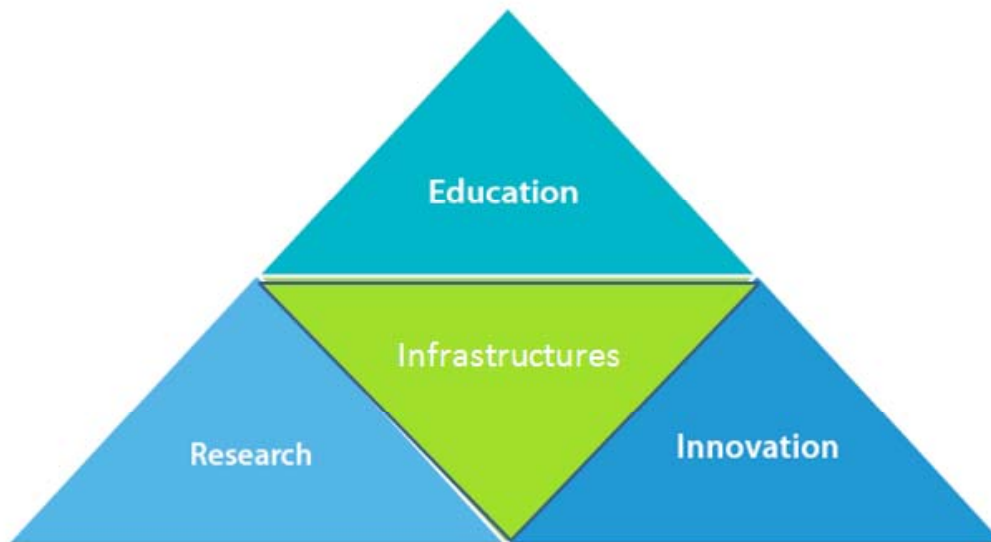


Figure 2: Infrastructures positioned within the knowledge triangle (adapted from [4])

Infrastructures – that is, strongly integrated resources either at a specific site (e.g. CERN) or in a distributed network – in general lie at the heart of the knowledge triangle – the beneficial combination of research activity, specialised education and innovation that advances our knowledge and understanding across all scientific and societal domains, see Figure 2.

#### *Innovation Infrastructures*

It is widely acknowledged that the industrial exploitation of nanotechnology in innovative products is still lagging, despite advances in nanoscience.

In order to sustain the expected considerable growth in nanoproducts, major investment in technological and manufacturing/business infrastructure is needed[2]. This includes metrology and standards which can be used at the nanoscale in support of conformity assessment of nanoproducts of all kinds.

Developments in nanotechnology place special demands on the required metrological infrastructure, while at the same time, the rate of nanotechnological development continues to increase in both volume and complexity. Demands are more extensive than can be provided by individual actors, simply because all stages of the innovation process have to be covered at the same time as nanotechnology is rapidly developing. A strengthening is needed of the existing network of European measurement facilities as well as investments in the development and introduction of new standards and measurement techniques, as part of the necessary infrastructure to support growth in nanotechnology. Few such standards and techniques exist today which can be used across the entire nanoscale range (1 nm to 100 nm) and existing

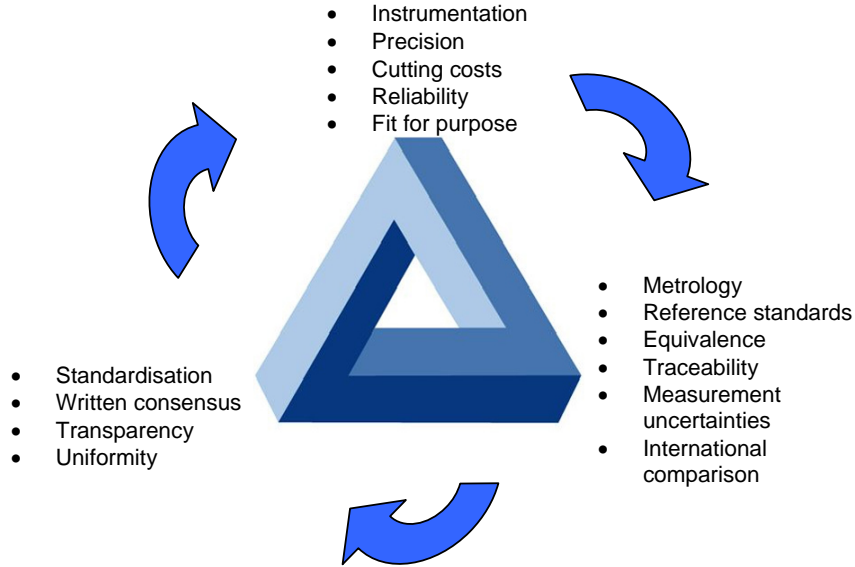


Figure 3 Triangle of standardisation, instrumentation and metrology, adapted<sup>1</sup>

measurement techniques and instrumentation will have to be developed further as whole new ranges of nanotechnological products will appear.

In the implementation of the priority themes for future European Nanometrology in the next decade (see Co-Nanomet European Strategy for Nanometrology Paper: ISBN 978-0-9566809-4-5) a number of dedicated infrastructures may be considered. Such infrastructures would work to consolidate effort at a Pan European level and enhance pathways to commercialisation of nanotechnologies. They may be applied as appropriate to the thematic area to be addressed. In some instances, a single centre may combine two or more roles of i) measurement instrumentation hub, ii) centre of excellence in measurement and iii) centre of metrology dissemination.

i) Coordinated measurement instrumentation hubs

Because of the cost of the necessary instrumentation, and in order to ensure efficient use of it, instrument hubs may be considered in specific technology areas. Where possible these hubs should be positioned around either national metrology institutes or large scale nanotechnology infrastructures. Examples of these include top class metrology tools of a value above €10m.

ii) Centres of measurement excellence

<sup>1</sup> Genesys whitepaper, ISBN 978-3-00-027338-4 (2009)

European centres of measurement excellence may be established in order to ensure that Europe maintains its strong research position in key areas of nanotechnology and associated metrology. The centres of excellence should be established as international, interdisciplinary centres drawing from the whole stakeholder base including industry, metrology institutes plus key research organisations. In this way nanometrology may be better positioned as an enabling part of the overall effort in contributing to major nanotechnology advances and exploitation. Such centres may provide opportunities and support for multidisciplinary research among investigators from a variety of disciplines and from different research sectors, including academia, industry and government laboratories.

The fostering of multidisciplinary research not only supports advances in knowledge, but also promotes the formation of relationships that enhance the transition of research results to a broader application base.

### iii) Centres of metrology dissemination

Centres of metrology dissemination may be established to ensure adequate levels of nanometrology knowledge and access to expertise for all key stakeholders across Europe. Such centres could be effectively linked with the high level priority themes defined in Vision 2020. They may foster the transfer of new technologies into products for commercial and public benefit under conditions of more rigorous understanding and controls. Hence they will also support the responsible development of nanotechnology in these fields. Linkages and input would be required from all key stakeholders including industry, NMIs, research organisations, standards and regulatory organisations and the Commission. They would provide a focal point for multiple agencies, including funding bodies, to support their planning and decision making processes for priority actions.

European industry has a further need for adequate access to calibration and test facilities and services. These centres could be established collaboratively between key partners such as EURAMET and European Accreditation, with the participation of the European Federation of National Associations of Measurement, Testing and Analytical Laboratories (EUROLAB) as well as relevant industry linking bodies.

Just as the nanometrology infrastructure approaches innovation in three ways, this triad can also be found again in the triangle of instrumentation, metrology and standardisation, see Figure 3. This figure graphically visualizes the interdependencies between state-of-the-art instrumentation, their

metrological characterization and finally the written agreement on how to implement a uniform, transparent and intercomparable measurement strategy for the instruments.

### *Education infrastructures*

One main aim of the CO-NANOMET project is to bring nanotechnology through to successful business by means of:

- relevant metrology tools
- suitably skilled human resources able to implement appropriately such tools
- a general dissemination of traceable nanometrology to the workplace.

A strengthening of a European educational infrastructure is needed in support of nanotechnological innovation through better measurements on the nanoscale.

With this in mind, one key observation is to place (nano)metrology in the right context, so that when people at the workplace have to choose the relevant metrology tools and human resources, they can relate product requirements – often in terms of specifications for conformity assessment – to the corresponding metrological requirements.

There are several means of disseminating nanometrology to the workplace. For example, new training material – in the form of courses, perhaps on the Internet (webinars, etc.), and compendia – is being developed – see CO-NANOMET Coordination of Education & Skills<sup>2</sup>. This is the task of the Centres of Dissemination CoDs supported by the NMIs.

The understanding of basic metrology concepts is limited:

Beyond the NMIs, a solid understanding of the basic metrology concepts is not sufficiently well-spread. This is the case for many industry branches, and results from an underexposure of pupils and students to these concepts, even at the academic, university level, where interest in the metrology subject is limited.

---

<sup>2</sup> <http://www.co-nanomet.eu/page1014/CoNanomet-Home/Coordination-Of-Education-And-Skills>

In making the Consultation of the CO-NANOMET task 4.3<sup>3</sup>, additionally studies have been made of:

- Programmes using local networks aimed at encouraging small to medium sized enterprises to exploit the opportunities offered by for example new micro- and nanotechnologies.
- Development of written standards (norms) as pedagogical material, e.g. guidelines

### *Research infrastructures*

At the national metrology level in Europe, there is already an extensive and increasing coordination of national metrological research, particularly thanks to a major European Metrology Research Programme<sup>4</sup> implemented on behalf of the European Union by the association EURAMET<sup>5</sup>. Nanometrological research is already included in a number of ERA-NET+ iMERAPlus projects in the 1<sup>st</sup> phase of the EMRP. As part of the major Art185 (former art 169) EMRP, there are plenty of opportunities for the formulation of new research projects in nanometrology, for instance, EMRP New Technologies Call 2011. This will have strong impact on the future structure of the NMI and their responsibility. For the future, in areas such as nanometrology, an opening up of future EMRP to wider researcher and stakeholder communities would be beneficial. The competitive process of application inherently leads to a formation of Centres of Excellence within the metrological fields. The CoEs will focus the research on their fields and interact with the stakeholders in order to define nanometrological requirements and register emerged needs.

In addition to this, new and multidisciplinary collaborative actions should be promoted, both for stimulating scalable application development for various nanometrological domains and for developing efficient middleware addressing outstanding issues with regard to measurement reliability, traceability, mutual recognition and further related topics within the fields of nanometrology.

In addition to EURAMET, during the Sixth Framework Programme, funding of research within nanotechnology infrastructures amount up to 40 M€ [3]. Support to Design Studies for new research infrastructures of clear European dimension and interest was introduced by the European Strategy Forum on Research Infrastructures ESFRI. A roadmap for pan-European research infrastructures was published<sup>6</sup>.

---

<sup>3</sup> CO-NANOMET European Consultation on Metrological Traceability, Standards and Dissemination of Metrology in Industrial Nanotechnology 2010

<sup>4</sup> [www.emrponline.eu](http://www.emrponline.eu)

<sup>5</sup> [www.euramet.org](http://www.euramet.org)

<sup>6</sup> ESFRI European Strategy Forum on Research Infrastructures European Roadmap for Research Infrastructures Implementation Report 2009 ISBN: 978-92-79-14602-2

Major upgrades of existing infrastructures are included, if the end result is intended to be equivalent to a new pan-European research infrastructure. All fields of science and technologies were considered. Design Studies have thus provided during FP6 the technical tools to address the conceptual design of new facilities in a bottom up fashion. In all cases, however, this instrument is not sufficient nor designed to produce a fully cost intensive production-ready detailed engineering design, and further commitment to advanced R&D is still required from the stakeholders.

Discussions are currently taking place within the European Commission to organise the support to selected ESFRI projects, after the successful completion of the Preparatory Phase. Such support under FP7 could take place under the budgetary year 2011 or 2012 and might be related for example to the strengthening of the "eco-system" of research infrastructures in specific fields. Additionally, further strategic support to the implementation of projects with substantial international cooperation could be given. Here an option presents itself for supporting the development of a comprehensive nanometrological infrastructure. In addition to addressing the needs of large scale radioation, the white paper<sup>7</sup> of the "Grand European initiative on Nanoscience and Nanotechnology using Neutron- and Synchrotron radiation Sources" GENNESYS also comments on the need for nanometrology research and technology. In the foreword it is stated that "Europe needs bright scientists, supported by efficient research infrastructures, to deliver on the promise of nanotechnology." In the foreword it is stated that "Europe needs bright scientists, supported by efficient research infrastructures, to deliver on the promise of nanotechnology." Such a dissemination of knowledge can e.g. be implemented by taking advantage of the FP7 Initial Training Networks (ITN)<sup>8</sup>, see also 3.2.

### **1.2 Funding options for infrastructures**

Regarding the funding of infrastructures, another report the Expert group of the ERA from 2008 [6] states that "the use of multiple source of funding (European Commission, Member States, private sector, and other institutions), different allocation procedure (call, negotiation), accountability (openness, transparency or efficiency) and complementarities amongst EU policies (cohesion, research, competition) will require a formal legal framework.", see Figure 4.

---

<sup>7</sup> Genesys whitepaper, ISBN 978-3-00-027338-4 (2009)

<sup>8</sup> [http://cordis.europa.eu/fp7/people/initial-training\\_en.html](http://cordis.europa.eu/fp7/people/initial-training_en.html)

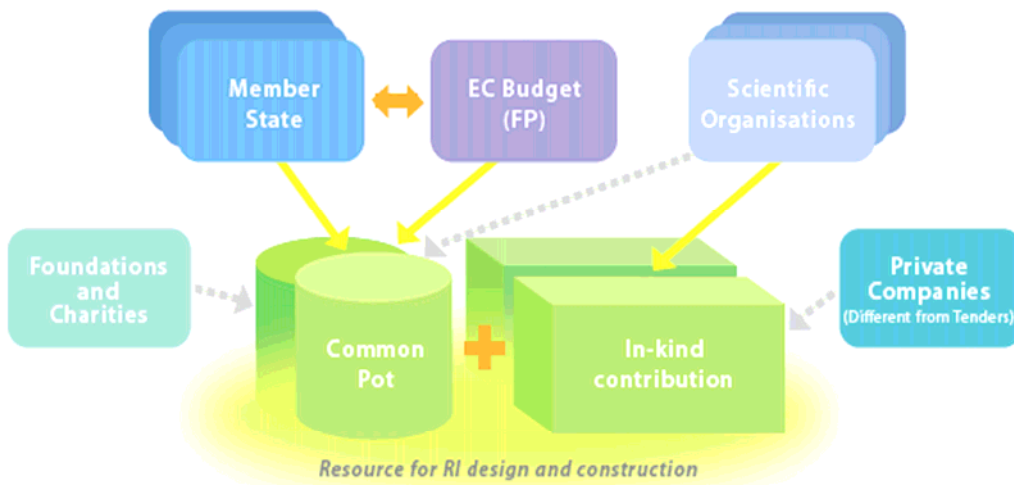


Figure 4: Proposed funding scheme for (Research) Infrastructures [4]

It should be noted that funding of 'open access' operations becomes more difficult in the current economy, however. Further funding possibilities include Joint Programming, the development of Public-Private Partnerships, Joint Technology Initiatives and the use of ERA-NET+.

*Joint Programming:*

Oposing the vast bulk of research programmes in Europe that run in an isolated way, leading to unwanted fragmentation or ineffectiveness, Joint programming aims at pooling national research efforts in order to make better use of Europe's precious public R&D resources and to tackle common European challenges more effectively in a few key areas<sup>9</sup>.

The European Council of March 2008 called on the Commission and Member States to explore the potential of Joint Programming, asking for joint activities to be launched by 2010. Areas for Joint Programming Initiatives are:

- Agriculture, food security and climate change
- Health, food and prevention of diet related diseases
- Cultural heritage, climate change and security

To date, the most developed joint programmes up until Framework FP7 are the Article 185 (ex 169). One such programme is indeed in metrology – the European Metrology Research Programme EMRP implemented by EURAMET.

By the end of 2010, the Council adopts a first set of initiatives for Joint Programming.

<sup>9</sup> [http://ec.europa.eu/research/era/areas/programming/joint\\_programming\\_en.htm](http://ec.europa.eu/research/era/areas/programming/joint_programming_en.htm)

It should then be possible to achieve the objective set by the 2008 Spring European Council: to launch common strategic activities, such as joint calls for proposals involving multi-national teams of researchers.

*Public-Private Partnerships (PPP):*

A recent article comments on PPP [8] comments on the consideration the public-private partnership (PPP) model for major construction and infrastructure projects from a local Danish point-of-view. A mixture of regulatory controversies among central government departments and strong public finances (making private finance largely redundant) can hinder the launch of PPPs. The article concludes that clear regulations are needed to support PPPs.

*Joint Technology Initiatives:*

Joint Technology Initiatives (JTIs)<sup>10</sup> are a means to implement the Strategic Research Agendas (SRAs) of a limited number of European Technology Platforms (ETPs). In these few ETPs, the scale and scope of the objectives is such that loose co-ordination through ETPs and support through the regular instruments of the Framework Programme for Research and Development are not sufficient. Instead, effective implementation requires a dedicated mechanism that enables the necessary leadership and coordination to achieve the research objectives. To meet the needs of this small number of ETPs, the concept of "Joint Technology Initiatives" has been developed. Platforms related to nanotechnology are the European Nanoelectronics Initiative Advisory Council ENIAC<sup>11</sup> and Nanotechnologies for Medical Applications<sup>12</sup>.

*Era-Net/Era-Net+:*

Springing from Era-Net Plus is the grant agreement no. 217257 - Implementing metrology in the European research area – Plus (iMERA-Plus), which was successfully launched in 2007 as part of the EMRP of EURAMET and was the first of a new type of medium-sized action launched under FP7 (ERA-NET Plus), which aimed at aligning and enhancing national programmes.

Another project NETWATCH has gone online<sup>13</sup>, a European Commission information platform on transnational R&D programme collaboration, with a current focus on the ERA-NET scheme. The objectives comprise providing information on Joint Calls, giving analysis and evidence of the impact of programme collaboration, supporting mutual learning among transnational programme networks. The NETWATCH database contains evidence of a Romanian project "Capacities - Development of RDI infrastructures and their better connection and use at national and

---

<sup>10</sup> [http://cordis.europa.eu/fp7/jtis/about-jti\\_en.html](http://cordis.europa.eu/fp7/jtis/about-jti_en.html)

<sup>11</sup> <http://www.eniac.eu/>

<sup>12</sup> <http://cordis.europa.eu/nanotechnology/nanomedicine.htm>

<sup>13</sup> <http://netwatch.jrc.ec.europa.eu/nw/>

international level", which has focussed on the support to R&D consortia involving companies and S&T organisations.

### ***1.3 European nanometrology facilities***

Amongst the European research infrastructures are the large-scale or singular facilities, scientific instruments, distributed facilities and interconnected networks, funded by Member States and supported by Community budget of the European Union and shared widely within and between scientific research communities.

This is also valid for the infrastructures of nanotechnology. A recent Co-Nanomet assessment has located more than European measurement facilities and instrumentations. They are listed in an online accessible database<sup>14</sup>, where they can be sorted and selected with respect to their measurement capability and location. The facilities comprise national metrology institutes (NMIs), public as well as private non-government organization (NGO), see Table 1 below.

---

<sup>14</sup> <http://search.co-nanomet.eu/?contentid=1172>, Capabilities Search

<b>Country</b>	<b>Facilities</b>	<b>Comment</b>
<b>EC States</b>		
Austria	10	Mix of UNI and GOV capability supported by strategic initiative Austrian Nano <sup>15</sup>
Belgium	14	Mix of RTO, GOV and UNI capability
Bulgaria	6	All GOV institutes from Bulgarian Academy of Sciences <sup>16</sup>
Cyprus	1	One UNI only
Czech Republic	22	Chiefly GOV Academy of Science <sup>17</sup> centres, supported by strategic action Nanotechnology.cz <sup>18</sup>
Denmark	9	Blend of UNI and RTO capability supported by the initiative NaNet <sup>19</sup>
Estonia	3	Major UNIs and one GOV centre
Finland	16	Broad spectrum of capability across UNI, RTO and GOV sectors supported by strategic initiative FinNano <sup>20</sup>
France	59	Many mixed UNI/GOV centres with national support from CNRS
Germany	125	Capabilities found in many GOV, RTO, LE and SME some technology mapping available <sup>21</sup>
Greece	7	All GOV institutes
Hungary	7	Mostly institutes from the Hungarian Academy of Sciences <sup>22</sup>
Ireland	8	All capability UNI based
Italy	36	Mix of mainly GOV, UNI and RTO supported by strategic initiative Nanotec IT <sup>23</sup>
Latvia	2	Major UNIs only
Lithuania	5	Major UNIs and GOV centres
Luxembourg	2	Two RTO only
Malta	1	One UNI has some capability
Netherlands	16	Significant LE and SME capacity focussed towards industrial access. Strategic support action Nanoned <sup>24</sup>
Poland	23	Some UNI, mainly GOV Polish Academy of Sciences institutes <sup>25</sup>
Portugal	8	Mostly UNI capability
Romania	6	All GOV institutes of Romanian Academy of Sciences <sup>26</sup>
Slovakia	9	Mostly UNI and branches of Slovak Academy of Sciences <sup>27</sup>
Slovenia	4	Mostly GOV institutes
Spain	35	Mix of centres, strategic support through NanoSpain <sup>28</sup>
Sweden	14	Significant RTO capability matching UNI sector
United Kingdom	63	Mix of centres with strategic national initiatives <sup>29</sup>
EU TOTAL	511	

<sup>15</sup> <http://www.nanoinitiative.at/>

<sup>16</sup> <http://www.bas.bg/>

<sup>17</sup> <http://www.cas.cz/>

<sup>18</sup> <http://www.nanotechnology.cz/>

<sup>19</sup> <http://www.nanet.nu/>

<sup>20</sup> <http://www.aka.fi/en-gb/A/Science-in-society/Research-programmes/Ongoing/FinNano/>

<sup>21</sup> <http://www.nano-map.de/>

<sup>22</sup> <http://www.mta.hu/index.php?id=406&type=0>

<sup>23</sup> <http://www.nanotec.it/>

<sup>24</sup> <http://www.nanoned.nl/>

<sup>25</sup> <http://www.english.pan.pl/>

<sup>26</sup> <http://www.acad.ro/def2002eng.htm>

<sup>27</sup> <http://www.sav.sk/?lang=en>

<sup>28</sup> [http://nanospain.org/nanospain\\_English.htm](http://nanospain.org/nanospain_English.htm)

<sup>29</sup> <http://www.innovateuk.org/deliveringinnovation/micronanotechnologycentres.ashx>

AC States		
Croatia	2	GOV institutes
Iceland	1	Only one UNI has capability
Israel	10	UNI and significant SME capability supported by strategic initiative Nanolsrael <sup>30</sup>
Liechtenstein	0	No capability, no NMI
Macedonia	0	No capability
Norway	7	Capability largely with UNI some RTO
Switzerland	16	Mostly UNI and GOV, supported by SNI initiative <sup>31</sup>
Turkey	7	Mix of UNI and GOV centres
AC Total	43	

**Table 1: Brief summary of identified nanometrology capabilities**

In order to allow metrological access and use of the facilities, the key concepts of metrology need to be installed. The main concept is the establishment of measurement traceability to the international system of units SI. As a consequence, the uncertainty of measurement can be evaluated, the measurement results become inter-comparable amongst the facilities and are mutually recognisable. First then a nanotechnology facility becomes a nanometrological facility.

For certain measurement tasks, however, a stable reproducibility of the measurements is sufficient, and the traceability is not immediately required.

A general list of metrological calibration and measurement capabilities can be accessed and searched online in the Key Comparison Database (KCDB) at the website of the International Bureau of Weights and Measures (BIPM)<sup>32</sup>.

A few findings regarding the European infrastructure of nanometrology shall be noted:

- 20 out of 34 National Metrology Institutes have no visible nanometrology capability
- Germany, United Kingdom, France, Italy and Spain account for more than 50% of the total European nanometrology facilities
- More than 75% of the nanotechnology facilities are from within the public sector
- The university research base is the single largest contributor to nanotechnology capability
- Profit-focussed organisations provide the clear majority of the private sector nanometrology contribution in France, Germany, Netherlands, United Kingdom and Israel
- Government funded Academies of Science in Bulgaria, Czech Republic, Hungary, Poland, Romania and Slovakia provide significant access to nanotechnological measurement facilities

<sup>30</sup> <http://www.nanoisrael.org/>

<sup>31</sup> <http://www.nccr-nano.org/nccr/>

<sup>32</sup> <http://www.bipm.org>

- Most evidently in Austria, Germany, Italy and Spain, regional government support of research infrastructure has created significant nanometrology capability

Compared with Japan or the USA, there are fewer researchers in Europe. According to a recent Communication from the commission to the council, the European parliament and the European economic and social committee, “Europe needs knowledge” [9]. An advanced infrastructure can assist to create rich environments, which in turn attract and retain researchers and experienced engineers and technologists. Transparency and open peer-reviewed access to infrastructures promote competition, enhance the international reputation and generate focal points for global collaboration.

#### ***1.4 Other infrastructures related to nanometrology***

##### *Modelling and simulation*

Scientists working on 10 research projects have been awarded precious computing time on JUGENE, one of the most powerful supercomputers in the world. The projects, which cover fields as diverse as astrophysics, earth sciences, engineering and physics, gained access to JUGENE thanks to the PRACE ('Partnership for advanced computing in Europe') project. Scientists in varied disciplines require access to supercomputers to solve some of the most pressing issues facing society today. PRACE is meeting this challenge head on by establishing a high performance computing (HPC) research infrastructure in Europe. Its work is supported by the Research Infrastructures budget lines of the EU's Sixth and Seventh Framework Programmes (FP6 and FP7), and it has been identified as a priority infrastructure for Europe by ESFRI, the European Strategy Forum on Research Infrastructures.

## 2 General approach to nanometrology infrastructures

Most nanometrology infrastructures are currently by the NMIs, since traceability to units at the nanoscale is primarily established at the highest national level.

In addition to this, nanotechnology infrastructures have been identified<sup>33</sup>. Most of them are funded by Member States and/or supported by European Community budget, private sectors. While the existing infrastructures must be strengthened, e.g. by cooperation in the EMRP, the establishment of traceability for relevant nanotechnology facilities is required in order to enable inter-comparability of measurement results and their mutual agreement. Appropriate methods are calibration by transfer standards such as reference material, or by direct instrumental comparison with a Pole of Excellence in the relevant field.

### **2.1 The strategy for the future infrastructure**

The infrastructure must encompass not only scientific but also technological developments. This will ensure that European stakeholders have access to

- Global traceable calibrations, including Inter-laboratory comparisons
- Metrology assistance in research and development
- Sound basis for forming public opinion
- Legislation that is based on proper standardisation

A proposed infrastructure consists of

- Infrastructure Management
- Advisory board
- Instrumentation hubs
- Centres of Excellence
- Centres of dissemination

Methods to promote resource exchange and pooling among Member States should be piloted by the advisory board.

Concepts to utilise existing resources more efficiently by sharing critical or unique resources are to be worked out by the management.

Plans for the financing have been discussed in 1.2. In addition, of the exploitation of further existing options can be taken into account, such as the ongoing EMRP or other funded programmes, where a cluster of national and international research co-operations are supported after a competitive and reviewed application process.

---

<sup>33</sup> <http://search.co-nanomet.eu/?contentid=1172>, Capabilities Search

## **2.2 Impact evaluation**

Calibration services that are already established or that will be developed in the further process can be used to attract customers in a free competition in Europe. This will improve the competences of the industry as well as demonstrate the created impact of the nanometrological infrastructure.

Any accomplishments of the infrastructure are to be visualised appropriately. This leads to common national and international level impact studies. It is envisioned that a board of external committees shall monitor and measure the impacts of infrastructures.

The impacts of nanometrology infrastructures relate to the impacts of the research, knowledge transfer and ultimately the innovation that they facilitate.

These can be classified as direct scientific impacts, the new knowledge created and the theoretical advancement of science achieved via the research they facilitate, and indirect or technological impacts, the innovations in the production of goods and services that arise as spin-offs from the development of research infrastructures or the benefits accruing from the advances in scientific knowledge that stem from their operation.

Following [5], other types of impacts may be defined apart from scientific and technological impacts. These are:

### *Economic impacts*

These are the short-term contribution to economic growth and employment arising from the construction and day-to-day operation of a nanometrology infrastructure, as well as medium to long-term effects on the economy relating to technological advances induced by the operations of a research institute.

### *Social impacts*

The contribution to general wellbeing arising from progress made in science, which stems from the research process and its contribution to improving the quality of life of citizens, as well as the creation of new jobs.

Type of impact	Measurement of impact:	Methods of analysis
Scientific impact	Scientific outputs, rate of utilisation, training and capacity building	Peer review; bibliometrics; statistical reports; administrative records held by nanometrology infrastructures; surveys of users
Technological impact	Actual and potential spin-off nanoproducts and measurement services; links to private sector; national statistical information on inputs and outputs	Survey of spin off companies and activities; in-depth interviews with scientific staff of nanometrology infrastructures; innovation surveys; factor productivity analysis
Economic impact	National and regional accounting input output models; autoregressive variance analysis models; analysis of administrative data held by the infrastructures	Contribution to GDP at regional and national levels; employment and incomes created at local, regional, national and pan-European levels
Social impact	Contribution to family and community wellbeing; amenity value of the facility, rate of employment	Synthetic reviews of evidence from science based on use of nanometrology; local population surveys
Political impact	Contribution to political stability, cohesion	Interviews with key informants; analysis of media publications
Environmental impact	Impact of nanomaterial on air, water quality; reduction of particle concentration	Synthetic reviews of evidence from science based on research infrastructures; analysis of environmental measures

Table 2 Overview of impacts of nanometrology infrastructures, inspired by [5]

#### *Political impacts*

The contribution to political stability and cohesion, resulting from the construction and operation of a nanometrology infrastructure and from the advances in science it facilitates.

#### *Environmental impacts*

There are direct effects relating to the construction and operation of the Instrumental Hubs of a nanometrology infrastructure (e.g. energy consumption, CO<sub>2</sub> footprint, water needs, radiation, other impacts on physical environment).

Indirect effects are e.g. the improvement in environmental conditions stemming from advances in science facilitated by a nanometrological research infrastructure. The environmental impact is immediately applicable to the increasing use of products enhanced with, e.g., engineered nanoparticles.

Due to the relatively different physical and chemical properties of nanomaterials, to the newness of synthetic nanoparticles and the mobility of aerosol and unbound nanoparticles, free nanoparticles are causing potential health and environmental side effects. Regulation of nanoparticles will require the development of nanometrological methods.

Regarding occupational health and workers safety, the lack of appropriate measurement and monitoring tools, of detailed information on hazards and exposure levels and use of nanomaterials are evident challenges.

Facilities that contribute to the nanometrological and nanotechnological infrastructure shall be committed to periodical impact assessment exercises. The different impact studies carried out at national and international level must be reviewed to strengthen the methods used to measure the scientific, social, economic, environmental impacts (both direct and indirect) of nanometrology infrastructures.

For this purpose, a board of independent experts within the field of nanometrology must be established as well as an advisory board. Current efforts of impact evaluation (e.g. ERAWATCH<sup>34</sup> or ERIDWatch<sup>35</sup> for infrastructures in particular) should be extended in such a way that they assist with monitoring the evolution of RIs, principally by collecting relevant information for impact assessments in a harmonised manner.

The concept of a 'common methodology' for impact assessments of RIs should draw on expertise developed in social, economic and environmental disciplines and will be multidisciplinary by definition and covering the whole ecosystem related to specific RIs.

All RIs of European relevance should be committed to carrying out periodical impact assessment exercises, monitored by external committees to provide information about the way they fulfil their goals and serve societal demands. The European Commission and/or ESFRI should gather and publish the results.

The different dimensions of the management of the RIs should be assessed, such as overall governance of the facilities, financial practices, management of human resources, innovation policy, intellectual property rights, etc. This should be designed to generate an agreed set of performance indicators.

The results of an impact assessment and monitoring of nanometrology infrastructures will have direct consequences in future regulation and aid the risk management of the infrastructures. The assessments help determine the critical mass of the infrastructure, and if necessary give indication for the need of a dynamic expansion or reduction of the infrastructure.

---

<sup>34</sup> <http://cordis.europa.eu/erawatch/index.cfm>

<sup>35</sup> <http://www.eridwatch.eu/>

### 3 Infrastructures in nanometrology

#### 3.1 Database of metrological services

The most longstanding resource containing nanometrology capability information is that held by the BIPM<sup>36</sup> in support to the Mutual Recognition Arrangement of the CIPM (CIPM MRA) of national measurement standards and of calibration and measurement certificates issued by national metrology institutes of members. A database Calibration and Measurement Capabilities – CMCs is available which covers wide ranging metrology capabilities, the most relevant to the scope of the Co-Nanomet project being those concerning Length. While this database undoubtedly holds a large amount of valuable information for the metrology community, when the focus is upon the nanoscale, the CMC is less useful in mapping capabilities. Aside from those national metrology institutes of selected member states, members of the BIPM are not in the main focussed upon the development of research-driven nanometrology techniques. It is the case that the National Metrology Institutes of the majority of EC states are more concerned with what is termed “legal metrology” – the underpinning of legislation concerning the quality of measurements for trade, safety, etc.<sup>37</sup> and understandably do not directly contribute to the nanometrology landscape at the present time. It is likely that the future will see significant adjustment of this position through strategic partnerships or other means, as nanometrology becomes increasingly significant in legislative terms.

YES	NO
Czech Republic, Denmark, Finland, France, Germany, Italy, Netherlands, Poland, Romania, Spain, Sweden, Switzerland, Turkey, United Kingdom	Austria, Belgium, Bulgaria, Croatia, Cyprus, Estonia, Greece, Hungary, Iceland, Ireland, Israel, Latvia, Liechtenstein, Lithuania, , Luxembourg, Macedonia, Malta, Portugal, Norway, Slovakia, Slovenia

Table 3 NMI coverage of nanometrology capability (e.g. surface texture, roundness, line spacing) from BIPM data

In summary, the BIPM database offers some information concerning nanometrology capabilities across the EC, but only within its member and associate organisations, thus capturing only a fraction of the capacity and capabilities that are actually available within research and other organisations throughout the EC. This is illustrated in Table 1, where NMI capabilities in the sub 100 nm dimensional measurement realm, as documented by the BIPM, are summarised for states encompassed by the capability mapping undertaken during this project.

<sup>36</sup> <http://www.bipm.org/>  
<sup>37</sup> <http://www.welmeq.org/>

It should be noted that while the BIPM website features regularly updated news items concerning the developing capabilities of member organisations, much of the information contained within the CMC database itself dates back as far as 2001. Clearly, an update of structured information available through the BIPM to potential nanometrology users would be of benefit. For this purpose, BIPM has been approached by the Co-Nanomet consortium to implement the option of filtering the database with respect to the keyword 'nano'. This is currently considered by BIPM.

### **3.2 Objectives of a nanometrological infrastructure**

The main task of the nanometrology infrastructure is to waylay a network to assist the stakeholders in carrying out their strategy in nanometrology. It is centred around the solving of specific problems, the establishment of traceability and the provision and transfer of metrological knowledge.

There are already existing networks that can be used to strengthen and expand the infrastructure in nanometrology.

#### *European Metrology Research Programme*

With respect to further advancement in the technological aspects of nanometrology, the European Metrology Research Programme EMRP<sup>38</sup> can be taken advantage of. EMRP is a metrology-focused European programme of coordinated research and development that facilitates closer integration of national research programmes. The EMRP is jointly supported by the European Commission and the participating countries within the European Association of National Metrology Institutes (EURAMET e.V.). The EMRP will ensure collaboration between National Measurement Institutes, reducing duplication and increasing impact.

Advantages of EMRP:

- As the main participants are NMIs, the coordination, sharing and distribution of existing knowledge as well as new research findings are immediate and inherent in the EMRP.
- The annual calls have a competitive nature, thereby enabling dynamic allocation of resources and allowing a flexible pan-European interaction between NMIs and stakeholders
- The forming of Centres of excellence is supported, too, as a group of experts is even more focused on a chosen research topic
- Collaboration beyond NMIs is initiated, as links to stakeholder interests and future impact are part of the projects

---

<sup>38</sup> <http://www.emrponline.eu/>

### *Initial training networks*

Marie Curie Initial training networks (ITN)<sup>39</sup> aim to improve early-stage researchers' career prospects in both the public and private sectors. The EURAMET EMRP indeed already reserves 10% of its budget (40 M€) for researcher excellence and mobility grants, including specifically non-NMI actors. This will be achieved through a transnational networking mechanism, aimed at structuring the existing high-quality initial research training capacity throughout Member States and Associated Countries.

The impact of Initial training networks is focused on the transfer and distribution of knowledge. ITN can be used to:

- Strengthen interdisciplinary and international cooperation
- Initialise the transfer of knowledge
- Train PhD students, preserving and potentially increasing the knowledge
- Bring in non-NMIs and establish new contacts, thereby enlarging the infrastructure

### **3.3 Infrastructure needs**

The necessary infrastructure for nanometrology in ten years' time that satisfies the vision will be based on the current decentralised European organisation of metrology. It consists of NMIs and IRMM at the most sophisticated level, accredited laboratories at the medium level and industrial production level at the working level. It must take into account and take note of the current tendency of specialisation and coordination between European NMIs. It should be built on the following cornerstones:

#### *Coordinated Instrument Hubs*

Because of the costs of the necessary instrumentation, and in order to ensure efficient use of it, once it is purchased, instrument hubs should be established. They should be centred around NMIs but should have connections to research centres and universities, who may possess instruments that cannot justifiably be installed at an NMI. Examples of this may be top class electron microscopes of a value above 10 million €.

---

<sup>39</sup> [http://cordis.europa.eu/fp7/people/initial-training\\_en.html](http://cordis.europa.eu/fp7/people/initial-training_en.html)

#### *Centres of Excellence*

European centres of excellence should be established in order to ensure that Europe maintains its strong research position in nano-science. They should be established as international, interdisciplinary centres with NMI's as equal partner participants.

#### *Centres of Dissemination*

Regional centres of dissemination should be established on order to ensure that European industry has adequate access to calibration and test facilities and services. An innovation infrastructure in nanometrology will network and integrate actors in each field – from policy makers to metrologists so that these can work together to tackle the major challenges. For instance, they could be established as a collaboration between EURAMET and other members of the 4E + C collaboration (European Accreditation, EUROLAB, the European laboratory Collaboration; EURACHEM and CEOC).

4 Registered services in nanometrology

4.1 Dimensional Nanometrology

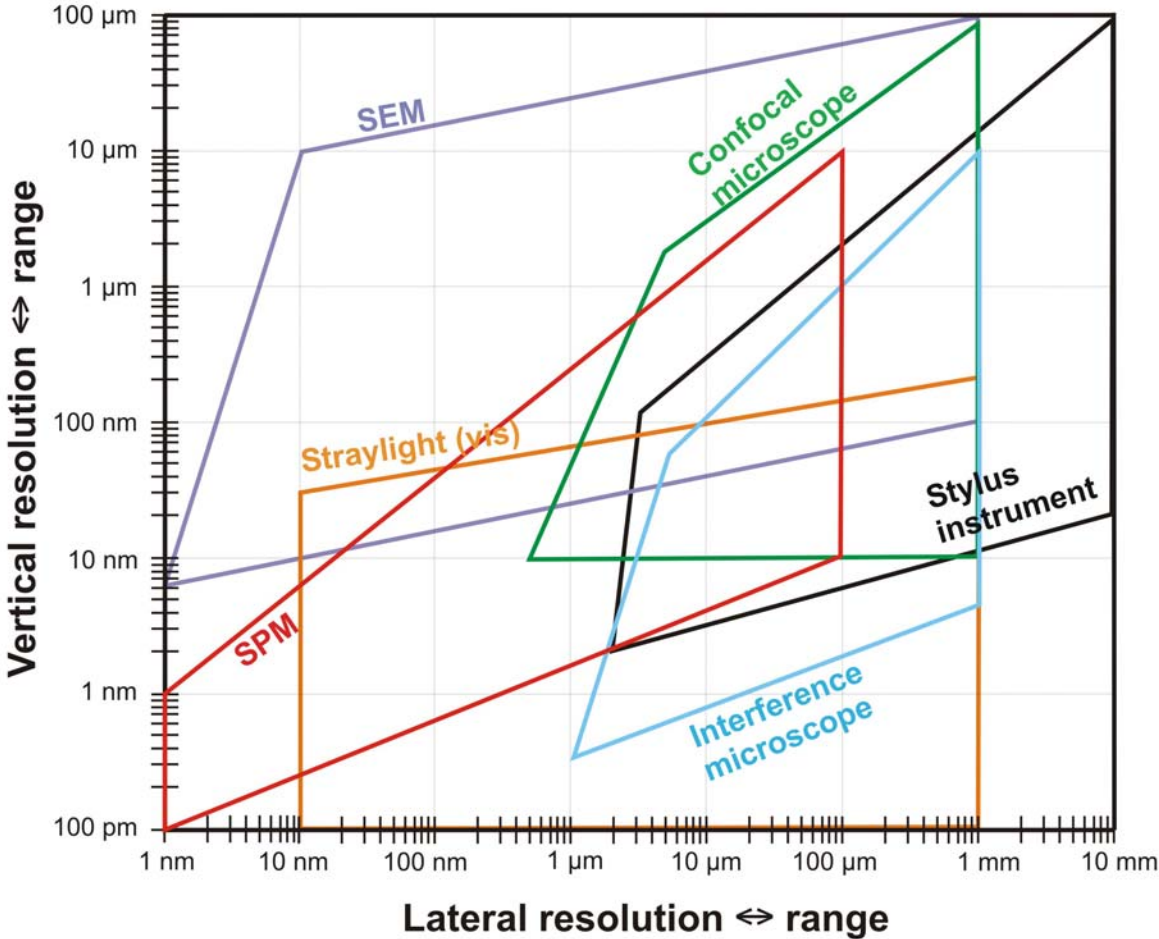


Figure 5 Measurement techniques and their typical dynamic ranges in the lateral (wavelength) and vertical (amplitude) directions

Dimensional nanometrology represents area of nanometrology with the highest amount of registered metrological services. The BIPM KCDB database appendix C contains more than 180 entries in Europe, distributed in up to 19 countries. Table 4 below lists the entries in the database in connection to the measurand. The measurands are taken from the Nanometrology Foresight Review [10], where a poll amongst 31 leading European metrology institutes yielded the most relevant measurands and measurement techniques. The first number per line gives the amount of laboratories that have registered a nanometrological service concerning the stated measurand, while the number in brackets indicates in how many different countries these services are distributed. It should be noted that the measurement of the average size of a particle population is

not registered as a metrological service. However, monodisperse particles suspended in liquid are available as Standard Reference Material (SRM) issued with a certificate by NIST, or as Certified Reference Material (CRM) from IRMM.

**Electrical nanometrology** is mostly identical to dimensional (line width, surface texture etc.) since the devices (nano)fabricated depend on the dimension. Furthermore for the ITRS roadmap the dimensional nanometrology is combined with thin film metrology and surface chemical analysis. As the measurands of the electrical nanometrology to a large extent are similar to those of the dimensional nanometrology, the comments for the dimensional nanometrology apply also here.

Measurand	Number of laboratories, number of different countries in brackets	
	Euramet countries	non-European
2D/3D standards	23 (7)	1
Line width (photo masks)	3 (2)	1
Pitch line standards, 1D-Grating	25 (7)	2 (2)
Surf. Texture. step height	12 (8)	10 (8)
Surf Texture, Roughness	36 (14)	18 (14)
Flatness	44(16)	10(5)
Particle size	0	0
Displacement	44 (19)	2(2)

**Table 4** Number of registered dimensional nanometrology service in the BIPM KCDB Annex C per measurand. The number in brackets denotes the number of countries in which these services are available.

The fast increasing fields of CNT and Graphene used as material for electrical devices have its own dynamics beyond the scope of this project.

## 4.2 Chemical and Thin Film Nanometrology

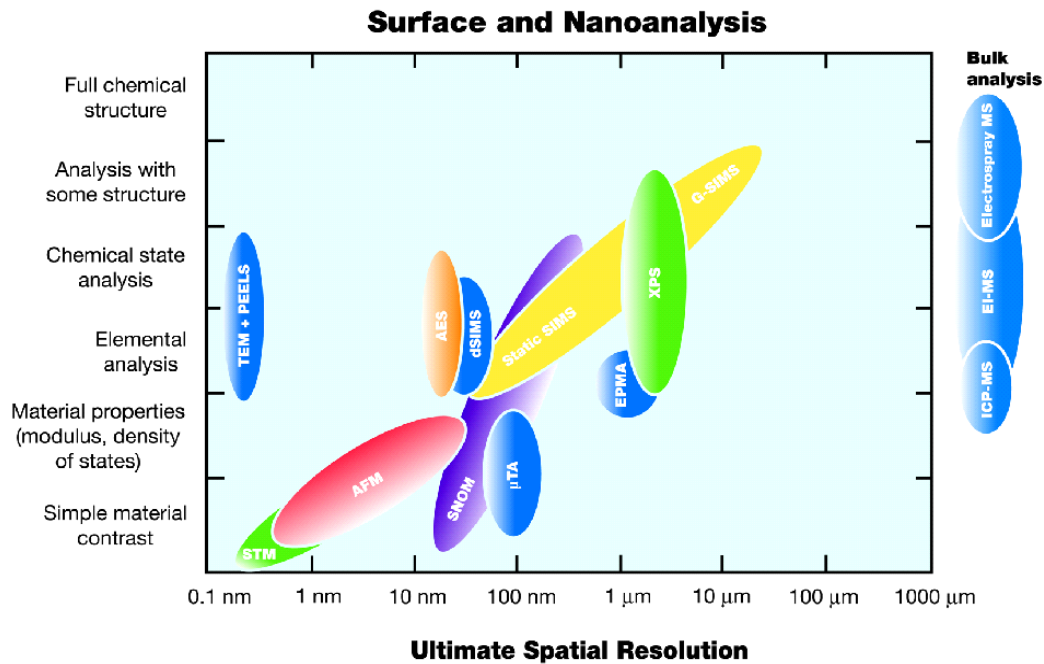


Figure 6 Methods of surface chemical analysis (NPL Website (2009), <http://www.npl.co.uk/nanoscience/surface-nanoanalysis/surface-and-nanoanalysis-research> © Crown copyright 2009. Reproduced by permission of the Controller of HMSO and the Queen's printer for Scotland)

More than 20 methods for chemical and thin film measurements were identified in the Foresight Review. Figure 6 shows an excerpt of these. Out of the many methods, however, only three techniques have registered metrological services in the BIPM KCDB. These are XPS, XRR and AFM, all related to thin film analysis. Reasons might be related to a relative late establishing of a CC-QM working group for surface analysis in 2003.

**4.3 Mechanical Nanometrology**

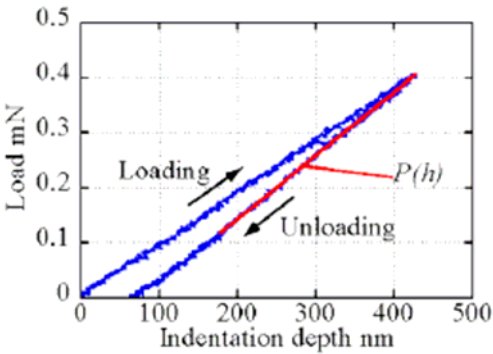
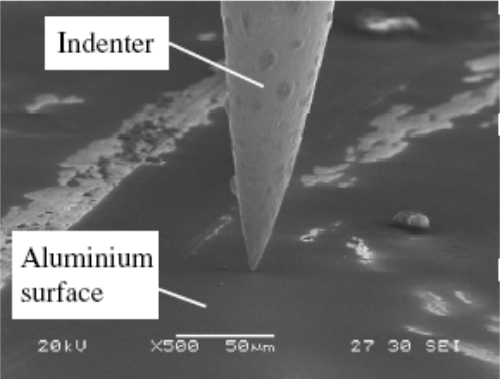


Figure 7 Indentation of sharp tungsten probe into aluminium in nanomechanical AFM [7] showing in-situ image of experiment and load-displacement curve

With regard to force, the experimental top-down development from micro-newton to nanonewton has been performed, but no service has been registered so far in the BIPM KCDB. Measurands encompass Nanoindentation. Nanomechanical (Hardness), Nanotribological AFM Mechanical Micro-/NanoForce.

#### 4.4 Nanometrology for Structured Materials

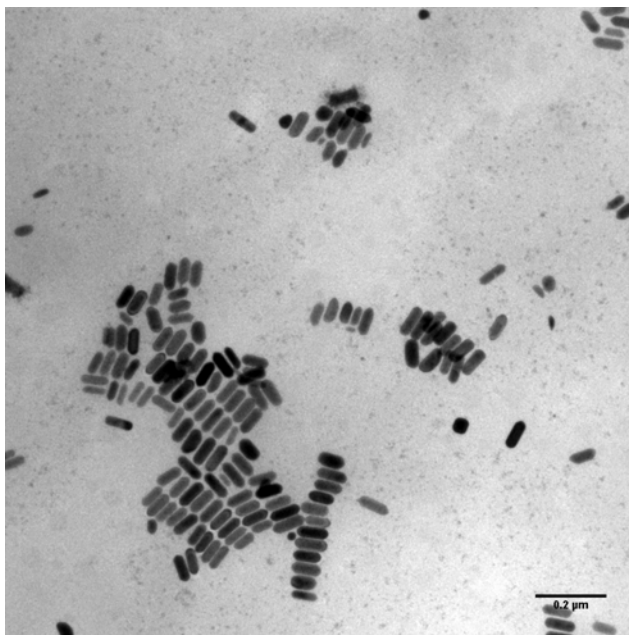


Figure 8 *Transmission electron image of gold nanorods (NPL)*

A Pan-European Research Infrastructure for Nanostructures (PRINS), [www.prins-online.eu](http://www.prins-online.eu) exists. The project focuses on all needed preparatory actions to enable in the following phase the construction of a Research Infrastructure called Pan-European Research Infrastructure for Nanostructures (PRINS), with the aim of enabling European innovative research for the ultimate scaling of electronics component and circuits.

Regarding the metrological services within nanonstructured materials, eight measurands for were identified in the Foresight Review. Out of these, only optical properties as measured by a refractometer is registered in the BIPM KCBD Annex C.

#### 4.5 Biological Nanometrology

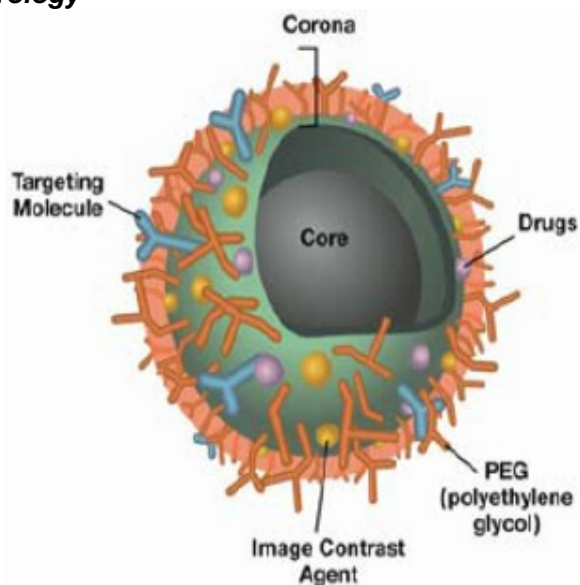


Figure 9 Schematic diagram of molecule on nanoparticle surfaces with core, drug layer and targeting molecules. Such complex structures are being used in nanomedicine and targeted drug delivery

Since bio-nano has developed very rapidly in the last few years, a metrological infrastructure has not manifested itself yet. The BIPM KCBD Appendix C does not contain any services related to the measurands relevant for biological nanometrology, such as the quantification, distribution, structure and activities of biological materials at the nanometer scale.

Also, activity standards for biological molecules are still not traceable to the SI.

However for bio-surfaces there is a large need for traceable measurements of:

- i) the number of molecules present,
- ii) molecular distribution
- iii) what their structures
- iv) whether they are active on the surface

Biological nanometrology therefore requires immediate action to establish a measurement infrastructure support to enable safe, reliable and high quality commercial products.

A first approach has been initiated: The EU-paper "Concept for a European Infrastructure in Nanobiotechnology - Final report of the FP7 Support Action EuroNanoBio" [11] notes as a top priority the strengthening of the contacts between key players in the field. Even though the infrastructure sketched in [11] represents a concept for nanobiotechnology, it can provide Instrumental Hubs and most likely parts of the regional Centres of Dissemination for the metrology infrastructure.

## 5 Capabilities and control of the infrastructure

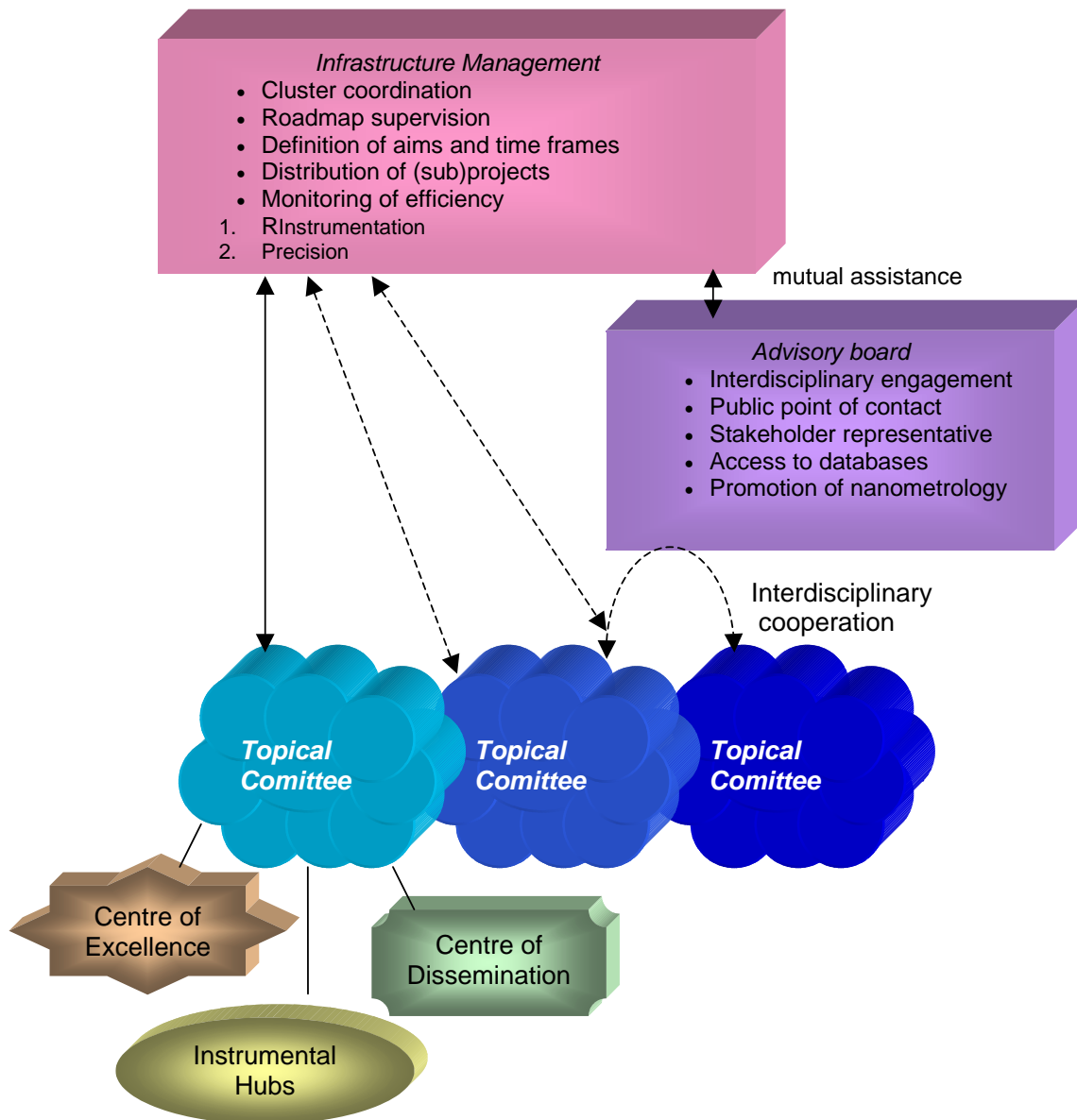


Figure 10 Diagram of European nanometrology infrastructure

This chapter introduces the vision of a future infrastructure in nanometrology. Action points concerning the construction, the communication and education and training are stated. A SWOT analysis concludes the vision. Figure 10 summarizes the structure and actions points in a diagram.

### 5.1 Action Points: Building of a distributed infrastructure in nanometrology<sup>[L5]</sup>

**1.** To cover the large range of scientific disciplines necessary for well-supported nanometrology and the diversity of application areas, a European infrastructure has to be built on a dedicated central management which in turn controls the clusters of regional Centres of Excellence, Centres of Dissemination and Coordinated Instrument Hubs. These Centres and Hubs should have world-class facilities and expertise within their field of nanometrology, as well as high levels of engagement between industry and academia. Integration to an already existing metrology “network” would be useful.

**2.** The Infrastructure Management connects and coordinates the nanometrology clusters to share knowledge and equipment, even interdisciplinary where necessary, focusing on results and assisting in the definition of the aims. It guides the distribution of nanometrology projects within an existing and further developing nanometrology infrastructure (e.g. Euramet), allocating fixed periods of time to the individual task. The Central Management monitors the critical mass of the clusters, and pro-actively engages the infrastructure development by dynamically re-allocating the affiliation of institutions within the clusters. The infrastructure can be reduced if necessary where redundancies appear, saving resources. It can also be locally expanded where a problem solution requires the expertise of further nanometrology facilities. An expansion of the infrastructure can be accomplished e.g. by promoting the development of more industrial-oriented research facilities, or via greater involvement of the private sector.

These means allow an efficient and resource conserving usage of the infrastructure, increasing its time of response to actual tasks.

It is recommended that the management, as described here, is embedded in the EURAMET e. V. organization.

**3.** Under the supervision of the Infrastructure Management, an advisory board improves the engagement between academic measurement disciplines, research centres and companies inside and between the involved clusters. This helps problem solving within the infrastructure. Acting as a public point of contact as well as a switch board, the advisory board relates and distributes metrology concepts, proposals or other kinds of requests of stakeholders and other parties of interest with. If necessary, the advisory board also assists the efficiency of the infrastructure by subdividing larger, possibly interdisciplinary, projects.

It will be the duty of EURAMET to set up the appropriate infrastructure advisory board, its structure and appropriate rules. The members of the advisory board should be from industry, academia, and NMIs.

4. Existing technical roadmaps for each of the fields of nanometrology , such as developed by EURAMET TC-L, should be monitored and adjusted actively in order to provide a constantly updated catalyst for collaboration between industry and academia within the infrastructure.

5. Set-up and upgrading of the regionally distributed clusters will require local, national and European political support and funding supplemented by private investments at a later more mature stage.

### **5.2 Communication and public engagement**

6. The advisory board should also support the stakeholders, especially SMEs, to help articulate their needs and interests to regulatory and standardisation bodies.

7. The infrastructure should provide pools of experts and professional communication tools necessary for engagement with the public.

8. Promotion of the capabilities of nanometrology to stakeholders, SMEs and the public in general should be facilitated by showcasing examples of successful exploitation of nanobiotechnology.

9. Engagement of the European nanometrology infrastructure with research centres outside Europe should be encouraged.

10. Public access to nanometrology and its services must be established. This can be done by setting up a public portal which is globally accessible. It must be connected to the BIPM KCDB to allow an overview of existing services of nanometrology. The link to the KCDB must be direct, however it should be modified instead to make nanometrology services clearly visible from non-nanometrological services. The public portal should also link to the database of the “European co-operation for Accreditation” (EA)<sup>40</sup>, which lists accredited calibration services.

It should be the task of EURAMET to set up the described “infrastructure portal”

---

<sup>40</sup> <http://www.european-accreditation.org/>

### **5.3 Education and training**

**11.** The highly interdisciplinary nature of nanometrology requires the integration of dedicated academic nanotechnology modules preferably at the MSc or PhD level. In order to promote metrology as such, education metrology should be part of the academic lecturing.

**12.** Because nanometrology touches on many important wider issues - especially within biological nanometrology - teaching an understanding of ethical and social aspects and training in science communication and public engagement should be included at the MSc and PhD level.

**13.** Due to the rapid development in nanotechnology, targeted education and training programmes for in-career training need to be developed, with focus on metrological issues. This is perhaps closest to the main aim of the CO-NANOMET project – to bring nanotechnology through to successful business: relevant metrology tools, suitably skilled human resources able to implement appropriately such tools and several means of disseminating nanometrology to the workplace have been studied.

## **5.4 SWOT Analysis**

This analysis states the strengths, weaknesses, opportunities and threats concerning the establishment of nanometrology infrastructures in Europe.

### *Strengths*

- Metrology in Europe is already coordinated by Euramet e. V. This body can handle the task related to the establishment and operation of the proposed European nanometrology infrastructure.
- Nanotechnological facilities are already existing

### *Weaknesses*

- Much of the current European nanotechnology instrumentation is not available for metrology purposes, i.e. it is not traceable, its measurement capability is not well characterised, and it is not part of an interlaboratory comparison program.
- Stakeholder access to metrology equipment is limited.

### *Opportunities*

- To expand EMRP projects on nanometrology to establish the necessary nanometrology infrastructures
- To use available national and European funding, dedicated to infrastructures, to improve the nanometrology infrastructure.

### *Threats*

- The lack of public understanding of metrology in general
- Planning of activities mainly on regional level rather than on a pan-European level. However, local activities if coordinated at EU-level might be useful.
- The public fear of “nano”. New innovative products do not receive the deserved acceptance, which in turn can hinder further advances in nanometrology

## 6 References

---

- [1] Report on the European Commission's Public Online Consultation, TOWARDS A STRATEGIC NANOTECHNOLOGY ACTION PLAN (SNAP) 2010-2015, [http://ec.europa.eu/research/consultations/snap/report\\_en.pdf](http://ec.europa.eu/research/consultations/snap/report_en.pdf)
- [2] A vision for strengthening world-class research infrastructures in the ERA, Report of the Expert Group on Research Infrastructures, ISBN: 978-92-79-14214-7 (2010)
- [3] COMMISSION STAFF WORKING DOCUMENT, Accompanying document to the COMMUNICATION FROM THE COMMISSION TO THE COUNCIL, THE EUROPEAN PARLIAMENT AND THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, Nanosciences and Nanotechnologies: An action plan for Europe 2005-2009. Second Implementation Report 2007-2009 {COM(2009)607 final}
- [4] ESFRI European Strategy Forum on Research Infrastructures European Roadmap for Research Infrastructures Implementation Report 2009 ISBN: 978-92-79-14602-2
- [5] A vision for strengthening world-class research infrastructures in the ERA, Report of the Expert Group on Research Infrastructures, ISBN: 978-92-79-14214-7 (2010)
- [6] Developing World-class Research Infrastructures for the European Research Area (ERA), Report of the ERA Expert Group, ISBN 978-92-79-08312-9 (2008)
- [7] Conclusions on research joint programming, 2982nd COMPETITIVENESS (Internal market, Industry and Research) Council meeting, Brussels, 3 December 2009
- [8] Petersen, Ole Helby, "Regulation of Public-Private Partnerships - The Danish Case", Videnskabelige tidsskrift, maj 2010, Public Money and Management, 30(3):175-182
- [9] COMMUNICATION FROM THE COMMISSION TO THE COUNCIL, THE EUROPEAN PARLIAMENT AND THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE: Nanosciences and Nanotechnologies: An action plan for Europe 2005-2009. Second Implementation Report 2007-2009{SEC(2009)1468}
- [10] Nanometrology Foresight Review ISBN 978-0-9566809-5-2
- [11] Concept for a European Infrastructure in Nanobiotechnology, Final report of the FP7 Support Action EuroNanoBio, January 2010