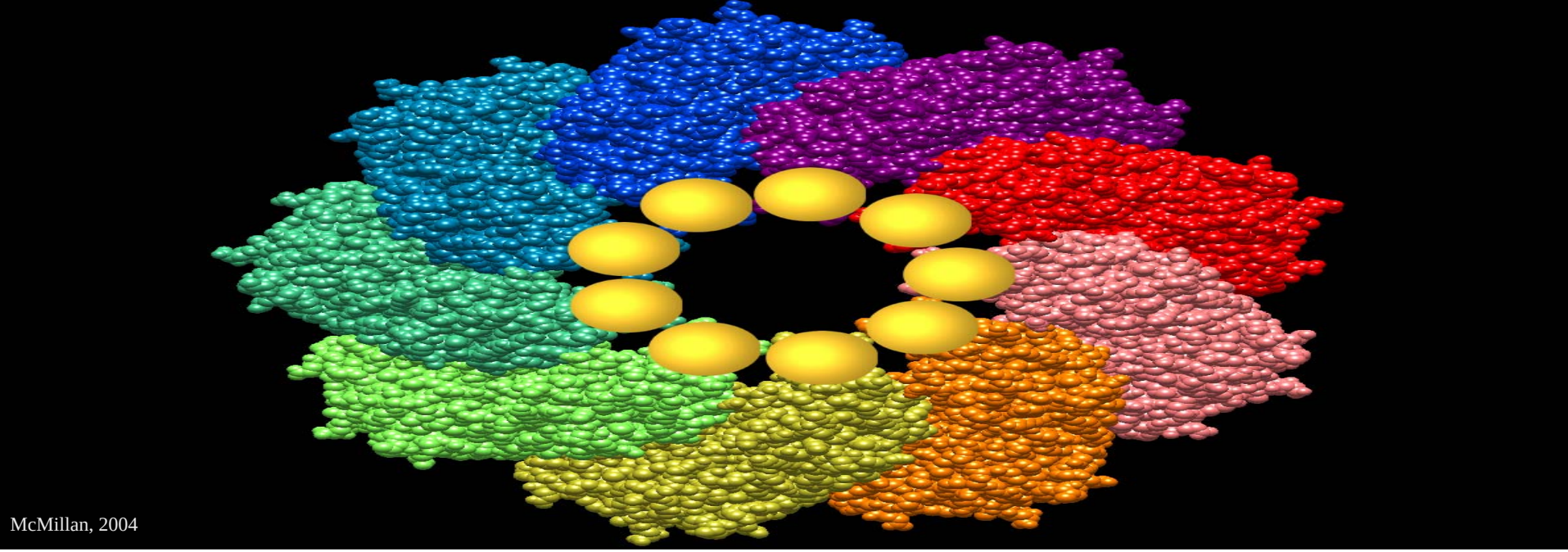


Environmental and health aspects of nanotechnology, and risk governance

Dr. M.C. Roco

U.S. Nanoscale Science, Engineering and Technology (NSET), NSTC
Senior Advisor for Nanotechnology, National Science Foundation
Presentation posted on **www.nsf.gov/nano**

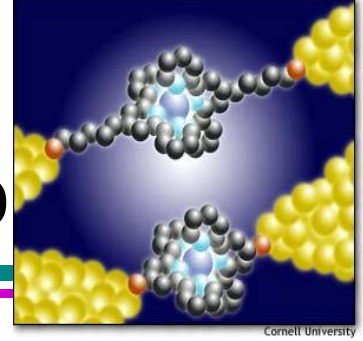
Washington, D.C., August 29, 2005

Topics

- **Nanotechnology brief**
- **Short and long term issues in societal implications: governance approach**
- **NNI activities in EHS and ELSI**

Nanotechnology

Definition on www.nano.gov/omb_nifty50.htm (2000)



- **Working at the atomic, molecular and supramolecular levels, in the length scale of approximately 1 – 100 nm range, in order to understand, create and use materials, devices and systems with fundamentally new properties and functions because of their small structure**

- **NNI definition encourages new contributions that were not possible before**

  - novel phenomena, properties and functions at nanoscale, which are nonscalable outside of the nm domain
  - the ability to measure / control / manipulate matter at the nanoscale in order to change those properties and functions
  - integration along length scales, and fields of application

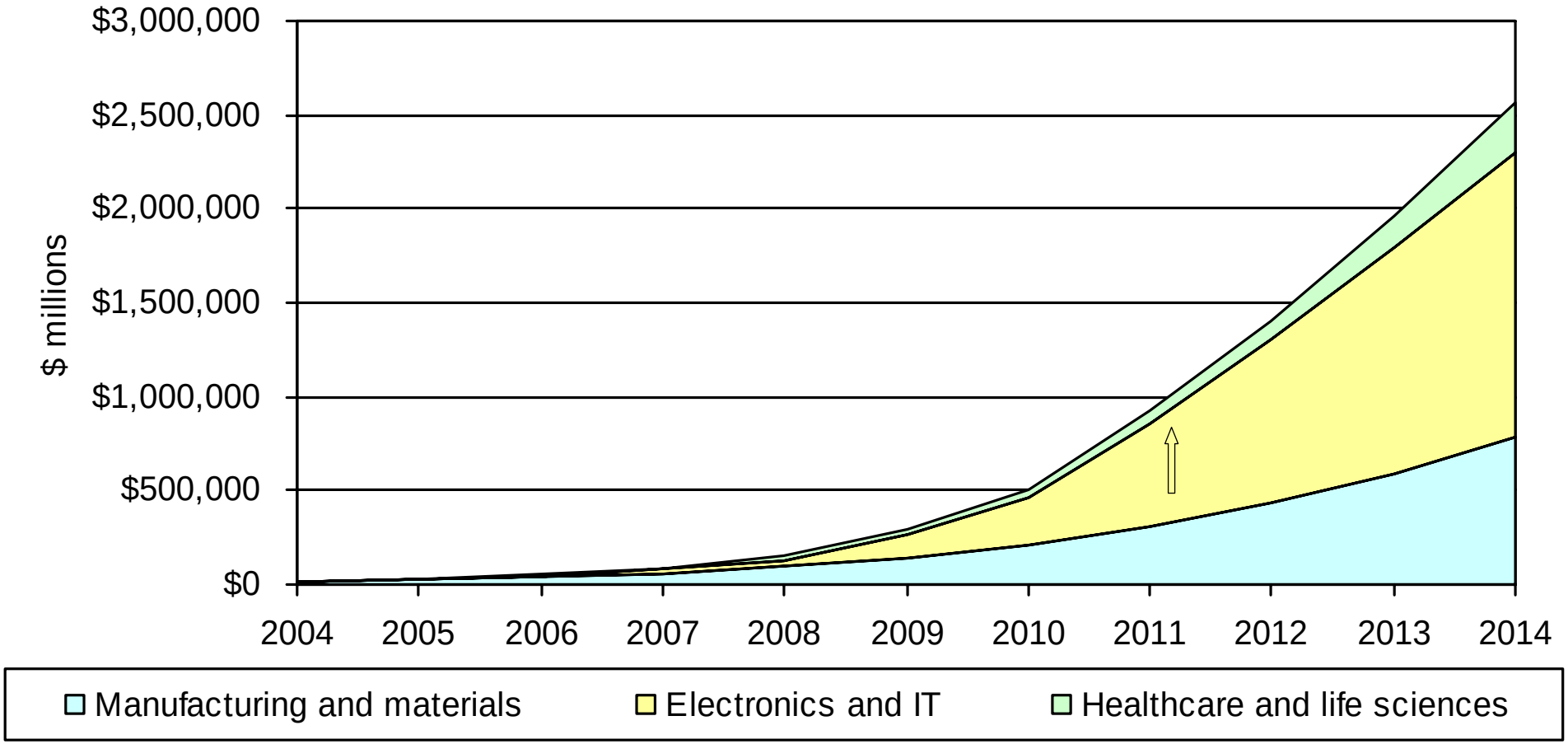
R&D towards the Next Industrial Revolution

1999 metrics, 2004 check the progress, 2015 to satisfy first criteria

Systematic control matter on the nanoscale will lead to a revolution in technology and industry

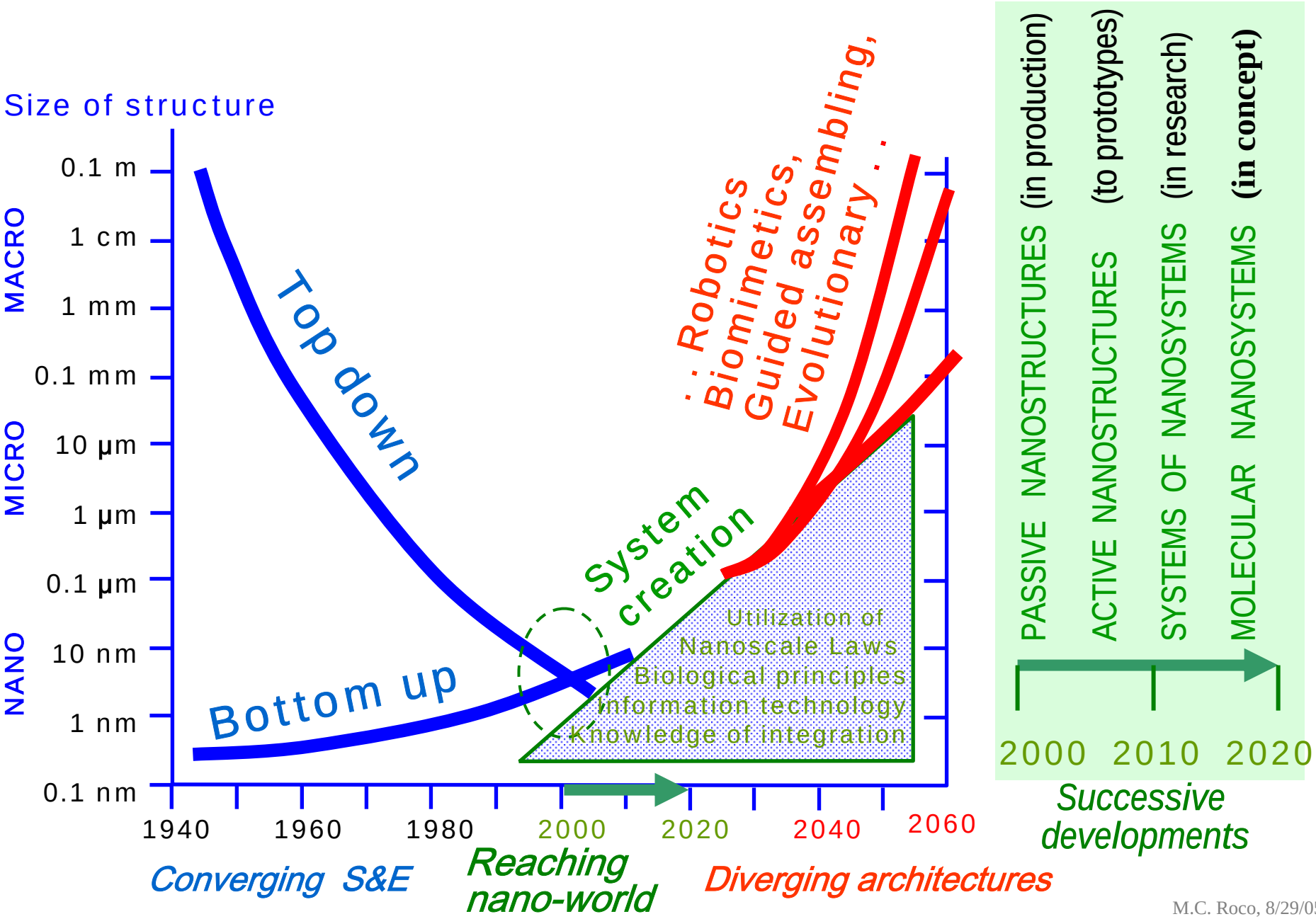
- **Changing the foundation of understanding, control, manufacturing and medicine from the macro and micro domains to the nanoscale, where all fundamental material properties and functions can be efficiently established and changed**
- **General purpose technology that will affect almost all sectors of the society. It will disrupt - structural changes - markets, industrial organizations and business models (ex: 50% of new products in advanced industrial areas will use NS&E by 2015)**

Global forecast, products sold incorporating emerging nanotechnology, 2004 to 2014, 3 sectors



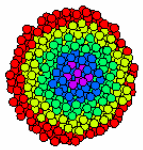
Source: October 2004 Lux Research Report “Sizing Nanotechnology’s Value Chain”

Reaching nano-world and system creation



M.C. Roco, 8/29/05

Timeline for beginning of industrial prototyping and nanotechnology commercialization: Four Generations



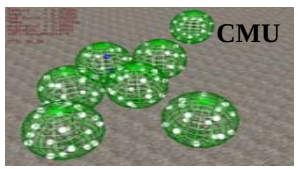
1st: Passive nanostructures (1st generation products)

Ex: coatings, nanoparticles, nanostructured metals, polymers, ceramics

~ 2000

2nd: Active nanostructures Ex: 3D transistors, amplifiers, targeted drugs, actuators, adaptive structures

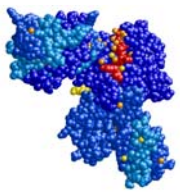
~ 2005



3rd: Systems of nanosystems

Ex: guided assembling; 3D networking and new hierarchical architectures, robotics, evolutionary

~ 2010



4th: Molecular nanosystems

Ex: molecular devices 'by design', atomic design, emerging functions

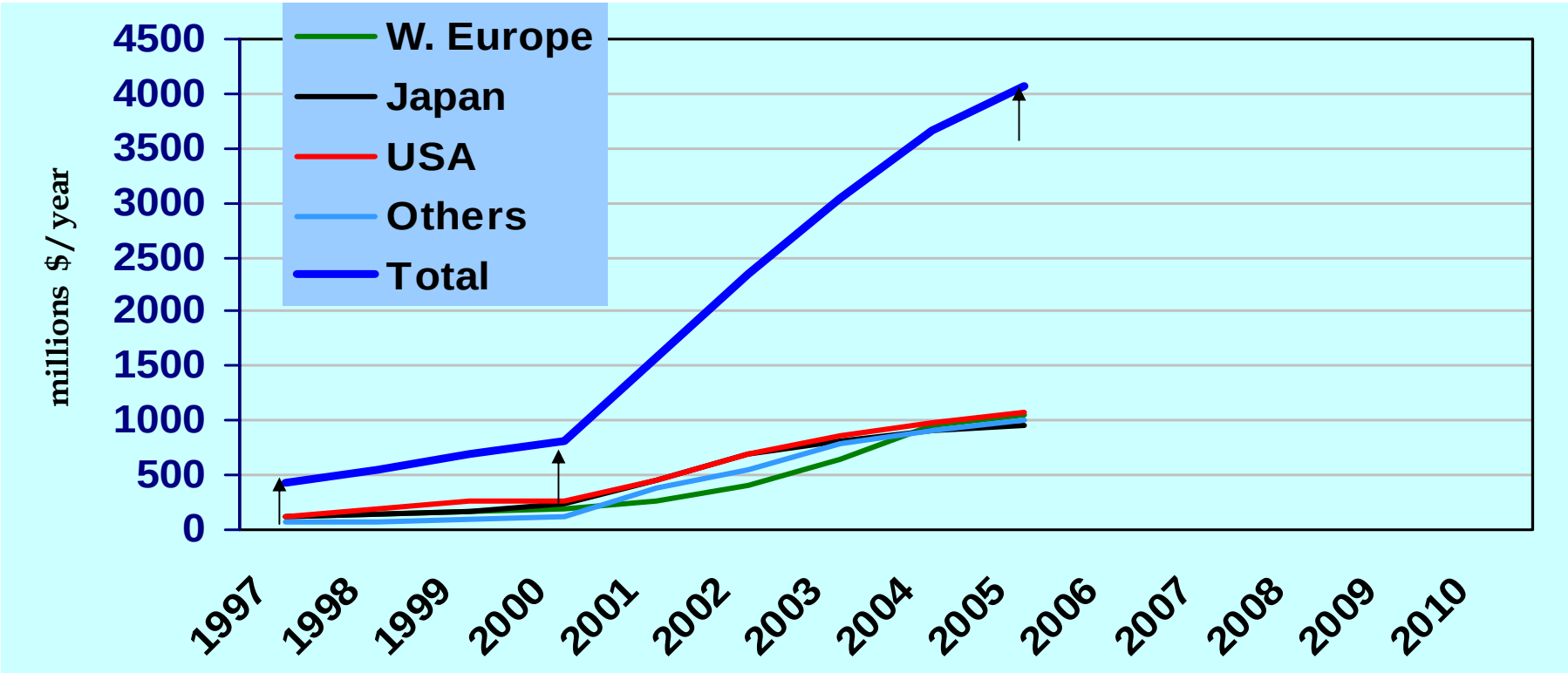
~ 2015-2020

R&D

AIChE Journal, 2004, Vol. 50 (5), MC Roco

Context – Nanotechnology in the World

Past government investments 1997-2005 (est. NSF)



Seed funding (1991 -)

NNI Preparation (vision / benchmark)

1st Strategic Plan (passive nanostructures)

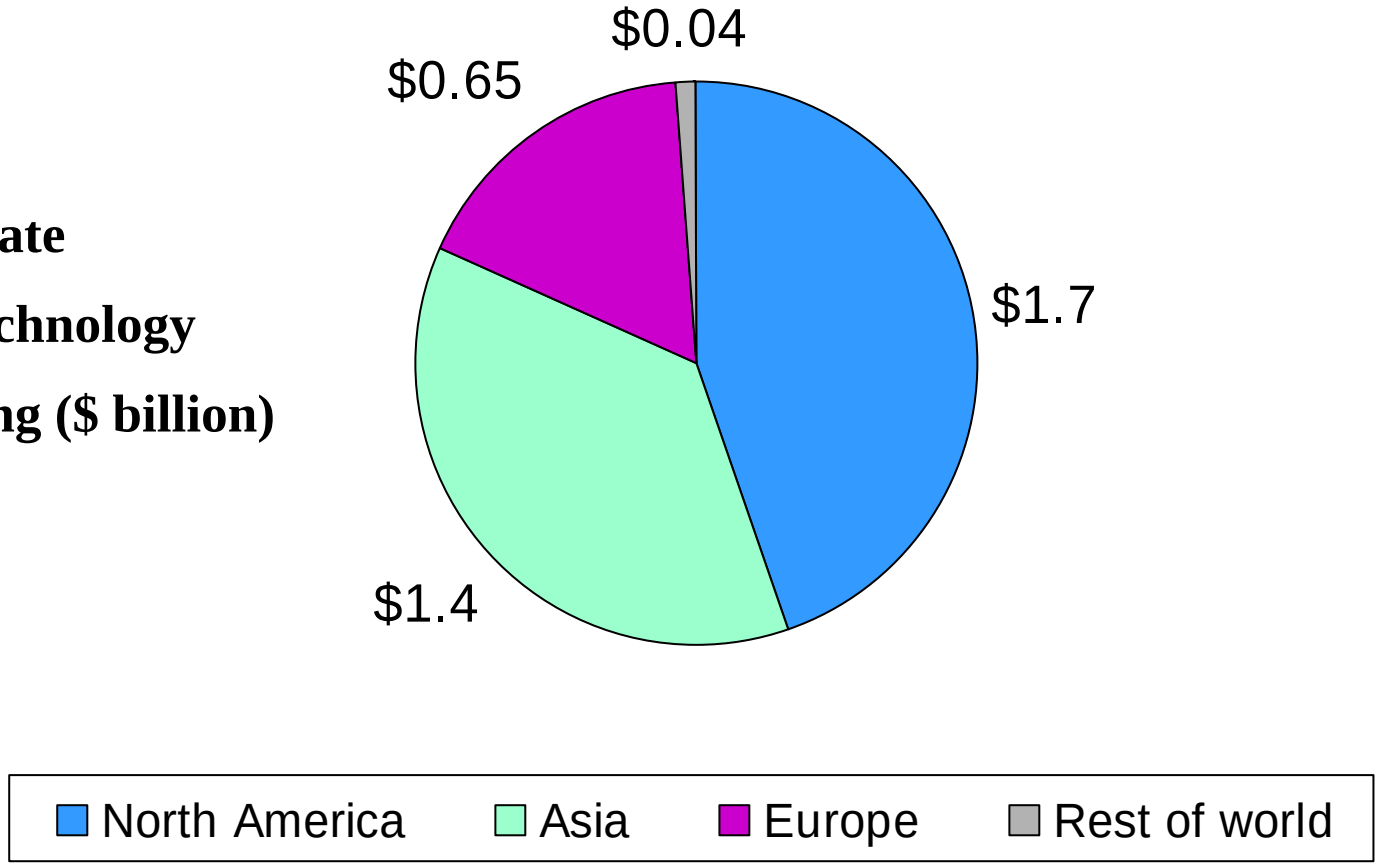
2nd Strategic Plan (active ns. & systems)

Total government expenditure in FY 2004 – about $3.7 billion

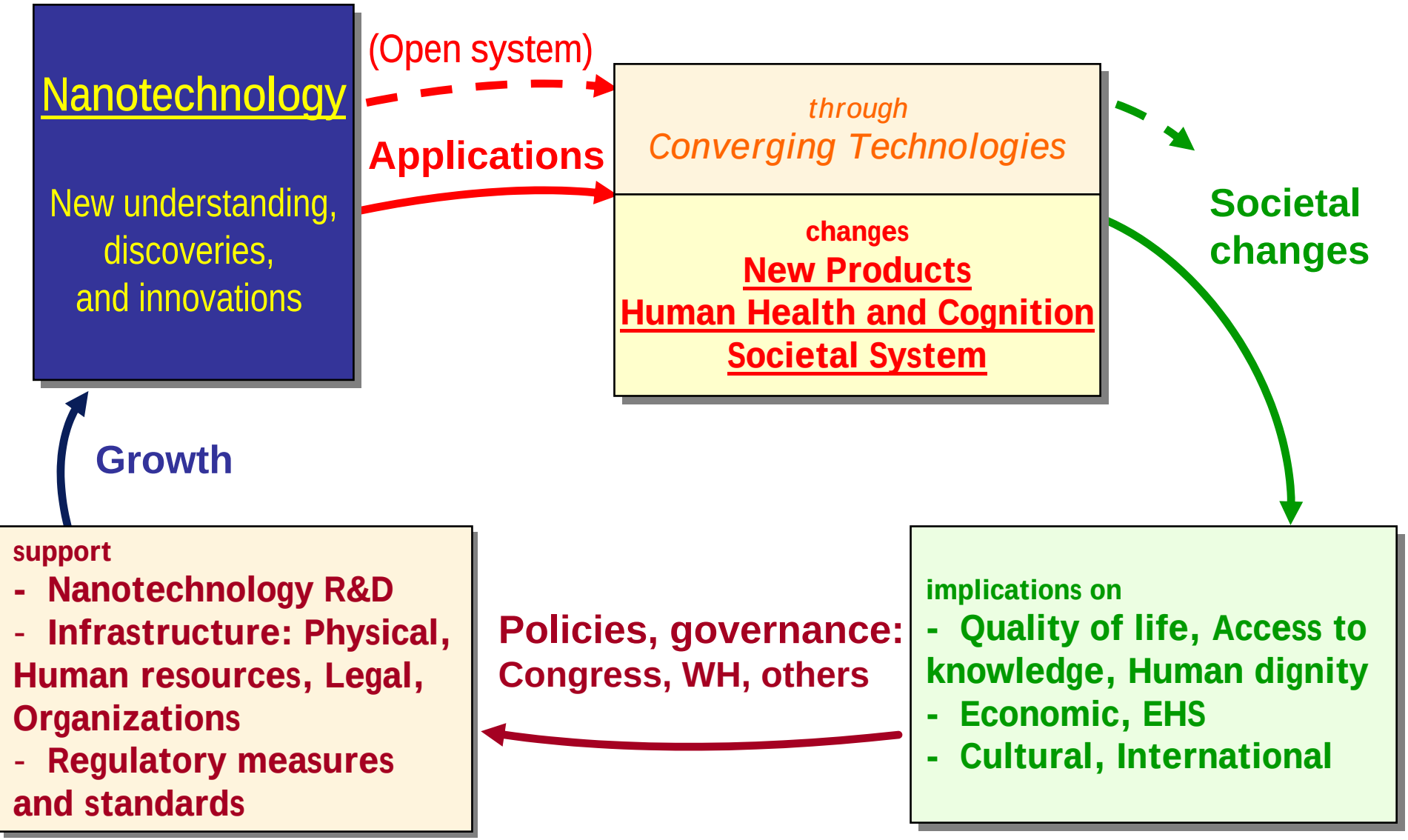
MC. Roco, 5/26/05

Established corporations will spend more than $3.8 billion globally on nanotechnology R&D in 2004

Corporate Nanotechnology Spending ($ billion)



Source: Lux Research reference study “The Nanotech Report 2004;” based on published spending figures, national statistics, Lux Research analysis

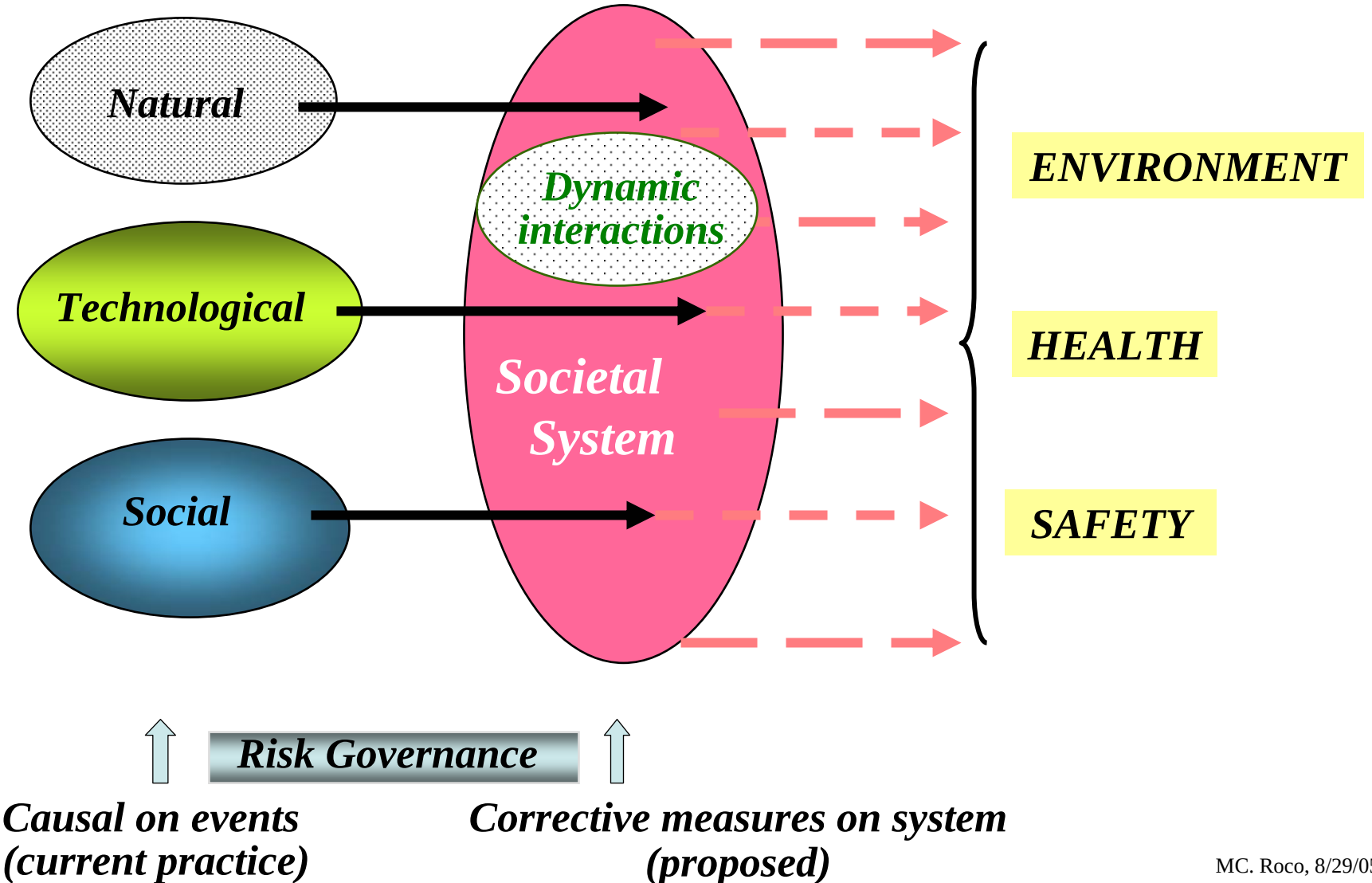


Nanotechnology in Society

J. Nanoparticle Research, 7(2), 2005

M.C. Roco, 8/29/05

Sources of EHS risks in the societal system and nanotechnology risk governance



Specific framework for risk governance of nanotechnology

Focus on risk analysis for the higher-risk, high production applications:

- **Open and complex system**
  - fundamental (high risk)
    - developments are not known (role organizations)
    - accelerated (upstream measures needed)
  - cross S,E&T (complex interactions)

- **With broad implications (general platform)**
  - affects most areas of economic activity, effect of the "food chain" of the

International Risk Governance Council (Geneva) Objective

- **Develop a framework for the governance of certain nanotechnology risks in the general context of emerging technologies**.

  Focus on the second generation of NT (active nanostructures), as well as longer term issues (related to nanosystems and molecular systems).

  Select higher risk applications with global governance aspects (international interactions).

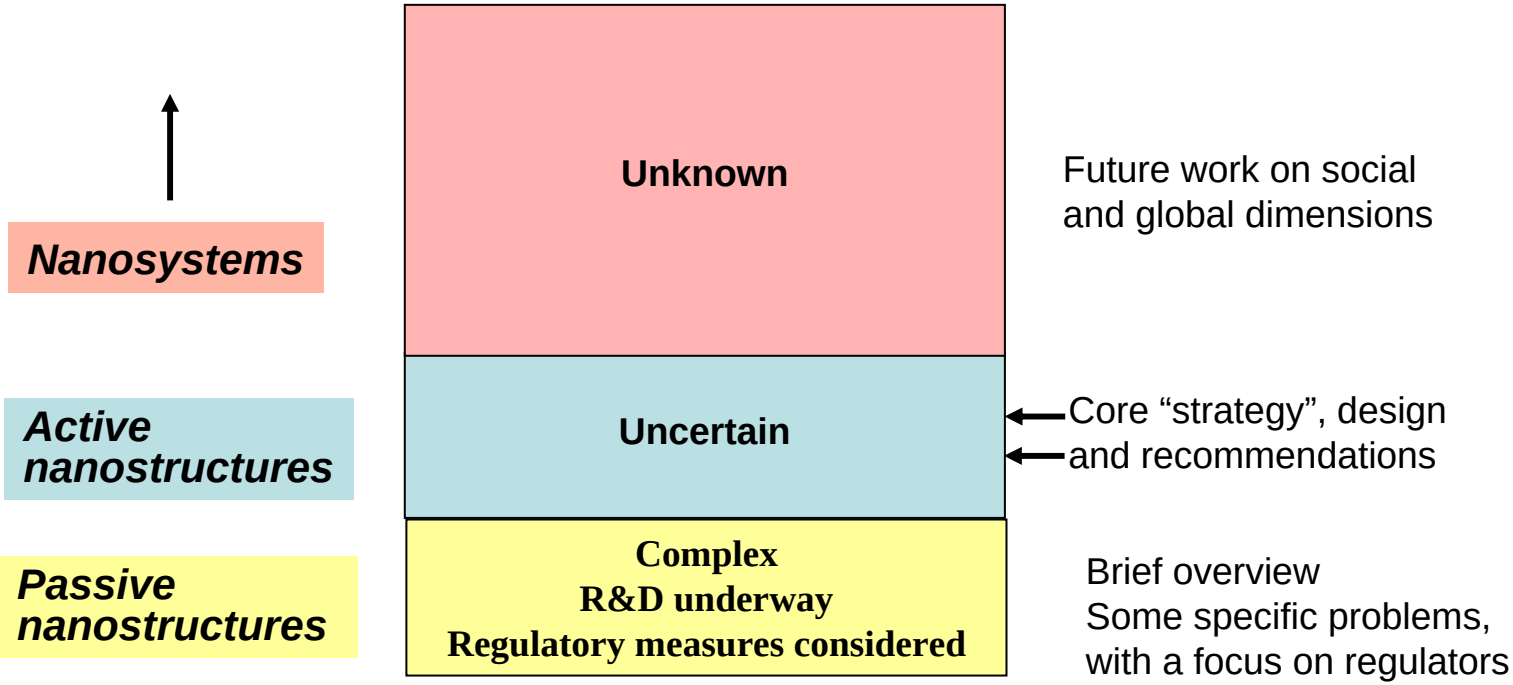
  Address global aspects that cannot be addressed by each country.

  Address longer term and broad societal implications of nanotechnology that are not well covered by national studies.

- **Apply basic principles of the IRGC risk governance framework*.**
- **Agree a common framework of governance recommendations based on consensus.**

* Currently undergoing peer review

Outcomes of the preparatory Workshop on May 19, 2005



Nanotechnology application areas

Timeline for beginning of nanotechnology commercialization:

Perceived higher risks areas

1st: Passive nanostructures Ex: Cosmetics (pre-market tests), Pharmaceuticals (incomplete tests for inflamatory effects, etc.), Food industry (no regulations in many situations), Consumer products

~ 2000

2nd: Active nanostructures Ex: Nano-biotechnology, Neuro-electronic interfaces, Nanoelectromechanical systems, Precision eng., Hybrid nanomanufacturing

~ 2005

3rd: Systems of nanosystems Ex: Converging technologies, Nanorobotics, Regenerative medicine, Brain-machine interface, Eng. agriculture

~ 2010

4th: Molecular nanosystems Ex: Neuromorphic eng., Complex systems, Human-machine interface

~ 2015-2020

only R&D

AIChE Journal, 2004, Vol. 50 (5), MC Roco

Proposed IRGC study on Nanotechnology Risk Governance - Key components

1. Develop preparatory materials

   a. Assess current approaches to Nanotechnology used in key countries

   b. Characterize nanoscale technologies using influence diagrams

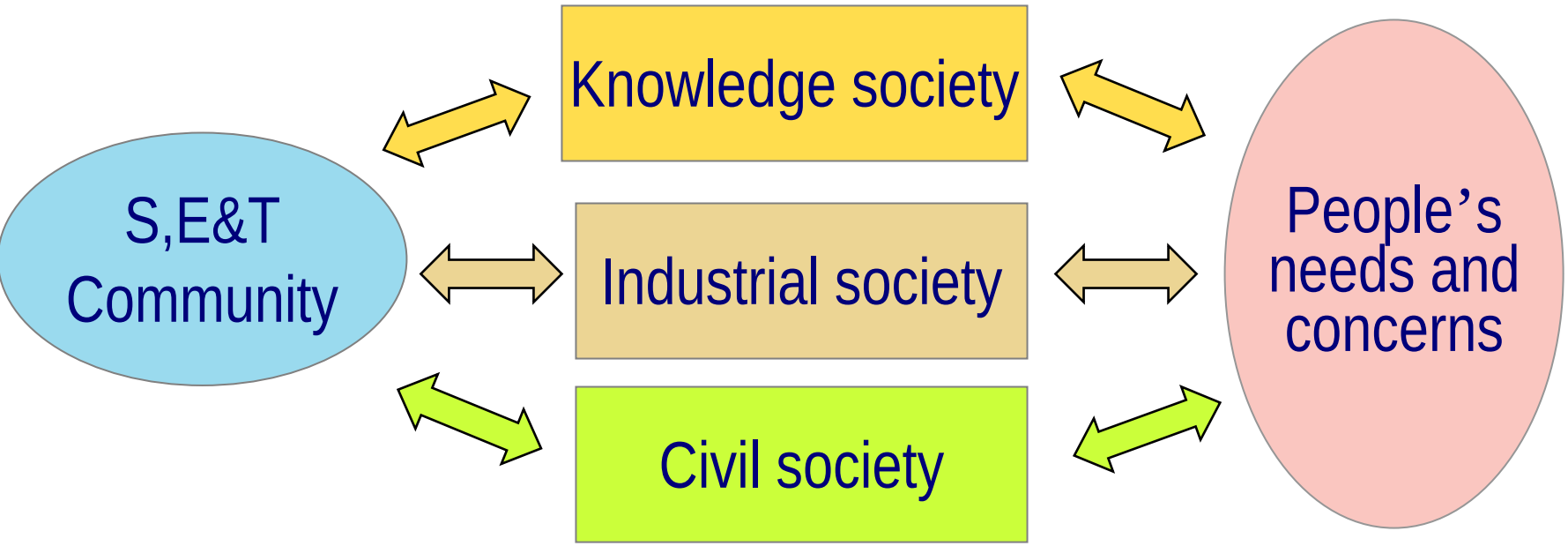
   c. Questionnaire to key stakeholders (public, politicians, NGOs, industry, academia) to survey "What are the most important issues/surrounding nanotechnology?"

2. Develop a framework for risk governance of nanotechnology applications

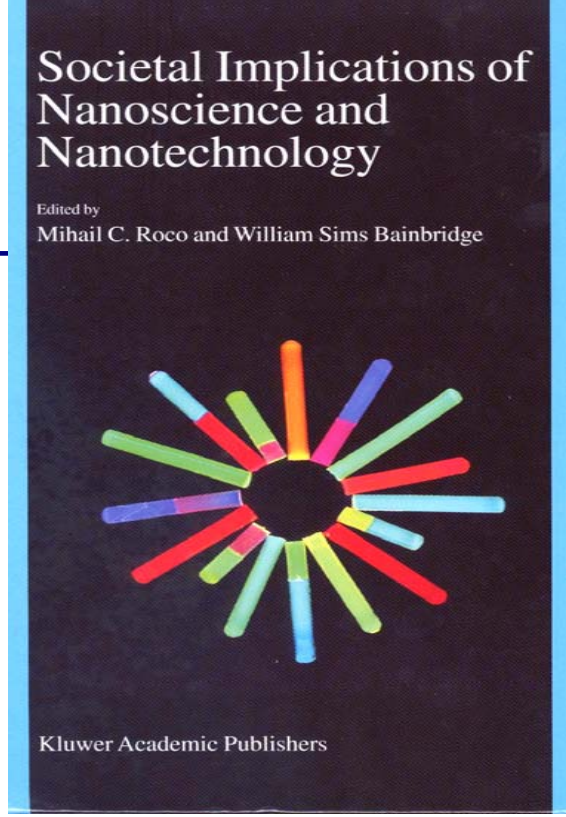
3. Agreeing the common framework(s) for governance

- Organize conference bringing the key stakeholders together with objective of achieving buy-in to optimal risk governance approaches
- Dissemination / interactions for implementation of recommendations

NBIC community and societal interactions



Societal Implications: Follow-up of the September 2000 report



http://nano.gov

- Make support for social, ethical, and economic research studies a priority:
  (a) New theme in the NSF program solicitations;
  (b) Centers with societal implications programs;
  (c) Initiative on the impact of technology, NBIC, HSD
- NNCO – communicate with the public and address Environmental, Health and and Safety issues, and unexpected consequences
- NSET's Nanostructures Environmental and Health Issues working group has been established in 8/2003, 12 agencies
- Workshop with EC (2001); Links to Europe, Americas, Asia; International Dialogue (26 countries, NSF-sponsored)

NSET
NEHI WG MEMBERSHIP

- Consumer Product Safety Commission
- Department of Agriculture
- Department of Commerce/National Institute of Standards and Technology
- Department of Defense
- Department of Energy
- Department of Labor/Occupational Safety and Health Administration
- Environmental Protection Agency
- Food and Drug Administration
- National Institute of Environmental Health Sciences
- National Institute for Occupational Safety and Health
- National Nanotechnology Coordination Office
- National Science Foundation
- Office of Management and Budget
- Office of Science and Technology Policy

NEHI PURPOSE

- Exchange of information among agencies
- Facilitate the identification, prioritization, and implementation of research and other activities
- Promote communication of information related to research on environmental and health implications of nanotechnology

NEHI ACTIVITIES/IMPACTS

(see www.nano.gov for links to agencies)

- Identify regulatory agency jurisdiction of nano-products
- Toxic Substances Control Act jurisdiction
- Chemical Abstract Service/American Chemical Society approach to nano-particles
- Terminology and nomenclature
- Regulatory agency position on research priorities
- Regulatory agency position statement on regulation of nano-products
- Question & answers for fielding questions from outside interests
- Inter-agency coordination

NNI Publications in 2005 including Societal Implications II (Sept. 2005)

Key issues in long term

- Respect human right to: access to knowledge and welfare; human integrity, dignity, health and safety
- Balanced and equitable R&D nanotechnology investment
- Environment protection and improvement (water, air, soil) Sustainable development, life-cycle of products, global effects (weather), eliminate pollution at the source
- Economic, legal, ethical, moral, regulatory, social and international (developed-developing countries) aspects Interacting with the public and organizations
- Adaptive/corrective approach for a complex system

Immediate and continuing issues:

- *EHS in research laboratories and industrial units*
- *Harmonizing nomenclatures, norms and standards*
- *Primary data and methodology for risk analysis*

NNI activities
for Environmental, Health and other Societal Implications

A. Align R&D investment with societal implications

B. Evaluate and implement regulatory standards

C. Coordinated measures for EHS and ELES

D. Periodical meeting for grantees,
setting research targets, and
interaction with industry and the public

E. International collaboration (International Dialog
for Responsible R&D of Nanotechnology)

A. NNI coordination for R&D investments

FY 2001-2005: About 10% budget for EHS/ELSI, incl. env. applications

- NSF research grants on environmental and societal implications
  All basic R&D areas, transport of nanoparticles; Programs since 2000
- NIH research on effects of nanoscale materials in the body
- EPA research grants on environmental implications of manufactured nanomaterials
- National Toxicology Program (NIEHS, NCTR, NIOSH)
  Project to study toxicity of nanotubes, quantum dots, and titanium dioxide
- NIST development of standards and measurements for nanoscale particles
- FDA and USPTO training and specialized activities
- USDA and DOE support fate and transport studies
- DOD supports exposure studies
- Solicitations (SI): NSF (ENV, SI), EPA-NSF-NIOSH, USDA, NIH

NSF environmental centers and interdisciplinary groups with research and education at the nanoscale

Center (details on www.nsf.gov/home/crssprgm/nano/nni01_03_env.htm)	**Institution**
Fundamental Studies of Nanoparticles Formation in Air Pollution	**Worcester Polytechnic Institute ($2.7M)**
Center for Advanced Materials for Water Purification	**University of Illinois at Urbana ($20.1M)**
Center for Environmentally Responsible Solvents and Processes	**University of North Carolina at Chapel Hill ($25.0M)**
Nanoscience in Biological and Environmental Engineering (estimated 50% in environment)	**Rice University ($11.8M)**
Environmental Molecular Science Institute	**Univ. of Notre Dame ($5M)**
NIRT: Investigating Nano-carbon Particles in the Atmosphere: Formation and Transformation	**University of Utah ($1.7M)**
NIRT: Nanoscale Processes in the Environment - Atmospheric Nanoparticles	**Harvard University ($1.6M)**
Center for Advanced Computational Environment	**SUNY Buffalo ($5.5M)**
NIRT: Nanoscale Sensing Device for Measuring the Supply of Iron to Phytoplankton in Marine Systems	**University of Maine ($0.9M)**

NNI projects supporting toxicity research (examples)

Project	Agency, Institution
National Toxicology Program ($0.5M in FY 2004 to $5M in FY 2008)	NIH/NIEHS, FDA/NCTR, NIOSH
Particle characterization for health and safety ($1.7M in FY 2004 rto $2.3M in FY 2005)	NIOSH
Nanotechnology Characterization Laboratory ($5M/yr, part of $144M/yr NCI for FYs 2004-2008)	National Cancer Institute
Multidisciplinary University Research on Nanoparticle Toxicity	Department of Defense supported center
Molecular function at the Nano-Bio Interface (component on nanostructures and cell behavior)	NSF/NSEC U. Pennsylvania
Nanomanufacturing Center for Enabling Tools (component on safe manufacturing)	NSF/NSEC Northeastern University
Size Dependent Neural Translocation of Nanoparticles	NSF/SGER, Rochester University
Reverse Engineering Cellular Pathways from Human Cells Exposed to Nanomaterials	NSF/SGER

National Toxicology Program organization

NTP Director
Dr. K. Olden,
Dir NIEHS

Policy Oversight

Executive Committee

ATSDR	NCI/NIH
CPSC	NIEHS/NIH
EPA	OD/NIH
FDA	NIOSH/CDC
NCEH/CDC	OSHA

Environmental Toxicology Program

External Science Oversight and Peer Review

Board of Scientific Counselors

Scientific Advisory Committee On Alternative Toxicological Methods

NIEHS

NCTR
National Center for Toxicological Research
U.S. Food and Drug Administration

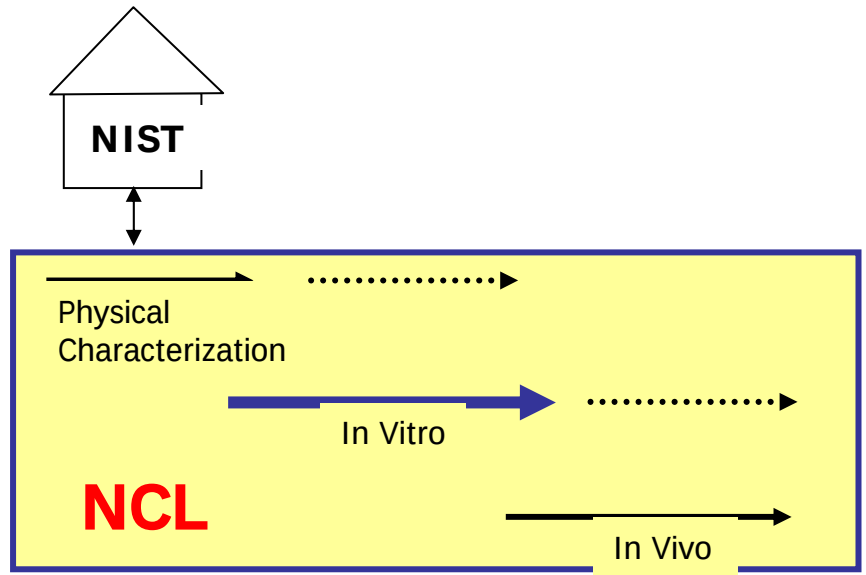
NIOSH

Nanotechnology Characterization Laboratory (NCI) Concept of Operations

For comparison and characterization of nanomaterials intended for cancer detection, diagnostics, and therapeutics in humans.

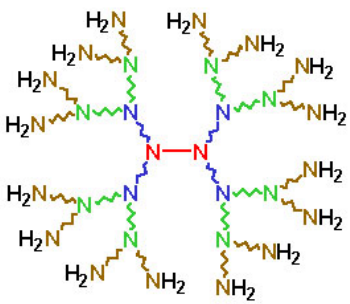
Sources of Nanomaterials

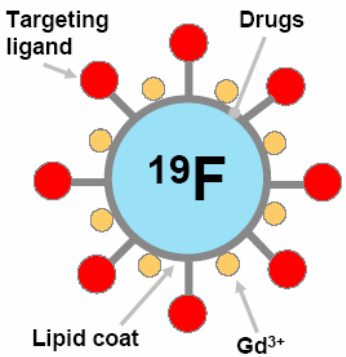
- Cancer Centers of Nanotech Excellence (CCNEs)
- Academia
- NNI
- Small Business
- NCI, NIH, NSF
- DoD, DoE
- Unconventional Innovative Program (UIP)

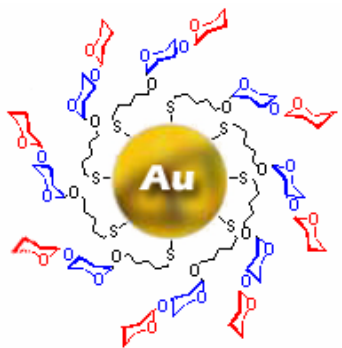


- Detection
- Diagnostics
- Therapeutics

Candidate Nanoparticles







MC Roco, 4/18/05

NNI projects supporting social implications (examples (1))

Project	Agency, Institution
Nanotechnology and its Publics	**NSF,** **Pennsylvania St. U.**
Public Information, and Deliberation in Nanoscience and Nanotechnology Policy (SGER)	**Interagency,** **North Carolina St. U.**
Social and Ethical Research and Education in Agrifood Nanotechnology (NIRT)	**NSF,** **Michigan St. U.**
From Laboratory to Society: Developing an Informed Approach to NSE (NIRT)	**NSF,** **U. of South Carolina**
Social and ethical dimensions of nanotechnology	**NSF,** **U. Of Virginia**
Ethics and belief inside the development of nanotechnology (CAREER)	**NSF,** **U. Of Virginia**
All centers, NNIN and NCN have a societal implications components	**NSF, DOE, DOD and NIH** **All nano centers and networks**

NNI projects supporting social implications (examples (2))

Project	Agency, Institution
Citizen Learning, Deliberation, and Reasoning in Internet-Mediated Technology Policy Forums	**NSF, North Carolina State University**
Public Information, and Deliberation in Nanoscience and Nanotechnology Policy (SGER)	**Interagency, North Carolina State University**
An Integrated Approach to Teaching Nanotechnology and Society (NUE)	**University of Wisconsin**
Nanotechnology: Content and Context (NUE)	**Rice University**
Undergraduate Exploration of Nanoscience, Applications and Societal Implications (NUE)	**NSF, Michigan Technological U.**
Assessing the Implications of Emerging Technologies (IGERT)	**NSF, MIT**
Nanoparticle Science and Engineering (IGERT)	**NSF, University of Minnesota**

Four NSF centers with national outreach fully or partially dedicated to societal dimensions

- **Center for Nanotechnology in Society (2005 -)**
- **Nanotechnology Center Learning and Teaching (Northwestern University, 2004 -)**
- **Center for Nanotechnology Informal Science Education (2005 -)**
- **Center for Hierarchical Nanomanufacturing (2005 -)**

US NSF - Nanoscale Science and Engineering - NSF ACTIVITIES, Solicitations and Their Outcomes - Microsoft I...

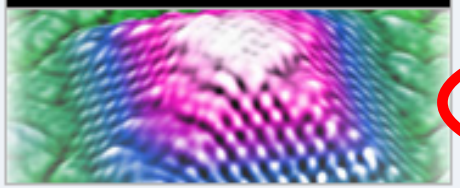
File Edit View Favorites Tools Help Address Links

National Science Foundation
WHERE DISCOVERIES BEGIN

SEARCH
NSF Web Site

HOME | FUNDING | AWARDS | DISCOVERIES | NEWS | PUBLICATIONS | STATISTICS | ABOUT | FastLane

NNI



Solicitations & Outcomes

New Items

Activities

Program Reviews

NSF & NNI Symposia

NSF & NNI Reports

NSF & NNI Reports

Links to Related Reports

NNI Endorsements

NNI Presentations

NSF National Nanotechnology Initiative (NNI)

Search for NSF awards by keywords
(go to the "Full text search", and complete the box with your keywords; Examples of keywords are nano*, selfassembl* and nanoparticle)

NSF press releases on Nanotechnology Research since January 2004

NSF press releases on Nanotechnology Research from 2003 to 2001

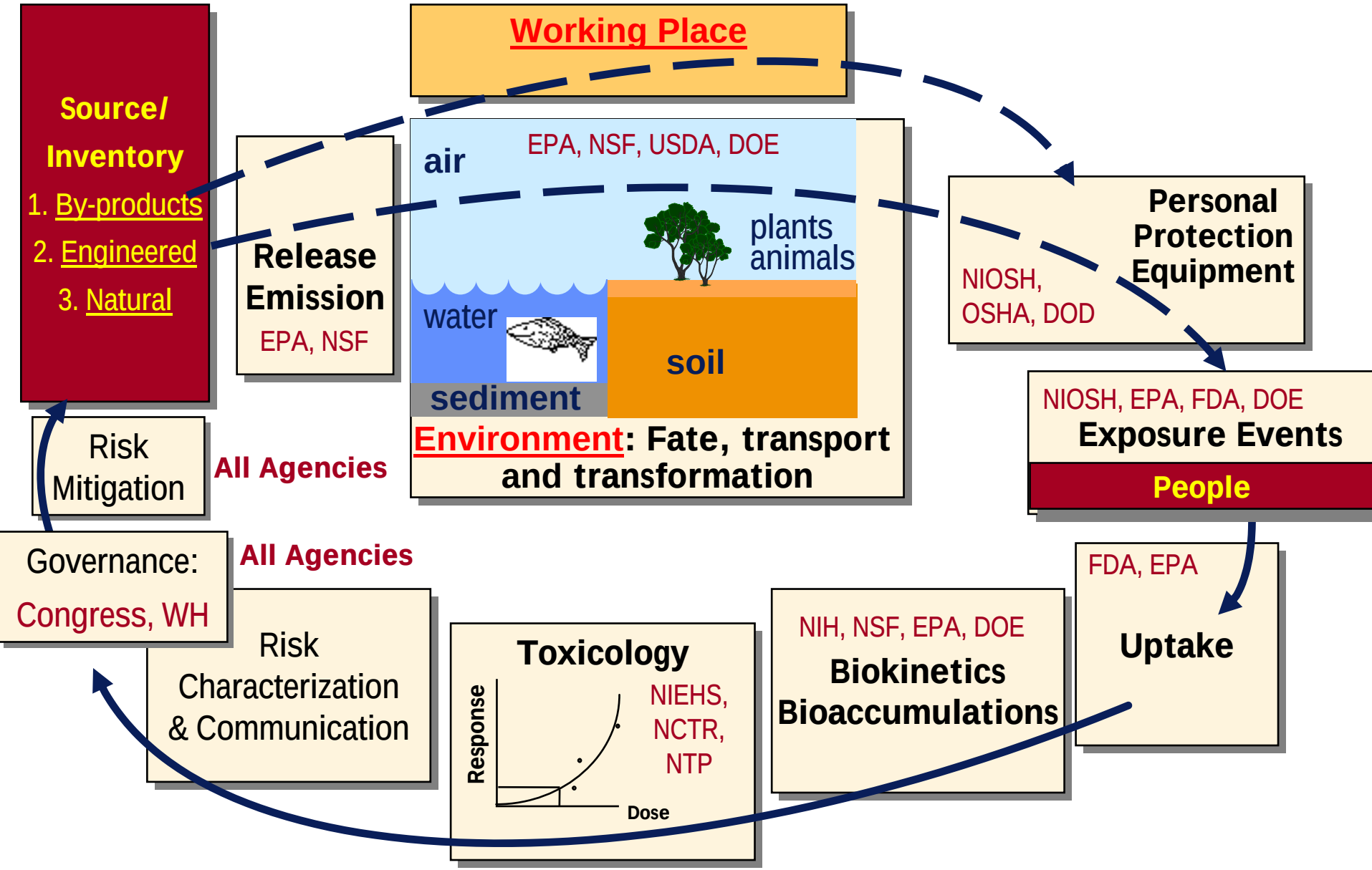
SOLICITATIONS AND OUTCOMES IN FY 2005

NSF Announcement 05-543: Nanoscale Science and Engineering Education (NSEE)
"Preparation workshop: Public Engagement in Nanoscale Science and Engineering"(PDF, 776KB)

NSF Announcement 04-043: Nanoscale Science and Engineering (NSE)
NSEC on "Nanotechnology in Society" workshop

Joint EPA-NSF-NIOSH solicitation for research in Environmental and Human Health Effects of Manufactured Nanomaterials

B. EHS research and regulatory topics for nanomaterials



Modified from a schematic by M. Alper
J. Nanoparticle Research, Vol. 7, 2005 (M. Roco)

C. *Current NNI coordinated measures for EHS*

- Develop statement on "Best practices" for research laboratories and industry units (NIOSH, NSF, DOE, NASA, DOD), and identify gaps
- Map of EHS responsibilities and contacts in each NNI agency
- Establish response approach to an unexpected event or an emergency

- Identify protective equipment suitable for nanoparticles and other nanostructured materials (OSHA, NIOSH, other agencies)
- Support development of instrumentation and metrology (NSF, NIST)
- Develop a unified, explicit nomenclature (agencies, ANSI)
- Develop standards for nanotechnology (NIST, ANSI, IEEE, ASME)

- Collaborative activities with industry (SRC, CCR, Phrma, IRI)
- Identify research and educational needs (Fundamental, GCs)

NSET Group: "Nanomaterials Environmental and Health Implications"

OSTP Group: "Risk Assessment of Nanotechnology" task force

D. NNI workshops on nano-environmental research

examples

- NSF, 9/2000: "Societal Implications of Nanoscience and Nanotechnology"
- NSF, 6/2002: "Nanoparticles and the environment" (grantees meeting, book)
- EPA, 11/2003: "Nanotechnology and the environment applications and implications" (grantees meeting, brochure)
- ACS, 3/2003: "Symposium on nanotechnology implications in the environment", New Orleans
- NNI, 5/2003: "Vision for environmental implications and improvement" *(interagency, report)*
- NSET/NNCO, 8/2003: Review of Federal Regulations (report)
- NNI, 9/2003: Interagency : grantees meeting (report);
- Wilson Center, 10/2003: EPA and FDA regulatory functions (report)
- NSET, 12/03 "Societal Implications of Nanoscience and Nanotechnology (II)"

C. *Current NNI coordinated measures for EHS*

- Develop statement on "Best practices" for research laboratories and industry units (NIOSH, NSF, DOE, NASA, DOD), and identify gaps
- Map of EHS responsibilities and contacts in each NNI agency
- Establish response approach to an unexpected event or an emergency

- Identify protective equipment suitable for nanoparticles and other nanostructured materials (OSHA, NIOSH, other agencies)
- Support development of instrumentation and metrology (NSF, NIST)
- Develop a unified, explicit nomenclature (agencies, ANSI)
- Develop standards for nanotechnology (NIST, ANSI, IEEE, ASME)

- Collaborative activities with industry (SRC, CCR, Phrma, IRI)
- Identify research and educational needs (Fundamental, GCs)

NSET Group: "Nanomaterials Environmental and Health Implications"

OSTP Group: "Risk Assessment of Nanotechnology" task force

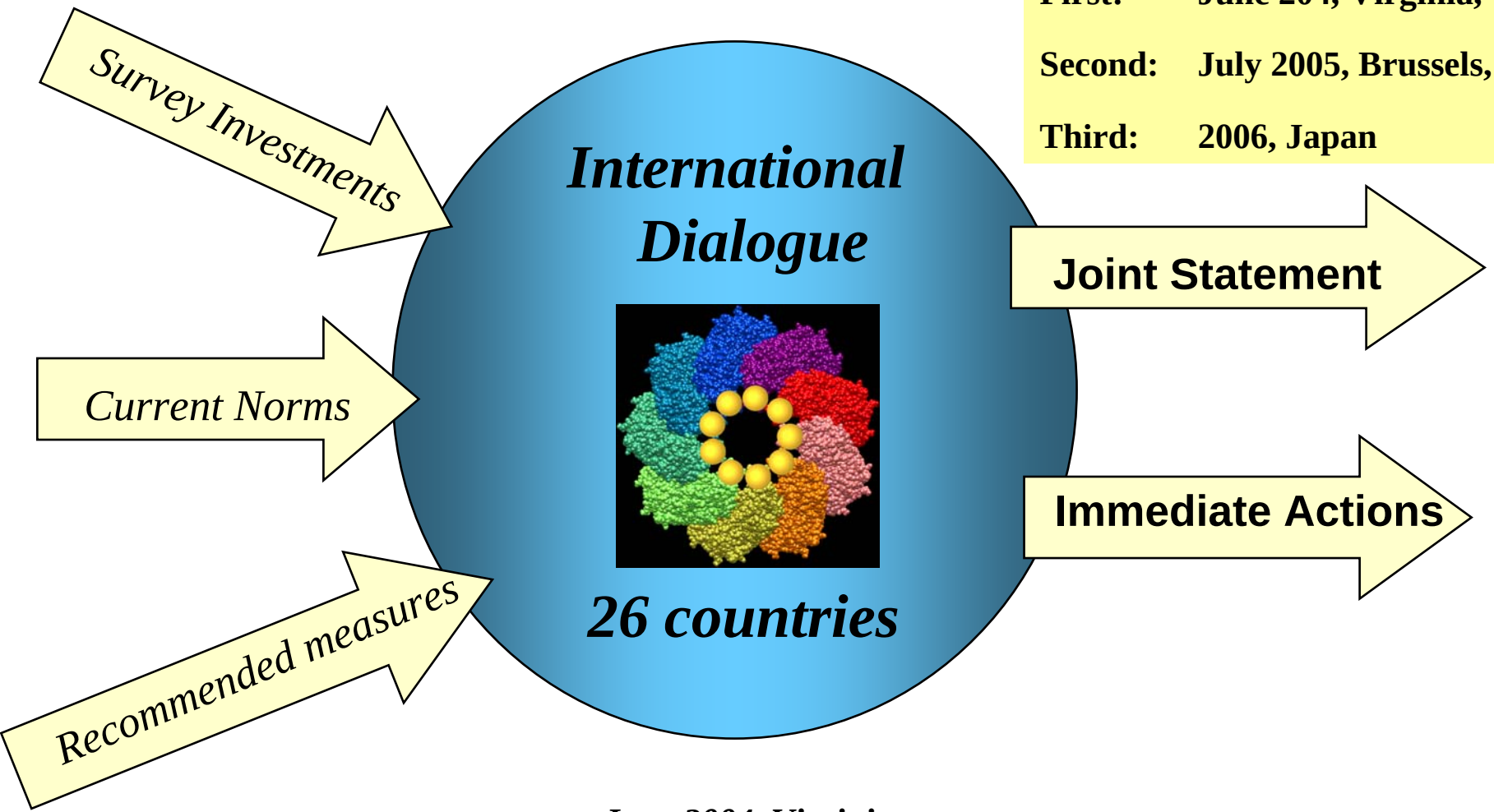
D. NNI workshops on nano-environmental research

examples

- NSF, 9/2000: "Societal Implications of Nanoscience and Nanotechnology"
- NSF, 6/2002: "Nanoparticles and the environment" (grantees meeting, book)
- EPA, 11/2003: "Nanotechnology and the environment applications and implications" (grantees meeting, brochure)
- ACS, 3/2003: "Symposium on nanotechnology implications in the environment", New Orleans
- NNI, 5/2003: "Vision for environmental implications and improvement" *(interagency, report)*
- NSET/NNCO, 8/2003: Review of Federal Regulations (report)
- NNI, 9/2003: Interagency : grantees meeting (report);
- Wilson Center, 10/2003: EPA and FDA regulatory functions (report)
- NSET, 12/03 "Societal Implications of Nanoscience and Nanotechnology (II)"

E. International Dialogue on Responsible Nanotechnology R&D

First:	**June 204, Virginia, USA**
Second:	**July 2005, Brussels, EC**
Third:	**2006, Japan**



June 2004, Virginia

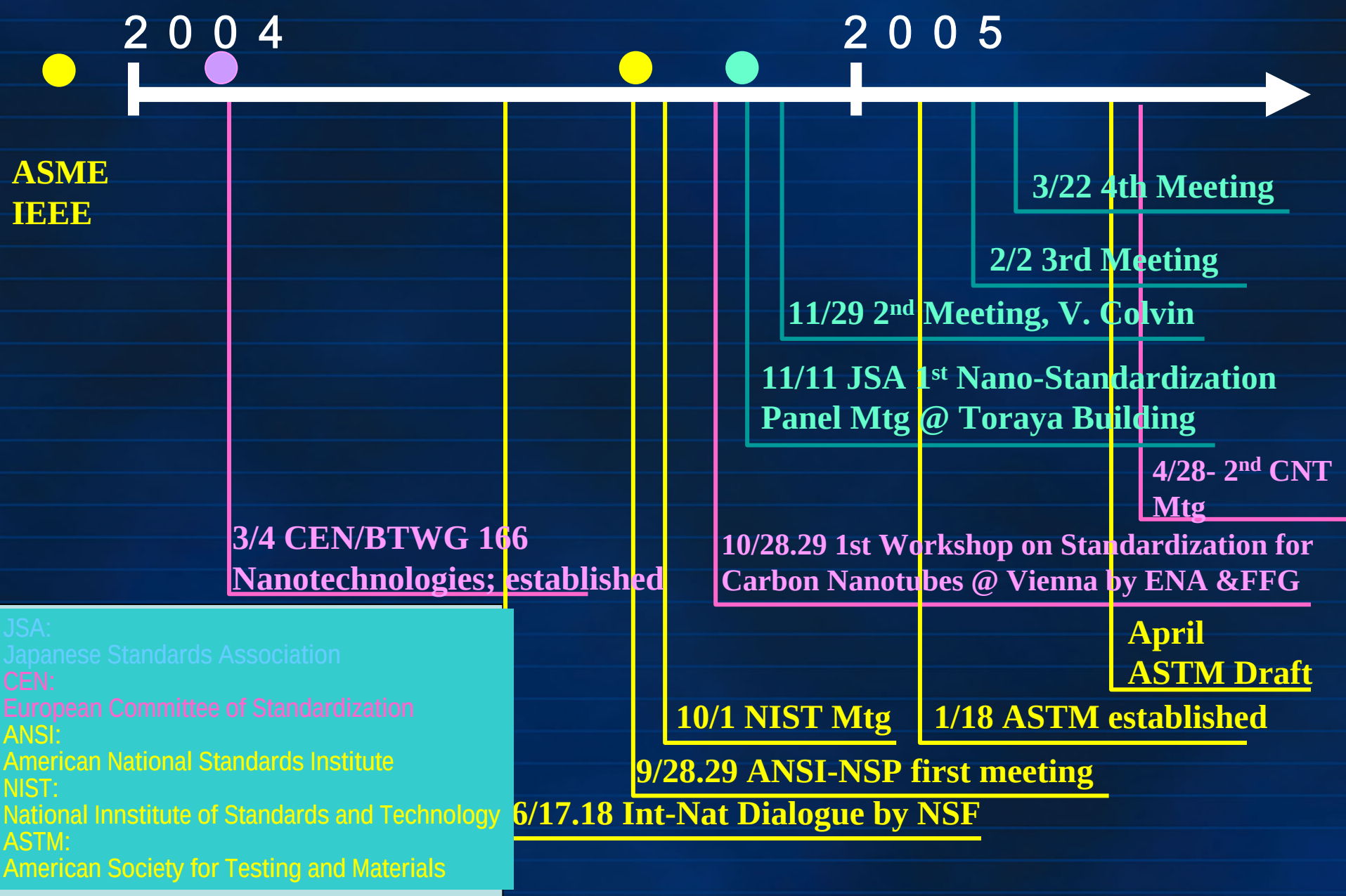
http://www.nsf.gov/home/crssprgm/nano/dialog.htm

International Dialogue on Responsible Nanotechnology R&D

Activities after the June 2004 International Dialogue on Responsible Nanotechnology (Virginia, U.S.)

- **October 2004/October 2005 - Occupational Safety Group**
- **November 2004 – OECD group on nanotechnology begins**
- **December 2004 – Meridian study for developing countries begins (next meeting in March 2005)**
- **December 2004 - International collaboration for nomenclature and standards has been initiated (ISO, ANSI)**
- **February 2005 – N-S Dialogue on Nanotechnology (UNIDO)**
- **May 2005 – Nano-world, MRS (Materials, Education)**
- **July 2005 – 2nd International Dialogue (host: EC)**
- **May 2005- - International Risk Governance Council initiate study on nanotechnology**

Trend of global nano-standardization



JSA:
Japanese Standards Association
CEN:
European Committee of Standardization
ANSI:
American National Standards Institute
NIST:
National Innstitute of Standards and Technology
ASTM:
American Society for Testing and Materials

Transforming and Responsible development of nanotechnology

Reaching at the building blocks of matter for all manmade and living systems, with the NBIC platform - makes transforming tools more powerful and unintended consequences more important than for other technologies

Besides the immediate and continuing societal implication issues, a long-term concern is a possible instability in human development, because perturbations created at the foundation of life and of the new transforming tools

There is a need for an anticipatory and corrective approach in

- **planning, to be both transforming and responsible**
- **in addressing societal implications for each major R&D program or project from the beginning**
- **risk governance of converging new technologies at the national and international levels**