PROJECT FINAL REPORT

Grant Agreement number: 604448

Project acronym: NANOMAG

Project title: Nanometrology Standardization Methods for Magnetic Nanoparticles

Funding Scheme: FP7

Period covered: from 2013-11-01 to 2017-10-31

Name of the scientific representative of the project's co-ordinator, Title and Organisation: Christer Johansson, Professor, RISE Acreo AB

Tel: +46 (0)727 23 33 21

E-mail: christer.johansson@ri.se

Project website address: www.nanomag-project.eu

4.1 Final publishable summary report

4.1.1 Executive summary

The NanoMag project objectives were to standardize and harmonize ways to measure and analyse the data for magnetic nanoparticle (MNP) systems. NanoMag brought together Europe's leading experts in; synthesis of magnetic single- and multi-core nanoparticles, characterizations of magnetic nanoparticles and national metrology institutes. In the consortium, we have gathered partners within companies, metrology institutes, universities and research institutes, all carrying out front end research and developing applications in the field of MNP systems. The NanoMag project was a for year project started in 2013 and ended in 2017. The objectives of the NanoMag project has been to improve and redefine existing analysing methods and in some cases, to develop new analyzing methods for MNPs. By using improved manufacturing technologies, we have synthesized MNPs with specific properties that have been analysed with a multitude of characterization techniques (focusing on both structural as well as magnetic properties) and the experimental results was correlated between different analysis techniques, and we obtained a self-consistent picture that describes how structural and magnetic properties are interrelated. In the NanoMag project we have used almost all existing analysis techniques to study MNPs. The project has defined standard measurements and techniques which are necessary for defining a magnetic nanostructure and quality control. The areas we have studied in the NanoMag project was focused on biomedical applications, for instance bio-sensing (detection of different biomarkers), contrast substance in tomography methods (Magnetic Resonance Imaging and Magnetic Particle Imaging) and magnetic hyperthermia (for cancer therapy). In the NanoMag project we have had an associated stakeholder committee group (17 members) of companies and universities in the fields of synthesis of MNPs and analysis techniques. These group have helped the NanoMag consortium in the different surveys we have sent out to understand the industrial needs and challenges in the fields of MNP synthesis, standardization and analysis methods. Four surveys were distributed to over 250 organizations and the answers were analysed to improve our standardization work and strategies. During the project NanoMag members have made substantial standardization contributions to ongoing ISO standardization work in the field of MNP systems. For most of the measurement methods standardization procedures (SOPs), uncertainty budgets and metrological descriptions has been developed. Over 50 new MNP systems (single- and multi-core particles) have been synthesized in the project and also SOPs for the synthesis of MNP systems have been developed. We have obtained improvements in reproducibility of MNP synthesis. In the project we have developed new MNP products and MNP analysis methods as a result of the work in the project. To reach out to the public with respect to basic MNP knowledge and MNP applications, four electronic-learning modules has been developed and will be available also after the NanoMag project. Over 80 new publications in international high impact journals and over 160 presentations and seminars have been carried out by NanoMag partners. During the project we have also developed a clearer nomenclature in order to describe structure and magnetic properties of MNPs and MNP ensembles. Surveys of measurement methods for MNPs and their pros and cons, classification of these methods including also classification of different types of MNP systems has been reported and published. In the project we have used Monte-Carlo simulations in order to explain the experimental results, which have led to improved modelling of MNP magnetic properties, especially the dynamic magnetic behaviour (for instance to be used in the magnetic hyperthermia field). Round Robin measurements (same analysis methods on the same MNP samples but in different labs utilizing the developed SOPs) using different types of MNP systems have been carried and the result was promising.

4.1.2 Project Context and Objectives

Activities and context of the NanoMag project can be seen below and which WP's the activities belongs to. The WPs are defined in figure 1 below.

• Synthesis of MNP with defined properties	WP1/WP3
• Improvement of existing analysis methods	WP2/WP4
• Development of new analysis methods	WP2/WP4/WP6
• Understanding of structural and magnetic properties	WP3/WP4/WP6
• Definition of standard measurements	WP4/WP5
• Definition of magnetic nanostructures and quality control	WP3/WP4/WP5
• Dissemination and exploitation	WP7
• Administration and management	WP8

The work-packages were organized and connected as shown in figure 1.

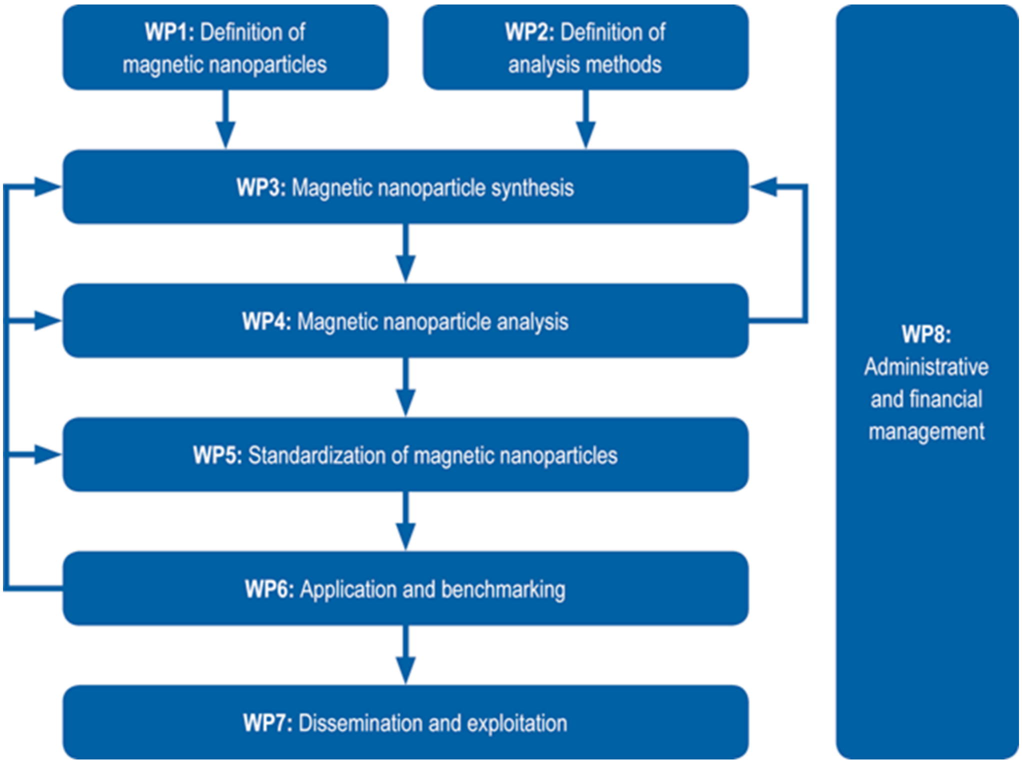


Figure 1 the work packages and how they are linked together.

The strategic objectives of the NanoMag project were:

- To identify analysis and characterization techniques that can be used as standardization measurements in the field of magnetic nanoparticle research and development and that will provide valuables tools to the manufacturing process of magnetic nanoparticles and the regulatory work on magnetic nanoparticles.
- Use new or improved analysis techniques to control the properties of magnetic nanoparticles that improve their specific application.
- Promote the standardization techniques so they can be used both in research as well in industry, SME or large companies.
- Provide/enable a traceable route for novel characterization techniques from a laboratory research towards the basis of new metrological standards, which do currently not exist in the area of magnetic nanoparticles.

The achievement of the strategic goals of the NanoMag concept requires the advancement in several complimentary characterization technologies.

The specific technical objectives of the project were:

- Correlate the magnetic and structural properties of magnetic nanoparticles.
- Develop new analysis techniques and models in the field of magnetic nanoparticles.
- Improve the traceability of the total magnetic nanoparticle "life time" from manufacturing to the specific application.
- To present standardized procedures for manufacturing magnetic nanoparticles with specific properties, for instance the size and size distribution and the aggregation state for a given material.

The overall workflow in the project can be seen in figure 2 below.

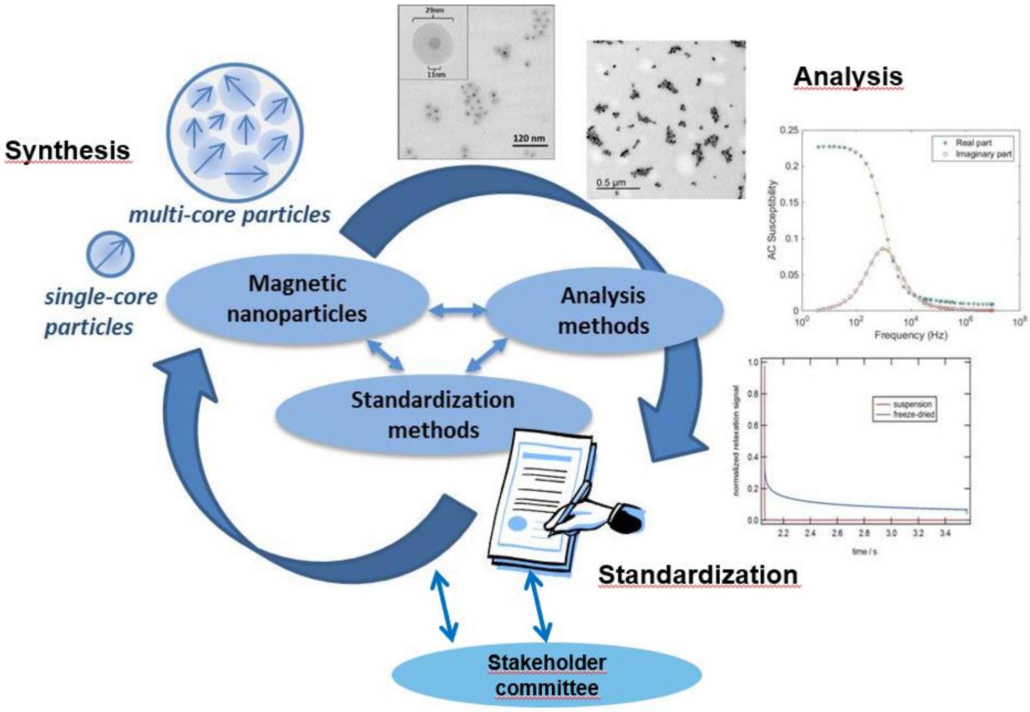


Figure 2 The workflow in the NanoMag project

In the application work package (WP6) we tested the new synthesized optimized MNP systems for each application area.

4.1.3 Main Scientific and Technical Results

The NanoMag project summarizing the actual results are listed below. Also, some recommendations for future work are listed in bold.

<u>MNP synthesis</u>

- Comprehensive description of synthesis routes
- Extensive synthesis of MNP covering different synthesis routes and MNP properties
- MNP series with gradually changing parameters
- Reproducibility of MNP synthesis in different labs

Improvement of existing analysis methods

- Overview and classification of MNP analysis methods
- SOPs and technical documentation
- Uncertainty budgets (in some cases)

Development of new analysis methods

- Numerical inversion techniques for reconstruction of distributed parameters
- Optical measurement of dynamic susceptibility

Understanding of structural and magnetic properties

- Comprehensive analysis of MNP series with gradually changing parameters
- Characterization of multi-core MNPs
- Neutron scattering measurements in combination with other characterization methods

Definition of standard measurements

- Metrological checklists
- SOPs and technical documentation
- Active participation in ISO/TC229 (ISO 19807 and PG14)

Definition of magnetic nanostructures and quality control

- Definition of structural concepts and terminology for single-core and multi-core particles
- Examples of comprehensive characterization of (complicated) MNPs, (e.g. nanoflowers)
- Quality control (Task 4.2 in the analysis work package WP4)

Dissemination and exploitation

- Stakeholder interaction (four online surveys, workshops)
- E-learning modules, four e-learning modules was developed in the project and available link from NanoMag website and hosted at the NPL website
- Scientific publications
- **Commercial exploitation of project results**
- **Follow-up project EMPIR MagNaStand (start 2017, coordinated by PTB)**
- PR activity (EuroNanoForum 2015, NanoMag was voted to be among the 10 best EU projects related to Nanoscience)

Main technical and scientific impacts in the project are listed below. Future work in bold.

- Clear nomenclature for describing structure and magnetic properties of MNPs and MNP ensembles
- Improvements in reproducibility of MNP synthesis. Over 50 new MNP systems were synthesized in the project.
- Surveys of measurement methods for MNPs and their pros and cons, classification of these methods including classification of different types of MNP systems
- A stakeholder committee group was formed in the NanoMag project that helped with the MNP surveys performed
- Standard operation procedures, uncertainty budgets and metrological descriptions were developed
- Improved modelling of MNP magnetic properties, especially: dynamic magnetic behaviour
- Correlation analysis between MNP parameters determined by different analysis methods
- Over 80 new publications in international high impact journals and over 160 presentations and seminars

- E-learning modules (NPL-web site, linked from the NanoMag website). 132 people have already enrolled to the first 2 modules. The number is expected to increase significantly when all modules are launched after the end of the project.
- Substantial contribution to ongoing ISO MNP standards (ISO 19807 ” Nanotechnology — Liquid suspension of magnetic nanoparticles — Characteristics and measurements', PG14 "Superparamagnetic beads for free cell DNA extraction)
- **Analysis service in the future (information will be collected at NanoMag homepage and PTB data server)**
- **Continuation with the MagnaStand EU project coordinated by Uwe Steinhoff (PTB).**
- Round Robin measurements (same analysis methods but in different labs) using different types of MNP systems

A detailed description of the results in each work package (WP) are given in the following sections.

WP1: Definitions of magnetic nanoparticles

Work undertaken

In WP1 we defined the MNP systems that were synthesized in WP3 and analysed in WP4. We will also decide the additional commercial MNP systems that were analysed in WP2. The work was separated into three parts:

- Definitions of single-core particles
- Definitions of multi-core particles
- Definitions of commercial magnetic nanoparticles

Scientific and Technical Results

3.1.2.1 Definition of single-core particles

In the initialization phase of the project, we have defined relevant parameters to be considered for identifying particles as single-core MNPs. We have listed the main structural and magnetic characteristics of single-core MNPs in D1.1. Single-core MNPs can be produced by several chemical methods. The main routes are the aqueous phase and the organic phase synthesis techniques. An overview of the most commonly used approaches both synthesis techniques has been prepared. As a result of this task, we agreed on a list of single-core MNPs prepared by different synthesis routes with a variety of structural and magnetic characteristics, and different surface modifications. Responsibilities and roles of the project partners in synthesizing these MNPs were defined.

3.1.2.2 Definition of multi-core particles

The main structural and magnetic characteristic of multi-core MNPs were summarized in D1.2. An overview has been compiled of multi-core MNP systems and their synthesis routes being appropriate to produce MNPs for different applications such as magnetic hyperthermia, magnetic resonance imaging magnetic particle imaging, magnetic separation and MNPs for bio-sensing and lab-on-chip platforms. Based on this, we identified multi-core MNPs to be synthesized and characterized in WP3. The most promising MNPs were selected for comprehensive analysis in WP4. We agreed on a list of multi-core MNPs with magnetic cores from magnetite or maghemite, with small size distributions, iron oxide core sizes in the range of 5 nm to 100 nm and hydrodynamic diameters below 100 nm or between 100 nm and 200 nm. The coating materials were dextran or carboxy dextran, starch, silica, polyethylene glycol or corresponding polymer derivatives.

3.1.2.3 Definition of commercial magnetic nanoparticles

We established a comprehensive survey on available commercial single- and multi-core MNPs based on the information of the involved partners in WP1 (MICROMOD, NANOPET, SP, CSIC, ACREO, TUE, UCL, PTB). In report D1.3, we compiled information available from internet product descriptions published on companies' websites. Four types of commercial players were identified: 1. Biomedical MNP manufacturer and companies placing MNP on the market for in-vitro applications, 2. Medical in-vivo injectable, 3. Technical engineering, and 4. Industrial chemicals supply. The project consortium decided to work with focus on biomedical commercial MNP according to Type 1. Six commercial MNP systems were defined for further analysis. Four of them are single- and multi-core MNPs with hydrodynamic diameter below 100 nm and different magnetic relaxation behaviour at room temperature, and two samples with larger particle size for magnetic separation and micro-sensing applications.

Impact on other Work Packages

The defined single- and multi-core MNPs were synthesised and initially characterized in WP3. The MNPs were utilized in our comprehensively studied in WP4 in order to improve and re-define the analysis methods. The defined MNPs were also used for our application and benchmark activities in WP6. The defined commercial MNPs were characterized in WP2 in order to decide which analysis technique and which models will be used in WP4 and which MNP parameters can be obtained.

WP2: Definitions of analysis methods

Work undertaken

In this work package, we have used the commercial single- and multi-core MNPs defined in WP1 for an initial characterization using various analysis technique. We have investigated the analysis techniques and decided which techniques we use in WP4 for the respective MNP system and which nanoparticle parameters were important for our standardization work in WP5. We have also studied which models are needed in order to determine relevant parameters for a deeper understanding of the MNPs. The work was divided into three parts:

- Analysis of the initial measurements
- Definition of characterization and analysis methods
- Definition of models

Scientific and Technical Results

3.2.2.1 Analysis of the initial measurement

A comprehensive overview (D2.1) has been prepared which comprises the structural and magnetic parameters of the commercial MNPs that we have defined in WP1. Here, we summarized the results obtained by the available analysis techniques in NanoMag. The parameters of the following commercial particle system were summarized:

- Micromod BNF multi-core particle with a hydrodynamic diameter of 80 nm.
- NanoPET FeraSpin-R multi-core particle system with a hydrodynamic diameter of 60 nm.
- Ocean Nanotech SHP25 and SHP20 single-core particles with hydrodynamic diameters of 25 nm and 20 nm respectively.

Along with the results of the characterization of the particle system, the overview D2.1 comprises for each analysis technique and based on the analysis results, a summary of the standard practice measurements including information on the sample preparation and amount, used concentrations, details on measurement systems and parameters, measurement time, calibrations and used models for data analysis. From these information, a measurement matrix has been generated which is shown in Table 1. It gives a summary of the analysis techniques that are available in NanoMag and the accessible structural and magnetic MNP properties.

Table 1: Overview of the analysis methods and accessible MNP properties

Parameter	SEM	TEM	Diffraction (X-ray, Neutron)	DC magnetometry	AC magnetometry	FMR	Magnetic separation	Mössbauer	MPS	MRX	RMF (MPR)	Small angle scattering	DLS & zeta-potential	AF4	NMR R1 and R2 relaxivities	Hyperthermia
Hydrodynamic size					X		X			X	X	X	X	X	X	
Core size	(X)	X	X[1]	X	X				X	X[2]	X	X				
Multicore aggregate size	X	X	(X)		X							X				
Particle shape	(X)	X										X		X		
Crystal structure		X	X													
Thickness of surface coating		(X)			X							X				
Chemical composition		X	X					X						X		
Binding state					X				X	X	X					
Determination of MNP concentration by comparison with a reference[3]				X		X	X		X	X			X	X		
Coercive field				X							X					
Saturation field				X												
Exchange bias field				X												
Total magnetic moment				X	X			X	X	X	X					
Spin structure			X					X								
DC susceptibility				X												
AC susceptibility					X											
Critical temperatures				X	X	X		X		X		X			X	
Relaxation times of an MNP ensemble					X	X		X		X					X	
Remanent magnetization				X												
Saturation magnetization				X												
Dipolar interaction between particles				X[4]	X[4]			X		X[4]		X				
Effective anisotropy				X	X	X		X		X						
Torque on the magnetization											X					
Particle surface charge													X			
R_1 and R_2 relaxivity															X	
Temperature rise due to AC field					X[5]											X

[1] Scherrer analysis can yield the average crystal coherence length, but not the particle distribution. [2] only E_A can be determined; If the anisotropy constant is known, the particle volume can be derived. [3] The concentration can be determined by e.g. ICP-MS, prussian blue staining or phenanthroline. [4] By investigating a concentration series. [5] The energy absorption can be estimated from by analysis of χ''. (X) = Derivable under favourable circumstances, e.g. if d_p >> resolution limit of the microscope

3.2.2.2 Definition of analysis methods and models

In the definition stage in WP2, a survey was compiled based on information on the data analysis, the structural and magnetic parameters that can be determined, assumptions or additional input parameters for the data analysis and a discussion on possible uncertainties and their magnitude. The survey further comprises information on interrelation with other analysis methods, proposals for measurement improvement and modifications for more reliable output parameters and modelling and simulations for the interpretation of measurement results.

Based on this survey the analysis methods were classified to:

Group 1: Structure, chemical composition and particle size distribution

- Conventional scattering techniques (XRD, ND)
- Small-angle scattering (SAXS, SANS)
- Electron microscopy (SEM, TEM)
- Dynamic light scattering (DLS), electrophoretic light scattering, zeta-potential
- Asymmetrical field flow fractionation (AF4)
- Inductively Coupled Plasma Mass Spectrometry (ICP-MS)
- Mössbauer spectroscopy

Group 2: Temperature and field dependent magnetization and resonance measurements

- Magnetization versus temperature (m vs. T)
- Isothermal magnetization measurements (m *v* H)
- AC susceptibility *vs*. temperature (AC *v T*)
- Ferromagnetic resonance (FMR)

Group 3: Frequency and time dependent magnetization/relaxation measurements

- Magnetorelaxometry (MRX)
- Frequency dependent AC-susceptibility (ACS)
- Magnetic particle spectroscopy (MPS)
- Rotating magnetic field method (RMF)

Group 4: Application oriented magnetic measurements

- NMR T_1- and T_2-Relaxivity
- Magnetic Separation
- Magnetic Hyperthermia
- Brownian relaxation measurements using on-chip relaxometry using a magnetoresistive sensor and optomagnetic sensing

Models were defined for those analysis techniques where modelling is needed to extract the MNP parameters from the measurement data.

Impact on other Work Packages

The results of the initial characterization were used in WP3 for the comparison of commercial MNPs and new synthesized single- and multi-core MNPs. The identified chemical, structural and magnetic characteristics that can be determined by our defined methods and models were studied in WP4 for the characterization of new synthesized MNPs. We continuously improved our analyses and assess our definitions within WP4 which provided the scientific background for our standardization work in WP5.

WP3: Magnetic nanoparticle synthesis

Work undertaken

In this WP we have synthesised magnetic single-core and multi-core particles with special magnetic, chemical and structural properties according to the definitions in WP1 and we used these MNPs for our analysis work in WP4 in order to define the analysis standard techniques in the standardization method work in WP5. We also used commercial magnetic nanoparticles for the comparison with the new synthesized MNPs.

Scientific and Technical Results

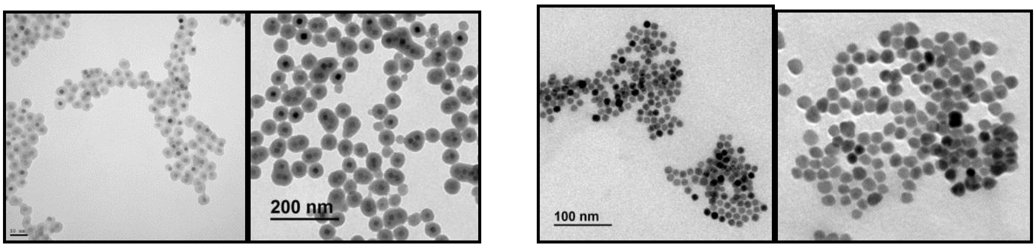
We have identified different synthesis routes susceptible for being standardized for the production of single- (task 3.1) and multi-core (task 3.2) magnetic nanoparticles suspensions for biomedical applications (Milestone MS3), according to the definitions in WP1.
Commercial nanoparticles were chosen from a broad range of manufacturers and suppliers marketing nanoparticles. The quantity and quality of information provided varies significantly between. The comparison of different commercial with new synthesized nanoparticles (WP2) was challenging and not feasible without their in-house characterization (task 3.3). For example, the Fe concentration provided by the manufacturer, which was critical for WP2, was not reliable and differed significantly from the actual measured values. Consequently, we elaborated a report describing the best way to determine the Fe concentration in those suspensions to assure uncertainty below 3%.
The resulting samples have been characterized by particle size, hydrodynamic size, Fe concentration, osmolality, pH, zeta potential and dispersion stability (task 3.4) and they have been compared with commercial samples selected in WP1 (task 3.3, D3.3). Only those having long-term colloidal stability (months) were distributed to WP4 and WP6 (D3.1 and D3.2) and a technical data sheets was designed.
We have developed standard operating procedures (SOP), describing the synthesis and surface modification of these iron oxide magnetic nanoparticles to obtain colloidal suspensions in water at pH 7 following recommendations from WP5. Second batches of single-core (D3.4) and multi-core particles (D3.5) prepared following these SOPs were delivered to WP4 and WP6.
We have analyzed the reproducibility of the selected synthesis methods and the inter-lab reproducibility based on the characterization results provided by WP4. The SOPs have been extended including more details on the experimental procedures and finally, non-expert labs have been invited to carry out the synthesis following the extended SOPs (work in progress).
We have analysed the key parameters controlling particle size, aggregation and colloidal stability. Analyses of the mechanism of particle formation and degradation have also been done in order to improve reproducibility and reaction yield.
A tight collaboration has been stablished between synthesis groups in WP3 for improving the synthesis of magnetic nanoparticles and its dispersion in water. Samples produced in this WP present high uniformity, good crystallinity, long term stability and good control of core, particle and hydrodynamic size, better than most of the commercial samples.

3.3.2.1 Selected MNP samples

Single-core particles
Magnetic nanoparticles with very low polydispersity (<10%) have been synthesized by high temperature decomposition of iron oleate and they have been coated with silica via microemulsions (Sample CSIC01) and dimercaptosuccinic acid, DMSA (Sample CSIC12) leading to single core particles (Fig. 1A). Silica and DMSA were chosen for the coating since they are well-studied materials, easily functionalizable and biocompatible. Silica and DMSA has been chosen for the coating since it is a well-studied material, easily

functionalizable and biocompatible. The synthesis and coating methods were optimized to control the particle size and coating thickness (Fig. 1B).

Other method that was explored to obtain single core particles without size selection was this involving the synthesis of antiferromagnetic precursors which were subsequently coated with silica and reduced to magnetite without change in morphology. Cores with different morphology were obtained (Fig. 1C). First, this approach has the advantage of low inter-particle interactions of as-synthesized antiferromagnetic nanoparticles. Moreover, it covers different core size ranges and allows obtaining different morphologies such as rhombohedra (CSIC09), discs or needles below 200 nm [4].
The synthesis and coating methods were optimized to control the particle size and coating thickness. On the other hand, cores with different morphology have been synthesized from antiferromagnetic precursors which were subsequently coated and reduced to magnetite without change in morphology. Examples of different core size from 12 to 20 nm, same coating thickness, different coating thickness from 14 to 24 nm, same core size 16 nm and different morphology, same silica coating, can be seen in figure 1 (A-C) below.



Silica DMSA

Fig. 1. A) Single core particles with different core size from 10 to 20 nm and same coating thickness, silica on the left and DMSA on the right.

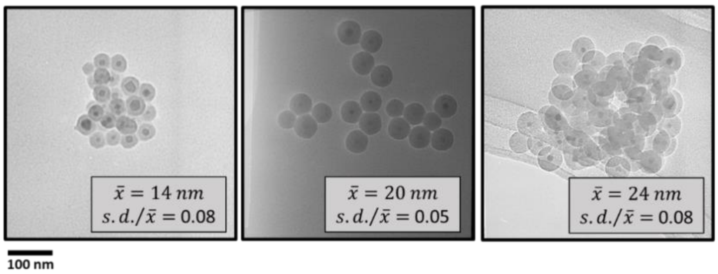


Fig. 1 B) Single core particles with different silica coating thickness from 14 to 24 nm and same core size 16 nm.

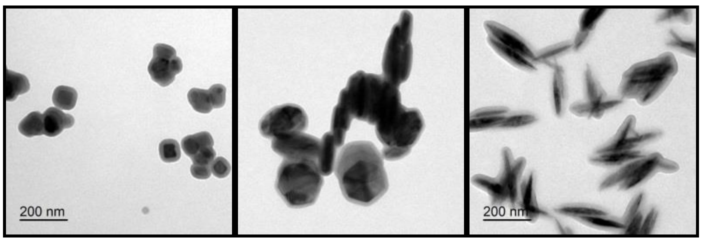


Fig. 1 C) Single core particles with different morphology and same silica coating.

Multi-core particles

Controlling number of cores per aggregates, same core size

BNF-Starch particles with nominal diameters of 80 nm and 100 nm were selected as commercially available multi-core particles from Micromod in WP1. Within WP3 Micromod followed different strategies to modify the coating process of the iron oxide cores of BNF particles (around 20 nm core size) to change the number of cores per aggregate and to obtain particles with a more uniform number of iron oxide crystals per particle to improve the magnetic particle properties (Table 1). Magnetic fractionation techniques and the peptization of iron oxide cores before coating led to a smaller and more uniform number of iron oxide cores per particle.

Table 1. Summary of multi-core particles derived from iron oxide cores of BNF particles.

	MM-03	**MM-04**	**MM-05**	**MM-06**
Core material	γ-Fe_2O_3/Fe_3O_4	γ-Fe_2O_3/Fe_3O_4	γ-Fe_2O_3/Fe_3O_4	γ-Fe_2O_3/Fe_3O_4
Coating material	dextran	dextran	starch	Poly(acrylic a Na salt
Functional groups	OH	OH	OH	COOH
PCS size (Z-Average)	79 nm	64 nm	115 nm	126 nm
PDI	0.06	0.10	0.08	0.12
Fe concentration	5.0 mg/ml	5.0 mg/ml	5.0 mg/ml	5.1 mg/ml
Comments	Magnetic Fractionation (pl design)	Peptization of oxide before coating	Magnetic Fractiona SEPMAG-Q100 [2]	Peptization coating in one st

The commercial and biocompatible sample FeraSpin R, which is synthesized by aqueous coprecipitation of Fe(II) and Fe(III) in the presence of carboxydextran as stabilizing agent, consists of clustered 5 nm iron oxide nanoparticles forming aggregates of various sizes (Fig. 2). Via magnetic fractionation different narrowly distributed size fractions of these aggregates were obtained by NanoPET, while all aggregates are composed of the same sized cores having a diameter of about 5 nm. From these the smallest size fraction FeraSpin XS, containing solely single-core particles, and a medium size fraction FeraSpin L were chosen for an extensive characterization in WP4.

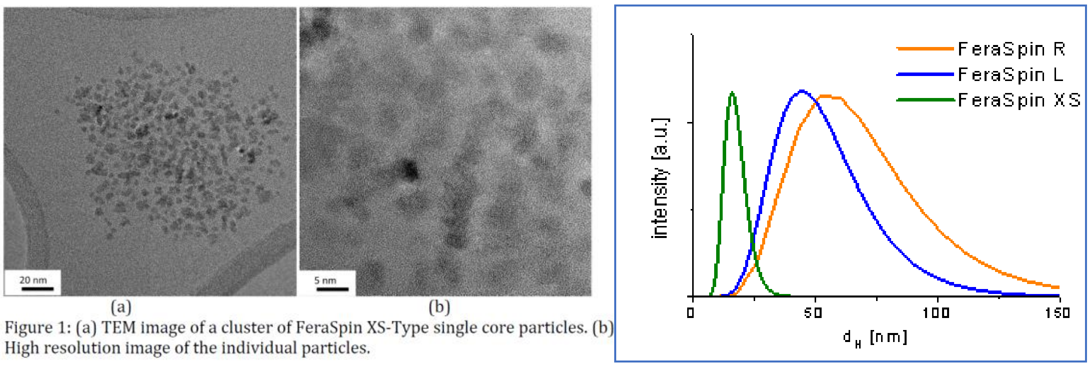


Fig. 2. TEM images of a cluster of FeraSpin XS (5 nm cores coated with carboxidextran) at different magnification and hydrodynamic size evolution of FerraSpin samples with the magnetic fractionation.

Controlling core-core interaction

Different strategies to obtain flower-shaped iron oxide assemblies in the size range 25-100 nm were examined (Fig. 3 A). The routes are based on the partial oxidation of $Fe(OH)_2$, polyol mediated synthesis or the reduction of iron acetylacetonate. The nanoparticles are functionalized either with dextran or citric acid and their long-term stability is assessed. Key synthesis parameters driving the self-assembly process capable of organizing colloidal magnetic cores into highly regular and reproducible multi-core nanoparticles were determined. This is the first step towards standardized protocols of synthesis and characterization of flower-shaped nanoparticles.

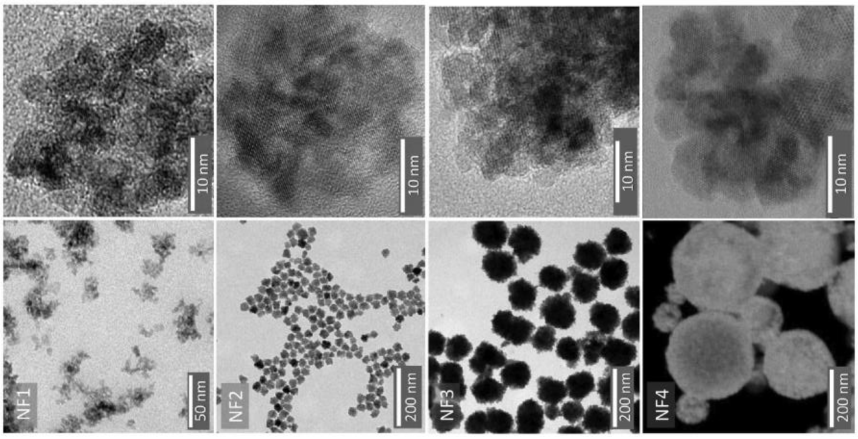


Fig. 3 A) Multicore samples with magnetic cores of around 10 nm self-organized forming larger nanoparticles of around 30 nm up to 150 nm (NPG3310, MM08, CSIC10, SP06) [1].

Different core size, same particle size

The polyol-mediated synthesis has been explored and developed for the preparation of well-controlled magnetic nanoparticles with different core size and arrangement to form the final multicore particles. A prolonged heating of the flowers (nanoflower nanoparticles) leads to particles with larger cores with interesting magnetic and colloidal properties (Fig. 3B).

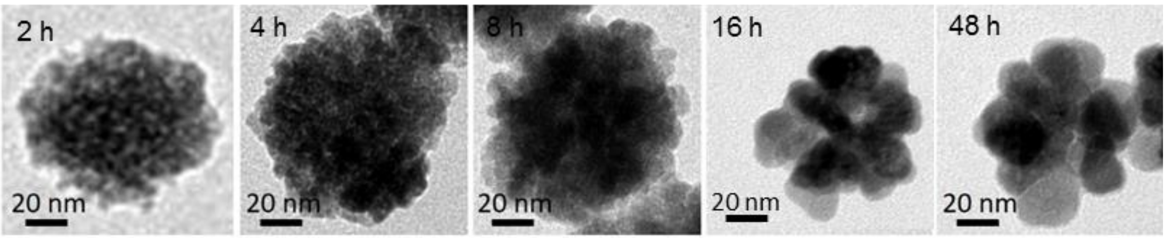


Fig. 3 B) Multicore nanoparticles prepared by the polyol process with different core size depending on the heating time, from 2 h up to 48 h [2].

Different coating

In order to have a broad portfolio of different nanoparticles covering a wide range of physical and magnetic properties, several other synthesis techniques and coating materials were utilized [11-14]. NPG3310 for example was synthesized by a partial oxidation pathway and coated by the biocompatible polymer dextran, inducing a steric stabilization (Fig. 3C). By using citric acid and coprecipitation, charge stabilised nanoparticles have been synthesized. Nanoparticles, being stabilised sterically and by charge, have been synthesized by using poly(acrylic acid) as coating material.

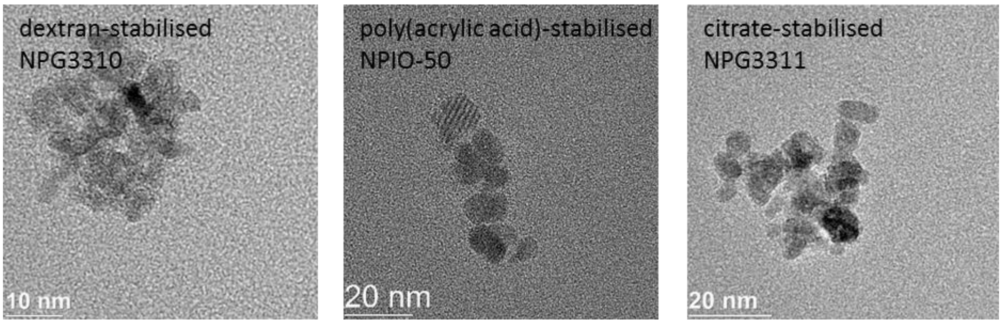


Fig. 3 C) TEM micrographs of dextran-, poly(acrylic acid)- and citrate stabilized multi-core samples synthesized by nanoPET.

Flower like particles of 100 nm core sizes have also been coated with dextran, citric acid, amino propyl silane (APS) and amino dextran with interesting colloidal properties and different surface charge, going from positive (+42 mV) with animodextran to negative (-30 mV) with citric acid and Z average sizes around 200 nm.

Different super-structure

SP synthesized nanoflowers (SP06) by means of sodium borohydride, which acts as reducing agent of iron (III) acetylacetonate ($Fe(acac)_3$). Nanoflowers synthesized by this route were embedded on polystyrene spheres via the emulsion solvent evaporation (ESE) process or encapsulated forming super-structures. The differences in nature of aggregation of the magnetic cores could lead to different modes of inter-particle magnetic interactions. This would have an impact on application oriented properties such as NMR relaxivities, hyperthermia etc.

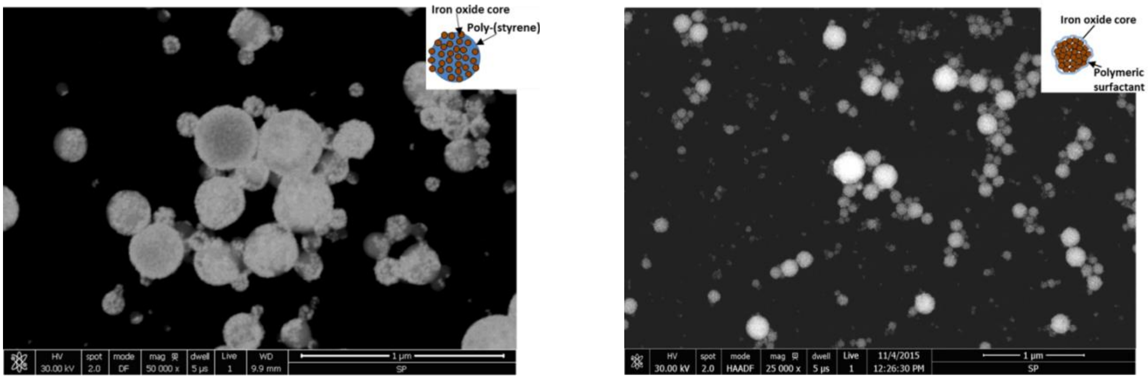


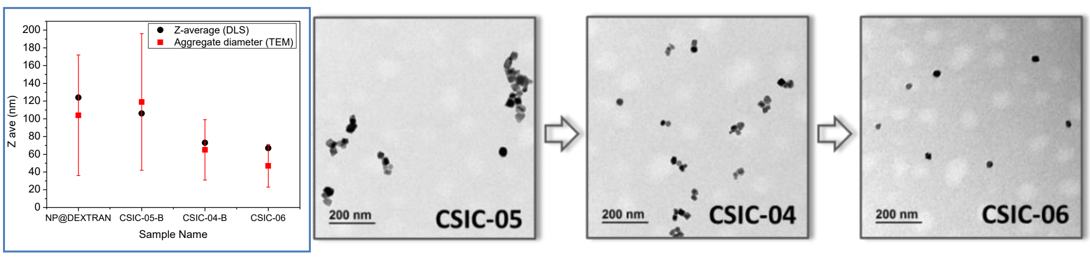
Fig. 3 D) Multicore MNPs with different modes of magnetic core aggregation (left: SP06 and right: SP0

Interesting series from single- to multi-core MNPs

Interesting series of magnetic suspensions going form multicore to single core nanoparticles were obtained with particles made of 5 nm cores by NanoPET as mentioned before (FeraSpain samples) and for 30 and 60 nm cores prepared by ICMM [15] and Micromod by magnetic fractionation after dextran coating (CSIC04, 5, 6) and sedimentation fractionation after PAA-Na coatings with different molecular weights (CSIC08) (Fig. 4A). We observed excellent reproducibility of CSIC05 and CSIC04.

Single-core and multi-core, including hollow spheres and nanoflowers, can be prepared by the polyol process (Fig. 4B). Sodium acetate (NaAc) can control the nucleation and assembly process to obtain the different particle morphologies that can be further stabilized in water by coating with citric acid. The particles are formed by burst nucleation and growth processes that determine the final nanostructure [2].

Finally, by controlling the internal structure of anisometric particles [4], we have developed single and multicore particles as those presented in Fig. 4C. The possibility of generating a discontinuous structure within a particle by forcing the pore formation may be an interesting strategy to develop new materials with tuned magnetic properties for biomedical applications.



A

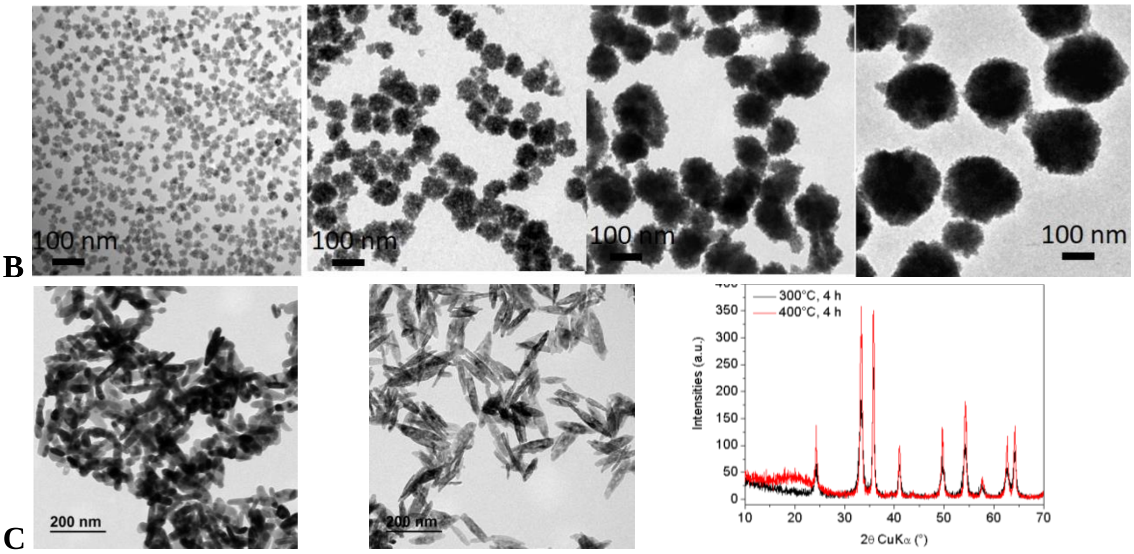


Fig. 4. A) From multicore to single core nanoparticles 30 nm cores coated with dextran (right-top and bottom, CSIC05-CSIC04-CSIC6) and subjected to magnetic fractionation. B) Single-core and multi-core (hollow spheres and nanoflower) prepared by the polyol process (DEG/EG). C) Needle shaped magnetic nanoparticles with different internal structure.

Multi-core nanoparticles prepared in different polyol media (DEG/EG) and in the presence of different reactants such as NaAc and NMDEA that modify the viscosity and the boiling point of the media [5], [6].

Impact on other Work Packages

The single- and multi-core MNPs synthesized in WP3 were characterized in WP4 and WP6.
Synthesized particles with defined properties were used in WP4 to verify, improve and harmonize the analysis methods to be standardized in WP5.

WP4: Magnetic nanoparticle analysis

Work undertaken

In WP4 we carried out the characterization and analysis work and we used the analysis methods and models that were defined in WP2. We have classified the analysis methods according standard methods that were used for all MNP samples and more specialized methods used for selected MNP systems. We studied single- and multi-core MNPs that were synthesized in WP3 and we compared our results with commercial MNP systems. We correlated the results obtained by different analysis techniques in order to get a self-consistent picture of the MNP systems. The work was divided into four parts:

- Characterization and analysis results from the single-core nanoparticles
- Characterization and analysis results from the multi-core nanoparticles
- Finely tuned characterization and analysis methods for the single-core and multi-core nanoparticles
- Correlation between analysis techniques

Scientific and Technical Results

Terminology for magnetic nanoparticles
A clear terminology for describing the structural and magnetic properties of single- and multi-core MNPs and MNP ensembles has been developed and published in [7]. Here, we also considered those definitions for MNPs that are available in existing standard documents. Such a summary of definitions of the MNP

components was essential for comparing the results among the project partners and among different measurement techniques, and it is indispensable for a coherent standardization structure MNP samples.

Classification of magnetic nanoparticles

The outcome of our characterization work in WP4 led to a classification of nanoparticles according to their number of cores inside a particle which leads to differentiation in single- and multi-core MNPs, and we reviewed different approaches for the synthesis of these MNP systems [8]. Both particle systems are shown in Figure 1. Single-core MNPs contain one magnetic core per particle and the core is covered by a matrix to prevent aggregation and agglomeration. In multi-core MNPs several cores exist within the matrix forming an individual unity.

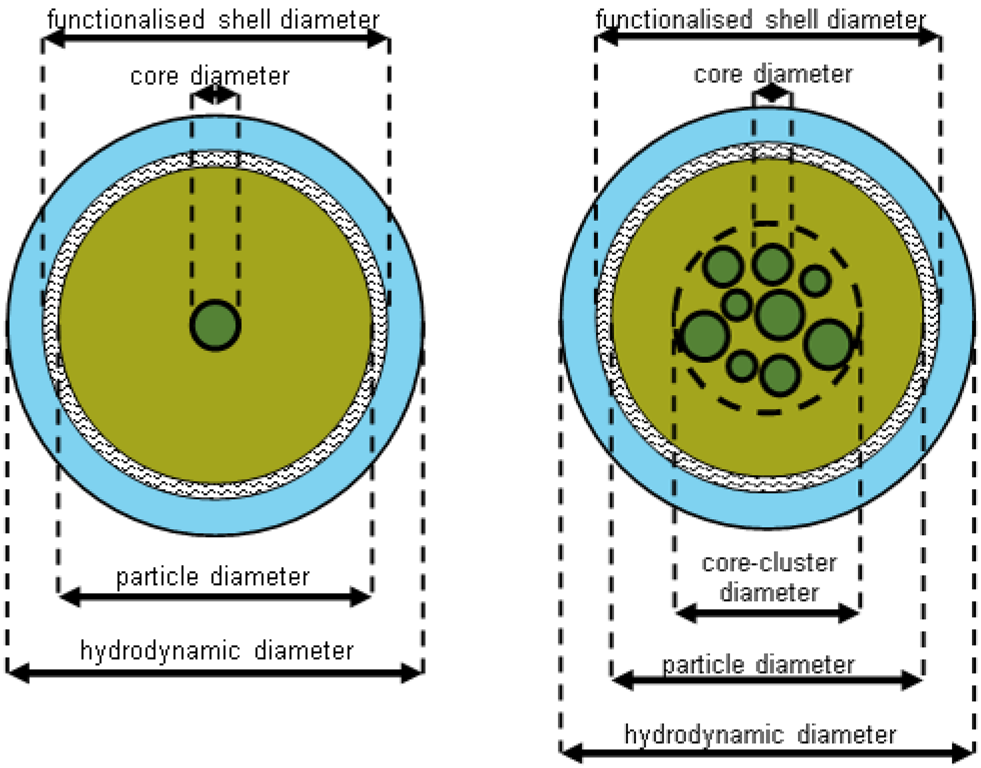


Figure 1: Schematic diagram of a single- (left) and a multi-core (right) MNP, taken from [7].

The arrangement of cores within a MNP sample has significant influence on the magnetic properties. Whereas in single-core MNPs in suspension the magnetic moment of the particle cores can rotate via Néel and Brownian rotation, in multi-core MNP systems Brownian rotation is suppressed as the cores are anchored in the matrix. Only Brownian rotation of the entire particle is allowed in this system. In addition to that, for describing the static and dynamic magnetization behavior, magnetic interaction between the cores in multi-core structures may become relevant if the cores are closely packed. This led to the concept described in [9], where we classified MNP systems according to their magnetic relaxation properties and particle size parameters which are determined by utilizing magnetic analysis techniques such as ACS or MRX and techniques like TEM and DLS capable to probe the core and particle size and the hydrodynamic size.

The complex inner structure of multi-core MNPs lead to unique magnetic properties and can explain for example their high performance in magnetic particle imaging [10], [11] or other biomedical applications [12]. This shows that especially multi-core MNPs needed a comprehensive characterization and a careful interpretation of structural and magnetic parameters including the correlation of different MNP parameters.

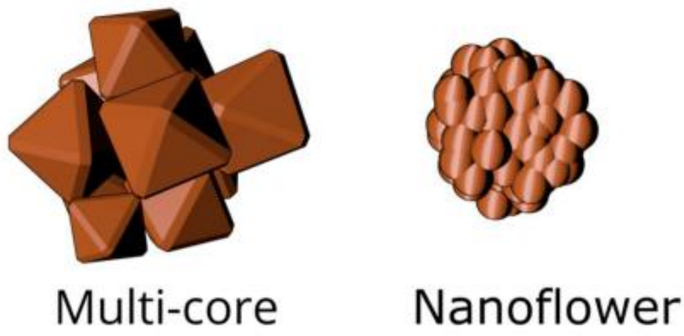


Figure 2: Schematic picture of two subclasses of multi-core MNPs

The so-called flower-shaped MNPs [13] or “nanoflowers”, as a special type of multi-core MNPs, have been intensively studied within WP4. These multi-core particles consist of clusters of strongly coupled cores which exhibit unique magnetic properties and thus they are potentially relevant in for example magnetic hyperthermia. Figure 2 shows the nanoflowers along the multi-core MNPs with relatively weak coupling between the cores. The focus of the characterization work was on the exploration of interaction between the nanocrystals inside an MNP. Thus, in [1] we classified the flower-shaped MNPs according their interaction between the cores and between the particles which can be adjusted by different synthesis routines. This enables us to tune the static and dynamic magnetic properties of MNPs for specific applications.

3.4.2.1 Classification of analysis methods

A classification of analysis methods into standard and advanced analysis techniques has been created and published in [14]. Standard techniques have large potential for standardization, whereas more advanced methods that provide additional information in order to gain a more detailed picture of an MNP system, however, due to their complexity and availability, these methods have limited potential to pose as standard methods for MNP characterization. Partners of the NanoMag consortium being experts in the field of nanoparticle research have assessed the analysis techniques considering different scientific, technological and economic aspects [14].

We furthermore developed a measurement matrix which provides information on the sample requirements (amount and sample forms) for each analysis technique and we gave an overview of the estimated cost of a single measurement using the technique and the types of sample, the method should be applied to.

Table 2 presents the outcome of the assessment of analysis methods as a classification into standard methods, advanced methods and intermediate methods. The latter could potentially serve as standard methods; however, their results have to be correlated with those obtained by other techniques. Note that some methods belong to several categories (e.g. Mössbauer and ND providing both structural and magnetic information). Detailed information on assessment of analysis methods have been published in [14] and in our report D4.1.

The results of this task had consequences for our subsequent analysis work as we used the standard methods for the characterization of all NanoMag samples, whereas the advanced methods are used to gain a deeper understanding of selected MNP systems. Furthermore, we have identified for our standardization work in WP5 a selection of commonly used techniques, which should undergo a standardization process with respect to the properties of MNPs. The experience from the present analysis of characterization methods for MNP provided valuable arguments in ongoing formal ISO standardization processes.

Table 2: Result of assessment of methods

	Standard method	Intermediate method	Advanced method
Structure, compositi size	DLS, SEM, TEM, A SAXS, ICP-MS	XRD, Mössbauer	XAFS, ND, SANS
Magnetic properties	DCM, ACS vs. ACS vs. T	FMR, MRX, MPS, RI Mössbauer	ND, SANS
Application orien methods	MPS, N magn. Separation, magn. Hyperthermia,	Chip-ACS	

3.4.2.2 Characterization and analysis results from the single-core MNPs

Our report D4.2 provided a detailed description of the structure and the magnetism of single-core MNPs and MNP ensembles and we pointed out that only a few measurement techniques are available which provide information on a single nanoparticle. The majority of techniques measure the properties of an MNP ensemble and in the simplest case, the MNPs can be considered to be identical. However, in practise, the MNPs exhibit some distribution of parameters, e.g. for MNP size, magnetic moment, magnetic anisotropy, etc. Here often a certain functional form for the probability density function in the model is assumed and is most cases a lognormal distribution is used. An alternative to that is the regularized inversion method which we have developed and published in [15]. The main advantage of the numerical inversion method is that no ad hoc assumptions regarding the line shape of the extracted distribution functions are required. This approach has been verified by comparing the results with the results obtained by standard model fits, i.e. where lognormal distribution was assumed.

Along with the basic description of single-core MNPs and ensembles our report D4.2 gave comprehensive summary of analysis methods and models for single-core MNP description. The information on each analysis techniques are summarized according the metrological checklist [16] which provides a guideline for the development of a standard. We furthermore presented an overview of the results of structural and magnetic characterization of single-core MNPs which have been synthesized within the project. As a consequence of the variety of analysis methods, there is some redundancy in parameters which helps one to verify and refine models. In [17] we have published the results of the comparison of single-core MNP sizes determined by different non-magnetic and magnetic analysis techniques. It was found that the mean core diameters determined from TEM, DCM, ACS and MRX measurements agree well although they are based on different models. We found good agreement among the results which proved the applicability of these techniques and their related models for the characterization of single-core nanoparticles. In a similar study, we found for single-core MNPs also very good agreement between core diameter obtained by TEM, DCM and MRX [18]. However, it turned out that in the investigation of multi-core MNPs large differences were present mainly caused by the applied models and the complex core structure.

In [4] we correlated structural and magnetic properties of large single-core MNPs using a variety of analysis methods was published in. We could demonstrate how the magnetic behavior is affected by the shape of the MNPs, their internal structure and the reduction process.

We could demonstrate in [19] that measurements of the complex susceptibility as a function of frequency on suspensions of thermally blocked MNP allow the simultaneous estimation of the hydrodynamic size and of the effective anisotropy constant.

The magnetic field dependence of the Brownian and Néel relaxation has been investigated using two single-core MNP systems [20]. Here we have shown that we are capable to model the dynamic magnetic behavior as a function of field amplitude and under application of an ac field superimposed by a static magnetic field.

In [21] the micro- and mesostructure of self-assembled mesocrystals composed of nanocubes with different edge lengths in the absence and presence of an applied magnetic field has been investigated. The results of this study are summarized in a qualitative phase diagram which outlines the preparation of mesocrystals and arrays with tunable micro- and mesostructure.

3.4.2.3 Characterization and analysis results from the multi-core MNPs

In our report D4.3 we presented a detailed description of the inner structure and the magnetism of multi-core MNPs. As in most cases interactions between the cores inside a nanoparticle must be considered for describing the magnetism of multi-core MNPs, we gave a detailed description of the magnetic interaction and relaxation properties on the basis of multi-core and flower-shaped MNPs. Report D4.3 also presented a comprehensive survey on the structural and magnetic properties of a selection of four multi-core MNPs that have been synthesized in our project. We summarized here information on each analysis techniques and models in accordance to the metrological checklist [16] and we considered particularities which arise from interactions in multi-core MNPs.

We were able to disclose the distribution of cores inside the MNPs and we could explain the magnetic behaviour which is significant affected by dipolar interactions between the cores [22]. Therefore, we studied the structural and magnetic properties of multi-core MNPs using a generalised numerical inversion technique.

In [23] we could show on the commercial FeraSpin series synthesized by nanoPET that FeraSpin XS can be described as individual nearly spherical single-core MNPs, while FeraSpin L consists of larger, slightly elongated clusters in which the interaction between the cores significantly alters the magnetic properties.

We comprehensively studied flower-shaped MNPs diverting core sizes and different packing densities inside a particle and thus variating interactions [1]. By comparing the results obtained from various analysis methods, we could disclose the inner structure of the core-clusters and link them to their magnetic properties. The heat generation of the flower-shaped MNPs in different stages of the synthesis was determined in [2] and compared with other particle types.

We explored the effect of the alignment of the magnetic easy axes on the dynamic magnetization of immobilized multi-core MNPs under an AC excitation field [24] and we obtained quantitative agreement between experiment and simulation. These results indicate that the dynamic magnetization of immobilized MNPs is significantly affected by the alignment of the easy axes.

Characterization of multi-core MNPs with application oriented methods

Large effort has been made in characterizing multi-core MNPs with application oriented methods with the aim to link the structural and magnetic characteristic and their performance in final application. We could show for example, how the amplitude and shape of the MPS spectra is affected by different physiological media [25]. Additionally, the observed linear correlation between MPS amplitude and shape alterations can be used to reduce the quantification uncertainty for MNP suspended in a biological environment.

In [26] we proposed a dual-frequency acquisition scheme to enhance sensitivity and contrast in the detection of different particle mobilities compared to a standard single-frequency MPI protocol. The method takes advantage of the fact, that the magnetization response of the tracer is strongly frequency-dependent, i.e. for low excitation frequencies a stronger Brownian contribution is observed.

In [27] we studied the structure and the magnetism of MNPs that were synthesized by a promising diffusion-controlled synthesis. From the characterization, we could demonstrate that a diffusion-controlled synthesis approach process allows to produce MNP suspensions with a large fraction of particles exhibiting a mean effective magnetic core size of about 28 nm which lies within the size range considered ideal for MPI.

We revealed how the particle size and concentration have influence on the separation of multi-core MNPs [28]. It was found that an increasing particle concentration leads to a reduction of the separation time for large nanoparticles due to the higher probability of building chains. For smaller MNPs the chain-formation is suppressed due to faster thermal fluctuation which led to concentration-independent separation times.

In [29] we explored the suitability of multi-core-MNPs in different polymer matrices to be used in MRI and we compared the MNPs with a MNP system approved for clinical use as contrast agent. Along with a comprehensive structural and magnetic analysis we could show that the synthesized MNPs exhibited higher R2 relaxivities and R2/R1 ratios compared to the commercial MNPs indicating their potential as new MRI contrast agents.

The effect of nanoclustering and dipolar interactions on the efficiency in magnetic hyperthermia was analyzed in [30]. We have shown that the magnetic hyperthermia performances of nanoclusters and single nanoparticles are distinctive and that nanoclustering of particles with randomly oriented easy axes is detrimental to the SAR. A decrease in ILP is observed when the nanocluster size and number of particles in the nanoclusters increase. This result is very interesting as in nanoflowers, where the cores inside the particles exhibit the same crystalline orientation, the SAR increases with increasing cluster size. For the individual MNPs, the SAR depends on particle concentration and thus increasing dipolar interaction.

We explored ellipsoidal MNPs subjected to an external AC magnetic field. First, the heat release is increased due to the additional shape anisotropy [31]. The rods can also dynamically reorientate perpendicular to the AC field direction. Importantly, the heating performance and the directional orientation can be controlled by changing the AC field treatment duration, thus opening the pathway to combined hyperthermic/mechanical nanoactuators for biomedicine.

3.4.2.4 Finely tuned characterization and analysis methods for the single-core and multi-core nanoparticles

The interaction among the NanoMag partners allowed to synthesize series of MNPs with varying structural and magnetic parameters. These model MNPs have been used to verify and to improve our analysis methods and the physical models.

Measurements on MNP series

As described in our report D4.4, a characterization strategy has been developed for MNPs which consist of the identical cores but different assembly size, with the aim to provide a consistent procedure for standardized analysis of multi-core nanoparticles. Along with a comprehensive structural and magnetic characterization we could show that the number of cores inside a MNP has significant influence on the heat generation in magnetic hyperthermia.Alongside other analysis techniques we utilized FMR and AF4 to derive a comprehensive understanding of the FeraSpin series synthesized by nanoPET [23]. We could disclose the coupling between the cores and we could show that FeraSpin R can be described as a superposition of the size fractions FeraSpin XS and L.

Verified and improved analysis methods

In [32] we demonstrated that improved SAXS in combination with SLS measurements delivered estimates of these morphological parameters and this information can then be transferred into a mean core distance inside the multi-core structure.

In [33] we could prove that ACS is capable to simulate the dynamic magnetic response of a sample possess a bimodal size distribution, proposed that the two particle sizes result in sufficiently deviating time constants. The numerical approach is more reliable when one particle fraction relaxes via Néel and the other via Brownian mechanism. Using Monte Carlo simulations for fitting the SAXS, we are also able to resolve the bimodality in the particle size. This result is important since only a few methods that can be used to dissolve a size distribution with more than one fraction.

The dependency of the Brownian and Néel relaxation times were studied by ACS as a function of frequency and field amplitude [20]. It was found that the Néel relaxation time decays much faster with increasing field amplitude than the Brownian one. Whereas the dependence of the Brownian relaxation time on the ac and dc field amplitude can be well explained with existing theoretical models, a proper model for the dependence of the Néel relaxation time on ac field amplitude for particles with random distribution of easy axes is still lacking. These findings are of great importance of applications where larger magnetic fields are used, e.g. MPI and magnetic hyperthermia.

In [34] we presented a new experimental approach to characterize an MNP system with respect to quantitative MRI. We could show that the hydrodynamic fractionation by AF4 and the subsequent structural and magnetic characterization of the size fractions by DLS, MALS, MPS and NMR enables us to evaluate the suitability of a MNP system for quantitative MRI and verify the theoretical predictions for the size dependence of relaxation rates at the same time. The approach could facilitate the choice of MNPs for quantitative MRI and helps clarifying the relationship between size, magnetism and relaxivity of MNPs in the future.

Along with the numeric inversion method presented above, we have developed a new method based on the iterative Kaczmarz algorithm that enables the reconstruction of the size distribution from magnetization measurements without *a priori* knowledge of the distribution form [35]. We concluded that this method is a powerful and intuitive tool for reconstructing particle size distributions from magnetization measurements. We have also used the Kaczmarz' algorithm for the determination of hydrodynamic size distribution from MRX measurements and we could show that this method is able to determine the hydrodynamic size distribution in agreement with either the known input distribution, in the case of simulated data, or other size estimates determined with different methods such as thermal magnetic noise spectroscopy and dynamic light scattering in the case of measured data [36].

In [37] we could identify the similarities and the differences in MRX and thermal magnetic noise spectroscopy. Both techniques are based on the same physical principle, i.e. the thermal fluctuations of the magnetic moment.

A new MPS setup was built which allows temperature dependent measurements in order to investigate the temperature dependence of the harmonics spectra [38].

Standard operation procedures

In preparation of our standardization work in WP5, Standard Operating Procedures (SOPs) for each analysis methods have been developed within WP4. For analysis methods being available at different facilities, a harmonized standard operation procedure has been compiled. The SOPs were published in our report D5.2. On the basis of the prepared SOPs, we have performed Round Robin tests, where we compared the MNP parameters measured by different partners. The results of these comparison studies were utilized to continuously improve the SOPs and to identify influence factors that were relevant for discrepancies among the results. However, within the project duration we were not able to finish our studies and to measure identical values at different institutes. This is still a challenge for future research projects.

Uncertainty budget calculation

In a Mössbauer study [39], we were able to identify independent influence factors that are relevant for the uncertainty of the mean isomer shift, used for the quantification of the magnetite content in MNPs, and we could derive a quantitative expression for the uncertainty budget. This concept has been applied at two different laboratories where the magnetite fraction values determined from the Mössbauer measurements agree within their respective uncertainties. This activity served as a model project for other analysis techniques in order to develop an uncertainty budget for all derived structural and magnetic parameters that are relevant for the reliable characterization of MNPs. Within the project we could identify the main influence factors for uncertainty for most of the analysis methods, however, we could not achieve the preparation of uncertainty budgets for all techniques. This should be solved in future research projects, for instance the newly started MagNaStand project in July 2017, coordinated by PTB where some of the NanoMag partners are participating (PTB, RISE Acreo, UCL, Micromod) as well as new partners from both industry and metrological institutes.

3.4.2.5 Correlation between analysis techniques

The comparison of MNP parameters is of utmost importance in order to get a self-consistent description of MNP systems. Consequently, we correlated our results in most of our activities. Our public report D4.5 gives an overview of the main results of a) correlation between the same MNP parameter determined by different techniques and b) the comparison of different MNP parameters. A consistent picture was found for the hydrodynamic particle size. However, quite some scatter between data was observed for core parameters, such as core size, effective anisotropy constant, and magnetic moment.

It was found that for single-core nanoparticles a number of methods consistently provide the same value for the core size and hydrodynamic size distribution. Slight differences can be attributed e.g. to the applied models. The situation is somewhat more complicated for multi-core MNP and nanoflowers.

Although there is a variety of analysis methods e.g. for determining the core size (TEM, DCM, MRX, ACS, SAXS, etc.), there is no best method which could be identified as standard one. However, the good agreement of size parameters, found when comparing techniques applied to the same sample, indicates that basically any of the methods can be applied.

The estimation of the effective anisotropy constant K remains an open task. Although a number of magnetic methods provide information on K, the physical background is manifold, ranging from the determination of the anisotropy energy via the Néel relaxation time to the intra-potential-well contribution in the dynamic susceptibility and the blocking temperature. A major problem for estimating the anisotropy constant applying the various methods is that all techniques require their very specific nanoparticles.

A remaining challenge for future research will be a better understanding of the effective parameters and their correlations for multi-core MNP and nanoflowers.

Impact on other Work Packages

The results and the finding in this work package have been utilized in WP3 for the improvement of MNPs and to synthesize MNPs with specific properties.

The scientific results of our work on the classification of MNP and the classification of analysis methods have been used in our standardization work in WP5.

The characterization of single- and multi-core MNPs has been utilized to harmonize and to improve the analysis methods. The correlation of results led to a better understanding of link between the structural and magnetic properties of MNPs. As a consequence, our achievements were relevant in the standardization work in WP5 and it provided the technological background for our cooperation in the ISO/TC 229.

The partners in WP4 have provided the technical and scientific content for the preparation of a SOP for each analysis technique considering the mandatory elements of the metrological checklist. This work was important for WP5 as standard operation procedures are an essential step toward a standardized MNP characterization. Furthermore, the development of uncertainty budgets was crucial for our standardization work

The extracted structural and magnetic properties were relevant in WP6 for the verification and improvement of application measurements.

WP5: Standardization of magnetic nanoparticles

Work undertaken

In WP5 we studied the results from the synthesis work in WP3 and the analysis result of WP4 obtained on new synthesized and commercial MNPs and we have defined standardization methods and parameters. The work was divided into three parts:

- Standardization strategies of magnetic nanoparticle systems
- Defined standardization methods and relevant parameters
- Standardization roadmap

Scientific and Technical Results

3.5.2.1 Standardization work strategies

Our report D5.1 presented an overview of the identified key physical parameters and the defined terminology to be used for classification and description of magnetic nanoparticle systems. This overview represented the state-of-the-art in science and technology which can be found in literature considering also existing standards and our knowledge we gained in WP4.
We further summarized commonly used analysis techniques for the characterization of MNPs. Here, we have drawn together the information contained within existing reports submitted by the NanoMag partners, and to structure it in a manner similar to the requirements listed within the ISO/IEC directives for the drafting of international standards.
We gave an overview of existing standardization work on sampling definitions, characteristics and measurements relating to MNPs, labelling, MNP manufacturing and on standard reference material for the MNP characterization. Finally, the standardization work strategies report D5.1 contained information on the current and future need for metrology of MNPs.
The main results of this task have been published in [7]. Along with a summary of the state-of-the-art in MNP science, the paper represents significant opportunities for future research projects, and are intended to provide an overview or roadmap of major topics which should be addressed within the coming years. This work is intended to act as a precursor to the future development of MNP standards. The standardization work and result are also reported in D5.2 (Defined standardization methods and relevant parameters) and D5.3 (Standardization road map).
A result of this activity is shown in Figure 3, a mix-and-match approach as a combinatorial map showing the suggested structure around which standards relating to MNP suspensions may be built. Underlying all of the other document types are the vocabulary standards and materials specifications class, whose content feeds into the development of each of the other document types. The connections between the different classes, and the manner in which they build upon the content of others is depicted by the arrows.

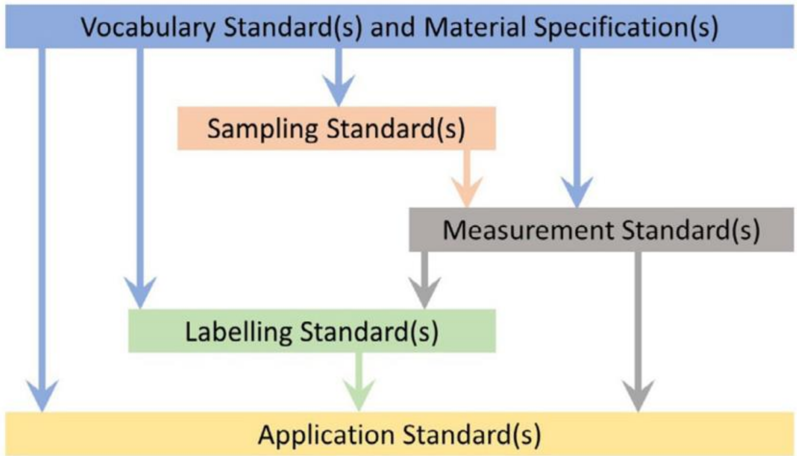


Figure 3: Diagram illustrating the framework for the standardization of liquid MNP products

The proposed structure is intended to allow the development and cross referencing of many interlinked standards with the least possible confusion or amendment. Each application standard can draw upon the specific documents which are relevant to it. Additional measurement and application standards may be developed as and when the need arises.

3.5.2.2 Defined standardization methods and relevant parameters

SOPs that have been developed in WP4 for all measurement techniques we used in NanoMag were published in D5.2. The SOPs have been prepared on the basis of a template [40] where the relevant points needed for a successfully preparation of a SOP are summarized. Furthermore, already existing standardization work was also considered in the SOPs. Furthermore, the SOPs have been established according the metrological checklist [16] providing guideline for a development of a standard. The SOPs have been used by the analysis partner for a standardized characterization of single- and multi-core MNPs. The synthesis project partners in WP3 have also developed SOPs describing established and harmonized synthesis routine to produce MNP reference systems. These reference systems cover single- and multi-core MNPs that may be used to test and verify different harmonized characterization procedures. The developed SOPs (analysis and synthesis) has only been used by NanoMag partners during the time of the project but will be used outside the NanoMag consortium in the new started MagNaStand project (EMPIR project coordinated by PTB).

We classified the relevant parameters according to parameters needed to identify the material, structural and magnetic parameters and properties assessing the MNP performance in final application. Here, we took up the NanoMag achievements and we considered also the outcome of our third survey where project partners and stakeholders have been asked what are the most important MNP properties that could be defined for an international standard. In order to transfer all our results to the ISO/TC 229 “Nanotechnology” and to the currently developing standard ISO 19807 [41] and ISO TC/229 N 1421 [42], four NanoMag partners (SP, NPL, PTB, CSIC) sent technical experts to their national standardization organizations, with the exception of CSIC, we entered also ISO/TC229 WG4 “Nanotechnologies- Material description” as technical experts. There, we used the NanoMag knowledge for active participation in the development of new standards, which was also acknowledged by the convenor of the committee.

Furthermore, within the NanoMag project, we gave recommendations of entire MNP analyses utilizing a variety of characterization methods. Flow charts illustrate divergent approaches of a particle system analysis focusing different requirements to the characterization output.

We made a proposal for a unified technical specification sheet that contains the relevant MNP parameters.

Another important finding of the NanoMag work is that the decision which MNP parameter are relevant in application and thus are important for standardization, this decision strongly depends on the specific application. There is not even one parameter that is always needed in the description of MNPs.

3.5.2.3 Standardization road map

Our report D5.3 (standardization road map) summarizes the standardization work within the NanoMag project. After a short survey of the definitions and the relevant parameters of MNPs, we illustrated the current market trends and application of MNPs. We further showed our standardization strategy (see Figure 3) that has been developed in [7].

We highlight the status and the roadmaps of European standardization bodies (CEN/IEC) with respect to the standardization of nanoobjects and for ISO/TC 229 “Nanotechnology”, where we in detail present the current and future activities in working group (WG)1 “Terminology and Nomenclature”, WG2 “Metrology and Characterization”, WG3 “Health, Safety and Environment” and WG4 “Material Specifications”.

According to Figure 3, the standardization of MNP definitions and terminology has the highest hierarchy for standardization. We thus gave an overview of which existing standard documents already cover the characteristics of MNPs and we gave a recommendation for a roadmap for MNP terminology standardization.

For the most relevant MNPs parameters and relating characterization methods that have been identified during our work and which were revealed by surveys, we summarized the available standards.

We further noticed that for none of the relevant MNP biomedical applications standard documents exist so far and we thus recommended also a roadmap for MNP application standardization.

Impact on other Work Packages

We gave feedback to WP3 regarding the synthesis of MNP system with specific properties with the aim to verify and harmonize analysis methods to be used for standardization.We were in strong collaboration with WP4 concerning the preparation of SOPs and Round Robin tests. We supported the partners in WP3 and WP4 in case of metrological issues and we provided the basis for the preparation of uncertainty budgets in WP4. We have continuously informed all NanoMag partners about the current activities at ISO to that they had the opportunity to contribute in the development of work items.

WP6: Application and benchmarking

Work undertaken

This work package concerned the application and benchmarking of nanoparticles produced within the project in WP3 as well as commercially available nanoparticles with the goal of tailoring the particle properties to achieve improved performance in the chosen applications. Three application oriented techniques were selected for this investigation, where each technique had its own set of requirements:

(1) Magnetic particle rotation
(2) Brownian relaxation
(3) Magnetic particle imaging

Below, we report the main results and achievements separately for each of the techniques and list the publications resulting from the work.

Scientific and Technical Results

3.6.2.1 Magnetic particle rotation

The work was divided in three tasks: First we demonstrated the feasibility of measuring the nano-mechanical stiffness of single proteins with MMPs (Task 6.1). In the next phase (Task 6.2) we investigated whether the nano-mechanical stiffness could be related to the change in shape also denoted as the conformation of a protein, which determines its function. In this study, we focused on cardiac troponin, a protein released into the bloodstream upon heart failure and therefore an important biomarker for cardiovascular diseases. In the third phase (Task 6.3), we explored the possibility to probe the interaction between functionalized MMPs during their approach to functionalized substrates, an important requisite for creating sandwiched proteins in applications.

All experimental work was carried out using a home-built quadrupole electromagnet, which acts as a magnetic torque tweezer in combination with a microscope in order to monitor the rotation of the MMPs. In order to visualize the rotation of a single MMP with the microscope, we used fluorescent particle labels to break the rotational symmetry. Within the project we used both commercial particles (Dynal M-270, Thermo-Fisher) as well as particles synthesized in the NanoMag consortium by partner SP. The latter turned out to have a broad size distribution and the biofunctionalization turned out to be significantly more challenging than for the commercially available particles. As a result, we decided to continue using the commercially available Dynal M-270 particles. These particles were analysed within the consortium using standard techniques described in WP5 as well as non-standard techniques quantifying the torque described in the deliverables 6.1 and 6.2.

An impressive result, which illustrates the achieved goals of both task 6.1 and 6.2 is shown in Figure 4. The angular deformation of a cardiac troponin protein complex is shown as function of time in a rotating magnetic field (Task 6.1). The three figures illustrate a reversible change in twisting amplitude that can be related to the conformation of the troponin complex present in a flow cell when the local calcium concentration is altered. These conformations correspond to different stages of heart muscle contraction induced by the local calcium concentration (Task 6.2).

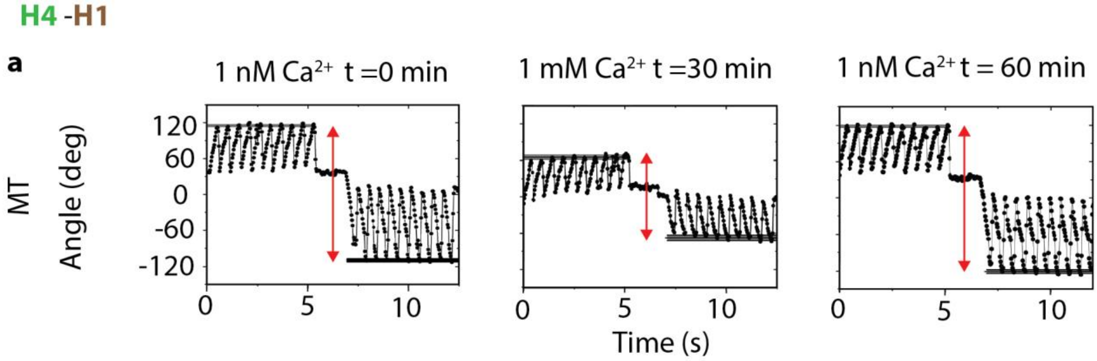


Figure 4**:** Angle of magnetic microparticle attached to substrate through a single troponin protein complex recorded for several cycles of rotating magnetic field. The rotation direction of the field is changed after approx. 5 min. Upon addition of Ca^{2+} (t = 30 min), a stiffening is observed as a reduction of the angle excursions. Upon a reduction of the Ca^{2+} concentration (t = 60 min) the curve obtained at t =0 min is recovered showing the stiffening to be reversible.

In biosensor applications, MMPs are magnetically pulled towards a surface to form the sandwiches that are described above. The interaction potential of functionalized MMPs with the antibody coated surfaces determines to a large extent the type of bond that will be formed and thereby the sensor performance. In task 6.3 we explored probing this interaction potential with rotating MMPs. We analysed both the magnetic field-induced particle rotation and the thermally induced random Brownian motion of the particle when it approaches the surface. We varied the distance between the particles and the surface by using a magnetic field to pull the particles towards the surface as well as the dilution of the buffer which influences the electrostatic repulsion between the particle and the surface.

The measurements successfully identify two regimes of interactions that can be described by the particle surface distance. These regimes can be explained by the particle-surface interaction potential (DLVO theory), which predicts two energy minima separated by an energy barrier.

Experimental parameters determine that particles are either within a few nanometers from the surface with a bond type that can be identified by the particle rotation behaviour (the primary minimum) or further away in a secondary minimum. In this secondary minimum MMPs rotate with a significant friction to the surface identified by the increasing phase lag to the rotating magnetic field. Here, the particles do not form a molecular bond indicated by the relatively large translational, Brownian, motion amplitudes.

These measurements prove that magnetic particle rotation can be used to probe the interaction between a functionalized MMP and a surface, which can be applied to optimize biosensor performance. The results obtained in this activity are documented in [43] and in the manuscripts [44], [45].

3.6.2.2 Brownian Relaxation

This activity utilizes nanosized particles with sizes in the range of 100 nm and below to detect and investigate biomolecules in a sample based on changes in the hydrodynamic size of the particles. The ability of a particle to rotate in response to a rotating or oscillating magnetic field (Brownian relaxation) depends on its size – smaller particles can rotate faster and follow the oscillating magnetic field up to higher frequencies than larger particles. Therefore, measurements of the ability of the particles to rotate as function of the frequency of the magnetic field can be used to estimate the size of the particles with attached molecules. Several ways to use such measurements for bio-detection have been investigated in the project.

The technique employed in the project is a newly developed and promising optomagnetic (OM) technique that measures the intensity of light transmitted through a suspension of nanoparticles in response to an oscillating magnetic field applied either along or perpendicular to the light path (Figure 5, right). The technique has been further developed in the NanoMag project and evaluated on all new synthesised MNP systems in the project. The technique takes advantage of the experimental fact that many particle systems are not spherical and have a remanent magnetic moment along their long axis. Therefore, an applied oscillating magnetic field produces a modulation of the intensity of transmitted light as the particles rotate to align their magnetic moments along the magnetic field.

In the project we have developed several setups for optomagnetic measurements (Task 6.4):

(1) a setup that combines centrifugal microfluidic disk with OM measurements [46] (Figure 5, left)
(2) a setup that allows for simultaneous real-time measurements at a controllable temperature in four chips [47]
(3) a setup that allows for easy change of wavelength of the light

The principle of the technique has been described in detail by Fock et al [48].

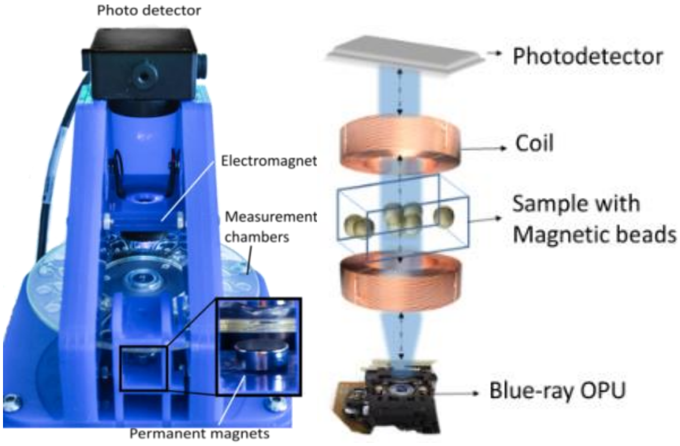


Figure 5: *left*: Experimental setup where the readout is integrated with lab-on-a-disk sample handling. [46] *right*: Principle of optomagnetic measurements. The synchronous modulation of the light transmitted through the sample in response to an oscillating magnetic field is measured using a photodetector.

We have developed a new quantitative method to determine the magnetic moment and the hydrodynamic size of particles using OM measurements [48]. The method was applied to all particle systems synthetized in WP3 and on some commercially available particle systems to identify the particle systems with the best performance and to gain knowledge on which of the parameters of the particle systems that are important for the quality of measurements on the particle suspensions (Task 6.5). We have also developed a method, which uses AC Susceptibility (ACS) and OM measurements vs. field *and* frequency to obtain directly the number-weighted magnetic moment and hydrodynamic size distribution, as well as the correlation between the distributions. The method utilizes the nonlinear response of the particle at high magnetic field strengths [49].

When used for bio-sensing, the optomagnetic method is used to measure changes in the hydrodynamic size distribution and/or changes in the extinction properties of the MNP dispersion upon binding of target bio-molecules to the MNPs. This binding could be detected as either an increase of the size of the individual nanoparticles or as a change of the signal due to clustering of the nanoparticles. Using commercial available magnetic nanoparticles (mainly multicore particles from partner Micromod with diameters of 80 nm or 100 nm) we have used this principle ourselves or in collaboration (Task 6.6) to detect:

- Coils of DNA formed by a rolling circle amplification (RCA) reaction [46]
- Monomerized (chopped up) rolling circle amplified DNA [50]
- Products formed from synthetic Dengue DNA by loop-mediated isothermal amplification (LAMP) and detected in real-time during the reaction [51]
- C-Reactive Protein (CRP) and comparing/benchmarking to a readout on the same samples using AC susceptibility [52]
- NS1 protein dengue biomarker in serum [53]
- prostate- specific antigen (PSA) using shape anisotropy enhanced optomagnetic measurement [54]
- Thrombin [55]
- the pH dependence of DNA triplex nanoswitches [47]

From the vast amount of particle systems synthesized in WP3, a limited set of candidates for bio-detection was identified, and one particle system (prepared by Micromod) was selected and optimized for bio-detection (Task 6.6). We obtained six different batches of this particle system, and optimized the probe density and the buffer used in the experiment. We were able to obtain slightly better performance with this system compared to our conventional commercially available magnetic nanoparticles (also from Micromod). We learned that the transition from a system showing reproducible physical properties to one that also has reproducible performance after surface functionalization and exposure to bioassay conditions should not be underestimated and is at least as demanding as defining the optimum physical properties.

During this activity, we have investigated and developed a new optomagnetic technique for characterization and bio-detection. The technique has been applied on the characterization of the hydrodynamic size and magnetic moment on essentially all particle systems in the project and the information obtained (when possible) has been compared to alternative determinations. A variety of setups have been developed and applied for the detection of a range of biomolecules using a range of different detection strategies (see references for more information). Most of these experiments were performed using commercially available nanoparticles produced by one of the project partners (Micromod), which were also subject to characterization in WP4. A particle system – also prepared by Micromod – that showed promising properties in physical measurements was selected and functionalized. However, the performance of this system when used for bio-detection, under the conditions tested, was found to be only marginally better than that used previously.

3.6.2.3 Magnetic particle imaging

The new tomographic imaging modality magnetic particle imaging (MPI) is able to combine high spatial and temporal resolution with excellent sensitivity, opening new opportunities in clinical applications. The principle of MPI is based on the nonlinear magnetization curve of superparamagnetic iron oxide nanoparticles and does not stress the patient with harmful radiation. An overview of current scanner topologies and tracer materials can be found in Panagiotopoulus et al. [56]. With optimized scanner topologies and advanced tracers, a spatial submillimeter resolution is possible. In 2015, Bringout et al. [57] introduced the first concept for a rabbit sized field free line MPI scanner. Also in 2015, Graeser et al. [58] introduced a magnet particle spectroscopy (MPS) device which is able to generate field free point and field free line field sequences while applying different possible offset fields. The flexibility of this measurement device allows the comparison of different particle responses of different field sequences with the same setup. A sensitivity study by Bente et al. [59] verified the linearity of the reconstructed signal of a permanent magnet field free line MPI scanner with respect to the particle concentration of Resovist (Bayer Schering Pharma AG, Berlin, Germany), which is used as a gold standard in MPI, and found a lower detection limit of 15 μg iron in magnetite. In 2017, Dieckhoff et al. [60] were able to demonstrate an improved MPI visualization of the liver applying Resovist and an enhanced system function approach and multiple patches reconstructions.

In task 6.7 of WP6, we investigated the suitability of particles that were synthesized, analyzed and standardized in the NanoMag consortium. The resolution study was performed using a magnetic particle scanning device (preclinical MPI scanner, Bruker BioSpin GmbH, Ettlingen Germany) and three MPS devices [Biederer et al., J. Phys. D Appl. Phys., 42(20), 2009; Graeser et al., Phys. Med. Biol., 62(9), 2017; Chen et al., IWMPI, 2017] to compare the particles regarding their sensitivity and spatial resolution. Over all, three commercial particles selected in WP1, 28 particles synthesized in WP3 by CSIC, nanoPET, micromod, DTU, and SP, as well as nine particles reproduced by nanoPET and micromod regarding to the acquired standard operating procedures of WP5 were available. For reconstruction model-based, hybrid-based as well as measurement-based reconstruction techniques were used as introduced amongst others in Schmidt et al. [61] and von Gladiss et al. (Phys. Med. Biol., 62(9), 2017). All measurement results were compared to the results of Resovist,

Using the results of MPS measurements [62], [63], all the above particles were compared in terms of signal strength in MPI both with and without the presence of magnetic offset fields. Twenty-five particles (two commercial, 14 synthesized, eight reproduced) were selected for further investigation considering their performance.

The evaluation of the measurement results identified some particles with a possible suitability for use in MPI. The spatial resolution as well as the sensitivity of the particles showed results comparable to those of Resovist. Figure 6 shows the reconstructed images of four particles with an emulated distance of 4 mT/µ0 corresponding to a spatial distance of 3.2 mm in the Bruker preclinical MPI scanner, including Resovist as reference, FeraSpin R and MM08 as positive examples and CSIC07 as a negative example.

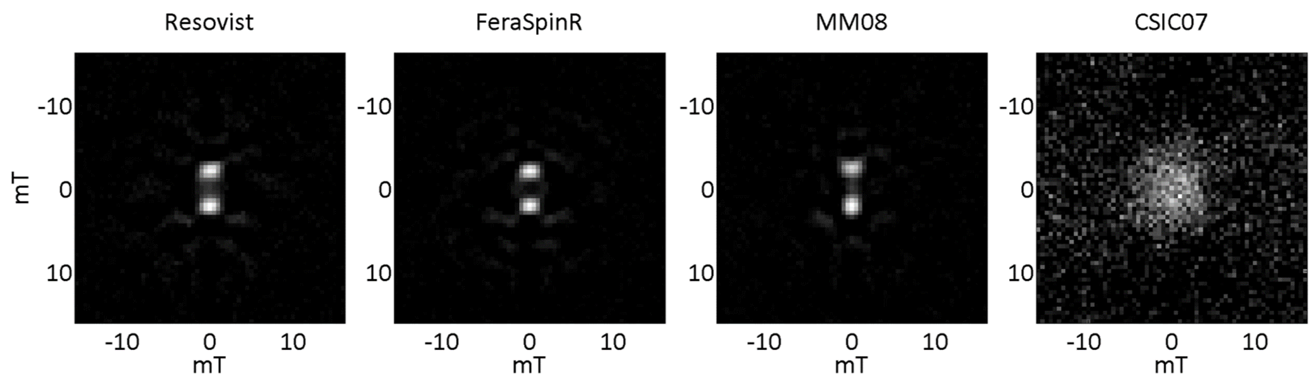


Figure 6: Reconstructed images of Resovist, FeraSpinR, MM08 and CSIC07 measured at 12 mT in *x*- and *y*-directions with a sample volume of 10 µl and with an emulated distance of 4 mT/µ0 corresponding to a spatial distance of 3.2 mm in the Bruker preclinical MPI scanner.

In order to match some of the chemical and structural parameters of the particles with a possible MPI suitability, parameters, such as the iron content, the particle shape and the core size as defined in the technical data sheets or characterized by consortium members, were investigated. The comparison of those parameters does not allow for the definition of a sharp quality criterion for the analysis and the synthesis in respect to MPI devices. Neither the different synthesis methods nor the different particle coatings used for the synthesis of the particles within the consortium seem to have a noticeable impact on the MPI suitability. It can be stated though that particles with an iron core below 30 nm and an irregular or flower-shaped core seem to be more suitable for MPI than particles with a spherical or rhombohedral core and a core size above 30 nm. The results of this activity will be documented in [64].

Impact on other Work Packages

The partners in WP6 were in strong collaboration with WP4 and have contributed in the standardization activities in WP5.

WP7: Dissemination and exploitation

The main results in WP7 (dissemination and exploitation) are listed under "Potential Impact and Main Dissemination Activities" section.

Potential Impact and Main Dissemination Activities (WP7: Dissemination and exploitation)

In the NanoMag project we see the following main impacts during the project.

- Clear nomenclature for describing structure and magnetic properties of MNPs and MNP ensembles
- Improvements in reproducibility of MNP synthesis. Over 50 new MNP systems synthesized in the project.

- Excellent surveys of many common measurement methods for MNPs and their pros and cons, classification of these methods including also classification of different types of MNP systems
- Stakeholder committee group connected to the NanoMag project.
- For some measurement methods: SOPs, uncertainty budgets, metrological descriptions
- Improved modelling of MNP magnetic properties, especially: dynamic behavior
- Correlation analysis between MNP parameters determined by different analysis methods
- Over 80 new publications in international high impact journals and over 160 presentations and seminars carried out by NanoMag partners
- E-learning modules (NPL-web site, linked from the NanoMag homepage)
- Substantial contribution to ongoing ISO MNP standards (ISO 19807 ” Nanotechnology — Liquid suspension of magnetic nanoparticles — Characteristics and measurements', PG14 "Superparamagnetic beads for free cell DNA extraction)
- Analysis service in the future (information will be collected at NanoMag homepage and PTB data server)
- Continuation with the MagnaStand EU project coordinated by Uwe Steinhoff (PTB).
- Round Robin measurements (same analysis methods but in different labs) using different types of MNP systems
- Our industrial partners in the project have commercialized some of the most promising MNP systems that was synthesized during the project

The dissemination after the NanoMag project ended are described in the NanoMag exploitation plan. Main results from the exploitation plan are described in the following text: “Within NanoMag project we have identified three main types of exploitable outcomes. These are areas where the work that is currently being done within the project can be used to generate impact, either directly, through the creation of best practice and standards, or indirectly, through the upskilling of researchers and industry in the use of MNPs.”

1. **Standardisation practices and procedures.** As with any emerging field of research that is finding applications in industry, there is a need to ensure that users are supplied with the correct information and supporting guidelines detailing what they are dealing with and how it should be used. This information is currently lacking in the field of MNPs and is a necessary part of building confidence in new products, from both users and investors, as well as ensuring that these products are used correctly, which is especially important in the many medical applications that exist.
2. **Services/measurement services.** As this project represents the formation of a measurement community for MNPs, it is important to be clear about the expertise and potential services that exist and can be offered to both industry and academia.
3. **Teaching aids** such as e-learning products, best practice guides, and reports on standard operation procedures (SOPs) that will make results accessible to users. Aimed more at students and new researchers moving into the field, the production of teaching and learning resources will help to train the next generation of researchers and provide established researchers with the capabilities and understanding to pursue further research into the use of MNPs in biomedical science.

These three outcomes are further described in the following pages.

Initiation of new standards

In 2015 ISO/TC229 WG4 “Nanotechnologies – Material specification” started independently of NanoMag the development of a material specification for MNPs (ISO 19807). Immediately, NanoMag reacted to this development by sending technical experts to the national standard developing organisations (SDOs) in the UK, Spain, Sweden and Germany, which are all countries with considerable industrial involvement in the MNP sector. This was necessary, because NaoMag was the dominant pre-normative activity focusing on MNPs in Europe. In addition, these SDOs have now documented plans to adopt ISO 19807 as a national standard. Except Spain, the NanoMag partners delegated their technical experts also to ISO/TC229 WG4, where they subsequently contributed to the development of ISO 19807. Currently ISO 19807 is in draft form with completion anticipated by the end of 2018. NanoMag partners PTB, NPL, RISE Acreo, MICROMOD, and UCL will continue to work on ISO 19807 within the follow-up project MagNaStand. A specific task in MagNaStand is to secure the public results of NanoMag and make it available for further MNP standardisation at ISO and CEN level.

In September 2016, ISO/TC229 WG4 started to prepare a Preliminary Work Item “Specification for superparamagnetic beads composed of nanoparticles for circulating tumour DNA extraction”. This proposal did not come from NanoMag members. It has now been accepted and ISO has started the development of the next standard involving MNPs under active contribution and involvement of the NanoMag members. This new standard will directly affect a number of European SMEs and larger companies working in the field. One European company, Roche-Diagnostics, has published a market turnover in 2014 of 2.6 bln € with their immunodiagnostics (including reagents and instruments), which are based on the use of MNPs[1].

The NanoMag project has brought immense input into the development of these new standards, which has been recognized several times by the ISO TC229/WG4 working group. In addition, an agreement has been reached with the respective European standardisation committee CEN/TC352 “Nanotechnologies” that the committee will support the developments at ISO and that, after finalization, it will adopt the ISO standards as European normative documents.

Participation in other relevant MNP projects

Five members of the NanoMag consortium (NPL, RISE Acreo, DTU, PTB, UCL) are also active in the TD COST network 1402 “RADIOMAG: Multifunctional Nanoparticles for Magnetic Hyperthermia and Indirect Radiation Therapy”. This research network with over 140 participants covers several aspects of a new cancer therapy based on MNPs. One workpackage is specifically dedicated to the standardisation of MNP characterisation, where the NanoMag partners are actively involved. Participation of NanoMag partners in a ring comparison of MNP heating characteristics was of a great importance, where the NanoMag consortium supported the data analysis and interpretation for a larger number of participants. Another goal within this is the setup of calibration samples for magnetic hyperthermia. The RADIOMAG network will continue running until late 2018, well after the end of NanoMag.

Follow-up projects of MNP analysis standardisation (MagNaStand)

Acknowledging the situation that NanoMag does not have the necessary funding for a continuous support of standardisation and it does not last long enough to finalise an ISO standards development, it was necessary to create a follow-up project achieving these goals. For this reason, some members of the NanoMag consortium initiated a new *co-normative* EMPIR project on MNPs, that in contrast to NanoMag, which is a *pre-normative* project. In June 2017, the new project MagNaStand went into operation. Participating NanoMag partners are PTB as the coordinator, NPL, UCL, RISE Acreo and Micromod.

From the beginning, a strong collaboration and transmission of the results between NanoMag and MagNaStand projects was envisaged. Specifically, in the MagNaStand working plan, a Task 3.1 is defined under the title;” Knowledge transfer from the pre-normative EU FP7 project NanoMag”. The aim of this task is to gather the metrological knowledge gained in the FP7 project NanoMag (2013-2017) and make it available for the international standardisation of MNPs. The information collected from NanoMag will be used within MagNaStand in the development of magnetic measurement methods, in the preparation of metrological checklists and in the development of new standards at a national and an international level.

[1] https://echa.europa.eu/documents/10162/8e0b0272-73d1-4e9a-8616-97ad9ee813d9

Measurement Services

One of the most direct ways for this project to generate impact is through ensuring that companies and researchers are aware of the services and expertise that exist in MNP metrology. In order to grow this awareness NanoMag is currently carrying out the following actions:

A reference sheet for methodological standards will be made free and publicly available and will be able to be downloaded from the NanoMag website (that still will be available and updated after the NanoMag project). This reference sheet will be designed for the customers that buy MNP systems to be used in specific applications (such as bio-separation, hyperthermia, or bio-sensing). Each of the application areas are interested in different specifications of the MNP systems, however knowledge of the particle size and particle morphology (single- or multi-core), and how to treat each of these, is required for each application. Additionally, specific magnetic saturation value and initial magnetic susceptibility are two important parameters that customers find valuable. This sheet will be updated on the NanoMag site up to two years after the end of the project. After this point, one suggestion would be that the synthesis partners will keep the NanoMag specifications for their MNP systems at their own websites. This would be preferable to leaving an out-of-date copy on the NanoMag website for later reference, however, it would require continued coordination.

The development of new samples or reproducing of old formulations and their characterisation – at cost – may be possible after the project's completion. It is desirable to maintain communication between the 17 partners of the NanoMag consortium after the project. This will create a post-NanoMag community and allow external companies to contact this community (through project coordinator Christer Johansson RISE Acreo as primary contact), if they require guidance on synthesis, analysis and standardisation of MNP systems. In this case the NanoMag partners might charge such companies individually for each specific consultancy or action.

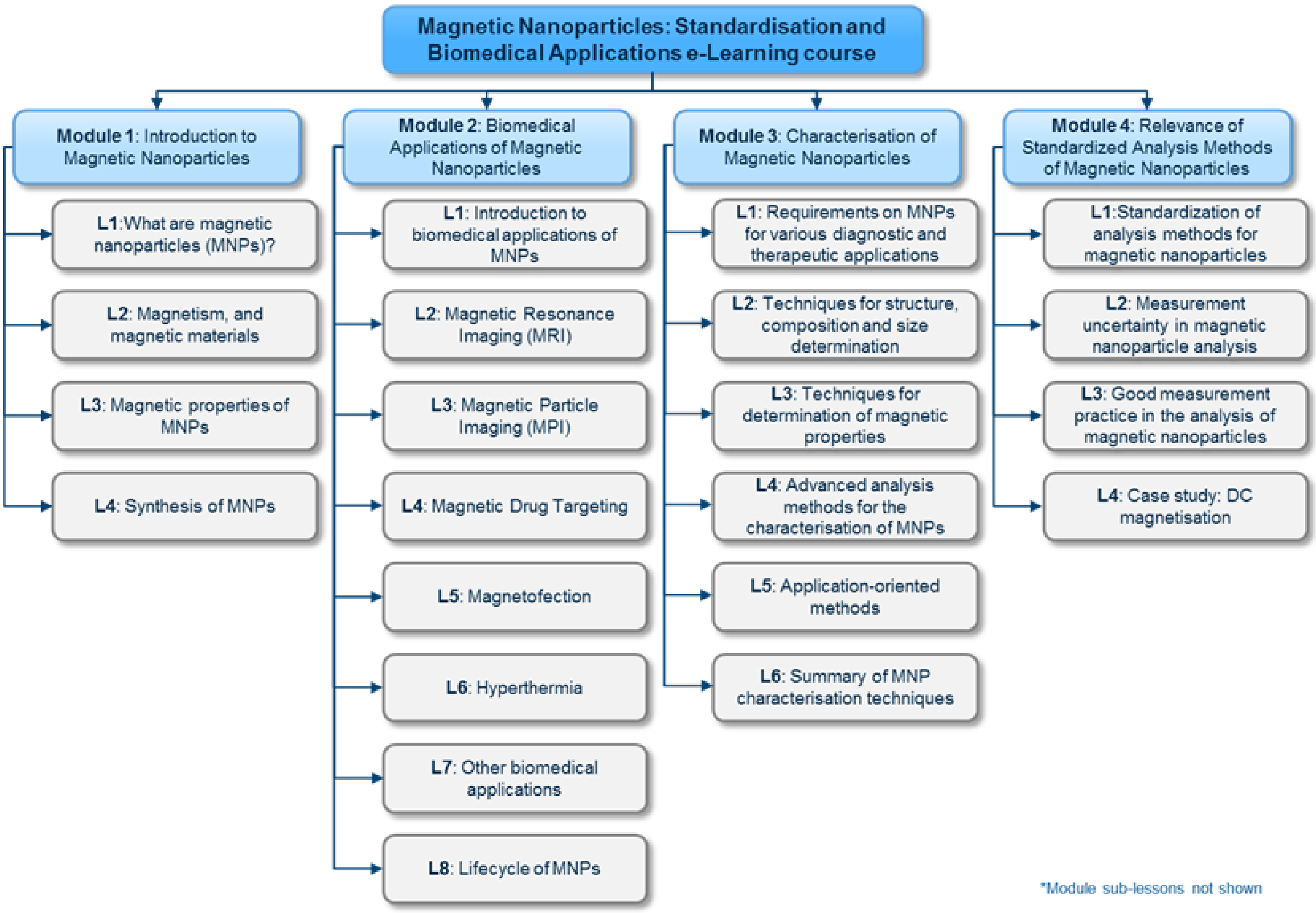
In order to facilitate this interaction between companies and the NanoMag community 'Yellow Pages' of NanoMag techniques and contacts is being generated and will be able to download this from the NanoMag website. This will be a directory stating what services each partner is capable of, which can be used be industry to find relevant points of contact and increase awareness of what the consortium as a whole can deliver. One example is an operation of the Core Facility "Metrology of Ultra-Low Magnetic Fields" at PTB since June 2017. PTB grants external scientists from universities, international metrology institutes and companies access to its know-how and its equipment for the measurement of extremely small magnetic fields, explicitly including the thorough characterization of magnetic nanoparticles.

This directory will be held on the NanoMag website. It would be efficient to have this stored with the reference sheet and linked across partner sites after updates of the NanoMag site cease. This would need to be well organised with defined leads and a main site to hold the curated document. This would then be shared with organisers of conferences and meetings on MNP systems to ensure that attendees are aware of the extent of the community that has been established to assist in the standardisation and assurance of MNP characterisation. The NanoMag website and the NanoMag data at the PTB server will be active after the NanoMag project has ended.

Teaching/Learning

We understand that the setting of standards and the provision of services alone will not produce impact if the requisite understanding does not exist in both the research and industrial communities. In order to grow this understanding, NanoMag is producing tools and guidance for education in MNPs.

The main thrust of this outcome is being pursued through production of a series of e-Learning modules under the common title *Magnetic Nanoparticles: Standardisation and Biomedical Applications*. The course comprises 4 modules, linked to the knowledge and skills generated by the NanoMag project, each of which covers a number of lessons on different subject areas and which will be freely available indefinitely. The content and structure of the course is summarised in the course map below.



Learners can take the modules individually as a stand-alone learning resource, or can undertake all four together as a full e-Learning course. Information on these modules, including links to the e-Learning course, can be found on the NanoMag website (www.nanomag-project.eu) and will remain live after the website curation ends, i.e. two years after the project completion. The modules themselves are held on the NPL e-learning website and will be accessible indefinitely. Up to now 132 people have already enrolled to the first 2 modules. The number is expected to increase significantly when all modules are launched after the end of the project.

For information on more routine processes, the project is developing best practice guides for specific MNP measurement/characterisation that will be easily contextualised to relate to product information. This will be led by PTB.

Stakeholder Surveys, Stakeholder meeting and Dissemination Conference

In order to maximise the output from the stakeholder participation, surveys were carried out in four main areas. The surveys were implemented online using SurveyMonkey. These questions were typically formatted in a binary or point based manner with the option to leave additional comments. The surveys were carried out over the course of 36 months and concentrated on four main areas:

- Initial assessment of stakeholder/consortium interests and views.
- Characterisation techniques of MNP's.
- Standards and role of standards in MNP industry.
- Performance of MNP's in applications

The objective of the first survey was to form an initial assessment of the stakeholder interests and gauge the general views of the stakeholder/consortium. The second survey concerned specific areas of characterisation techniques of MNPs. The third survey concerned specific areas of standardisation and the role of standards in the MNP industry. The fourth, and final, NanoMag survey looked at applications of

MNPs and whether available particles limit performance of these applications. It also included questions on the importance of MNPs' characteristics (such as single or multiple magnetic cores, hydrodynamic size and colloidal stability) to their purpose.

During the project, we have had two major meetings, in connection to the ordinary project meetings, with the NanoMag stakeholder committee (PTB Berlin M18 and at SP Stockholm M36). During these meetings, we have discussed the standardization parameters that are important in industry and how these are applied for instance in MNP synthesis process and analysis. We have also discussed the project result uptake and how the results can be further be used in the future.

The final dissemination conference (deliverable D7.8) took place at Waterfront Hotel in Göteborg, Sweden on 25-26 September 2017. The presentations were chosen to show the most scientific impacts in the project related to; I) synthesis, II) analysis and II) applications. In total 52 attended the conference. The NanoMag stakeholder committee was represented by Barry Moskowitz and Joachim Schwender (Ferrotec), Lluis Martinez (Sepmag), Filiz Ibraimi (Lifeassays), Grete Irene Modahl (Thermofisher), Jose Maria Abad (Nano Immunotech) and Gunnar Schütz (Bayer). Also, external participants invited by NanoMag partners attended the conference. We got a very good response from both the stakeholders and the NanoMag partners that the conference was very much appreciated.

Group picture from the final dissemination conference in Göteborg, September 2017.

During the project, over 80 publications submitted to international journals and over 180 presentations at international conferences and seminars disseminating the NanoMag results (listed in template A1 and A2)

Website and Contact

The NanoMag homepage can be found at http://www.nanomag-project.eu/home.html.

Contact:
Christer Johansson, Professor
Senior Expert
RISE Research Institutes of Sweden
Division ICT – RISE Acreo AB
+46 72 723 33 21
Arvid Hedvalls Backe 4, 400 14 Göteborg, Sweden
christer.johansson@ri.se

References

[1] H. Gavilán et al., "Colloidal Flower-shaped Iron Oxide Nanoparticles: Synthesis Strategies and Coatings," *Particle and Particle Systems Characterization, accepted,* 2017.

[2] H. Gavilán et al., "Formation mechanism of maghemite nanoflowers synthesized by polyol mediated process," *Chemistry of Materials, submitted,* 2017.

[3] Y. Luengo et al., "Counterion and solvent effects on the size of magnetite nanocrystals obtained by oxidative precipitation," *J. Mater. Chem. C,* no. 4, pp. 9482-9488, 2016.

[4] H. Gavilán et al., "How shape and internal structure affect the magnetic properties of anisometric magnetite nanoparticles," *Acta Materialia,* no. 125, pp. 416-424, 2017.

[5] F. Vita et al., "Tuning morphology and magnetism of magnetite nanoparticles by calix[8]arene-induced oriented aggregation," *CrystEngComm,* no. 18, pp. 8591-8598, 2016.

[6] H. Gavilán et al., "Controlling the size and the shape of uniform magnetic iron oxide nanoparticles for biomedical applications," *Chapter 1 in Clinical Applications of Magnetic Nanoparticles ISBN: 978-1-138-05155-3 Edited by Nguyen T. K. Thanh, CRC Press,* 2017.

[7] J. Wells et al., "Standardisation of Magnetic Nanoparticles in Liquid Suspension," *J. Phys. D: Appl. Phys.,* no. 50, p. 383003, 2017.

[8] L. Gutierrez et al., "Synthesis methods to prepare single- and multi-core iron oxide nanoparticles for biomedical applications," *Dalton Trans.,* no. 44, pp. 2943-2952, 2015.

[9] S. Bogren et al., "Classification of Magnetic Nanoparticle Systems—Synthesis, Standardization and Analysis Methods in the NanoMag Project," *Int. J. Mol. Sci.,* no. 16, pp. 20308-20325, 2015.

[10] F. Ludwig et al., "Optimization of Magnetic Nanoparticles for Magnetic Particle Imaging," *IEEE Trans. Magn.,* no. 48(11), pp. 3780-3783, 2012.

[11] D. Eberbeck et al., "Multicore Magnetic Nanoparticles for Magnetic Particle Imaging," *IEEE,* no. 49, pp. 269-274, 2013.

[12] S. Dutz et al, "Ferrofluids of magnetic multicore nanoparticles for biomedical applications," *J. Magn. Magn. Mater.,* no. 321, pp. 1501-1504, 2009.

[13] P. Hugounenq et al., "Iron oxide monocrystalline nanoflowers for highly efficent magnetic hyperthermia," *J. Phys. Chem. C,* no. 116, pp. 15702-15712, 2012.

[14] O. Posth et al., "Classification of analysis methods for characterization of magnetic nanoparticle properties," *Proc. IMEKO XXI World Congress,* pp. 1362-1367, 2015.

[15] P. Bender et al., "Distribution functions of magnetic nanoparticles determined by a numerical inversion method," *New J. Phys.,,* no. 19, p. 073012, 2017.

[16] "ISO/TS229-IEC/TC113/JWG2 Metrological check-list for the use in preparation and evaluation of ISO NWIPs and ISO WDs, ISO/TC N 673," 2010.

[17] F. Ludwig et al., "Size analysis of single-core magnetic nanoparticles," *J. Magn. Magn. Mater.,* no. 427, pp. 19-24, 2017.

[18] F. Ludwig et al., "Dynamic Magnetic Properties of Optimized Magnetic Nanoparticles for Magnetic Particle Imaging," *IEEE Transactions on Magnetics,* no. 50(11), pp. 1-4, 2014.

[19] F. Ludwig et al., *IEEE Trans. Magn., in press,* 2017.

[20] J. Dieckhoff et al., "Magnetic-field dependence of Brownian and Néel relaxation times," *J. Appl. Phys.,* no. 119, pp. 043903-1-8, 2016.

[21] E. Wetterskog et al., "Tuning the structure and habit of iron oxide mesocrystals," *Nanoscale,* no. 8, p. 15571, 2016.

[22] P. Bender et al., "Structural and magnetic correlations of multi-core nanoparticles revealed by a generalised numerical inversion method," *Sci. Rep.,* no. 7:45990, 2017.

[23] E. Wetterskog et al., "Size and property bimodality in magnetic nanoparticle dispersions: single domain particles vs. strongly coupled nanoclusters," *Nanoscale,* no. 9, pp. 4227-4235, 2017.

[24] T. Yoshida et al., "Effect of alignment of easy axes on dynamic magnetization of immobilized magnetic nanoparticles," *J. Magn. Magn. Mater.,* no. 427, pp. 162-167, 2017.

[25] N. Löwa et al., "Magnetic nanoparticles in different biological environments analyzed by magnetic particle spectroscopy," *J. Magn Magn. Mater.,* no. 427, pp. 133-138, 2017.

[26] T. Viereck et al., "Dual-frequency magnetic particle imaging of the Brownian particle contribution," *J. Magn.*

Magn. Mater., no. 427, pp. 156-161, 2017.

[27] D. Heinke et al., "Diffusion-Controlled Synthesis of Magnetic Nanoparticles," *International Journal on Magnetic Particle Imaging*, no. 2(1), pp. 1603001-1-4, 2016.

[28] K. Witte et al., "Particle size- and concentration-dependent separation of magnetic nanoparticles," *J. Magn. Magn. Mater.*, no. 427, pp. 320-324, 2017.

[29] J. Sommertune et al., "Polymer/Iron Oxide Nanoparticle Composites—A Straight Forward and Scalable Synthesis Approach," *Int. J. Mol. Sci.*, no. 16, pp. 19752-19768, 2015.

[30] D. F. Coral et al., "Effect of Nanoclustering and Dipolar Interactions in Heat Generation for Magnetic Hyperthermia," *Langmuir*, no. 32 (5), pp. 1201-1213, 2016.

[31] K. Simeonidis et al., "In-situ particles reorientation during magnetic hyperthermia application: Shape matters twice," *Sci. Rep.*, no. 6, p. 38382, 2016.

[32] W. Szczerba et al., "SAXS analysis of single- and multi-core iron oxide magnetic nanoparticles," *J. Appl. Cryst.*, no. 50, pp. 481-488, 2017.

[33] A. Lak et al., "Resolving particle size modality in bi-modal iron oxide nanoparticle suspension," *J. Magn. Magn. Mater.*, no. 380, pp. 140-143, 2015.

[34] A. Joos et al., "Size-dependent MR relaxivities of magnetic nanoparticles," *J. Magn. Magn. Mater.*, no. 427, pp. 122-126, 2017.

[35] D. Schmidt et al., "Finding the magnetic size distribution of magnetic nanoparticles from magnetization measurements via the iterative Kaczmarz algorithm," *J. Magn Magn. Mater.*, no. 431, pp. 33-37, 2017.

[36] J. Leliaert et al., "Interpreting the magnetorelaxometry signal of suspended magnetic nanoparticles with Kaczmarz' algorithm," *J. Phys. D: Appl. Phys.*, no. 50, p. 195002, 2017.

[37] J. Leliaert et al., "The complementarity and similarity of magnetorelaxometry and thermal magnetic noise spectroscopy for magnetic nanoparticle characterization," *J. Phys. D: Appl. Phys.*, no. 50, p. 085004, 2017.

[38] S. Draack et al., "Temperature-dependent MPS measurements," *International Journal on Magnetic Particle Imaging*, p. 3(1), 2017.

[39] J. Fock and L. K. Bogart et al., "Uncertainty budget for determinations of mean isomer shift from Mössbauer spectra," *Hyperfine Interact.*, no. 237(1), pp. 1-11, 2016.

[40] http://www.nanopartikel.info/en/nanoinfo/methods/992-operating-instructions.

[41] "ISO 19807 Nanotechnology -- Liquid suspension of magnetic nanoparticles -- Characteristics and measurements".

[42] "ISO N 1421 Nanotechnologies – Specification for superparamagnetic beads composed of nanoparticles for circulating tumor DNA extraction".

[43] F. A. Gutierrez Mejia, "Proteins with a Twist: Torsion Profiling of Proteins at the Single Molecule, PhD Thesis, Technical University of Eindhoven," 2016.

[44] C. M. Moerland et al., "Rotating Magnetic Beads for Lab-on-a-Chip Biosensing – A Comprehensive Review," *Lab Chip, invited review - in preparation,* 2017.

[45] F. A. Gutierrez Mejia et al., "Single Protein Conformation Switching Revealed by Antibody Targeting and Torque," *in preparation,* 2017.

[46] M. Donolato et al., "Quantification of Rolling Circle Amplified DNA Using Magnetic Nanobeads and a Blu-Ray Optical Pick-up Unit," *Biosens. Bioelectron.*, no. 67, pp. 649-655, 2015.

[47] G. A. S. Minero et al., "Optomagnetic Detection of DNA Triplex Nanoswitches," *Analyst*, no. 142(4), pp. 582-585, 2017.

[48] J. Fock et al., "Characterization of fine particles using optomagnetic measurements," *Phys. Chem. Chem. Phys.*, no. 19, p. 8802, 2017.

[49] J. Fock et al., "Field-Dependent Dynamic Magnetic and Optical Responses from Magnetic Nanoparticle Ensembles Displaying Brownian Relaxation," *in preparation*, 2017.

[50] A. Mezger et al., "Scalable DNA-Based Magnetic Nanoparticle Agglutination Assay for Bacterial Detection in Patient Samples," *ACS Nano*, no. 9(7), pp. 7374-7382, 2015.

[51] G. A. S. Minero et al., "Sequence-Specific Validation of LAMP Amplicons in Real-Time Optomagnetic Detection of Dengue Serotype 2 Synthetic DNA," *Analyst*, 2017.

[52] J. Fock et al., "Comparison of Optomagnetic and AC Susceptibility Readouts in a Magnetic Nanoparticle Agglutination Assay for Detection of C-Reactive Protein," *Biosens. Bioelectron.*, 2016.

[53] P. Antunes et al., "Quantification of NS1 Dengue Biomarker in Serum via Optomagnetic Nanocluster Detection,"

Sci. Rep., no. 5, p. 16145, 2015.

[54] B. Tian et al., "Shape Anisotropy Enhanced Optomagnetic Measurement for Prostate-Specific Antigen Detection via Magnetic Chain Formation," *Biosens. Bioelectron.,* no. 98, pp. 285-291, 2017.

[55] R. Uddin et al., "Lab-on-a-Disc Agglutination Assay for Protein Detection by Optomagnetic Readout and Optical Imaging Using Nano- and Micro-Sized Magnetic Beads," *Biosens. Bioelectron.,* no. 85, pp. 351-357, 2016.

[56] N. Panagiotopoulos et al., " Magnetic particle imaging: current developments and future directions," *International Journal of Nanomedicine,* no. 10, p. 3097, 2015.

[57] G. Bringout et al., "Concept of a rabbit-sized FFL-scanner," *International Workshop for Magnetic Particle Imaging,* p. 49, 2015.

[58] M. Graeser et al., "A Device for Measuring the Trajectory Dependent Magnetic Particle Performance for MPI," *International Workshop for Magnetic Particle Imaging,* p. 96, 2015.

[59] K. Bente et al., "Sensitivity study for an MPI FFL scanner," *International Workshop on Magnetic Particle Imaging,* p. 88, 2015.

[60] J. Dieckhoff et al., "In vivo liver visualizations with magnetic particle imaging based on the calibration measurement approach," *Physics in Medicine and Biology,* no. 62(9), p. 3470, 2017.

[61] D. Schmidt et al., "Imaging characterization of MPI tracers employing offset measurements in a two dimensional magnetic particle spectrometer," *International Journal on Magnetic Particle Imaging,* p. 2, 2016.

[62] C. Debbeler et al., "MPS study on new MPI tracer material," *International workshop on Magnetic Particle Imaging,* p. 113, 2016.

[63] C. Debbeler et al., "Investigation on new MPI tracer material," *International Workshop on Magnetic Particle Imaging,* p. 71, 2017.

[64] C. Debbeler et al., "Resolution study on new MPI tracer material," *International Workshop on Magnetic Particle Imaging,* in preparation 2018.

4.2 Use and dissemination of foreground

Section A (public)

- Table A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.
- Table A2: List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

TABLE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency,Volume	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
1	Counterion and solvent effects on the size of magnetite nanocrystals obtained by oxidative precipitation	*Y. Luengo*	Journal of Materials Chemistry C	*Vol. 4, No. 40*	*RSC*	CAMBRIDGE CB4 0WF, CAMBS, ENGLAND	*2016*	*9482-9488*	DOI: 10.1039/C6TC03567A	
2	Tuning Morphology and Magnetism of Magnetite Nanoparticles by Calix[8]arene-Induced Oriented Aggregation	F. Vita	CrystEngComm	18	RSC	UK	2016	8591-8598	DOI: 10.1039/x0xx00000x	
3	Studies of the Colloidal Properties of Superparamagnetic Iron	G. B. da Silva	J. Braz. Chem. Soc.	28	Sociedad Brasileira de	Brazil	2017	731-739	DOI: http://dx.doi.org/10.21577/0103-5053.20160221	

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

	Oxide Nanoparticles Functionalized with Platinum Complexes in Aqueous and PBS Buffer Media				Quimica					
4	Superlattice growth and rearrangement during evaporation-induced nanoparticle self-assembly	E. Josten	Scientific Reports	7	Nature Publishing Group	UK	2017	2802	DOI: 10.1038/s41598-017-02121-4	yes
5	Characterization of fine particles using optomagnetic measurements	J. Fock	Phys. Chem. Chem. Phys.	19	RSC	UK	2017	8802-8814	DOI: http://dx.doi.org/10.1039/C6CP08749C	
6	Controlling the size and the shape of uniform magnetic iron oxide nanoparticles for biomedical applications.	H. Gavilán	Clinical Applications of magnetic Nanoparticles		CRC Press/Tylor & Francis	USA/UK	To be published		ISBN: 978-1-138-05155-3.	
7	Analysis of ac susceptibility spectra for the characterization of magnetic nanoparticles	F. Ludwig	IEEE Trans. Magn.	PP,99	IEEE Magnetics Society	USA	2017	1	DOI: 10.1109/TMAG.2017.2693420	
8	Structural and magnetic properties of multi-core nanoparticles analysed using a generalised numerical inversion method	P. Bender	Scientific Reports	7	Nature Publishing Group	UK	2017	45990	DOI: 10.1038/srep45990	yes
9	Commentary on the clinical and preclinical dosage limits of interstitially administered magnetic fluids for therapeutic hyperthermia based on current practice and efficacy models	P. Southern	International Journal of Hyperthermia		Informa Healthcare	UK				

10	The anisotropy of the ac susceptibility of immobilized magnetic nanoparticles – the influence of intra-potential-well contribution on the ac susceptibility spectrum	F. Ludwig	IEEE Trans. Magn.	PP,99	IEEE Magnetics Society	USA	2017	1-1	DOI: 10.1109/TMAG.2017.2692038	
11	On the interpretation of Mössbauer spectra of magnetic nanoparticles	J. Fock	JMMM	445	Elsevier	NL	2017	11-21	DOI: https://doi.org/10.1016/j.jmmm.2017.08.070	
12	Formation mechanism of maghemite nanoflowers synthesized by polyol mediated process	H. Gavilán	ACS Omega		ACS	USA	2017		Accepted	
13	Sequence-specific validation of DNA amplicons in LAMP for real-time detection of Dengue virus DNA using magnetic nanoparticles	G.A.S. Minero	Analyst	142	RSC	UK	2017	3441-3450	DOI: dx.doi.org/10.1039/C7AN01023K.	
14	Unraveling viscosity effects on the hysteresis losses of magnetic nanocubes	D. Cabrera	Nanoscale	9	RSC	UK	2017	5094-5101	DOI: 10.1039/C7NR00810D	
15	Nanopartículas en biomedicina (in Spanish)	E. Esteban	Biotech Magazine	24	Biotech	Spain	2014			yes
16	Precise control over shape and size of iron oxide nanocrystals suitable for assembly into ordered particle arrays	E. Wetterskog	Science and Technology of Advanced Materials	15	Taylor & Francis	UK	2014	55010	DOI: https://doi.org/10.1088/1468-6996/15/5/055010	yes
17	Lab-on-Blu-ray: Low-cost analyte detection on a disk	M. Donolato	Proc. 18th Int. Conf. on Miniaturized Systems for				2014	2044-2046		

			Chemistry and Life Sciences (MicroTAS 2014), San Antonio, Texas, USA, pp. 2044-2046 (2014).							
18	Practical Applications of Asymmetrical Flow Field-Flow Fractionation (AF4): A Review	M. Leeman	LCGC Europe,	Volume 28, Issue 12			2015	642–651		
19	Effective Particle Magnetic Moment of Multi-Core Particles	F. Ahrentorp	JMMM	380	Elsevier	NL	2015	221-226	DOI:10.1016/j.jmmm.2014.09.070	
20	Resolving particle size modality in bi-modal iron oxide nanoparticle suspensions	A. Lak	JMMM	380	Elsevier	NL	2015	140-143	DOI:10.1016/j.jmmm.2014.08.050	
21	Synthesis Methods to Prepare Single- and Multi-core Magnetic Nanoparticles for Biomedical Applications	L. Gutiérrez	Dalton Trans.	44	RSC	UK	2015	2943-2952	DOI: 10.1039/c4dt03013c	
22	Magnetic nanoparticle detection using domain wall-based nanosensor	H. Corte-Léon	J. Appl. Phys.	117	AIP	USA	2015	17E313	DOI: http://dx.doi.org/10.1063/1.4914365	
23	Improving magnetic properties of ultrasmall magnetic nanoparticles by biocompatible coatings	R. Costo	J. Appl. Phys.	117	AIP	USA	2015	64311	DOI: http://dx.doi.org/10.1063/1.4908132	
24	Degradation of magnetic nanoparticles mimicking lysosomal conditions followed by ac	L. Gutiérrez	Biomedical Engineering /Biomedizinische	60(5)		D	2015	417-425	DOI: 10.1515/bmt-2015-0043	

	susceptibility		Technik							
25	Scalable DNA-based magnetic nanoparticle agglutination assay for bacterial detection in patient samples	A. Mezger	ACS Nano	9	ACS	USA	2017	7374-7382	DOI: 10.1021/acsnano.5b02379	
26	Blu-ray based optomagnetic aptasensor for detection of small molecules	J. Yang	Biosens. Bioelectron.	75	Elsevier	NL	2016	396-403	DOI:10.1016/j.bios.2015.08.062	
27	Polymer/Iron Oxide Nanoparticle Composites—A Straight Forward and Scalable Synthesis Approach	J. Sommertune	International Journal of Molecular Science	16	MDPI	CH	2015	19752-19768	DOI:10.3390/ijms160819752	
28	Classification of Magnetic Nanoparticle Systems—Synthesis, Standardization and Analysis Methods in the NanoMag Project	S. Bogren	International Journal of Molecular Science	16	MDPI	CH	2015	20308-20325	DOI: 10.3390/ijms160920308.	
29	Magnetic scanning gate microscopy of a domain wall nanosensor using microparticle probe	H. Corte-Léon	JMMM	400	Elsevier	NL	2016	225-229	DOI:10.1016/j.jmmm.2015.07.116	
30	Quantification of NS1 dengue biomarker in serum via optomagnetic nanocluster detection	P. Antunes	Scientific Reports	5	Nature Publishing Group	UK	2015	16145	DOI: 10.1038/srep16145	yes
31	Thermal magnetic noise spectra of nanoparticle ensembles	J. Leliaert	Appl. Phys. Lett.	107	AIP	USA	2015	222401	DOI:10.1063/1.4936890	
32	Turn-on optomagnetic bacterial DNA sequence detection using volume-amplified magnetic nanobeads	R.S. Bejhed	Biosens. Bioelectron.	66	Elsevier	NL	405-411		DOI: 10.1016/j.bios.2014.11.048	
33	Optomagnetic read-out	R.S.	Biotechnolo	10	Wiley-	USA	2015	469-472	DOI: 10.1002/biot.201400615	

	enables easy, rapid, and cost-efficient qualitative biplex detection of DNA sequencies	Bejhed	gy Journal		Blackwell					
34	Magnetophoretic transport line system for rapid on-chip attomole protein detection	R.S. Bejhed	Langmuir	31	ACS	USA	2015	10296-10302	DOI: 10.1021/acs.langmuir.5b01947	
35	Magnetic nanobeads present during enzymatic amplification and labeling for a simplified DNA detection protocol based on AC susceptometry	R.S. Bejhed	AIP Advances	5	AIP	USA	2015	127139	DOI: http://dx.doi.org/10.1063/1.4939570	yes
36	Classification of analysis methods for characterization of magnetic nanoparticle properties	O. Posth	Proc. XXI IMEKO World Congress "Measurement in Research and Industry", Prague, Czech Republic				2015	1362-1367		
37	Uncertainty budget for determinations of mean isomer shift from Mössbauer spectra	J. Fock	Hyperfine Interactions	237	Springer	D?	2016	23	DOI:10.1007/s10751-016-1253-1	
38	Detection of a magnetic bead by hybrid nanodevices using scanning gate microscopy	H. Corte-Léon	AIP Advances	6	AIP	USA	2016	56502	DOI: 10.1063/1.4943147	yes
39	Magnetic particle	J. Wells	IEEE Trans.		IEEE				DOI:	

	nanosensors implementing nucleation events in perpendicular anisotropy materials		Magn.		Magnetics Society				10.1109/TMAG.2016.2524074,	
40	SOL-GEL MAGNETIC MATERIALS	L. Gutiérrez	In The Sol-Gel Handbook. Synthesis, Characterization, and Applications		WILEY-VCH,		2015	813-840	ISBN: 9783527334865	
41	Interacting Superparamagnetic Iron(II) Oxide Nanoparticles: Synthesis and Characterization in Ionic Liquids	B.C. Leal	Inorg. Chem.	55	ACS	USA	2016	865-870	DOI: 10.1021/acs.inorgchem.5b02320	
42	Effect of Nanoclustering and Dipolar Interactions in Heat Generation for Magnetic Hyperthermia	D. Coral	Langmuir	32	ACS	USA	2016	1201-1213	DOI: 10.1021/acs.langmuir.5b03559	
43	Magnetic-field dependence of Brownian and Neel relaxation times	J. Dieckhoff	J. Appl. Phys.	119	AIP	USA	2016	43903	DOI: 10.1063/1.4940724	
44	Diffusion-Controlled Synthesis of Magnetic Nanoparticles	D. Heinke	International Journal of Magnetic Particle Imaging	2	ISP	D	2016	1	DOI: 10.18416/ijmpi.2016.1603001	
45	Imaging Characterization of MPI Tracers Employing Offset Measurements in a two Dimensional Magnetic Particle Spectrometer	D. Schmidt	International Journal of Magnetic Particle Imaging	2	ISP	D	2016	1	DOI: 10.18416/ijmpi.2016.1604002	
46	Magnetic readout of	M.F.	Chapter in		Springer				DOI: http://dx.doi.org/10.1007	

	rolling circle amplification products	Hansen	“Rolling Circle Amplification (RCA): Toward New Clinical Diagnostics and Therapeutics”		International Publishing,				/978-3-319-42226-8	
47	Lab-on-a-disc agglutination assay for protein detection by optomagnetic readout and optical imaging using nano- and micro-sized magnetic beads	R. Uddin	Biosens. Bioelectron.	85	Elsevier	NL	2016	351-357	DOI: http://dx.doi.org/10.1016/j.bios.2016.05.023	
48	In-situ particles reorientation during magnetic hyperthermia application: Shape matters twice	K. Simeonidis	Scientific Reports	6	Nature Publishing Group	UK	2016	38382	DOI: 10.1038/srep38382	yes
49	Finding the magnetic size distribution of magnetic nanoparticles from magnetization measurements via the iterative kaczmarz algorithm	D. Schmidt	JMMM	431	Elsevier	NL	2017	33-37	DOI: 10.1016/j.jmmm.2016.09.108	
50	Size analysis of single-core magnetic nanoparticles	F. Ludwig	JMMM	427	Elsevier	NL	2017	19-24	DOI: 10.1016/j.jmmm.2016.11.113	
51	Tuning the structure and habit of iron oxide mesocrystals	E. Wetterskog	Nanoscale	8	RSC	UK	2016	15571-15580	DOI: 10.1039/c6nr03776c	
52	Magnet-bead based microRNA delivery	P. Müller	Stem Cells Internationa	2016	Hindawi	Egypt	2016	7152761	DOI: http://dx.doi.org/10.1155/2016/	yes

	system to modify CD133 + stem cells		l						7152761	
53	Multi-scale magnetic nanoparticle based optomagnetic bioassay for sensitive DNA and bacteria detection	B. Tian	Anal. Methods	2016	RSC	UK	2016	5009-5016	DOI: dx.doi.org/10.1039/c6ay00721j	
54	Blue-ray optomagnetic measurement based competitive immunoassay for Salmonella detection	B. Tian	Biosens. Bioelectron.	77	Elsevier	NL	2016	32-39	DOI: 10.1016/j.bios.2015.08.070	
55	Size and property bimodality in magnetic nanoparticle dispersions: single domain particles vs. strongly coupled nanoclusters	E. Wettersk og	Nanoscale	9	RSC	UK	2017	4227-4235	DOI: 10.1039/c7nr00023e	
56	Colloidal Flower-shaped Iron Oxide Nanoparticles: Synthesis Strategies and Coatings	H. Gavilán	Particle & Particle Systems Characteriza tion	34	Wiley	USA	2017	1700094	DOI: 10.1002/ppsc.201700094	
57	How shape and internal structure affect the magnetic properties of anisometric magnetite nanoparticles	H. Gavilán	Acta Materialia	125	Elsevier	NL	2017	416-424	DOI: 10.1016/j.actamat.2016.12.016	
58	Interpreting static and dynamic magnetization behavior of magnetic nanoparticles in terms of magnetic moment and energies	U. Steinhoff	JMMM		Elsevier	NL	2016		DOI: 10.1016/j.jmmm.2016.11.021	
59	Magnetic Nanoparticles in Different Biological Environments analyzed by Magnetic Particle	N. Löwa	JMMM	427	Elsevier	NL	2017	133-138	DOI: https://doi.org/10.1016/j.jmmm.2016.10.096	

	Spectroscopy									
60	Comparison of optomagnetic and AC susceptibility readouts in a magnetic nanoparticle agglutination assay for detection of C-reactive protein	J. Fock	Biosens. Bioelectron.	88	Elsevier	NL	2017	94-100	DOI: https://doi.org/10.1016/j.bios.2016.07.088	
61	Exchange-biased AMR bridges for magnetic field sensing and biosensing	M.F. Hansen	IEEE Trans. Magn.	53	IEEE Magnetics Society	USA	2016	4000211	DOI: 10.1109/TMAG.2016.2614012	
62	Optomagnetic detection of DNA triplex nanoswitches	G.A.S. Minero	Analyst	142	RSC	UK	2017	582-585	DOI: 10.1039/c6an02419j	
63	Dual-frequency magnetic particle imaging of the Brownian particle contribution	T. Viereck	JMMM	427	Elsevier	NL	2016	156-161	DOI: https://doi.org/10.1016/j.jmmm.2016.11.003	
64	Size analysis of single-core magnetic nanoparticles	F. Ludwig	JMMM	427	Elsevier	NL	2016	19-24	DOI: https://doi.org/10.1016/j.jmmm.2016.11.113	
65	Effect of alignment of easy axes on dynamic magnetization of immobilized magnetic nanoparticles	T. Yoshida	JMMM	427	Elsevier	NL	2016	162-167	DOI: https://doi.org/10.1016/j.jmmm.2016.10.040	
66	The Complementarity and Similarity of Magnetorelaxometry and Thermal Magnetic Noise Spectra for Magnetic Nanoparticle Characterization	J. Leliaert	J. Phys. D: Appl. Phys.	50	IOP	UK	2017	85004	DOI: 10.1088/1361-6463/aa5944	
67	Interpreting the magnetorelaxometry signal of suspended magnetic nanoparticles	J. Leliaert	J. Phys. D: Appl. Phys.	50	IOP	UK	2017	195002	DOI: 10.1088/1361-6463/aa695d	

	with Kaczmarz' algorithm									
68	Combined anomalous Nernst effect and thermography studies of ultrathin CoFeB/Pt nanowires	J. Wells	AIP Advances	7	AIP	USA	2016	55904	DOI: dx.doi.org/10.1063/1.4973196	yes
69	Switchable bi-stable multilayer magnetic probes for imaging of soft magnetic structures	T. Wren	Ultramicroscopy	179	Elsevier	NL	2017	41-46	DOI: dx.doi.org/10.1016/j.ultramic.2017.03.032	
70	V-shaped domain wall probes for calibrated magnetic force microscopy'	R. Puttock	IEEE Trans. Magn.	PP,99	IEEE Magnetics Society	USA	2017	1-1	DOI: 10.1109/TMAG.2017.2694324	
71	Detection of individual iron-oxide nanoparticles with vertical and lateral sensitivity using domain wall nucleation in CoFeB/Pt nanodevices	J. Wells	AIP Advances	7	AIP	USA	2017	56715	DOI: http://dx.doi.org/10.1063/1.4975357	yes
72	Magnetic scanning gate microscopy of CoFeB lateral spin valve	H. Corte-Léon	AIP Advances	7	AIP	USA	2017	56808	DOI: dx.doi.org/10.1063/1.4977891	yes
73	Size and property bimodality in magnetic nanoparticle dispersions: single domain particles vs. strongly coupled nanoclusters	E. Wetterskog	Nanoscale	9	RSC	UK	2017	4227-4235	DOI: 10.1039/C7NR00023E	
74	Hybrid normal metal/ferromagnetic nanojunctions for domain wall tracking	H. Corte-Léon	Scientific Reports	7	Nature Publishing Group	UK	2017	6295	DOI: 10.1038/s41598-017-06292-y	yes
75	Calibration of multilayered magnetic force microscopy probes	V. Panchal	Scientific Reports	7	Nature Publishing Group	UK	2017	7224	DOI: 10.1038/s41598-017-07327-0	yes
76	Angular Magnetoresistance of	H. Moham	IEEE Trans. Magn.	PP,99	IEEE Magnetics	USA	2017	1-1	DOI: 10.1109/TMAG.2017.2718623	

	Nanowires with Alternating Cobalt and Nickel Segments	mad			Society					
77	Nanoscale thermoelectrical detection of magnetic domain wall propagation	P. Krzysteczko	Phys. Rev. B	95	APS	USA	2017	220410(R)	DOI: https://doi.org/10.1103/PhysRevB.95.220410	
78	On the 'centre of gravity' method for measuring the composition of magnetite/maghemite mixtures, or the stoichiometry of magnetite-maghemite solid solutions, via 57Fe Mössbauer spectroscopy	J. Fock	J. Phys. D: Appl. Phys.	50	IOP	UK	2017	265005	DOI: https://doi.org/10.1088/1361-6463/aa73fa	
79	Shape anisotropy enhanced optomagnetic measurement for prostatespecific antigen detection via magnetic chain formation	B. Tian	Biosens. Bioelectron.	98	Elsevier	UK	2017	285-291	DOI: https://doi.org/10.1016/j.bios.2017.06.062	
80	Distribution functions of magnetic nanoparticles determined by a numerical inversion method	P. Bender	New Journal of Physics	19	IOP	UK	2017	73012	DOI: https://doi.org/10.1088/1367-2630/aa73b4	yes
81	Standardisation of Magnetic Nanoparticles in Liquid Suspension	J. Wells	J. Phys. D: Appl. Phys.	50	IOP	UK	2017	383003	DOI: http://iopscience.iop.org/article/10.1088/1361-6463/aa7fa5	
82	Size-dependent MR relaxivities of magnetic nanoparticles	A. Joos	JMMM	427	Elsevier	NL	2017	122-126	DOI: https://doi.org/10.1016/j.jmmm.2016.11.021	

TABLE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities[4]	Main leader	Title	Date	Place	Type of audience[5]	Size of audience	Countries addressed
1	*Conference*		*European Conference on Nanotechnologies*	*26 February 2010*				
2	International Workshop on Magnetic Particle Imaging (Poster)	K. Lüdtke-Buzug (UZL)	Viscosity Affected Determination of Iron Concentration of MPI Tracers Based on µCT	March 2014	Berlin, Germany	Scientific	200	International
3	4th Zing Bionanomaterials conference (Invited)	Quentin Pankhurst (UCL)	Translational R&D in Healthcare Biomagnetics	April 2014	Nerja, Spain	Scientific	--	International
4	Intermag Conference (Oral)	ALL	Magnetic, structural and particle size analysis of single- and multi-core magnetic nanoparticles in the NanoMag project	May 2014	Dresden, Germany	Scientific	--	International
5	Magnetic carrier Conference (Poster)	C. Jonasson (Acreo)	Effective Particle Magnetic Moment of Multicore Particles	June 2014	Dresden, Germany	Scientific	--	International
6	Magnetic carrier Conference (Poster)	K. Lüdtke-Buzug (UZL)	Micro-CT based Determination of Ferrofluid Iron Concentration	June 2014	Dresden, Germany	Scientific	--	International

[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.
[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias ('multiple choices' is possible.

7	Magnetic carrier Conference (Oral)	Christer Johansson (Acreo)	EU FP7: NanoMag	June 2014	Dresden, Germany	Scientific	--	International
8	Magnetic carrier Conference (Poster)	F. Ludwig (TUBS)	Resolving particle size modality in bi-modal iron oxide nanoparticle suspensions	June 2014	Dresden, Germany	Scientific	--	International
9	Scientific & Clinical Applicatuons of Magnetic Carriers Conference (Poster)	Q. A. Pankhurst (UCL), C. Johansson (Acreo)	Estimating the power absorption of tailored iron oxide nanoparticles from AC susceptibility measurements	June 2014	Dresden, Germany	Scientific	--	International
10	UK Colloids Conference (Invited)	Quentin Pankhurst (UCL)	Translational R&D in Healthcare Biomagnetics	July 2014	London, UK	Scientific	--	International
11	Optimization and Inverse Problems Workshop (Oral)	Uwe Steinhoff (PTB)	Experimental Sensitivity Analysis of Magnetorelaxometric Imaging	Sept 2014	Delft, Netherland	Scientific	--	International
12	FOM BioPhysics meeting (Poster)	Leo J. van Ijzendoorn (TUE)	On torque generation in superparamagnetic particles (v1)	Sept 2014	Veldhoven, Netherland	Scientific	--	National
13	1st meeting of the CNB nanobiomedicine iniciative Workshop (Oral)	M. Puerto Morales (CSIC)	Nanometrology, Standardization Methods for the synthesis of Magnetic Nanoparticles with applications in biomedicine	October 2014	Madrid, Spain	dissemination towards industry	--	International
14	48th DGBMT annual conference (Poster)	K. Lüdtke-Buzug (UZL)	Characterization of Superparamagnetic Nanoparticles using a Micro-CT Phantom: Estimation of Iron	October 2014	Hannover, Germany	Scientific	--	International

			Concentration in Ferrofluids					
15	MoBi2014 Workshop¿? (Oral)	Nicole Gehrke (nanoPET)	EU FP7: NanoMag	October 2014	Jena, Germany	dissemination towards industry	--	International
16	Nanomedicine workshop (Poster)	Larss Nilsson (SOLVE)	Helping nano-entities discover their nano-identity	October, 2014	Malmö University, Sweden	Scientific/**not funded by NanoMag**	--	International
17	18th Int. Conf. on Miniaturized Systems for Chemistry and Life Sciences (MicroTAS 2014) (Poster)	M. F. Hansen (DTU)	Lab-on-Blu-ray: Low-cost analyte detection on a disk	Oct. 26 - Oct. 30, 2014	San Antonio, Texas, USA	Scientific	--	International
18	Biosensor conference (Poster)	M. F. Hansen (DTU)	Comparison of optomagnetic and AC susceptibility readouts in a magnetic nanoparticle agglutination assay for detection of C-reactive protein	May 25-27, 2016	Gothenburg	Scientific	--	International
19	Brokerage Event for Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing (Oral)	Lars Nilsson (SOLVE)	Nanomedicin therapy for cancer	November 2014	Brussels, Belgium	dissemination towards industry/**not funded by NanoMag**	--	International
20	Brokerage Event for Nanotechnologies, Advanced Materials, Biotechnology and	Lars Nilsson (SOLVE)	Next generation tools for risk governance of nanomaterial	November 2014	Brussels, Belgium	dissemination towards industry/**not funded by**	--	International

	Advanced Manufacturing and Processing (Oral)					**NanoMag**		
21	FOM BioPhysics meeting (Poster)	Leo J. van Ijzendoorn (TUE)	On torque generation in superparamagnetic particles (v2)	Jan 2015	Veldhoven, Netherland	Scientific	--	National
22	ICMS Outreach symposium (Poster)	Leo J. van Ijzendoorn (TUE)	On torque generation in superparamagnetic particles (v2)	Jan 2015	Eindhoven,Netherland	Scientific	--	International
23	Multifun Final Workshop (Oral)	M. Puerto Morales (CSIC)	Improving Magnetic Properties of Ultrasmall Iron Oxide Nanoparticles by Biocompatible Coatings	Feb 2015	Madrid, Spain	Scientific	--	International
24	Multifun Final Workshop (Poster)	M. Puerto Morales (CSIC)	Synthesis Strategies of Single-Core Magnetic Nanoparticles	Feb 2015	Madrid, Spain	Scientific	--	International
25	EMIM meeting (Oral, Poster and Flyers)	Nicole Gehrke (nanoPET)	EU FP 7: NanoMag – Standardization of Analysis Methods for Magnetic Nanoparticles	March 2015	Tübingen, Germany	Scientific	595	International
26	IWMPI Workshop (Poster)	Nicole Gehrke (nanoPET)	EU FP 7: NanoMag – Standardization of Analysis Methods for Magnetic Nanoparticles	March 2015	Istambul, Turkey	Scientific/Industry	--	International
27	IWMPI Workshop (Poster)	K. Lüdtke-Buzug (UZL)	Evaluation of a Cotton-Mouton Relaxometer for the Characterization of Superparamagnetic Iron Oxide Nanoparticles	March 2015	Istambul, Turkey	Scientific/Industry	--	International
28	BME research day meeting (Poster)	Leo J. van Ijzendoorn (TUE)	Magnetic analysis of superparamagnetic particles	April 2015	Eindhoven,Netherland	Scientific	--	International
29	6th International Congress –	Quentin	Biomedical applications	April 2015	Graz, Austria	Scientific	--	International

	BioNanoMed (Invited)	Pankhurst (UCL)	of magnetic nanoparticles					
30	5th Zing Bionanomaterials Conference (Invited)	Quentin Pankhurst (UCL)	Translational R&D in Healthcare Biomagnetics	April 2015	Carvoeiro, Portugal	Scientific	--	International
31	ICMM-CNIC Workshop on Chemistry and molecular imaging (Oral)	M. Puerto Morales (CSIC)	Nanometrology Standarization Methods for Magnetic Nanoparticles	May 2015	Madrid, Spain	Scientific	--	International
32	FRONTIERS IN BIOMAGNETIC PARTICLES Conference (Oral)	M. Puerto Morales (CSIC)	Effect of the transformations of nanoparticles in biological matrices on their magnetic properties	June 2015	Asheville, USA	Scientific	--	International
33	FRONTIERS IN BIOMAGNETIC PARTICLES Conference (Poster)	M. Puerto Morales (CSIC)	Effect of the transformations of nanoparticles in biological matrices on their magnetic properties	June 2015	Asheville, USA	Scientific	--	International
34	EuroNanoForum Conference (Exhibition Stand)	A. Fornara (SP)	NanoMag presentation - top 10 EU projects in the Future Flash! Best Project competition	June 2015	Riga, Latvia	Scientific/Industry	--	International
35	EuroNanoForum Conference (Poster)	Larss Nilsson (SOLVE)	Helping nano-entities discover their nano-identity	June 2015	Riga, Latvia	Scientific/Industry	--	International
36	EuroNanoForum Conference (Poster)	Larss Nilsson (SOLVE)	SOLVE the challenges of nanomaterial properties and performance	June 2015	Riga, Latvia	Scientific/Industry	--	International
37	FerroFluid Workshop 2015 (Poster)	Uwe Steinhoff	Aspects of a standardized	June 2015	Rostock, Germany	Scientific	--	International

		(PTB)	characterization and description of nanomagnetic suspensions for biomedical applications					
38	FerroFluid Workshop 2015 (Oral)	Uwe Steinhoff (PTB)	Imaging characterization of magnetic nanoparticles for Magnetic Particle Imaging using offset field supported Magnetic Particle Spectroscopy	June 2015	Rostock, Germany	Scientific	--	International
39	10th Materials Days symposium (Invited)	M. Puerto Morales (CSIC)	Synthesis methods to prepare single- and multi-core iron oxide nanoparticles for biomedical applications	June 2015	Rostock, Germany	Scientific	--	International
40	10th Materials Days symposium (Invited)	Quentin Pankhurst (UCL)	Nanomagnetism in Biology and Medicine	June 2015	Rostock, Germany	Scientific	--	International
41	10th Materials Days symposium (Oral*)	Christer Johansson (Acreo)	NanoMag project - standardization of analysis methods for magnetic nanoparticles.	June 2015	Rostock, Germany	Scientific	--	International
42	ICM Conference (Invited)	M. Puerto Morales (CSIC)	Efficient and safe magnetic iron oxide nanoparticles for biomedicine	July 2015	Barcelona, Spain	Scientific	--	International
43	ICM Conference (Oral)	O. Kazakova (NPL)	Scanning gate microscopy of a domain wall nanosensor	July 2015	Barcelona, Spain	Scientific	--	International
44	ICM Conference (Oral)	Christer Johansson	Static and dynamic magnetization behavior	July 2015	Barcelona, Spain	Scientific	--	International

		(Acreo)	of magnetic multi-core nanoparticles					
45	ICM Conference (Oral)	Quentin Pankhurst (UCL)	Field and frequency dependence of the SAR/ILP value in magnetic hyperthermia using magnetic multi- and single core particles	July 2015	Barcelona, Spain	Scientific	--	International
46	ICM Conference (Oral)	P. Svedlindh (UU)	On-chip attomol level detection of proteins using forced magnetic bead transport	July 2015	Barcelona, Spain	Scientific	--	International
47	ICM Conference (Oral)	M. F. Hansen (DTU)	Optomagnetic read-out system for detection of pathogens based on magnetic nanobead dynamic	July 2015	Barcelona, Spain	Scientific	--	International
48	ICM Conference (Oral)	Christer Johansson (Acreo)	Static and dynamic magnetization behavior of magnetic multi-core nanoparticles	July 2015	Barcelona, Spain	Scientific	--	International
49	ICM Conference (Poster)	P. Svedlindh (UU)	Highly anisotropic dynamical magnetic properties of needle-shaped arrays of iron oxide nanocubes	July 2015	Barcelona, Spain	Scientific	--	International
50	ICM Conference (Poster)	L.Fernández-Barquín (UC)	SANS, Mössbauer and magnetic characterization of interacting iron oxide nanoparticles	July 2015	Barcelona, Spain	Scientific	--	International
51	ICM Conference (Poster)	Quentin Pankhurst	Field and frequency dependency on the	July 2015	Barcelona, Spain	Scientific	--	International

		(UCL)	SAR value in magnetic hyperthermia using magnetic multi- and single-core particles					
52	ICM Conference (Poster)	M. Puerto Morales (CSIC)	Synthesis Strategies of Single-Core Magnetic Nanoparticles	July 2015	Barcelona, Spain	Scientific	--	International
53	ICMAT2015 Conference (Invited)	M. Puerto Morales (CSIC)	Effect of the Counter-Ions and the Solvent in the Synthesis of Magnetite Nanocrystals by Oxidative Precipitation	July 2015	Singapore	Scientific	--	International
54	XXI IMEKO World Congress (Oral)	Uwe Steinhoff (PTB)	Classification of analysis methods for characterization of magnetic nanoparticle properties	August 2015	Prague, Check republic	Scientific	--	International
55	The International Conference on the Applications of the Mössbauer Effect – ICAME (Invited)	Quentin Pankhurst (UCL)	Biomedical applications of magnetic nanoparticles	Sept 2015	Hamburg, Germany	Scientific	--	International
56	The International Conference on the Applications of the Mössbauer Effect – ICAME (Poster)	M. F. Hansen (DTU)	Biomedical applications of magnetic nanoparticles	Sept 2015	Hamburg, Germany	Scientific	--	International
57	Wyatt Europe workshop/User meeting (Invited)	Larss Nilsson (SOLVE)	nanoparticles, macromolecules and proteins	Sept 2015	Dernbach, Germany	Industry	--	National
58	UK Regenerative Medicine Platform - Safety Hub Workshop - Nanoparticles	Quentin Pankhurst (UCL)	Biomedical applications of magnetic nanoparticles	Sept 2015	Liverpool, UK	Scientific	--	International

	for Cell Tracking (Invited)							
59	29. Treffpunkt Medizintechnik Conference (Oral)	Nicole Gehrke (nanoPET)	EU FP 7: NanoMag – Standardization of Analysis Methods for Magnetic Nanoparticles	Sept 2015	Berlin, Germany	Scientific/Industry	--	National
60	49th DGBMT annual Conference (Poster)	K. Lüdtke-Buzug (UZL)	Synthesis of Superparamagnetic Iron Oxide Nanoparticles under Ultrasound Control	Sept 2015	Luebeck, Germany	Scientific/Industry	--	International
61	FOM BioPhysics meeting (Poster)	Leo J. van Ijzendoorn (TUE)	On torque generation in superparamagnetic particles (v3)	Sept 2015	Veldhoven, Netherland	Scientific	--	National
62	NanoCity meeting 2015 (poster)	Leo J. van Ijzendoorn (TUE)	On torque generation in superparamagnetic particles (v3)	Sept 2015	Amersfoort, Netherland	Scientific/industry	--	International
63	EMN Workshop 2015 (Invited)	Olga Kazakova (NPL)	Novel Graphene-based Nanosensors	Sept 2015	San Sebastián, Spain	Scientific	--	International
64	ANMM Workshop (Invited)	Olga Kazakova (NPL)	Domain-wall based magnetic nanosensors	Sept 2015	Iasi, Romania	Scientific	--	International
65	ISO Technical Committee 229 "Nanotechnologies", Working Group 4 "Material Specifications" (Oral)	Uwe Steinhoff (PTB)	Nanometrology – Standardization Methods for Magnetic Nanoparticles	Sept 2015	Edmonton	Scientific	--	International
66	BIOTECHNICA (industrial fair) oral	Joachim Teller, Fritz Westphal	Representing NanoMag project	October 2015	Hannover	Scientific	--	International
67	Nanocon (Invited)	M. Puerto Morales	Prospects for magnetic	Oct 2015	Brno	Scientific	--	International

		(CSIC)	nanoparticles in in vivo biomedical applications: synthesis, biodistribution and degradation					
68	RadioMag COST project meeting (Oral)	Christer Johansson (Acreo)	EU FP7 NanoMag project - standardization of analysis methods for magnetic nanoparticles.	Oct 2015	Limassol	Scientific	--	International
69	49th DGBMT annual conference (Oral)	Uwe Steinhoff (PTB)	Characterizing the imaging performance of magnetic tracers by Magnetic Particle Spectroscopy in an offset field	Sept. 2015	Luebeck	Scientific	--	International
70	Contrast Media Research (Oral)	F. Wiekhorst (PTB)	Magnetic Nanoparticles in Biomedicine - how magnetic measurements support their application	November, 2015	Berlin	Scientific	--	International
71	IWMPI (Poster)	Uwe Steinhoff (PTB)	Imaging Characterization of MPI Tracers Employing Offset Measurements in a two Dimensional Magnetic Particle	March 2016	Lübeck	Scientific	--	International

			Spectrometer					
72	IWMPI (Poster)	F. Wiekhorst (PTB)	Determining magnetic impurities and nonspecific magnetic nanoparticle adhesion of MPI phantom materials	March 2016	Lübeck	Scientific	--	International
73	IWMPI (Poster)	Nicole Gehrke (nanoPET)	Diffusion-Controlled Synthesis of Magnetic Nanoparticles	March 2016	Lübeck	Scientific	--	International
74	16 TH INTERNATIONAL CONFERENCE ON SMALL-ANGLE SCATTERING (Poster)	A.F. Thünemann (BAM)	Metrology of magnetic iron oxide nanoparticles	September 2015	Berlin	Scientific	--	International
75	Internat. Workshop on Magnetic Particle Imaging (IWMPI 2016) (Poster)	F. Ludwig (TUBS)	Dependence of Brownian and Neel relaxation times on magnetic field	March 2016	Lübeck	Scientific	--	International
76	15th German Ferrofluid Workshop (Poster)	F. Ludwig (TUBS)	Magnetic-field dependence of Brownian and Neel relaxation times on ac magnetic field	June 2016	Rostock	Scientific	--	International
77	15th German Ferrofluid Workshop (Poster)	L. Fernández-Barquín (UC)	Mossbauer, SANS and magnetic characterization of interacting iron oxide nanoparticles	June 2016	Rostock	Scientific	--	International
78	Next-Generation Nanomagnetic Medicine	M. Puerto Morales	Preparation of magnetic	Nov 2015	Japan	Scientific	--	International

	Meeting,JAIST (Oral)	(CSIC)	nanocrystals for biomedical applications					
79	Next-Generation Nanomagnetic Medicine Meeting,JAIST (Oral)	M. Puerto Morales (CSIC)	The fate of magnetic nanoarticles in biological systems: biodistribution and transformations over time	Nov 2015	Japan	Scientific	--	International
80	Workshop: Magnetic Nanoparticles for biomedical applications, ICMM (Oral)	M. Puerto Morales (CSIC)	The Nanomag Project	Dec 2015	Madrid	Scientific	--	International
81	Workshop: Magnetic Nanoparticles for biomedical applications, ICMM (Oral)	M. Puerto Morales (CSIC)	Synthesis of irregular shaped iron oxide magnetic nanoparticles and study of their magnetic properties.	Dec 2015	Madrid	Scientific	--	International
82	Proc. 19th Int. Conf. on Miniaturized Systems for Chemistry and Life Sciences (MicroTAS 2015) (Poster)	M. F. Hansen (DTU)	Integration of agglutination assay for protein detection in microfluidic disc using Blu-ray optical pickup unit and optical fluid scanning	October, 2015	Geongju, Korea,	Scientific	--	International
83	Joint MMM-Intermag (Oral)	Olga Kazakova (NPL)	Detection of a magnetic bead by hybrid nanodevices using scanning gate microscopy	Jan 2016	San Diego, US	Scientific	--	International

84	Joint MMM-Intermag (Poster)	Olga Kazakova (NPL)	Magnetic particle nanosensing by nucleation of domain walls in ultra-thin CoFeB/Pt	Jan 2016	San Diego, US	Scientific	--	International
85	IWMPI (Poster)	Nicole Gehrke (nanoPET)	Diffusion-Controlled Synthesis of Magnetic Nanoparticles	March 2016	Lübeck	Scientific	--	International
86	International Conference on Fine Particle Magnetism (ICFPM) NIST, (Oral)	M. F. Hansen (DTU)	Characterization of fine particles using optomagnetic measurements	June 13-17, 2016	Maryland, USA	Scientific	--	International
87	ICMS Outreach symposium, TUe (Poster)	Leo J. van Ijzendoorn (TUE)	On torque generation in superparamagnetic particles (v3)	Jan 2016	Eindhoven	Scientific	--	International
88	International Workshop on Magnetic Particle Imaging (IWMPI) (Poster)	K. Lüdtke-Buzug (UZL)	MPS study on new MPI tracer material	March 2016	Lübeck	Scientific	--	International
89	2016 EU-Japan Collaborative Research on Nanomagnetic Medicine workshop, UCL (Oral) E91:E105	M. Puerto Morales (CSIC)	Effect of magnetic nanoparticle clustering and dipolar interactions in heating efficiency	9-10 May 2016	London, UK	Scientific	--	International
90	Reunion bienal del grupo especializado de qumica inorgánica del estado sólido de la RSEQ (Invited)	M. Puerto Morales (CSIC)	Perspectives in the use of magnetic nanoparticles in cancer diagnosis and treatment	20-22 June 2016	Torremolinos, Malaga	Scientific	--	International

91	2nd International Conference on Polyol Mediated Synthesis, University of Shiga Prefecture (Oral)	M. Puerto Morales (CSIC)	Polyol mediated synthesis to obtain Single-Core and Flower-like shaped Multi-Core magnetite nanoparticles	July 11-13, 2016	Hikone, Japan,	Scientific	--	International
92	International Conference on Hyperfine Interactions and their Applications (HYPERFINE 2016) (Invited Plenary)	Quentin Pankhurst (UCL)	Biomedical applications of magnetic nanoparticles	July 2016	Leuven, Belgium	Scientific	--	International
93	8th Joint European Magnetic Symposia - JEMS2016 (Poster)	L. Fernández-Barquín (UC)	Influence of Coating thickness on the magnetic properties of Iron-Oxide nanoparticles	21-26 August 2016	Glasgow, UK.	Scientific	--	International
94	11th International Conference on the Scientific and Clinical Applications of Magnetic Carriers 2016 (Poster)	Uwe Steinhoff (PTB)	Interpreting static and dynamic magnetization behavior of magnetic nanoparticles in terms of magnetic moment and energies	May, 2016	Vancouver	Scientific	--	International
95	11th International Conference on the Scientific and Clinical Applications of Magnetic Carriers 2016 (Poster)	F. Ludwig (TUBS)	Standardization of the analysis of single-core magnetic nanoparticles	May, 2016	Vancouver	Scientific	--	International
96	11th International	C. Grüttner	Particle size- and	May 31-June 4,	Vancouver	Scientific	--	International

	Conference on the Scientific and Clinical Applications of Magnetic Carriers (Poster)	(MM)	concentration-dependent separation of magnetic nanoparticles	2016				
97	11th International Conference on the Scientific and Clinical Applications of Magnetic Carriers 2016 (Poster)	L. Fernández-Barquín (UC)	Numerical inversion methods to analyze magnetization data	May, 2016	Vancouver	Scientific	--	International
98	International Symposium on Field-and-Flow-Based Separations (FFF2016) (Oral)	F. Wiekhorst (PTB)	A Novel Magnetic FFF Detector for the Quantification and Characterization of Magnetic Nanoparticles	2016	Dresden	Scientific	--	International
99	International Conference on Fine Particle Magnetism 2016 (Oral)	L. Fernández-Barquín (UC)	Spin coupling in an iron oxide nanoparticle ensemble analyzed with polarized neutron scattering	2016	Gaithersburg	Scientific	--	International
100	EMSA 2016 (Oral)	Olga Kazakova (NPL)	Domain Wall Nanosensors Based on Ultra-thin CoFeB Films	2016	Torino	Scientific	--	International
101	EMSA 2016 (Invited)	Olga Kazakova (NPL)	Domain-wall based magnetic nanosensors for magnetic bead	2016	Torino	Scientific	--	International

			detection					
102	European Magnetic Sensors and Actuators (EMSA) conference, http://www.emsa2016.it/ (Oral)	M. F. Hansen (DTU)	Planar Hall effect bridges for magnetic field sensing and biosensing	July 12-15, 2016	Torino	Scientific	--	International
103	22nd International Conference on DNA Computing and Molecular Programming (DNA22) (Poster)	M. F. Hansen (DTU)	Optomagnetic studies of pH-switchable nanoparticles agglutination via triplex DNA formation	4-8 September 2016	Munich, Germany	Scientific	--	International
104	The 20th International Conference on Miniaturized Systems for Chemistry and Life Sciences (Poster)	M. F. Hansen (DTU)	Optomagnetic studies of pH-switchable nanoparticles agglutination via triplex DNA	9-13 October 2016	Dublin, Ireland	Scientific	--	International
105	INTERMAG (Oral)	M. Puerto Morales (CSIC)	Magnetite Nanoparticles Assembled in Flower-like Structures with Tunable Magnetic Properties from Superparamagnetic to Ferrimagnetic	24-28 April 2017	Dublin	Scientific	--	International
106	INTERMAG (Invited)	M. Puerto Morales (CSIC)	Standardization methods for the synthesis of single-core and multi-core	24-28 April 2017	Dublin	Scientific	--	International

			magnetic nanoparticles for medical applications					
107	Workshop on magnetic nanoparticles for hyperthermia - experiments and simulations (Oral)	M. Puerto Morales (CSIC)	Standardizing the synthesis of magnetic nanoparticles	18-20 January 2017	Santiago de Compostela, Spain	Scientific	--	International
108	Magnetic carrier Conference 2016 (Poster)	F. Ludwig (TUBS)	Size analysis of single-core magnetic nanoparticles	June 2016	Vancouver	Scientific	--	International
109	Magnetic carrier Conference 2016 (Oral)	F. Ludwig (TUBS)	Dual-frequency magnetic particle imaging of the Brownian particle contribution	June 2016	Vancouver	Scientific	--	International
110	Magnetic carrier Conference 2016 (Poster)	F. Ludwig (TUBS)	Effect of alignment of easy axes on dynamic magnetization of immobilized magnetic nanoparticles	June 2016	Vancouver	Scientific	--	International
111	Magnetic carrier Conference 2016 (Poster)	F. Ludwig (TUBS)	Harnessing viscosity effects to taylor the dynamic magnetic response of magnetic nanoparticles	June 2016	Vancouver	Scientific	--	International
112	Intermag 2017 (Oral)	F. Ludwig (TUBS) Christer	Analysis of ac susceptibility spectra for the	April 2017	Dublin	Scientific	--	International

		Johansson (Acreo)	characterization of magnetic nanoparticles					
113	Intermag 2017 (Poster)	F. Ludwig (TUBS) Christer Johansson (Acreo)	The anisotropy of the ac susceptibility of immobilized magnetic nanoparticles – the influence of intra-potential-well contribution on the ac susceptibility spectrum	April 2017	Dublin	Scientific	--	International
114	VIII Meeting of the Spanish Users Society (SETN2016) (Oral)	L. Fernández-Barquín (UC)	Spin coupling in magnetic nanoparticle ensembles analyzed with polarized SANS	26th-29th June 2016	Bilbao, Spain	Scientific	--	International
115	14th International Conference on Magnetic Fluids (Poster)	Uwe Steinhoff (PTB)	Finding the magnetic size distribution of magnetic nanoparticles from magnetization measurements via the iterative kaczmarz algorithm	July, 2016	Ekaterinburg	Scientific	--	International
116	BMT 2016 (Poster)	F. Wiekhorst (PTB)	Magnetic Characterization of Phantom Materials by Magnetic Particle Spectroscopy	2016	Basel	Scientific	--	International

117	MMM 2016 (Oral)	Olga Kazakova (NPL)	Magnetic scanning gate microscopy of CoFeB lateral spin valve	2016	San Diego	Scientific	--	International
118	MMM 2016 (Oral)	Olga Kazakova (NPL)	Local studies of domain wall dynamics using anomalous Nernst effect	2016	San Diego	Scientific	--	International
119	MMM 2016 (Oral)	Olga Kazakova (NPL)	Ultrasensitive detection of single iron oxide nanoparticles by nucleation of domain walls in CoFeB nanostructures	2016	San Diego	Scientific	--	International
120	UK Institute of Physics, Medical Physics Group Workshop on Dissemination and Impact (Invited)	Quentin Pankhurst (UCL)	Translational R&D in Nanoparticulate Medical Devices	21 Oct 2016	London, UK	Scientific	--	International
121	SF Nano Annual Meeting (Invited)	Quentin Pankhurst (UCL)	Magnetic Nanoparticles for Sentinel Node Detection	12-14 Dec 2016	Paris, France	Scientific	--	International
122	SEPnet Student-led Conferences: Functional scanning probe techniques (Oral)	Olga Kazakova (NPL)	V-shaped domain wall probes for calibrated magnetic force microscopy	March, 2017	Southampton	Scientific	--	International

123	SEPnet Student-led Conferences: Functional scanning probe techniques (Oral)	Olga Kazakova (NPL)	Magntic Force microscopy imaging using a domain wall	March, 2017	Southampton	Scientific	--	International
124	Intermag 2017 (Invited)	Olga Kazakova (NPL)	Current Induced Domain Wall Motion in Cylindrical Nanowires	24th-28th April 2017	Dublin	Scientific	--	International
125	Intermag 2017 (Oral)	Olga Kazakova (NPL)	Magnetic Force microscopy imaging using a domain wall	24th-28th April 2017	Dublin	Scientific	--	International
126	Intermag 2017 (Oral)	Olga Kazakova (NPL)	Controllable multi-stable probes with low/high magnetic moment	24th-28th April 2017	Dublin	Scientific	--	International
127	Intermag 2017 (Poster)	Olga Kazakova (NPL)	Demonstration and metrology of a magnetic nanoparticle sensor using anomalous Nernst effect read-out	24th-28th April 2017	Dublin	Scientific	--	International
128	TOPO 2017 (Poster)	Olga Kazakova (NPL)	Calibrated Magnetic Force Microscopy with Domain Wall Probes	April, 2017	San Francisco	Scientific	--	International
129	International Workshop on Magnetic Particle Imaging (IWMPI) (Poster)	K. Lüdtke-Buzug (UZL)	Investigation on new MPI tracer material	March 2017	Praque	Scientific	--	International

130	International Baltic Conference on Magnetism (Invited)	Quentin Pankhurst (UCL)	Biomedical Applications of Magnetic Nanoparticles	21-23 August 2017	Svetlogorsk, Russia	Scientific	--	International
131	Euroanalysis 2017 (Oral)	M. F. Hansen (DTU)	Optomagnetic Sequence-Specific Detection of Dengue Target DNA	Aug. 28 – Sep 1., 2017	Stockholm, Sweden	Scientific	--	International
132	Euroanalysis 2017, Aug. 28 – Sep 1., 2017, (Oral)	M. F. Hansen (DTU)	An integrated lab-on-a-disc approach to detect inflammatory biomarkers from whole blood	Aug. 28 – Sep 1., 2017	Stockholm, Sweden	Scientific	--	International
133	7th Symposium on Nucleic Acid Chemistry and Biology (Poster)	M. F. Hansen (DTU)	Dual kinetic and mechanistic profiling of rolling circle amplification using real-time optomagnetic studies	Sep. 3-6, 2017	Cambridge, UK	Scientific	--	International
134	43rd International Conference on Micro and NanoEngineering (MNE2017) (Oral)	M. F. Hansen (DTU)	Automated rolling circle amplification and optomagnetic product detection in an injection molded all-polymer chip – optimization of amplification temperature	Sep. 18-22, 2017	Braga, Portugal	Scientific	--	International
135	German Ferrofluid Workshop in Dresden (Oral)	F. Ludwig (TUBS)	The anisotropy of the ac susceptibility of magnetic	July 2017	Dresden	Scientific	--	International

			nanoparticle suspensions					
136	MMM 2017 (Oral)	F. Wiekhorst (PTB)	Towards Quantitative Magnetic Particle Imaging: A Comparison with Magnetic Particle Spectroscopy	6-10 Nov, 2017	Pittsburgh, USA	Scientific	--	International
137	COST-RADIOMAG2017 (Oral)	Uwe Steinhoff (PTB)	Steel balls as heating phantoms in magnetic hyperthermia	27-28 April 2017	Bilbao	Scientific	--	International
138	IBCM 2017 (Invited)	M. Puerto Morales (CSIC)	Standardization methods for the synthesis of magnetic nanoparticles for medical applications	20-24 August, 2017	Kaliningrad	Scientific	--	International
139	ICMAT17 de Singapur (Oral)	M. Puerto Morales (CSIC)	Preparation of bimetallic magnetic nanocrystals by oxidative precipitation	18-23 June, 2017	Singapore	Scientific	--	International
S1	seminar	Gladis Amalia Ruiz Estrada	Toxicity and biodistribution of PEG coated magnetic nanoparticles after injection in Wistar rats	11/04/2014	Facultad de Ciencias, University of Santander	Scientific	30 people	National
S2	Seminar	M.P. Morales	Nanotechnology for the detection and	23/03/2015	Universidad Carlos III de Madrid	Scientific	50 people	National

			treatment of cancer					
S3	seminar	Diego Alba Venero	Study of the super spin glass-superferromagnetism transtion with neutrons	27/02/2015	Facultad de Ciencias, University of Cantabria	Scientific	15 people	National
S4	seminar	Philipp Bender	Magnetic particle nanorheology: Novel approaches based on magnetization, optical transmission and SANS measurements.	13/03/2015	Facultad de Ciencias, University of Cantabria	Scientific	15 people	National
S5	Seminar at Vinca institute	Maria del Puerto Morales	Magnetic nanoparticles for the detection and treatment of cancer	25/09/2015	Belgrade, Serbia	Scientific	20 people	National
S6	Seminar	Lucia Gutierrez	Nanopartículas magnéticas para aplicaciones biomédicas	15/05/2015	Colegio Escuela Profesional María Auxiliadora, Zaragoza.	Scientific	50	National
S7	IBME, University of Oxford	Quentin Pankhurst	Translational R&D in Healthcare Biomagnetics	20/01/2015	Oxford, UK	Scientific	60	National
S8	PTB	L. Trahms, U. Steinhoff	NanoMag	online	PTB news	Scientific	---	National
S9	e-Learning, Module 2: Biomedical Applications of Magnetic Nanoparticles	Oliver Posth, Uwe Steinhoff, Michael Lingard,	NanoMag	online	NPL e-learning courses	Scientific	---	National

		Olga Kazakova						
S10	Seminar at Inst. Laue-Langevin	Philipp Bender	Polarized SANS as advanced characterization technique within the NanoMag project	07/04/2016	Grenoble, France	Scientific	---	National
S11	Seminar	Lucia Gutierrez	Nanotoxicity: Is our body able to deal with magnetic particles?	21/10/2015	Young Scientist MeetingsICMM/CSIC	Scientific	30	National
S12	Seminar	Lucia Gutierrez	Detection of magnetic nanoparticles for biomedical applications in biological matrices	11/02/2015	Facultad de Ciencias, University of Zaragoza	Scientific	15 people	National
S13	The Embassy of Japan in the UK	Quentin Pankhurst	Biomedical applications of magnetic nanoparticles', presented at 'Japan-UK Joint Workshop on Life Science and Biomedical Engineering',	03/12/2015	London, UK	Scientific	---	National
S14	University of York	Quentin Pankhurst	Translational R&D in Nanoparticulate Medical Devices', presented at 'Nanostructures for	04/12/2015	York, UK	Scientific	---	National

			Medical Applications - Opportunities, Challenges and New Approaches’,					
S15	University of Florida	Quentin Pankhurst	‘Healthcare Biomagnetics’, presented to the Institute for Cell Engineering & Regenerative Medicine, University of Florida, Gainesville FL, USA, 16th February 2016.	16/02/2016	Florida, USA	Scientific	---	National
S16	UCL	Quentin Pankhurst	An Academic’s Perspective on Translational R&D’, presented to the OSNIRO Workshop on Venture Capital Funding,	01/03/2016	London, UK	Scientific	---	National
S17	Summer School UAM, Magnetic nanoparticles,	M.P. Morales	Magnetic colloids	42539	Madrid	Scientific	25	National
S18	Summer school, Zaragoza University, Nanoscience: New challenges and opportunities for biotechnology	Sabino Veintemillas	Synthesis routes for the preparation of uniform magnetic nanoparticles	19-21/07/16	Jaca, Huesca, Spain	Scientific	50	National
S19	CSIC	Olga Kazakova	Domain-wall based magnetic nanosensors for	19/10/2016	Madrid, Spain	Scientific	30	National

			metrology and bio applications					
S20	The IEEE Magnetic society 2017 Summer School	Puerto Morales	Magnetics for bio applications	June 19 - 23 2017	Universidad International Menendez Pelayo (UIMP), Santander, Spain.	Scientific	100	National
S21	Summer school "Materials for Biomedical Applications"- MATBIO2017	Puerto Morales	Magnetic nanoparticles for therapeutic Applications	19-22 June 2017	Materials Science Institute of Barcelona (ICMAB-CSIC)	Scientific	100	National
S22	KAUST	Olga Kazakova	Domain-wall based magnetic nanosensors for metrology and bio applications	November, 2016	Jeiddah, Saudi Arabia	Scientific	200	National
S23	PTB, Germany	Hector Corte-Leon	Magnetic domain wall-based nanosensors	2017	Braunschweig, Germany	Scientific	50	National
S24	Leeds Univ	Hector Corte-Leon	Magnetic domain wall-based nanosensors	2017	Leeds, UK	Scientific	30	National
S25	seminar	Olga Kazakova	Domain-wall based magnetic nanosensors for metrology and Life Science applications	30-may-17	Institut Neel (CNRS) Grenoble, France	Scientific	50	National
S26	Departmental seminar	Quentin Pankhurst	Biomedical Applications of Magnetic Nanoparticles	22-mar-17	University of Leeds	Scientific	45	National

S27	Seminar	Uwe Steinhoff	Standardization of properties and characterization of magnetic nanoparticles: status and perspectives	9 December 2016	AGH, Academic Center of Materials and Nanotechnology, Kraków, Poland	Scientific	30	National
S28	IEC SC62D/JWG22 and ISO TC121/SC3/JWG14 meeting	Uwe Steinhoff	Metrology and standardization of magnetic nanoparticles	9 February 2017	PTB, Berlin	Scientific	25	National
S29	MagNaStand Industrial Stakeholder Workshop	Uwe Steinhoff	MagNaStand – Towards an ISO standard for magnetic nanoparticles	4 July 2017	PTB, Berlin	Scientific	25	National
S30	MagNaStand Industrial Stakeholder Workshop	Uwe Steinhoff	Current ISO/TC229 WG4 activities related to standardisation of magnetic nanoparticles and beads	4 July 2017	PTB, Berlin	Scientific	25	National
S31	MagNaStand Industrial Stakeholder Workshop	James Wells	Standardisation of magnetic nanoparticles – state of the art and future needs	4 July 2017	PTB, Berlin	Scientific	25	National
S32	MagNaStand Industrial Stakeholder Workshop	Quentin Pankhurst	Biomedical applications of magnetic nanoparticles	4 July 2017	PTB, Berlin	Scientific	25	National

S33	MagNaStand Industrial Stakeholder Workshop	Craig Barton	Stakeholder needs in magnetic nanoparticle related industry and research – lessons learned from the NanoMag project	4 July 2017	PTB, Berlin	Scientific	25	National

Section B (Confidential[6] or public: confidential information to be marked clearly)
Part B1

This section is not applicable in the NanoMag project.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Right	Confidential Click on YES/N	Foreseen emba date dd/mm/yyyy	Application reference(s) (EP123456)	Subject or title of applicatio	Applicant (s) (as on the application)

[6] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[7] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/ NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
1. Commercial exploitation of R&D results	magnetic nanoflower-shaped iron-oxide nanoparticles with citrate coating	YES	16.11.2016	IMAGING AND HEAT-ASSISTED THERAPY, BIOSENSOR	M72.1.1, C20.5.9	IMMEDIATELY	NONE	MICROMOD, CSIC
2. Commercial exploitation of R&D results	HIGH FREQUENCY AC SUSCEPTOMETER	YES			M72.1.1, M72.1.9, C20.5.9	2018	FILED IN 2010 (E.G. SE1050526 A1)	RISE ACREO

1. Summary: “Magnetic Nanoflower-Shaped Iron-Oxide Nanoparticles with Citrate coating”

micromod (MM) has established a standard-operating procedure (SOP) for the synthesis of magnetic nanoflower-shaped iron oxide nanoparticles based on a previous literature report (Lartigue et al. 2012, doi: 10.1021/nn304477s) by a thermal decomposition process in a polyol reaction medium. Excellent reproducibility in size and yield along with consistent magnetic properties was achieved. CSIC has the developed a citrate coating for magnetic nanoparticles, which was used by MM to stabilize the magnetic nanoflower-shaped iron-oxide nanoparticles and to enhance their biocompatibility for utilization in life-sciences and analytics. Moreover, an application in medical imaging and heat-assisted therapies or a combination of both is of particular importance. The synthesis amended by an additional coating based on micromod’s background has been published in partial (Gavilán et al. Part. Part. Syst. Charact. 2017, 1700094).

The citrate-coated particles will be available on webpage www.micromod.de by 01.01.2018 and have already been advertised on trade fairs like Biotechnica as well as in key account communications with micromod customers. For the next three years micromod expects an annual revenue of 10 TEuro per acquired key customer.

2. Summary: “High Frequency AC susceptometer”

RISE Acreo has during the NanoMag project further developed a high frequency AC susceptometer to be used for dynamic magnetic measurements of for instance dispersed MNP systems (but also for powder material or other solid samples). The start of the design and construction of this instrument was during the EU FP7 NMP Nano3T project (focused on magnetic hyperthermia, 2008-2011). The instrument will be a valuable asset to magnetic hyperthermia studies.

We have also added Key Exploitable Results (KER) information in the exploitation plan (deliverable D7.5) regarding a new sensing system (opto-magnetic system) developed and verified at DTU in the project.

4.3 Report on societal implications

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	604448
Title of Project:	Nanometrology Standardization Methods for Magnetic (Nanoparticl
Name and Title of Coordinator:	Christer Johansson, Professor

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screer Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No*** ***0Yes 0No***
2. Please indicate whether your project involved any of the following issues (tick bo	***YES***
RESEARCH ON HUMANS	
• Did the project involve children?	No
• Did the project involve patients?	No
• Did the project involve persons not able to give consent?	No
• Did the project involve adult healthy volunteers?	No
• Did the project involve Human genetic material?	No
• Did the project involve Human biological samples?	No
• Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	No
• Did the project involve Human Foetal Tissue / Cells?	No
• Did the project involve Human Embryonic Stem Cells (hESCs)?	No
• Did the project on human Embryonic Stem Cells involve cells in culture?	No
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	No
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifest ethnicity, political opinion, religious or philosophical conviction)?	No
• Did the project involve tracking the location or observation of people?	No
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	No
• Were those animals transgenic small laboratory animals?	No
• Were those animals transgenic farm animals?	No
• Were those animals cloned farm animals?	No
• Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	No
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)	No
DUAL USE	
• Research having direct military use	No
• Research having the potential for terrorist abuse	No

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of peo who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		1
Work package leaders	2	4
Experienced researchers (i.e. PhD holders)	22	39
PhD Students	3	15
Other		

4. How many additional researchers (in companies and universities) were recrui specifically for this project?	8
Of which, indicate the number of men:	3

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

■ Yes
○ No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
■	Design and implement an equal opportunity policy	○	○	○	■	○
❑	Set targets to achieve a gender balance in the workforce	○	○	○	○	○
■	Organise conferences and workshops on gender	○	○	○	■	○
❑	Actions to improve work-life balance	○	○	○	○	○

○ Other:

7. Was there a gender dimension associated with the research content – i.e. wherever people were focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered addressed?

○ Yes- please specify

■ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open da participation in science festivals and events, prizes/competitions or joint projects)?

■ Yes- please specify: Open days at CSIC for pupils and public showing the concept of magnetic nanoparticles

○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory bookl DVDs)?

■ Yes- please specify: Four electronic-learning modules developed in the project focused on magnetic nanoparticles, standardization and their applications

○ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

■ Main discipline[8]:

○ Associated discipline[8]:

○ Associated discipline[8]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the resea community? *(if 'No', go to Question 14)*

○ Yes
■ No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NG patients' groups etc.)?

○ No
○ Yes- in determining what research should be performed
○ Yes - in implementing the research
○ Yes, in communicating /disseminating / using the results of the project

[8] 1.2, 1.3, 1.5, 2.2, 2.3, 3.1, 3.3.

11c	**In doing so, did your project involve actors whose role is mainly to organise dialogue with citizens and organised civil society (e.g. professional mediat communication company, science museums)?**	○ ■	Yes No

12. Did you engage with government / public bodies or policy makers (including internatio organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ■ Yes - in implementing the research agenda
- ■ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by pol makers?

- ■ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields? Enviroment, Food Safety, Public Health, Research and Innovation

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Mon Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ■ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in pe reviewed journals?	82
To how many of these is open access[9] provided?	10
How many of these are published in open access journals?	10
How many of these are published in open repositories?	
To how many of these is open access not provided?	72
Please check all applicable reasons for not providing open access:	
■ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ■ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[10]: ……………	
15. How many new patent applications ('priority filings') have been ma *("Technologically unique": multiple applications for the same invention in different jurisdict should be counted as just one application of grant).*	**0**

16. Indicate how many of the following Intellect Property Rights were applied for (give number in e box).	Trademark	**0**
	Registered design	**0**
	Other	**0**

17. How many spin-off companies were created / are planned as a direct resul the project?	**0**
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison w the situation before your project:

■ Increase in employment, or	■ In small & medium-sized enterprises
❑ Safeguard employment, or	■ In large companies
❑ Decrease in employment,	❑ None of the above / not relevant to the project
❑ Difficult to estimate / not possible to quantify	

19. For your project partnership please estimate the employment effect result directly from your participation in Full Time Equivalent (*FTE = one pe working fulltime for a year*) jobs:	*Indicate figure:*

[9] Open Access is defined as free of charge access for anyone via Internet.
[10] For instance: classification for security project.

Difficult to estimate / not possible to quantify	■

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or me relations?

○ Yes ■ No

21. As part of the project, have any beneficiaries received professional media / communicat training / advice to improve communication with the general public?

○ Yes ■ No

22 Which of the following have been used to communicate information about your project to general public, or have resulted from your project?

■	Press Release	■	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
❑	Brochures /posters / flyers	❑	Website for the general public / internet
❑	DVD /Film /Multimedia	❑	Event targeting general public (festival, confere exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	■	English
■	Other language(s)		

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology
5.2 Economics
5.3 Educational sciences (education and training and other allied subjects)
5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
6.2 Languages and literature (ancient and modern)
6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]