PREFACE

The European GENNESYS Project on Nanomaterials Science and Technology

During the last decade, worldwide attention has been drawn to the enormous potential of nanoscience and nanotechnology. Today, novel nanomaterials are no longer the concern of scientists alone; rather, they are starting to have a real effect on many industrial technologies, including electronics, telecommunications, chemicals, transport, medicine, energy, and the environment. These technologies all depend on the development of materials that can withstand the highest mechanical and thermal loads, transfer data at the greatest speeds, safely store data in the smallest dimensions, ensure biocompatible transplants, remove monoxides from car exhausts, or separate protons and electrons infuel cells. There are great expectations for the future of nanomaterials science, and most countries have already established nanomaterials science and technology programmes.

As material systems and device structures become nanosized and nanostructured, new challenges are emerging: how to grow and design these artificial material structures in a precise and reproducible manner and secondly, how to analyse their three-dimensional structure, properties, and functions with the highest level of precision. It is apparent that detailed knowledge of the chemical, electronic, and magnetic structure of nanomaterials is a prerequisite to being able to tailor their functions in a controlled way.

Modern analytical technologies based on synchrotron radiation and neutron facilities carry the potential to investigate the chemical, electronic, and magnetic structure of any given material structure under any possible environment in a non-destructive way. In the last 30 years, x-ray and neutron technologies have experienced breathtaking development in new types of sources, sophisticated analytical schemes, and robust theories. We have witnessed a revolution in x-ray techniques with the availability of synchrotron radiation. Modern synchrotron radiation facilities provide highly brilliant x-ray light with tailored properties. Synchrotron radiation and neutron facilities have developed revolutionary new ideas and experimental schemes to characterise nanomaterials, nanophenomena, and nanoprocesses. These schemes encompass diffraction, diffuse scattering, inelastic scattering, magnetic scattering, tomography, spectroscopy, microscopy, and all kinds of highly sophisticated combinations. The future development of x-ray nanobeams with beam size down to a few nanometres will lead to a further revolution in x-ray technology. Future pulsed neutron sources will enable new kinds of investigations into the structure and dynamics of magnetic, soft, and biological materials.

While twenty years ago, it was something very special to carry out an experiment at a synchrotron radiation or neutron facility, research at dedicated synchrotron radiation and neutron facilities has become routine today. These facilities produce tailored radiation and deliver it with a reliability of close to 100%, together with an impressive arsenal of sophisticated instrumentation and dedicated sample environments. They also have learned how to optimise user access and operation. Users are now assisted by a "local contact team" who assist them in getting the most information from their samples. Facilities also have specialised theory groups that offer professional help in quantitative data interpretation. In a nutshell, current synchrotron radiation and neutron facilities house a mature analytical potential of the highest calibre. This potential will prove essential in overcoming analytical challenges in the development of advanced materials.

Many materials scientists have only a passing knowledge of the analytical potential provided by synchrotron radiation and neutron facilities and their use in their own research. Likewise, the operators of these facilities do not know the roadmaps of nanomaterials development and what the current and future analytical needs in the development of novel materials really are.

In autumn 2002, a high level group composed of nanoscientists and experts from the synchrotron radiation and neutron facilities met in Grenoble to discuss the future role of the synchrotron radiation and neutron facilities for the development of nanomaterials and nanotechnology in Europe. There it was decided to launch a new European initiative named GENNESYS (Grand European Initiative on Nanoscience and Nanotechnology using Neutron and Synchrotron Radiation Sources), in order to bring these rapidly developing communities together. At a European kick-off meeting in November 2004 in Stuttgart, the overall strategy for the GENNESYS enterprise was formulated and approved.

A primary mandate of the GENNESYS initiative has been the collection of the relevant information from European and worldwide research laboratories about the future trends and needs in advanced analysis for the development of nanomaterials and nanotechnology. Recognised scientists and technologists familiar with these topics have been asked to contribute to this exercise. The entire European research community (universities, research institutes, funding agencies, and private company laboratories, as well as policymakers representing individual countries, and the European Community), is actively integrated into this unique European project.

A further task of the GENNESYS initiative has been:

- To assess the state of the art of nanomaterials science and technology;
- To highlight and prioritise future challenges and research needs, and set out a suitable time frame for addressing them;
- To pinpoint the areas of research in nanoscience and nanotechnology that will most benefit from joint research strategies with synchrotron radiation and neutron sources;
- To review and forecast the effects which increased use by nanomaterials scientists will have on large-scale facilities;
- To formulate a European research programme for "nanomaterials science and technology exploiting the analytical potential of existing and emerging European synchrotron radiation and neutron facilities."

The final results have culminated in the compilation of this GENNESYS White Paper, providing a vision of progress in this field and any new kinds of joint research strategies, research partnerships, new experimental equipment, novel operating modes of synchrotron radiation and neutron beamlines that will have to be developed. Special efforts will ensure that sufficient resources will be made available to promote this important research initiative.

The GENNESYS White Paper has produced new insight into the problems of nanomaterials development and has arrived at conclusions and recommendations about what must be done to advance this important field in Europe. The GENNESYS task forces revealed an urgent need for in-situ and non-destructive analysis of nanophenomena and nanomaterials and a strong need to monitor not only the function of a material but also its performance and its failure behaviour on the atomic scale. They have also brought to light that the synthesis of nanomaterials needs improved in-situ monitoring of the relevant growth parameters. The structure of functional interfaces and its change during operation will become of key importance for future nanotechnologies; thus, the in-situ investigation of such buried interfaces under environmentally and technologically relevant conditions must become a major effort. GENNESYS also disclosed a considerable need for the characterisation of materials on all length scales, high-throughput analysis of materials, combinatorial capabilities and robotic analysis. A most promising future field of in-situ analysis is real-time x-ray and neutron study of microscopic and mesoscopic processes. The development of catalysis, for example, requires demanding real-time x-ray studies beyond the picosecond time resolution, a request that has been put forth by industry. Likewise, the use of synchrotron radiation and neutron facilities for nanometrology and nanostandardisation will rapidly emerge and grow.

For key areas in the development of nanomaterials and nanotechnology, GENNESYS recommends multidisciplinary Science Centres and Technology Centres to be installed at synchrotron radiation and neutron facilities. This new type of institute will focus all necessary research efforts, attract the best scientists in the field, and provide the essential (synthesis, analysis, modelling) infrastructure, including tailored analytical technology from the associated synchrotron radiation or neutron facilities, for direct characterisation and monitoring of phenomena and processes.

The GENNESYS project also points to several critical problems in Europe's nanomaterials research which have to be overcome in the near future. Among these problems are the fragmentation of efforts in nanomaterials research, the lack of clear European research careers in nanomaterials science as well as the lack of public awareness of the importance of fundamental research in nanomaterials science for the advancement of our society and for the benefit of the European citizen.

In addition, the GENNESYS project has arrived at recommendations for materials science curricula. Since nanomaterials science is an interdisciplinary research effort merging the traditional fields of physics, chemistry, engineering, and biology, the appropriate education of young scientists is essential. One dangerous option currently being pursued in Europe is to replace the traditional research fields by a general materials science curriculum. The development of advanced materials, however, requires experts in a particular field who do not 'swim along the coast'. Finding the proper education scheme which produces top-notch experts who at the same time, have the necessary literacy in neighbouring fields, is an unsolved challenge.

The GENNESYS team members are convinced that the initiative will substantially contribute to the solution of all these rather difficult problems. Europe is a melting pot of different nations and cultures. This multicultural character carries a unique potential that must be exploited much more efficiently in advancing science and technology. Materials science, the textbook example of 'border-crossing' or intersecting research fields, could serve as a model to demonstrate what joint European forces can achieve. This is part of the broader vision of GENNESYS.

I am deeply indebted to all my colleagues who have devoted considerable efforts during the last years in making this GENNESYS White Paper possible. I am convinced this document will have a profound and sustainable impact on the development of nanotechnology in Europe.

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