Guest View

Mihail C. Roco

*Dr. Mihail C. Roco is the **Senior Advisor for Nanotechnology at the US National Science Foundation (NSF)** and **key architect of the National Nanotechnology Initiative**. Dr. Roco is credited with 13 patents, and has written or co-written more than 200 articles and 15 books, including "Nanotechnology: Societal Implications – Maximizing Benefits to Humanity" (Springer Science, November 2006), significantly advancing the body of literature in the field.*

Under his stewardship, the US government investment in nanotechnology has increased from about USD 3 million in 1991 to USD 1.3 billion in 2005. Prior to joining the National Science Foundation, he was a professor of mechanical engineering at the University of Kentucky. Dr. Roco is a Correspondent Member of the Swiss Academy of Engineering Sciences, Fellow of the American Society of Mechanical Engineers, Fellow of the American Institute of Chemical Engineers, and Fellow of the Institute of Physics. He is a member of several honorary boards and was elected Engineer of the Year by the US Society of Professional Engineers and NSF in 1999 and again in 2004. Dr. Roco coordinated the preparation of the US National Science and Technology Council (NSTC) reports on "Nanotechnology Research Directions" (NSTC, 1999) and the "National Nanotechnology Initiative" (NSTC, 2000).

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ISO Focus: *How do you see the development of nanotechnologies and what are the applications with the greatest potential in the short and medium term? What subjects are most interesting from your personal perspective?*

Mihail Roco: Nanotechnology is defined here as the control and restructuring of matter at the nanoscale in the range of about one atom to 100 molecular diameters (roughly 1 to 100 nm), where specific phenomena enable novel applications.

Nanotechnology, like biotechnology or information technology, describes a single essential technological capability with numerous applications in classical and emerging industries, medicine and the environment. It can be used to create materials, devices and systems with fundamentally new properties because of their modified nanostructure.

All natural, manmade products and living systems have a nanostructure, the first level at which atoms and molecules form organized assemblies. Our ability to change such nanostructures is now limited by relatively rudimentary measurement and fabrication tools, and by our poor understanding of nanoscale interactions and systems.

There is a need to have clear definitions and common approaches, as this is currently lacking and this is where standardization can play a role.

There is also a critical need for better tools and standards for measuring and restructuring matter with atomic precision. Measurement and controlled utilization of quantum phenomena and self-assembling processes are special challenges, as is the characterization of nanoscale phenomena in biological systems at the sub-cellular level.

The current capabilities of nanotechnology for systematic control and manufacture are expected to evolve into four overlapping generations of products and processes by 2020 : passive nanostructures, active nanostructures, systems of nanosystems with three-dimensional features, and heterogeneous molecular nanosystems.

While nanoscale components have dominated research in the last five years, the field is now moving toward active nanostructures and nanosystems, molecular and systems biology in medicine, integrating nanotechnology with applications that will change the basic paradigms of electronics and advanced materials.

"Nanotechnology has a broad reach, which requires a proactive and anticipatory governance approach."

Key applications with strong contributions in the short-term are nanostructured catalysts and pharmaceuticals, nanoelectronics components, and multifunctional materials. Typically we have improved current products by incorporating nanocomponents.

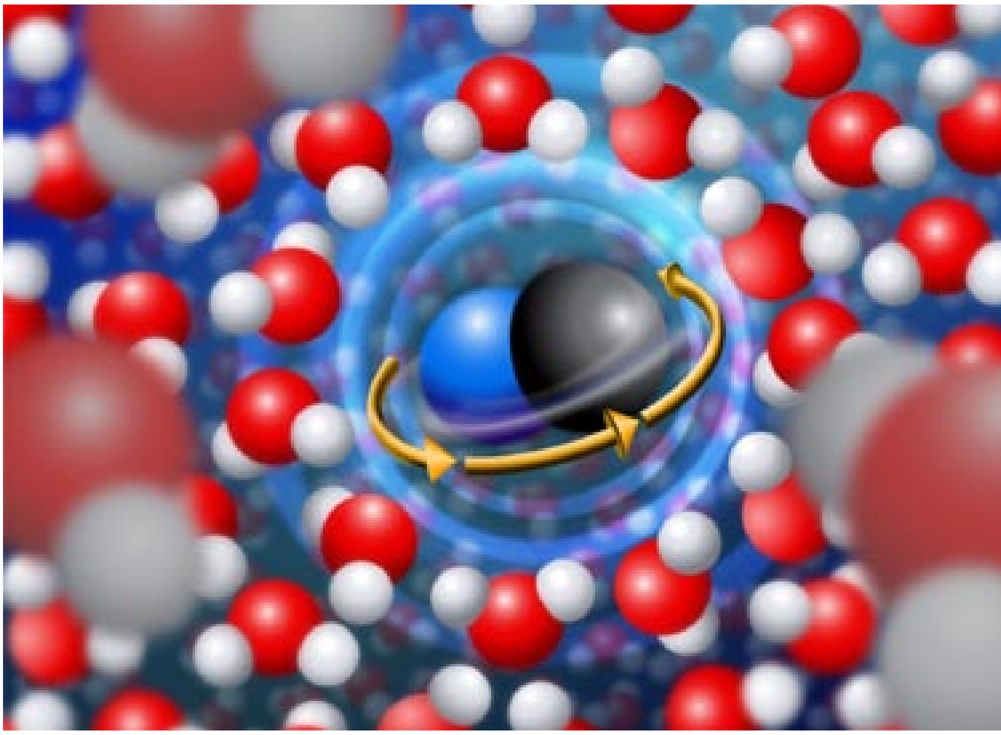
The long-term applications will be products with novel nanosystems that are designed with specific architectures for selected applications. New architectures will be developed to implement new principles of operation for transistors and computers of much smaller size, treat chronic diseases and cancer, assemble artificial organs, change basic industrial processes in classical industries to save raw materials and energy, and create new consumer goods such as electronic paper and clothes that change colour.

There will be exciting developments, for example we will better understand the connection between the nanostructure and behaviour of materials, and uncover basic mechanisms in living systems.

The transformative capabilities resulting from such breakthroughs will include new manufacturing capabilities, molecular medicine, more efficient energy conversion and storage, and new frontiers for space exploration.

Advances in nanoscale science and engineering will shift the focus of technology from improving machines to better serving people.

ISO Focus: *How can standardization contribute to the successful development of nanotechnologies and which are presently the most mature or sensitive areas to be addressed by international standardization?*



Mihail Roco: Nanotechnology metrology standards and the development of standard materials are needed as a basis for effective manufacturing, trade and communication.

Standards can apply to various nanotechnology applications because there are similar nanostructures and measuring needs. We should attempt to establish common standards for metrology for as many applications as possible, rather than developing specialized standards for each application.

The best approach begins with clear and unifying terminology for the field before defining standards for measurement and characterization, processing and product design.

Currently most established measurements and standards are those related to point and time averages using surface probes and electronic beams. The main challenge is to reduce the averaging domains in measurements (that is, to increase the spatial and temporal resolutions).

Another challenge is to extend the standards to simultaneously measure two or more parameters, such as chemical composition, mechanical properties, biological properties, magnetic behaviour and temperature.

Standards for soft nanostructures, such as biosystems, lag behind those for hard nanostructures, such as ceramics and nanoelectronics. Measurement of basic phenomena and processes such as quantum effects phenomena and self-assembly will become essential.

Standards for design, manufacturing and online process control are increasing in importance to ensure reliability which is important as nanoscale manufacturing is rapidly expanding, estimated at more than 25 % per year.

More challenging are standards for future generation nanotechnology products and processes, such as for system architectures and the dynamic behaviour of nanostructures and nanosystems – areas where standards also may play a key role in the development of science.

Nanotechnology is still in an early phase of development, and preparation for the future should be an important component of ISO activities.

This nanograph of Dr. Roco was recorded at Oak Ridge National Laboratory using piezoresponse force microscopy with a technique known as scanning probe microscopy, which can image and manipulate materials on the nanoscale. First, the biased SPM tip was used to orient the electric dipole moments within a thin layer of ferroelectric material up and down in a pattern corresponding to Dr. Roco's face. Then the area was rescanned in imaging mode. The interaction between the polarization pattern imposed within the layer and the periodic voltage on the tip caused sum-nanometer deflections, which were mapped to produce this representation. Each picture element is approximately 50 nanometers in diameter; the distance from chin to eyebrow is approximately 2.5 micrometers.

ISO Focus: *What is the role of international cooperation in supporting the development, dissemination and acceptance of nanotechnology-based products?*

Mihail Roco: Nanotechnology requires the integration of many scientific, engineering and technical disciplines. Applications of nanotechnology will penetrate nearly all sectors and spheres of life—communication, health, labour, mobility, housing, recreation, energy, food—and will be accompanied by changes in the social, economic, ethical, ecological, and international spheres.

We need to cooperate to take full advantage of the new technology. For example, nanotechnology can play a key role in addressing major challenges common to humanity such as clean water and energy supply.

But conflicts over perceived risks of nanotechnology could undermine its ability to meet these challenges. While isolated measures may help, there needs to be a global framework for nanotechnology governance that allows stakeholders to play constructive and responsible roles.

Since 2005, ISO has engendered broad international support for nomenclature and standardization of the entire field. We need technical contributions from individual national organizations and mutual understanding to globally advance nanotechnology standardization. We also need a vision for the nomenclature and standards for the next generation of nanotechnology products.

ISO Focus: *You have played a prominent role in the International Risk Governance Council (IRGC). Considering ISO's open and transparent process and its organized technical structure, what role do you think ISO should play in the field of risk governance for nanotechnology?*

Mihail Roco: IRGC has promoted an open and integrated system of governance involving all stakeholders, and ISO is an excellent partner in this open system.

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The proposal to start nanotechnology-related activities at ISO was made in an international forum, in 2004, at the first International Dialogue for Responsible Development of Nanotechnology.

IRGC has proposed recommendations for a proactive and adaptive approach to the global governance of nanotechnology. The fast pace of development, global coverage and cross-sector impact call for an unprecedented level of collaboration from research to nomenclature and standards.

We need to develop integrated governance that will enable innovation and to adopt incentive-based regulations and policies that will safeguard the public while allowing society to reap the benefits of nanotechnology.

IRGC views the stakeholder groups involved as operating within a dynamic ecosystem of interlocking dependencies. The task is therefore to create an adaptive, collaborative environment enabling different parties to play their part in the ecosystem.

Activities should be undertaken in different spheres and at different levels, with a strong emphasis on sharing outcomes and for adopting best practices. In order to establish international standards, ISO needs member organizations to make detailed proposals.

In turn, the member bodies need the collaboration of industry and academia to provide data to develop standards and to listen carefully to the concerns of both public and civil society organizations.

The evaluation process should be transparent and allow many players from various countries to participate. That creates confidence in decisions and a viable international standards activity that can become a reference for government, industry, and the public and civil society actors.

ISO Focus: *Do you believe that nanotechnologies open new areas and issues for standardization in terms of engagement of "societal stakeholders"* *(including e.g. consumers and environmental groups) – considering in particular the shared responsibility between government and industry to provide adequate information, responding to expectations and concerns of the public ?*

Mihail Roco : Nanotechnology has a broad reach, which requires a proactive and anticipatory governance approach including two-way interactions between the providers and users of nanotechnology research and products.

"It offers a technology platform for industry, biomedicine, the environment and an almost infinite array of potential applications."

It offers a technology platform for industry, biomedicine, the environment and an almost infinite array of potential applications. It reaches the basic level of organization of atoms and molecules, where fundamental changes occur for both manmade materials and living systems.

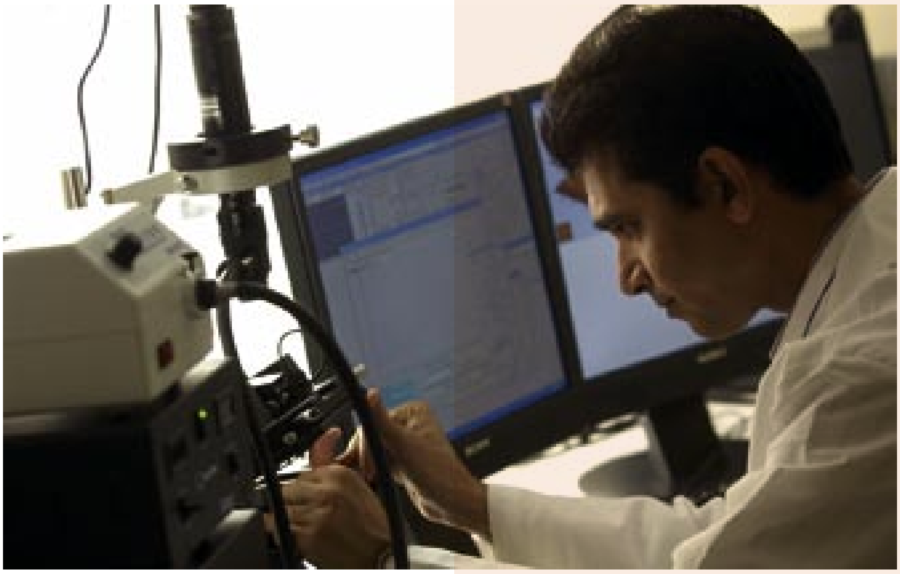
It reverses the trend of specialization of scientific disciplines, providing unifying concepts for research and education, and leading to system integration in engineering and technology. It has broadened manufacturing capabilities.

Difficulties in measurements and on-line process control are more pronounced than in any other manufacturing field. Nanotechnology research and development has advanced faster than the capacity of regulators to assess the social and environmental impact.

It has highlighted the need to develop common approaches and a common basis for communication. This is particularly true because it is difficult to visualize processes and develop intuitive concepts at the nanoscale. All developed countries and many developing countries now invest in nanotechnology (more than 60 countries since 2000).

Because of these factors, the role of common nomenclature (beginning with the term "nanotechnology" itself) and standards (common for as many domains of science and areas of relevance) is more essential than in other fields.

Exchanges of correct and reliable information are important in the communication among various actors, in public perception and in the framing of new technology.



Nanotechnology Characterization Laboratory (NCL) scientist, ***Anil Patri****, measuring the size and shape of colloidal gold nanoparticles with an atomic force microscope (AFM) as part of the physicochemical tier of the NCL's nanoparticle characterization assay cascade (*http://ncl.cancer.gov/*).*

Suitable nomenclature and standards are necessary in order to allow global governance to be transformative, responsible, participatory and visionary. It is notable that ISO/TC 229, similar to UNESCO (committee on ethics in nanotechnology), OECD (two working parties on development and implications of nanotechnology, respectively), the American Society for Testing and Materials (ASTM) - International Committee E56 on Nanotechnology and IRGC (nanotechnology working group), is becoming a key player in an open source ecosystem, hosting working groups on terminology and nomenclature, measurement and characterization, processes, and EHS aspects. ■

The National Science Foundation

The US National Science Foundation (NSF) is an independent federal agency created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…"

With an annual budget of about USD 5.6 billion, NSF covers all areas of science and engineering except for clinical testing done by America's colleges and universities. About 10,000 new awards are made each year—with an average duration of three years—to fund specific research proposals that have been judged the most promising by a rigorous and objective merit-review system.

Most of these awards go to individuals or small groups of investigators. Others provide funding for research centres, instruments and facilities that allow scientists, engineers and students to work at the outermost frontiers of knowledge.

NSF's goals are discovery, learning, research infrastructure and stewardship. NSF supports about 3,000 research awards and trains more than 10,000 students and teachers in nanoscale science and engineering with an annual budget of USD 360 million in fiscal year 2006. ■