Co-Nanomet

Co-ordination of Nanometrology in Europe

Report on Future Training Requirements

REPORT ON FUTURE TRAINING REQUIREMENTS

This deliverable is associated to the Task 3.2 Developing European Skills in Nanometrology:

In line with the rapid development associated with nanotechnology, training needs within nanometrology are under constant development. To define and focus future training development, a training needs analysis has been completed. Having defined a set of key skills required within the field, these have been mapped on to a matrix of knowledge/skill level against skill type as a basis on which to plan future training provision. For a given technical area e.g. traceability (see Table 1 below) the matrix defines the level of skill required; varying from an awareness of concepts only at one extreme to the application of specialist knowledge at the other. Against this, the stage at which such training should be applied is defined e.g. training delivery to degree level students. This model then differentiates those areas which should be delivered through the education system and those to be delivered through a vocational training route.

The training needs analysis provides a guidance list of topics to be considered in future training curricula addressing a range of business sectors and technologies environments.

	1. Awareness of concepts only	2. Expenence of the application of such skills	3. Application of specialist knowledge
Analytical instrumentation	Degree level students	Higher degree students	Company employee
Traceability, qualification and validation principles	Higher degree students	Company employee	Role for consultants

Table 1: Matrix of key skills against required knowledge levels

Training strategy

All training initiatives implemented as a result of this analysis should be aligned with the “European Education Environment”. This strategic framework for education and training recognises that knowledge, and the innovation it sparks, are the EU's most valuable assets, particularly in light of increasing global competition.

The long-term strategic objectives of EU education and training policies are:

- Making lifelong learning and mobility a reality;
- Improving the quality and efficiency of education and training;
- Promoting equity, social cohesion and active citizenship;
- Enhancing creativity and innovation, including entrepreneurship, at all levels of education and training.

Recommendations and common principles have been developed in the areas of key competences for learners, quality assurance in higher education and in vocational education and training, quality of mobility, validation of non-formal and informal learning, lifelong guidance and the recognition of qualifications abroad.

According to the “New skills for new jobs” education report, training and jobs are inseparable; there is a relation of interdependence between them.

This can be found across all strategies, policies or measures taken at European and world level by competent bodies.

Thus, at European level, we know several components are included in the Lifelong Learning Strategy, the UNESCO perspective, and according the OECD point of view, including:

- Skills for life and career
- Flexibility and adaptability
- Initiative and self-targeting
- Social and cross-cultural skills
- Productivity, Coordination & project management and responsibility
- Skills for learning and innovation
- Creativity and Innovation
- Critical thinking and problem solving
- Communication & collaboration
- Digital skills and competences
- Media, ICT and computer skills

With the focus on nanotechnology and nanometrology, research brings an increasing demand for qualified staff. With the development of new products and services, the demand for well trained staff in industrial fields of work, such as production, quality assurance and in marketing and distribution will also increase.

To develop the commercial potential of nanotechnology, industry and society are required to equally share quantitative characterization and reliable measurement techniques, in order to sustain the competitiveness and confidence in future products and services. Integrating metrology in production processes, so that it provides reproducibility, low cost, speed and is user-friendly.

Educational programs have to be implemented to improve the capabilities of the university and companies, creating a multidisciplinary community dedicated to applied research in nanoscale metrology.

Qualification profiles contain characteristics of knowledge, skills and faculties, that are prerequisites for certain jobs in nanometrology. They cover further education, the development of intermediate qualifications, academic degrees and higher degrees.

The current scope of research activities in nanotechnology is the reason for the high demand for personnel with high level university degrees.

A variety of business environments are interested in this kind of personnel training in nanotechnology issues. Notable industries are, for example:

- automotive, both in exterior coatings such as improvements in vehicle efficiency and the environmental improvement;
- electronics, developing new devices;
- construction, external and structural changes in materials;
- textile, improving the fabric properties;
- medical and pharmaceutical, researching new treatments based in improved drugs.

Nanotechnology as production technology is currently in a transitional phase from basic research or applied science to production. At this stage of development, nanotechnology will demand in medium-term personnel with intermediate-level qualifications.

The demand for staff with qualifications below university level is comparatively low at present. Nevertheless, there are studies that record cases of a lack of qualified staff below university level.

Employees with qualifications below university level need particular interdisciplinary knowledge and strong social competences to take part in cooperation and innovation processes in the enterprises.

	Laboratory assistant	Specialist in documentation	Product adviser for nano applications	Analytical instrumentation	Traceability	Validation	Etc.
Below University level / Company employee							
Degree level							
Higher degree level							

Cross-sector orientation of nanotechnology requires interdisciplinary knowledge not only in natural sciences such as physics, chemistry and biology, but also in engineering sciences.

A corresponding acknowledgement of degrees, at the international level, can be guaranteed by the use of a recognised credit-transfer system for academic recognition, for example the European Credit Transfer System (ECTS) and the European Credit system for Vocational Education and Training (ECVET), allowing transparency and recognition of vocational education and training. These systems should allow the control of levels in the nanometrology field as a certification procedure rather than in superior levels as in vocational training levels.

Besides validation and recognition of training by a credit transfer system, a qualitative assessment and validation of prior learning should be conducted to stress the didactic approach/method of training measures.

An approach to the qualification offers should be developed and a modular system of training implemented.

In addition, the modules of further training themselves should be combined and based on each other. The modules can be combined either in transversal or in vertical reading depending on the need.

	Introduction/ Basics	Production/ process	Documentation	Analytical instrumentation	Traceability/ Validation	Research and development	Etc
Engineered nanoparticles	Module i	Module ii	Module iii	Module iv	Module v	Module vi	
Nanobiotechnology	Module ...	Module ...	Module ...	Module ...	Module ...	Module ...	
Thin Films and Structured Surfaces	Module ...	Module ...	Module ...	Module ...	Module ...	Module ...	
Critical Dimension	Module ...	Module ...	Module ...	Module ...	Module ...	Module ...	
Modelling and Simulation	Module ...	Module ...	Module ...	Module ...	Module ...	Module ...n	

Structure of the professional qualifications system

The proposed structure consists of professional qualifications arranged by level of qualification. In a first approach, it is necessary to divide the qualifications into different levels depending on the final job. The three levels of professional qualification are based on the professional competency required for each

productive activity, taking into account different criteria such as knowledge, initiative, autonomy, responsibility and complexity, amongst others, necessary for the accomplishment of each activity.

Qualification levels

The management of the skill levels is conducted on the basis of the professional competence required in the production systems, according to criteria of the activity to develop as knowledge, initiative, autonomy, responsibility, and complexity:

- Level I: Vocational training and companies employees

This level includes low-level employees who have a basic understanding of the occupation through education or experience. They perform routine or moderately complex tasks that require limited exercise of judgement and provide experience and familiarisation with the employer's methods, practices and programmes. They may assist staff in performing tasks that require skills equivalent to a level II and may perform higher-level work for training and developmental purposes. These employees work under close supervision and receive specific instructions on required tasks and the results expected. Work is closely monitored and reviewed for accuracy.

- Level II: Degree level or deeply laboratory experience

Able to work independently on individual projects and ultimately to manage project groups, they can write reports and clearly document experimental work. At this level, employees need to be able to gather and analyse relevant information from a wide variety of sources and identify and propose solutions to problems. Besides this, they will have technical and computing skills.

- Level III: Requires an advanced degree (Master or Ph.D.)

Fully competent employees who have a sufficient level of experience in the role to plan and conduct work requiring judgment and independent evaluation, selection, modification and application of standard procedures and techniques. These employees use advanced skills and diversified knowledge to solve unusual and complex problems. They may supervise or provide direction to staff performing tasks requiring skills equivalent to level I and II. These employees will receive only technical guidance and their work will be reviewed for effectiveness in meeting the establishment procedures and expectations.

The professional qualifications

- Definition:

A Professional Qualification (PQ) is defined as a set of professional competences that can be acquired through vocational education and training modules or any other kind of learning structure, as well as through work experience. It is understood that a person is qualified when he or she achieves the expected outcome during his or her professional performance, with reasonable resources and quality levels. From a formal point of view, a qualification is a group of competences (knowledge and capabilities) that satisfy occupations and job posts in the labour market.

The competence of one person comprises the whole range of personal, professional and academic knowledge and capabilities of that person, acquired following different paths and at all levels available.

At the same time, a competence unit is the minimum set of professional qualifications which can be partially recognized and accredited.

- The professional qualification structure:

Each qualification has a general competence that defines briefly the employee's essential tasks and functions. Other elements are also described, including the professional environment in which the qualification takes place, the corresponding productive sectors and the relevant occupations or posts that can be accessed with that qualification.

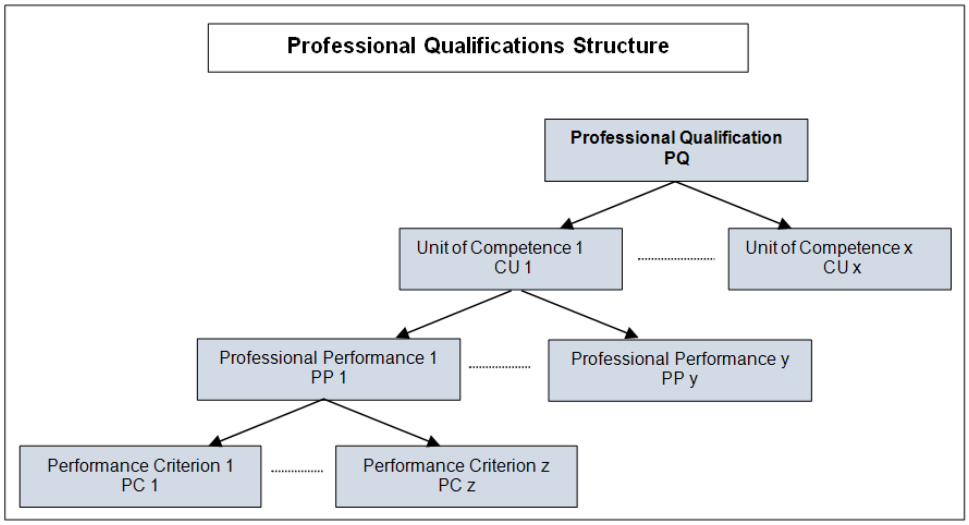
- The Competence Unit:

Every qualification consists of Competence Units (CU). The competence unit is the minimum set of professional competences that can be partially recognised and accredited. Every competence unit is linked to a learning module that describes the necessary learning to acquire that particular competence unit.

This structure facilitates the assessment and accreditation of every competence unit acquired by an employee, both through work experience and non-formal or informal learning. Recognised and accredited competence units can be accumulated in order to obtain the accreditation of a qualification. Each competence unit will have a standardised format, which includes its identification information and the specifications of that competence.

The competence units are divided into Professional Performances (PP). These establish the expected behaviour of one person, i.e. the expected consequences or results of the activities performed by that person. They help to show whether person is competent in a competence unit.

The Performance Criteria (PC) express the acceptable level of one professional performance to meet the productive organisation's targets and are reference guides for the assessment of professional competences.



Professional qualifications structure

The associated skills training

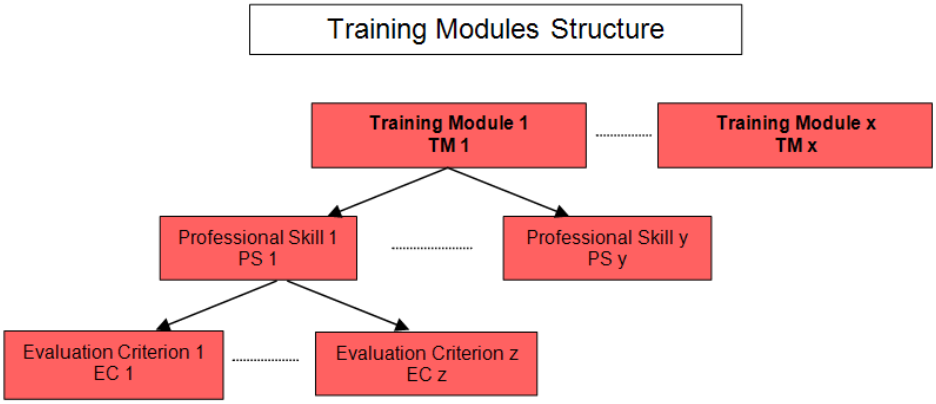
- The Training Module (TM):

Each competence unit is associated with a learning module, which describes the necessary learning to acquire that competence unit.

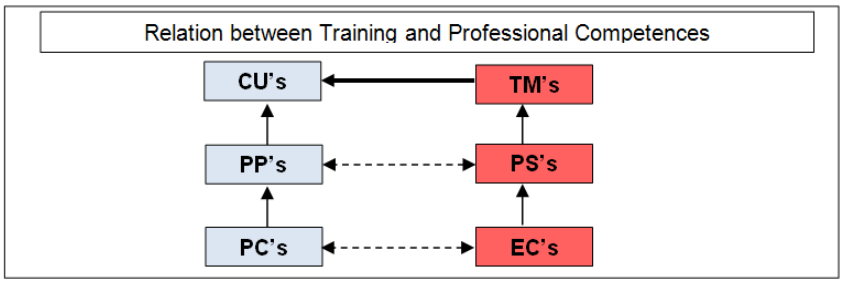
A Training Module (TM) is a coherent set of training associated with the units of competence that make up skills. It is the smallest unit of training to determine the diplomas and professional certificates.

Training specifications contain Professional Skills (PS), the expression of the expected outcomes of peoples' learning situations at the end of the training module.

The Evaluation Criteria (EC) is a set of details for each capacity that indicate the degree of detail acceptable to it. They define the scope and level of ability and the context in which it is to be evaluated.



Training modules structure



Relations between training and professional skills

Each competence unit is associated with a learning module, which describes the necessary learning to acquire that competence unit.

As a first step, and trying to simplify this difficult task, five Action Groups have been analysed to define levels of training required for each task performed in each of the areas. With this information five matrices have been developed containing the key skills against the skill levels required in each specialty (annexes I, II, III, IV and V).

From this group of matrices, specific training programs needed to cover all aspects required by industry and research institutions can begin to develop. It will be necessary to consolidate the professional qualifications and the general training structure in order to balance the training offer and implement the new professional skills into the nanotechnology market, while avoiding duplicities in nanometrology training programs.

Summary

A training needs analysis has been completed for the emerging field of nanometrology. Key roles or functions have been defined against the important nanometrology areas of:

- Measurement of thin film thickness
- Scanning probe, scanning electron microscopes and critical dimension

- Engineered nanoparticles
- Metrology in nanobiotechnology
- Modelling and simulation

For each role, key skill requirements have been identified and the level at which training in this area should be delivered has been assessed.

The outputs of this analysis will act as a guide to training providers in the field, from both industry, academia and NMIs, to direct their future training development and provision.

ANNEXE I: MEASUREMENT OF THIN FILM THICKNESS KEY SKILLS

Detailed below, the specified field of nanometrology is broken down into key roles or functions. For each role, key skill requirements are identified and the level at which training in this area should be applied to deliver such skills.

In some instances, the role may be performed by workers with different levels of training. For this reason, in some cases more than one training level is specified.

The different required levels are explained below and the colour code is as follows:

LEVEL 1	Vocational training and company employees
LEVEL 2	Degree level or high laboratory experience
LEVEL 3	Requires an advanced degree (Masters or PhD)

Role of Function	**Key Skill Requirements**	**Training level Required**	
Laboratory assistant	Basic equipment use and sampling	1	2
Specialist for documentation on nanobiotechnology	Data processing	1	2
	Data bank	2	
	Research	2	
Quality assurance	Standards	1	2
	Working conditions	1	2
	Health & Safety	2	
	Environmental risk	3	
Production techniques	Deposition: PVD, CVD, PECVD, electrodeposition, electron-beam , photo-assisted, molecular beam epitaxy, atomic layer deposition	2	
	Reaction: thermal oxidation, chemical derivatisation, surface treatment, plasma oxidation, chemical phase synthesis	2	
Basic research:	Materials	2	
	Instruments	2	
	Chemical	3	
	Electrical and magnetic	3	
	Synthesis of nanoparticles	3	
	Mechanical	3	
	Optical	3	
	Thermal	3	
	Surface	3	
Materials	Reference	3	
	Storage and preparation	2	

Measurement equipment	Methods for particle characterization	3
	Measuring techniques: Thickness (1)	3
	Measuring techniques: Surface properties and chemistry (2)	3
	Measuring techniques: Structure (3)	3
	Measuring techniques: Optical (4)	3
	Measuring techniques: Mechanical (5)	3
	Measuring techniques: Electrical (6)	3
	Measuring techniques: Thermal (7)	3
	Measuring techniques: Magnetic (8)	3
	Measuring techniques: Porous films (9)	3
	Equipment maintenance	1
	Software of instruments	2
	Calibration	3

Measurement requirements and results	Thickness	2
	Chemical composition	2
	Structure	2
	Conformality, uniformity and integrity	2
	Surfaces and interfaces	2
	Impurities and dopants	2
	Mechanical properties	2
	Validation	3
	Uncertainty & Traceability: thickness and area mass	3
	Data evaluation	3

Further details for specified keys skills requirement:

(1) Thickness

a) Cross section

Scanning electron microscopy (SEM)

Focused Ion beam microscopy (FIB)

Transmission electron microscopy (TEM)

b) Step-Height

Atomic Force Microscopy (AFM)

Profilometry

c) Optical

X-ray Reflectivity (XRR)

Optical reflectometry (OR)

Spectroscopic ellipsometer (SE)

Optical interferometry (OI)

d) Analytical Methods

X-ray photoelectron spectroscopy (XPS)

Auger electron spectroscopy (AES)

X-ray fluorescence (XRF)
Electron Beam XRF microanalysis (EDX/EPMA)
Fourier transform infrared spectroscopy (FTIR)
Rutherford backscattering (RBS)
Medium energy ion scattering (MEIS)
Secondary ion mass spectrometry (SIMS)

(2) Chemical composition
a) Composition
XPS
AES
b) Molecular structure
Static SIMS
c) Surface energy
Contact angle
d) Work Function
Kelvin probe
Ultraviolet Photo-Electron Spectroscopy (UVPES)
e) Impurities
TXRF
SIMS

(3) Structure
a) Crystalography
XRD
GAXRD
GIXRD
EBSD
TEM
B) Internal nanostructure
SEM
TEM
EBSD

(4) Optical
a) n, k
Spectroscopic ellipsometry
b) Reflectivity
Spectrophotometry

(5) Mechanical
a) Modulus, Hardness, Viscoelasticity
Nanoindentation
AFM
b) Scratch resistance
Nanoscratch tester
c) Friction

Pin-on-disc
Nanotribology test system
AFM (lateral force microscopy)

d) Stress

XRD
EBSD
Raman

e) Adhesion

Peel test
Pull-off test
Indentation test
Flexure test

(6) Electrical

a) Sheet resistance

Four point probe

b) Carrier mobility

Hall measurement

c) Dielectric breakdown strength

Capacitor microfabrication

(7) Thermal

a) Thermal conductivity

Micro-thermal analysis

b) IR emissivity

IR spectrophotometry

(8) Magnetic: Coercitivity

Vibrating sample magnetometry

(9) Porous films

a) Porosity, pore size distribution

Adsorption measurements

b) Surface area

BET

ANNEXE II: SCANNING PROBE, SCANNING ELECTRON MICROSCOPES AND CRITICAL DIMENSION KEY SKILLS

Detailed below, the specified field of nanometrology is broken down into key roles or functions. For each role, key skill requirements are identified and the level at which training in this area should be applied to deliver such skills.

In this case the required training level is separated into three different specialities:

- Service: Related to the use of facilities
- Development: Point of view of engineering issues
- Research: Dedication to research of new solutions

The different required levels are explained below and the colour code is as follows:

LEVEL 1	Vocational training and company employees
LEVEL 2	Degree level or high laboratory experience
LEVEL 3	Requires an advanced degree (Masters or PhD)

Role or Function	**Key Skill Requirements**	**Training level Required**		
		Service	Development	Research
Laboratory assistant	Basic equipment use and sampling	1		
Specialist for documentation	Data processing	1		
	Data bank	1	2	
	Research	1	2	
Quality assurance	Standards: transfers from NMI's. Comparability and mutual recognition	1	2	
	Guidelines and written standards	1	2	
	Working conditions	1	2	
	Health & Safety		2	
	Environmental risk		2	3
Application fields	Nanoelectronics	1	2	3
	Components of a nanophotonic systems	1	2	3
	Engineered nanoparticles (ENP ENAG)	1	2	3
	Fabrication of nanometer-scale structures (nanoelectromechanical systems - NEMS)	1	2	3
	Surface structure of nanocoatings	1	2	3
	Wear, impact and scratch resistance	1	2	3
	Friction & Lubrication	1	2	3
	Wetability by liquids	1	2	3
	Easy-to-clean surfaces, self-cleaning surfaces	1	2	3

Basic research:	Materials	1	2	3
	Application fields: Nanoelectronics; components of a nanophotonic systems; engineered nanoparticles; fabrication of nanometer-scale structures (nanoelectromechanical systems - NEMS); surface structure of nanocoatings; wear, impact and scratch resistance; friction & lubrication; wettability by liquids; easy-to-clean surfaces, self-cleaning surfaces		2	3
	Instruments		2	
Materials	Reference		2	3
	Storage and preparation		2	3
Measurement instrumentation and techniques	Scanning Probe Microscopes (1)		2	3
	Scanning Electron Microscopes (SEM, TEM)		2	3
	Critical Dimension measurements		2	3
	Position measurement techniques: capacitive, inductive, incremental based, strain gauges, interferometers	1	2	3
	Equipment maintenance	1	2	3
	Software of instruments	1	2	3
	Calibration (by laser interferometers)	1	2	3
Measurement requirements and results	Distance	1	2	2
	Angle	1	2	2
	Pitch	1	2	2
	Height	1	2	2
	Width	2	2	3
	Diameter	2	2	3
	Geometry	2	2	3
	Roughness, surface texture	1	2	3
	Thickness	1	2	3
	Volume (shape)	1	2	3
	Validation	2	2	3
	Uncertainty & Traceability: thickness and area mass	2	2	3
	Data evaluation	2	2	3

Further details for specified keys skills requirement:

(1) Scanning Probe Microscopes (SPM)

Atomic Force Microscope (AFM)
Scanning force microscope (SFM)
Frictional force microscope (FFM)
Magnetic force microscope (MFM)
Electrostatic force microscope (EFM)
Kelvin probe force microscope (KPFM)
Near-field acoustic microscope (SNAM)
Tunnelling acoustic microscope (TAM)

ANNEXE III: ENGINEERED NANOPARTICLES KEY SKILLS

Detailed below, the specified field of nanometrology is broken down into key roles or functions. For each role, key skill requirements are identified and the level at which training in this area should be applied to deliver such skills.

In some instances, the role may be performed by workers with different levels of training. For this reason, in some cases more than one training level is specified..

The different required levels are explained below and the colour code is as follows:

LEVEL 1	Vocational training and company employees
LEVEL 2	Degree level or high laboratory experience
LEVEL 3	Requires an advanced degree (Masters or PhD)

Role or Function	Key Skill Requirements	Training level Required	
Laboratory assistant	Basic equipment use and sampling	1	2
Documentation	Data processing	1	2
	Data bank	2	
	Research	2	
Quality assurance	Standards	1	2
	Working conditions	1	2
	Health & Safety	2	
	Environmental risk	3	
Basic research	Materials	2	
	Instruments	2	
	Results	3	
Materials	Reference (airborne, suspension, powder)	3	
	Storage and preparation	2	
Measurement equipment	Methods for particle characterization	3	
	Measuring systems (*)	3	
	Equipment maintenance	1	
	Software of instruments	2	
	Calibration	3	
Measurement and results	Measurement properties	1	2
	Modelling	3	
	Image processing	2	
	Statistics programmes	2	
	Validation	3	
	Uncertainty & Traceability	3	
	Data evaluation	3	

Further details for specified keys skills requirement:

(*) Measuring Systems
Gas Adsorption (surface area and pore width distribution (nanotubes)
Dynamic Light Scattering (particle size determination)
Differential Centrifugal Photosedimentation (PSD)
US Attenuation (PSD)
Small Angle X-ray Scattering (PSD)
Differential mobility (Aerosol PSD)
Electron microscopy (PSD and shape analysis)

ANNEXE IV: METROLOGY IN NANOBIOTECHNOLOGY KEY SKILLS (Health Care focus)

Detailed below, the specified field of nanometrology is broken down into key roles or functions. For each role, key skill requirements are identified and the level at which training in this area should be applied to deliver such skills.

In some instances, the role may be performed by workers with different levels of training. For this reason, in some cases more than one training level is specified..

The different required levels are explained below and the colour code is as follows:

LEVEL 1	Vocational training and company employees
LEVEL 2	Degree level or high laboratory experience
LEVEL 3	Requires an advanced degree (Masters or PhD)

Role or Function	**Key Skill Requirements**	**Training level Required**	
Laboratory assistant	Basic equipment use and sampling	1	2
Specialist for documentation on nanobiotechnology	Data processing	1	2
	Data bank	2	
	Research	2	
Quality assurance	Standards	1	2
	Working conditions	1	2
	Health & Safety	2	
	Environmental risk	3	
Basic research: **- Molecular biology** **- Nanobiotechnologycal products** **- Medical technology (diagnostics and therapeutics)** **- Pharmaceutics** **- Cosmetic procedures**	Materials	2	
	Instruments	2	
	Bioproduction/fermentation	3	
	Biomimetical procedures	3	
	Synthesis of nanoparticles	3	
	Tissue engineering	3	
	Genetic therapy	3	
	Cancer therapy by nanobiotechnology	3	
Materials	Reference	3	
	Storage and preparation	2	
Measurement equipment	Measuring techniques: Analysis&Diagnostics (1)	3	
	Measuring techniques: Imaging&Localization (2)	3	
	Equipment maintenance	1	
	Software of instruments	2	
	Calibration	3	

Measurement requirements and results (Depends on the application or product)	Biological systems in the medical field	3
	Diagnostic applications	3
	Safety, risk and health perspective (effects of exposure, toxicity, biocompatibility)	2
	Production and manufacturing: monitoring biological and biochemical production processes	2
	Validation	3
	Uncertainty & Traceability	3
	Data evaluation	3

Measurement characteristics	Identification, detection and quantitative determination of concentrations of specific biological substances	2
	Localization and imaging of specific biological substances or structures in cells and tissues	2
	Interactions between biological entities	3
	Quantification and localization of nanoparticles in complex systems (diagnostic applications and cancer therapy)	3
	Implant material characteristics such as surface roughness and topography parameters, surface chemical properties, chemical stability/degradability, and coating thicknesses and morphology.	3
	Biocompatibility	3
	Environmental and health effects of nanoparticle exposure	3

Further details for specified keys skills requirement:

(1) Analysis & Diagnostics

Circular Dichroism (CD) Spectroscopy
Dynamic Light Scattering (DLS)
Electron diffractions (TEM, SEM)
ELISA (Enzyme-Linked Immunosorbent Assay)
Fluorescence Correlation Spectroscopy (FCS)
Fluorescence Labelling
Fourier Transform Infrared Spectroscopy (FTIR)
Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES)
Inductively Coupled Plasma Mass Spectrometry (ICP-MS)
Magnetic Tweezers
Nuclear Magnetic Resonance (NMR)
Quartz Crystal Microbalance (QCM)
Quantitative Real Time PCR
Spectroscopic Ellipsometry
Surface Plasmon Resonance (SPR)
Optical Waveguide Lightmode Spectroscopy (OWLS)

(2) Imaging&Localization

Atomic Force Microscopy (AFM)
Coherent Anti-Stokes Raman Spectroscopy (CARS)
Confocal Laser Scanning Microscopy (CLSM)
Spinning Disk Confocal Microscopy
Differential Interference Contrast microscopy (DIC)
Desorption Electrospray Surface Ionisation(DESI)
Fluorescence Imaging with One-nanometre Accuracy (FIONA)
Fluorescence Lifetime Imaging Microscopy (FLIM)
Fluorescence Recovery After Photobleaching (FRAP)
Förster Resonance Energy Transfer (FRET)
Matrix Assisted Laser Desorption Ionisation Mass Spectrometry (MALDI-MS)
Near-field Scanning Optical Microscopy (NSOM or SNOM)
Photo Activated Localisation Microscopy (PALM)
Raman Spectroscopy: Surface Enhanced (SERS) and Tip Enhanced (TERS)
Scanning Electro Chemical Microscopy (SECM)
Scanning Electron Microscopy (SEM)
Scanning Ion Conductance Microscopy (SICM)
Secondary Ion Mass Spectrometry (SIMS)
Small Angle Neutron Scattering (SANS)
Stimulated Emission Depletion (STED)
Sum Frequency Generation Spectroscopy (SFG)
Total Internal Reflection Fluorescence Microscopy (TIRFM)
Transmission Electron Microscopy (TEM)
X-ray Photoelectron Spectroscopy (XPS)

ANNEXE V: MODELLING AND SIMULATION KEY SKILLS

Detailed below, the specified field of nanometrology is broken down into key roles or functions. For each role, key skill requirements are identified and the level at which training in this area should be applied to deliver such skills.

In some instances, the role may be performed by workers with different levels of training. For this reason, in some cases more than one training level is specified..

The different required levels are explained below and the colour code is as follows:

LEVEL 1	Vocational training and company employees
LEVEL 2	Degree level or high laboratory experience
LEVEL 3	Requires an advanced degree (Masters or PhD)

Role of Function	**Key Skill Requirements**	**Training level Required**	
Laboratory assistant	Basic equipment use and sampling	1	2
Specialist for documentation	Data processing	1	2
	Data bank	2	
	Research	2	
Quality assurance	Standards	1	2
	Referenced data	1	2
	Working conditions	1	2
	Health & Safety	2	
	Environmental risk	3	
Applications	Experimental fabricating and measuring nanoscale devices	2	
	Analysis of the physical properties of nanoobjects	2	
	Calculate the size range in which the wanted physical effect occurs	2	
	Estimate measurement uncertainties (virtual instrument)	2	
	Analytical theory	2	
Basic research	Materials	2	
	Realistic models	2	
	Modelling materials and structures	2	
	Simulation of integration processes	2	
	Design of novel equipment	2	
	Extensibility and portability of the software	2	
	Validation and verification of the modelling code	2	
	Software development	3	
	New applications: green electronics, organic and large area electronics, bio-markers, bio-chip & drug design, drug delivery on a spot	3	

Modelling & Simulation techniques	Finite Element Modelling (FEM)	2
	Density Functional Theory (DFT)	2
	Monte Carlo Methods	2
	Molecular Dynamics (MD)	3
	Ab-initio Molecular Dynamics	3
	Dissipative Particle Dynamics	3
	Field Theory Polymer Simulation	3

Techniques for nanopaticles characterisation	Diffraction and pair distribution function	3
	Monte Carlo Modelling of SEM	3
	Monte Carlo Modelling of AFM	3

Techniques for modelling processes	Time dependent Monte Carlo methods	3
	Raman spectroscopy and related calculations	3
	Photophysics	3
	Molecular transport and molecular nanometrology	3

Measurement equipment for experimental techniques	Atomic Force Microscopy (AFM)	3
	Electron microscopy: TEM, SEM, LEEM	3
	X-ray and neutron scattering. Optical measurements: IR, Raman, FT-IR	3
	Near-edge X-ray absorption fine-structure spectroscopy (NEXFAS)	3
	Equipment maintenance	1
	Software of instruments	2
	Calibration	3

Measurement requirements and results	Size and shape	2
	Structure	2
	Aspect ratio	2
	Volume vs surface	2
	Conductivity	2
	Magnetic properties	2
	Morphology and topography	2
	Validation	3
	Uncertainty & Traceability	3
	Data evaluation	3