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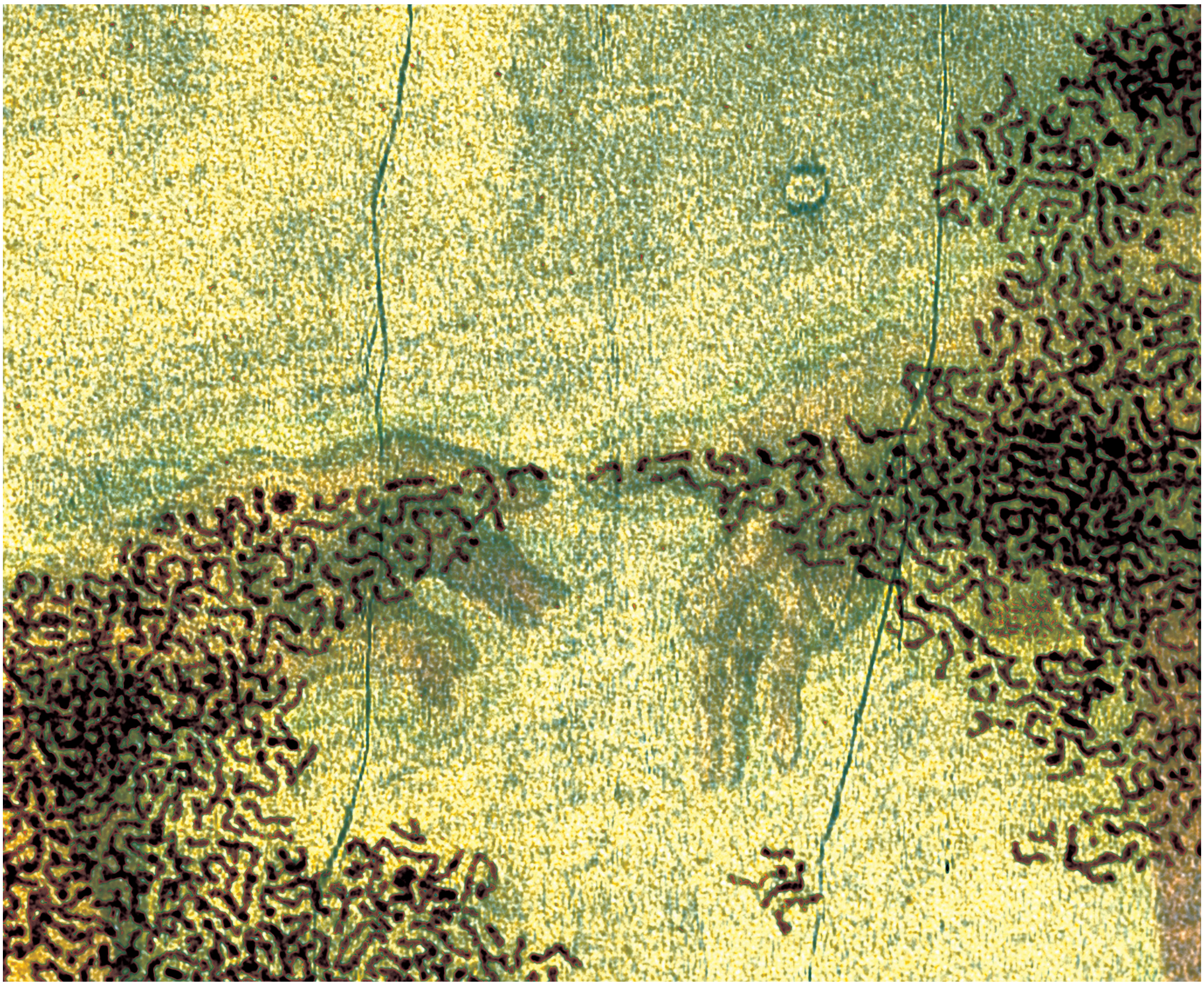

Ethical Aspects of Nanotechnology

A Statement by the Working Group of Commissioners for Environmental Affairs of the Protestant Church in Germany (EKD)

14

English translation

Evangelische Kirche von Westfalen

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Edited by
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Ethical Aspects of Nanotechnology

A Statement
by the Working Group of Commissioners for Environmental Affairs
of the Protestant Church in Germany (EKD)

Arbeitsgemeinschaft der Umweltbeauftragten (AGU)
der Evangelischen Kirche in Deutschland (EKD)

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May 2007

The cover picture "aN ANgelO" was designed by Daniela Fenske, a qualified chemist and scientific employee of the Faculty of Physical Chemistry 1, University of Oldenburg. The picture made by a transmission electron microscope was produced in cooperation with the working group of Professor Katharina Al-Shamery (Physical Chemistry 1) and Junior Professor Joanna Kolny-Olesiak (Institute of Physics – Energy and Semiconductor Research) at Oldenburg University. Nano & Art Prize 2005 motivated the creation of this kind of image as an aesthetical piece of art. At this competition sponsored by the Degussa AG, the picture achieved a placing among the top 20.

The particles displayed here are platinum nanoparticles. "aN ANgelO" shows a detail of about 285 x 318 nanometers. Each platinum nanowire measures about 2,5 x 14 nm, a nanometre corresponding to one billionth of a meter (1 nm = 10-9 m) or approximately one millionth of the diameter of a hair.

The particles shown were produced by chemical synthesis. Thus, it has become possible to modify the structure and size (and in particular the uniform distribution) of these nanoparticles in a purposeful way.

German version:
Ethische Aspekte der Nanotechnologie
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1 Introduction

The term "nanotechnology" covers a great variety of uses in a great variety of areas in our technological / engineered world. The application of nanotechnology is designed to lead to completely new solutions that will improve the manufacturing, use and waste disposal of products. It is generally agreed that nanotechnology is a cross-disciplinary technology that will bring new strategies to a wide range of possible applications.

As with every new technology, great expectations are often suggested for the economic possibilities and potentials of nanotechnology. But here, too, it is important to try to estimate the potential risks and to take sufficient precautions in order to prevent possible threats to health and environment.

This paper deals above all with the development of ethical criteria for assessing nanotechnology by taking into account aspects of health and environment.

2 What is nanotechnology?

To date, there is no universally applicable definition of nanotechnology. In 2002, the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung [BMBF]) published a report defining nanotechnology as "the production, study and application of functional structures whose dimensions are in the region of less than one hundred nanometres."[1] In Greek "nanos" means "dwarf", so the term describes something very tiny. In science, the prefix "nano" means one billionth, for example one billionth of a meter: one nanometer = 10^{-9} m. Structures called nanostructures range in size from a few up to several hundreds of atoms or molecules (nanoclusters or nanoparticles). They are able to form wires, tubes, or layers that correspond in at least one dimension to the definition of the BMBF cited above.

The particular uniqueness of nanostructures is directly linked to the dimension of these structures. The aim of nanotechnology is not merely to develop smaller and smaller components, as has been important in computer technology from the beginning. When entering the nanoworld, scientists discovered that the material properties of, for example, metals or chemical compounds changed. The main reason for this is that nanostructures, in relation to their size, have a very large sur-

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1 Bundesministerium für Bildung und Forschung (BMBF) (ed.): Nanotechnologie in Deutschland – Standortbestimmung. Bonn, 2002 (all German quotations were translated into English by the editors)

face area. Thus, properties such as electrical conductivity, magnetism, fluorescence, reactivity, melting point, mechanical hardness, and light-refraction abilities are subject to alteration and can be quite surprisingly different than at the macro scale.

When applying energy, molecules can be stimulated to form defined structures whose properties can differ from macroscale structures. Nano-structured crystals and surface layers have already been developed.

Pat Mooney, a Canadian technology critic, described nanotechnology as follows: "Many things that sound like science fiction have already been made in the laboratory. What still seems to be a dream will happen in the very near future."[2]

3 Fields of application

As with every cross-sectional technology, the fields of application of nanotechnology are highly diverse. An overview is given in the report "Nanotechnology" published by the Office of Technology Assessment at the German Bundestag (Büro für Technikfolgenabschätzung des Deutschen Bundestages [TAB][3]), in the German magazine Politische Ökologie 101[4], and in the study of the Swiss Re[5]. The TAB-report sums up seven fields of application:

- Surface functionalization and refinement;
- catalysis, chemistry and materials synthesis;
- energy conversion and energy use;
- construction;
- nanosensors;
- data processing and data transmission;
- life sciences (biotechnology).

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[2] „Ein technologischer Tsunami kommt auf uns zu", Interview mit Pat Mooney, Politische Ökologie 101, Ökom Verlag, Munich, 2006

[3] Paschen et al.: TA-Projekt Nanotechnologie, Arbeitsbericht Nr. 92, Berlin, 2003

[4] Politische Ökologie 101, Nanotechnologie, September 2006, Ökom Verlag, Munich

[5] Swiss Re (ed.): Nanotechnology „Small size – large impact?" Schweizerische Rückversicherungsgesellschaft, Zurich 2004, www.swissre.com [Swiss Re (ed.): Nanotechnologie, Kleine Teile – große Zukunft?, Schweizerische Rückversicherungsgesellschaft, Zürich, 2004, www.swissre.com]

4 Economic potential

The economic potential of nanotechnology is generally estimated to be very high. Accordingly, in order to introduce nanotechnical products to the market, three alliances have already been established worldwide: US NanoBusiness, the European NanoBusiness Association (Europäische Nanowirtschaftsgesellschaft) and the Asia-Pacific Nanotechnology Forum.

In 2004, the European Research Commissioner at that time, Philippe Busquin, declared: "Nanotechnology offers the golden opportunity for the founding of new enterprises based on science and it has revolutionary potential for developing new manufacturing processes. It is extremely important to create a favourable environment for nanotechnological innovations."[6] Accordingly, by means of the 7th Framework Program for Research, the EU will financially support nanotechnology research for the period from 2007 until 2013 with 4.8 billion Euros. The Federal Government of Germany spent 330 million Euros on nanotechnology research in 2006 by means of funding autonomous support programs and by institutional funding of scientific organisations.[7] In Germany, public funds of totalling nearly 1.1 billion Euros were invested between 2002 and 2005. Some 9.6 billion US-Dollars were spent worldwide on nanotechnology research and development in 2005.[8]

In a study, the German Federal Ministry of Education and Research estimates that already today 50,000 jobs in industry depend directly or indirectly on nanotechnology.[9] Around 550 enterprises in Germany deal with the development, production and marketing of nanotechnological products.[10]

According to a study by the US market research institute Lux Research which publishes a report on the economic development of nanotechnology every year, the world market volume of nanotechnological products in 2005 amounted to 32 billion US-dollars.[11] Adopting a wide definition of nanotechnological products, the Federal Government of Germany assumes that the world market influenced in one way or another by nanotechnology currently amounts to approximately 100 billion

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6 Cited in: Andrea Reiche: Im Reich des Allerkleinsten, Politische Ökologie 101, Nanotechnologie, Ökom Verlag, Munich, 2006

7 Bundestag-Drucksache 16/2322, 31.07.2006

8 http://www.luxresearchinc.com/press/RELEASE_TNR4.pdf

9 http://www.bmbf.de/pub/nano_initiative_aktionsplan_2010.pdf

10 Bundestag-Drucksache 16/2322, 31.07.2006

11 http://www.luxresearchinc.com/press/RELEASE_TNR4.pdf

Euros.[12] All these figures, however, are only estimations: No one knows the exact amount of nanotechnological compounds contained in products nor to which extent nanotechnologies are used in manufacturing processes. The label "nano" is often used to promote products, but some of these products do not contain any elements corresponding to the definition cited above. "Nano" meanwhile has become a fashionable label.

On its homepage, an US-American consumer protection organisation lists 200 products containing nanotechnological materials.[13] Other experts estimate that the number of products already on the market amounts to 500.[14] About 150 products containing the term "nano" in their trade name are registered at the German Patent and Trade Mark Office. At the European level, 550 products labelled nano are listed as Community trademarks.[15]

In a study[16] the IKU-Institute specifies the following products:

- sun blockers with higher UV protection and for the more sensible skin contain oxide particles;
- cosmetics with nanoparticles;
- nanoscale toner particles for copiers and printers;
- paints and coatings that absorb UV rays;
- scratch-proof car paints;
- textiles that are water and dirt repellent;
- textiles that have improved sun protection owing to oxide particles;
- safety clothing that prevents static build-up;
- improved antireflection coating and greater scratch resistance in spectacle lenses;
- optimised electronic chips, hard disks, RAM memory, diode lasers, displays, accumulators;
- more efficient use of energy in light diodes in display boards, rear lights and torches;

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12 Bundestag-Drucksache 16/2322, 31.07.2006

13 www.nanotechproject.org

14 Wolfgang Silanus: Die unsichtbare Revolution, Natur und Kosmos 08/2006

15 Bundestag-Drucksache 16/2322, 31.07.2006

16 Environmental Research Plan of the Federal Ministry of Environment, Nature Conservation and Nuclear Safety: Synthetic Nanoparticles. Focus on environmental and health aspects, by iku GmbH, Dortmund, on behalf of the Federal Environmental Agency, August 2005 [IKU-Institut (ed.): Synthetische Nanopartikel, Studie im Rahmen des Umweltforschungsplanes des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit, August 2005]

- golf clubs and tennis racquets containing carbon nanotubes (CNT) with greater stability and improved playing properties;
- admixtures of nanoparticular materials in babies` nappies to enhance moisture absorption, in cling films for greater stability and gas permeability.

As the scope of possible applications is expected to extend considerably, the patenting of nanoparticles is of great strategic importance. Similar to the patenting of biotechnological inventions, both a controversy as to the coverage of the patents and a debate regarding the differentiation between product patents and process patents may arise. In patent law, chemical elements are not patentable. Therefore, the description of nanotechnological inventions must refer to the specific properties defined by the size and structure of the materials.

The following table from a report of the German Federal Environment Agency (Umweltbundesamt) shows the state of development in summer 2006:[17]

[17] Umweltbundesamt: Nanotechnology: Opportunities and Risks for Humans and the Environment, Background Paper, August 2006 [UBA (ed.): Nanotechnik: Chancen und Risiken für Mensch und Umwelt, Hintergrundpapier, Umweltbundesamt, Dessau, August 2006]

	Already available on the market	*Awaiting marketability*	*Under development*	*Concept status*
Chemistry	Inorganic nanoparticles Carbon black Polymer dispersions Micronized active substances Surface refinement Easy-to-clean coatings	Chemical sensors Nano-layered silicates Organic semi-conductors Dendrimers Aerogels Polymers Nanocomposites Gloss paints	CNT composite materials Highly efficient hydrogen storage systems	Self-healing agents
Automotive engineering	Fillers for car tyres Components with hard coatings Antireflective coatings Scratch-resistant paints	Nanopigments Magnetoelectronic sensors Fuel cells Nanocomposites Fuel additives Anti-fogging coatings Polymer wind-screens	Thermoelectric waste heat recovery	Smart paints Ferrofluid shock absorbers
Electronics	GMR HDD	CMOS electronics <100 nm Polymer electronics FRAM MRAM	PC RAM Molecular electronics RTD Millipede	DNA computing Spintronics
Optical industry	White LED	Ultraprecision optics OLED	CNT FED Quantum cryp-tography EUVL optics Quantum dot laser Photonic crystals	
Life sciences	Biochips Sun Blockers	Antimicrobials Magnetic hyper-thermia Drug delivery Contrast media	Biosensors Lab-on-a-chip Tissue engineering	Neuronal coupling to artificial systems Biomolecular motors

Environmental engineering	Membranes for sewage treatment	Catalytic exhaust gas converters	Filter systems to collect ultrafine particular matter Products for treatment of groundwater and soil	

Legend:
GMR-HDD: Giant Magnetic Head – Hard Disk Drive
CMOS: Complementary Metal Oxide Semiconductor
FRAM: Ferroelectric Random Access Memory
MRAM: Magnetic Random Access Memory
PC RAM: Personal Computer Random Access Memory
RTD: Resistance Temperature Detector
DNA: Deoxyribonucleic Acid
LED: Light Emitting Diode
OLED: Organic Light Emitting Diode
CNT-FED: Carbon Nanotube Field Emission Display
EUVL: Extreme Ultraviolet Lithography

5 Possible risks and risk assessment activities

Potential risks of nanoproducts have been discussed for years already, but more emphasis has previously been laid on identifying their benefits and potentials. In a background paper of the German Federal Environment Agency it is stated that: "Questions arising as to the implications of the exposure to nanoparticles for humans and the environment have not yet been sufficiently elucidated."[18]
Effects to be taken into account are

- effects on the environment;
- effects on the health of the employees during the production process;
- effects on the health of the users of nano-products;
- effects on the health of patients who have been diagnosed and treated by nanotechnological remedies;

[18] Umweltbundesamt: Nanotechnology: Opportunities and Risks for Humans and the Environment, Background Paper, August 2006 [UBA (ed.): Nanotechnik: Chancen und Risiken für Mensch und Umwelt, Hintergrundpapier, Umweltbundesamt, Dessau, August 2006]

- effects on the health due to the accumulation of nanoparticles in the environment.

New nanotechnology research and development projects are being pursued at full stretch, but security research still lags behind regarding financial funding and the increase of knowledge. One problem among others is the difficulty to give a universally valid description of nanostructures. In principle, each single case has to be examined separately in view of its possible impact on health and environment. What has to be taken into account here is not only the production process, but the entire life cycle including the disposal of the product. And the issue must be clarified whether nanomaterials are released from the product into the environment and if so how they subsequently act there.

From the viewpoint of safety examination of chemicals there are still questions to be answered:

- Are these nanostructures stable? Persistent? Degradable?
- Do they accumulate?
- Do they remain separate or do they spontaneously form agglomerations (do they clot)?
- Do they interact with surfaces, with materials?

How do nanostructures act in living organisms?

- Are they absorbed by the body?
- If yes: Which pathway do they take?
- If yes: How do they function there?

5.1 Health aspects

5.1.1 Absorption by inhalation

There is intense public discussion about the health risks caused by small dust particles of PM 10 or less (particles of less than 10 micrometers in diameter, 1 µm = 1/1000 mm). In order to meet these risks, the EU-Directive on particulate matter was enacted. Fine dust particles are respirable and this is why they are more harmful than coarse dust. But fine dust particles are not identical to nanoparticles, although they may contain nano-sized particles. The essential difference is that nanoparticles have defined sizes and structures. How nanoparticles act in the lung is an urgent question that must be clarified as soon as possible. To date, most of the studies dealing with the possible hazards of nanoparticles focus on the consequences of inhalation exposure.

Because of their size, nanoparticles are respirable and may reach the alveolar level of the lung. Being very small, they are not identified as foreign bodies and thus they are not eliminated by the macrophages (scavenger cells). Inflammatory processes in the lungs may result. The transfer from pulmonary alveoli into the bloodstream has been demonstrated as well as the direct passage of particles from the nose into the brain.[19]

Up until now, the kind of dangers which workers who are exposed to nanoparticles have to face, are hardly assessable. Standardized methods for measuring the concentration of the particles at the place of work are also lacking. In this context, the development of effective protective outfit is an important preventative measure. In its study published in 2004, the Swiss Re fears that the use of breathing masks preventing the intrusion of nanoparticles will render sufficient breathing impossible.[20] In order to exclude such risks, it is common practice to use colloidal solutions of nanoparticles or other compound forms in the production process.

5.1.2 Absorption through the skin

Another conceivable pathway is through the skin. As a great number of cosmetic articles containing nanoparticles are already available on the market, this issue must be examined very carefully, too. Sun blockers which contain the white pigment titanium dioxide in the form of nanoparticles are known in public. The advantage of these products is supposed to be that ultrafine particles offer protection against harmful ultraviolet rays without leaving a white film on the skin. Absorption through intact skin has not yet been proven.[21]

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[19] Umweltbundesamt: Nanotechnology: Opportunities and Risks for Humans and the Environment, Background Paper, August 2006 [UBA (ed.): Nanotechnik: Chancen und Risiken für Mensch und Umwelt, Hintergrundpapier, Umweltbundesamt, Dessau, August 2006]

[20] Swiss Re (ed.): Nanotechnology: Small size – large impact? Schweizerische Rückversicherungsgesellschaft, Zürich 2004, www.swissre.com [Swiss Re (ed.): Nanotechnologie: Kleine Teile – große Zukunft?, Schweizerische Rückversicherungsgesellschaft, Zürich, 2004, www.swiss.re.com]

[21] Umweltbundesamt: Nanotechnology: Opportunities and Risks for Humans and the Environment, Background Paper, August 2006 [UBA (ed.): Nanotechnik: Chancen und Risiken für Mensch und Umwelt, Hintergrundpapier, Umweltbundesamt, Dessau, August 2006]

5.1.3 Absorption via the alimentary canal

Absorption via the alimentary canal is also possible. Since there are already plans to use nanoparticles in foods and drugs, corresponding research as to how nanoparticles travel through the human body and what impacts they may make – whether intended or not – is necessary. Nanoparticles are probably capable of crossing the intestinal membrane and subsequently entering the lymphatic system. It is also assumed that they cross the blood-brain and placenta barriers and penetrate cell membranes. Although this property might be very desirable with regard to drug treatment, when, for example, drugs are to be administered to the brain (drug delivery and drug targeting), the possible incidence of unwelcome and perhaps negative side effects must be investigated very carefully. Whether this occurs and what consequences it may have, should be the object of research.

The use of nanoparticles in the food industry is an especially delicate issue. A consumer conference, held in Germany in 2006, came to the conclusion that the use of nanotechnology in packaging materials can be useful if it leads to better hygiene and food safety. However, the use of nanotechnology in food itself was judged more critically since the exact impact of nanoparticles on the human body remains to be clarified. The conference called for a special approval procedure for nanotechnologically modified products and also for a mandatory labelling for "nano".[22] But the Federal Environment Agency (Umweltbundesamt) demands also research into the question whether nanoparticles migrate from packaging materials into foodstuffs.[23]

5.1.4 Medical application (nanomedicine)

By applying nanotechnology to medicine, named nanomedicine, scientists hope to find various new approaches to diagnosis and therapy, in particular for the treatment of cancer and cardiovascular diseases. In the field of diagnostic imaging, na-

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[22] Federal Institute for Risk Assessment (ed.): Consumer Vote on Nanotechnology in Foods, Cosmetics and Textiles, Berlin, 2006 [Bundesamt für Risikoforschung (ed.): Verbrauchervotum zur Anwendung der Nanotechnologie in den Bereichen Lebensmittel, Kosmetika und Textilien, Berlin, 2006]

[23] Umweltbundesamt: Nanotechnology: Opportunities and Risks for Humans and the Environment, Background Paper, August 2006 [UBA (ed.): Nanotechnik: Chancen und Risiken für Mensch und Umwelt, Hintergrundpapier, Umweltbundesamt, Dessau, August 2006]

noparticular contrast agents which directly target sick cells could enhance early diagnosis and improve the control of therapeutic efficiency. In the case of chronic diseases, nanochips could be implanted in the patients. By permanent monitoring, the opportunity of reacting quickly to a life-threatening status would be increased:[24] Critical values having been identified, a specially tailored nano drug could be released into the body immediately. Due to their special coating, the nano globules would attach to and enter only diseased cells in order to release the life-saving drug.

Great hopes are put into the precise application of drugs. So, for example, tumor cells will be aimed at and destroyed without damaging healthy tissues. In the future, using "drug vehicles", medical agents will be released only where required.[25] This type of therapy will probably be less harmful to patients, but it will inevitably lead to a cost increase as well. Thus, the issue of equality of access and of participation will arise again. There already are concerns about the possible threat of a "nano divide". The toxicology of nanoparticles is, of course, a matter of special concern: Nanoparticles are deliberately introduced into the human body in order to deploy their effects.

In the field of implantation medicine, research deals with the biocompatibility of materials. For example, by the structuring of suitable proteins, bone cements have been developed which enable a quick transformation into biological bone. Thus, bone diseases may be treated more quickly and effectively and hospital duration may be shortened.[26] There is hope of improving the quantity and quality of cells and tissues respectively by cultivating them on nanostructured substrates.[27] Already available is the product "Nanit®active"[28], a product for sensitive teeth that is almost completely made up of the same components as human teeth and, together with saliva, forms a tooth-analogical protective layer.

These technologies are further developed in nanobiotechnology (cf. below 6.4). The combination of nanotechnology and modern biotechnologies may lead to an intensified intervention in cellular and gene regulation processes of living beings.

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[24] Beratungskommission Gentechnik und Biotechnologie der Evangelischen Kirche in Hessen und Nassau: Zwischen Hoffnung und Entsetzen. Theologisch-Ethische Reflexionen zur Biochiptechnologie, ETHICA 13 (1, 2005), 49-68

[25] Heike E. Krüger-Brand: Viele Chancen, unbekannte Risiken, in: Deutsches Ärzteblatt, Jg. 104, Heft 9, 02.03.2007

[26] Prof. Dr. Wolfgang Pompe, information, given personally, 03-02-2007

[27] Heike E. Krüger-Brand: Viele Chancen, unbekannte Risiken, in: Deutsches Ärzteblatt, Jg. 104, Heft 9, 02.03.2007

[28] www.nanit-active.de

When cellular regulation processes have been understood sufficiently well, accurately focussed interventions will be implemented. The contribution attributed to nanostructures is considered very high due to their ability to cross cell membranes. The development of new diagnostic and treatment methods is likely.

To date, 130 medicines and 125 diagnostic tests based on nanotechnology are assumed to be under clinical investigation.[29] Since nanomedicine deals not only with diagnosis and therapy, but also with medical products, it could some day also be used for enhancement purposes, i.e. for the enhancement of human beings, either by extending human abilities utilizing nanotechnological support or by creating hybrid human-machine-systems.

5.2 Environmental aspects

Nanoparticles may give new impulses to environmental technology. For example, metallic or ceramic nanoparticles are used in exhaust gas catalytic converters in order to improve the combustion of gases such as nitric oxides and carbon monoxide, which are harmful to the environment. Here, it is essential to find out whether nanoparticles are released from catalytic converters into the environment and if so what kind of effects they have.

However, the impact of nanoparticles on the environment has hardly been a subject of research so far. The German Federal Environment Agency (Bundesumweltamt) cites several studies reporting on the harmful effects on aquatic organisms caused by the absorption of carbon nanostructures (C60 molecules, Buckminster-Fullerenes) and nanoscale titanium dioxide.[30]

A great number of nanotechnological substances are bactericidal. But what proves beneficial in the treatment of waste water and in filter technology may disturb the food chain in aquatic ecosystems. At the biological cleaning stage of sewage treatment, the bactericidal activity of some nanomaterials can cause an upset of the microbial balance. The question arises whether for the larger part of the population functional underwear or socks really need to have bactericidal properties?

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[29] Günter Virt: Was können bioethische Dokumente bewirken?, a lecture held on june 16th, 2006, at a symposium held in honour of Werner Wolbert on his 60th birthday.

[30] Umweltbundesamt: Nanotechnology: Opportunities and Risks for Humans and the Environment, Background Paper, August 2006 [UBA (ed.): Nanotechnik: Chancen und Risiken für Mensch und Umwelt, Hintergrundpapier, Umweltbundesamt, Dessau, August 2006]

Cf. also TA-Swiss: Nano! Nanu? Publifocus „Nanotechnologien und ihre Bedeutung für Gesundheit und Umwelt", Bern, 2006 (www.ta-swiss.ch)

Since nanoparticles function completely differently from larger structures of the same chemical composition, it is impossible to make predictions about their effect on environment and toxicology on the base of their chemical composition. Nanostructures must be treated just like any other new autonomous chemicals and each case has to be examined individually in view of its environmental impact. Experience regarding risk research in the field of genetically modified organisms shows that it is essential to study the different organisms not only in the laboratory, but also in their ecosystems because mutual interactions in particular of microorganisms are subject to disturbances. Here special care and attention must be given.

5.3 Risk research

Research activities concerning risk assessment are clearly modest both in quantity and available funding. Nevertheless, it must be stated that the importance of finding answers to a host of questions still unanswered has been recognized both economically as well as politically. In 2006, the Federal government of Germany reported on numerous activities engaged by the responsible ministries, authorities and by industry as well, in order to gage the need of further investigation with regard to the safety evaluation of nanotechnological products. Both industry and research institutions are involved in the following projects funded by the German Federal Ministry for Education and Research (BMBF): NanoCare, INOS (Identification and Assessment of the Effects of Engineered Nanoparticles on Human and Environmental Health) and TRACER (Toxicological Assessment and Evaluation and Functionalisation of Carbon Nanotubes). Since the beginning of 2006, these projects aim to identify and develop scientific guidelines for examining the influence of nanoparticles on health. According to the Federal Government, in the period from 2007 until 2009, research funds amounting to approximately 7.6 million Euros will be spent on projects dealing with health and ecological issues. In comparison: In 2006 alone, nanotechnology as a whole was funded by the Federal Government with the sum of 330 million Euros.[31]

At the European level, safety investigation was integrated into research framework programs. EU projects such as “Nanosafe 1+2”, “IMPART/Nanotox”, “Particle-Risk” and “Nanoderm” deal with the risk assessment of nanomaterials. The nanotechnology action plan of the European Commission has the task of initiating measures for establishing an economy friendly, integrated and responsible handling of

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[31] Bundestags-Drucksache 16/2322, 31.07.2006

nanotechnology research and development (R & D) without neglecting social needs (safety, transparency, information)"[32], but it obviously does not give high priority to safety research.

The Swiss Reinsurance Company Swiss Re founded the "International Risk Governance Council IRGC". This initiative aims, among other things, to contribute to the understanding and management of potential risks of nanotechnology to health, safety, environment, economy and society. In 2006, a "White Paper on Nanotechnology Risk Governance" was published.[33] In September 2006, the OECD established a working subgroup within its Chemicals Committee which will deal with the possible risks of artificially engineered nanomaterials to human health and the environment.

5.4 Legal regulation of nanotechnology

"According to present knowledge, the federal government so far does not see the need of changing existing norms, laws, and decrees/regulations because of nanotechnological developments. Both the existing legal and sublegal framework and the new European chemical law in preparation (REACH) provide flexible instruments to recognize possible risks and to take measures to counteract them, if necessary. […] Overall, there exists no separate duty to label products containing nanoparticular substances at present."[34]

However, this assessment of the Federal government has not met with undivided approval. Because of the lack of sufficient information about the impact of nanoparticles on human health and the environment, the Federal Environment Agency, for instance, states that

"A preferential need for research and information has become apparent in the following fields particularly:

- Information on use and application of nanoparticles: exposure scenarios covering the life cycle of nanoparticles;

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[32] Bundestags-Drucksache 16/2322, 31.07.2006

[33] htpp://www.irgc.org/irgc/_b/contentFiles/IRGC_white_paper_2_PDF_final_version.pdf

[34] Bundestags-Drucksache 16/2322, 31.07.2006

- information on release potentials;
- assessment of impact [...]."[35]

In order to realize these objectives, the use of nanoparticles in products must be made transparent. These products, therefore, need to be labelled. Besides that, the term "nanoparticle" must be clearly defined to ensure that products are not presented in a misleading manner. At the present time, the same CAS nomenclature (CAS: Chemical Abstract System, system for the characterization of chemical substances) is used to describe both the chemical character of nanoparticles as well as that of their macrostructural equivalents which are chemically identical, but have definitely different properties. International risk research would be facilitated if a separate CAS system for nanoparticles could be set up. Gene technology is also relatively new and its effects on health and environment have not yet been fully examined. Here, however, the need for regulation and the importance of an accompanying monitoring were recognized by the authorities both at the German federal and the European level and corresponding laws and directives were passed.

The legislation of gene technology and the efforts to amend the European chemical law impressively demonstrate the degree to which the regulatory efforts of legislators and authorities are subject to conflicting interests. This is why a serious attempt should be made to ensure the independence of authorities and to provide them with comprehensive documentation of balanced background information. This is highly necessary for the examination of all issues waiting to be solved. In addition, reports from laymen concerning their experience in the use of methods and products should be taken into account.

6 Anthropological and ethical aspects

So far, nanotechnological innovations and products already available on the market are mainly involved with new surface coatings, filters and other technical products. In addition, there are products linked to the fields of cosmetics, medicine and nutrition. Firstly, we will consider these real life products from an ethical point of view. In a second step, we will widen our perspectives towards research directions

[35] Umweltbundesamt: Nanotechnology: Opportunities and Risks for Humans and the Environment, Background Paper, August 2006 [UBA (ed.): Nanotechnik: Chancen und Risiken für Mensch und Umwelt, Hintergrundpapier, Umweltbundesamt, Dessau, August 2006]

which strive to establish a synthesis between modern biotechnology (genetic engineering, cell biology) and nanotechnology. This branch of research is called "nanobiotechnology".

The ethical assessment of nanotechnology can profit from experience made in other fields. But although nanotechnology draws upon ethical issues derived from other areas there is no need for "nanoethics" as a discipline in its own rights.[36]

At the present time, it seems uncontested that there is no fundamental argument from an ethical point of view against nanotechnology as such. Therefore, our analysis will focus on the responsible use of this new technology. Ethical reflection is founded on an ethics of responsibility developed, for example, by Heinz Eduard Tödt already several years ago.[37] An ethics of responsibility illuminates different aspects of potential consequences resulting from the application of this new technology. It is of importance to accumulate not only adequate knowledge for the sake of the active use of nanotechnology, but also a high degree of knowledge for the sake of orientation to be introduced into the ethical discourse.

Along with such ethical considerations, it is indispensable to develop some ideas about the Christian image of human beings and to place them foremost. These reflections form the background and the basis for assessment from a Protestant point of view.

6.1 Reflections on a Christian image of human beings

In the Bible, the question of human beings is given a central role. It is situated within the horizon of a relationship to God. By turning towards God, human beings also begin to understand themselves: "What is human?" the Psalmist asked: "When I consider your heavens, the work of your fingers, the moon and the stars, which you have prepared: What is humankind that you take thought of it, and the son of

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[36] Cf. Armin Grunwald: Ethische Aspekte der Nanotechnologie. Eine Felderkundung, in: Technikfolgenabschätzung. Theorie und Praxis 13 (2, 2004), p. 71-78. Grunwald emphasizes that new questions arise owing to the fact that formerly separate lines of ethical reflection, above all bioethics and technical ethics, converge in the field of nanotechnology. The proposal to instigate an independent "nano-ethics" seems to him to be exaggerated. Accompanying research programs on nanotechnological issues have of course been set up a long time ago, cf. the European project "NanoCap" (Nanotechnology Capacity Building; www.nanocap.eu) and in Germany the „Nanooffice" at the Center for Interdisciplinary Technology Studies at Darmstadt Technical University (www.nanobuero.de), „CINSAT" at the University of Kassel (www.cinsat.de) or the NanoGruppe Marburg (www.nano-marburg.de)

[37] Heinz Eduard Tödt: Perspektiven theologischer Ethik, Munich, 1988

humankind that you care for him? Yet you have made human a little lower than God, and you crown him with glory and majesty!" (Psalm 8,3-5) The Psalmist's question points towards an answer, even though it is an ambivalent one, because it emphasizes the lowliness of human beings in comparison with heaven and stars and, at the same time, emphasizes their honour and glory. Within this ambivalence, the human being is the creature recognized by God.

Being created in the image of God constitutes the special dignity of humankind. It is thus the task and obligation not to instrumentalize humans and never to use humans for extrinsic purposes. This dignity of human beings is prior to any human judgement; it derives exclusively from the fact of being a human being and is independent of its state of development, health and consciousness.

Christian ethics assumes furthermore that the biblical mandate to "replenish the earth, and subdue it" (Gen 1,28), "to cultivate and to keep it" (Gen 2,15) is also extended to include the evaluation of human interventions that can nowadays be made. Nature is not sacrosanct – it can and should be dealt with by humans, the "created cocreator".[38] God created human beings as free and responsible. This is why humans are capable of acting in a self-determined way, whether good or bad. Human beings are responsible for all what they have done with regard to God and with regard to their fellow creatures and present and future generations. Being in the image and likeliness of God, humanity is obliged to shape nature, theologically defined as creation, in a reasonable and appropriate way and to treat it with responsibility. Here research and science must be included as well. Nanotechnology in particular seems to be an especially appropriate candidate as playing ground for "religious techno-naturalism", and thus critical reflection is highly necessary.[39]

One of the aims of nanotechnology is to supply medical help, by firstly providing basic scientific knowledge for the development of therapeutics. From a Christian point of view, this aim is worth pursuing. The commandment of charity is an appeal to help people in distress; disease and pain are exemplary situations of human suffering. This is why the treatment of the sick and efforts to heal diseases have such a long tradition in church history. But this does not mean that therapeutic goals

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[38] Cf. Philip Hefner: The Human Factor. Evolution, Culture and Religion, Minneapolis: Fortress Press, 1993, and Philip Hefner, Technology and Human Becoming, Minneapolis: Fortress Press, 2003

[39] Cf. Jan C. Schmidt: Technological Creationism. Prospective Perspectives of the Theology-Technology Dialogue in the Framework of Nanotechnology, in: Streams of Wisdom? Science, Theology and Cultural Dynamics. Hubert Meisinger, Willem B. Drees and Zbigniew Liana (ed.). Studies in Science and Theology. Yearbook of the European Society for the Study of Science and Theology. Vol. 10. Lund University 2005, 211-228

and promises can be reached without any restriction. In fact, therapeutic promises need careful and sober examination. One has to bear in mind that medical treatment and therefore also medical research must be devoted to helping and healing (this is the so-called therapeutic imperative or the physician's obligation to consider foremostly the welfare of his patients).

6.2 Ethical aspects of nanotechnology

6.2.1 Effect assessment

Many beneficial properties are ascribed to products engineered by nanotechnology. From an ethical point of view, the question is whether these positive effects were critically analyzed for the whole life-cycle of the product including the production process, the application of the product, its disposal and recycling.

As the example of asbestos sadly demonstrates, the very positive properties of a material may also prove to have negative impacts on the human organism. Today, there is evidence to show that, due to their constitution, respirability, and insufficient biological degradability, asbestos fibres cause a variety of serious diseases. It took decades until the numerous warnings of the negative effects of asbestos were taken seriously and its use was restricted and then finally prohibited.

Although when introducing new materials, the consequences of their use may seem difficult to assess, potential negative effects should be explored and examined carefully. In doing this, materials suspected of being problematic, especially due to their ability to cross the blood brain barrier, will be prevented from being widely used from the start.

6.2.2 Risk assessment

In nanotechnology – as in any other new technology – it is practically impossible to anticipate potential risks because of a lack of essential knowledge and experience. However, as the study "Late lessons from early warnings" illustrates by referring to a great number of examples,[40] experiences made in other areas where environment and health hazards have occurred can be used to develop fundamental strategies of risk assessment which are applicable to nanotechnology as well.

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[40] http://reports.de.eea.europa.eu/environmental_issue_report_2001_22/de/index_html_local

This is why the properties of nanotechnological products should be characterized at a very early stage and in the most comprehensive way possible. Following this, a definition of product classes could perhaps be implemented as well. Classification is an important means of regulating substances. It is insufficient to use the properties of standard chemical substances as parameters with regard to toxicological assessment as the properties of nanoparticles may differ completely. Therefore, the concept of substantial equivalence is absolutely inappropriate for the description of nanosubstances.

In order to observe the long-term effect on health and environment, products containing nanoparticles must be marked. In addition, life-cycle analysis and monitoring programs have to be implemented. There is an urgent need for suitable analysis and measuring methods for detecting and identifying nanoparticles. These methods must be internationally comparable in order to ensure international knowledge exchange. It is essential to develop standardized procedures and adequate standards (CEN, ISO).

Above all, it is necessary to clarify whether nanoparticles attached to surface coatings release themselves and subsequently deploy their effects on the environment and living organisms. In particular, bactericidal nanoparticles could constitute a very real risk.

Due to their dimensions, it is theoretically possible that nanoparticles can spread worldwide through the media of air and water. This process is certainly not reversible. If these particles are not degradable, they are likely to accumulate in the environment. Then, a potentially harmful effect could have disastrous consequences. Using an example from another field, one can name chlorofluorocarbons (CFCs) which damage the ozone layer in the higher atmosphere. Despite this effect being well known, international reaction came very late.

The precautionary principle should be applied in order to assess potential nanotechnological risks: If there is minor evidence of any health and environmental hazards, the use of nanoparticles must be controlled very carefully or even totally prevented.[41]

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[41] Cf. Hans Jonas` (not undisputed) concept of "heuristics of fear" as a principle of risk assessment elucidated in:

Hans Jonas: The Imperative of Responsibility: In Search of an Ethics for the Technological Age, Chicago, 1984 [Hans Jonas: Das Prinzip Verantwortung. Versuch einer Ethik für die technologische Zivilisation, Frankfurt, 1984]

6.2.3 Weighting costs and benefits

By the use of nano-based techniques an increase of both resource and energy efficiency is anticipated. In a great number of fields of application, benefits of nanotechnology appear to exist and they are estimated to be quite high. Nevertheless, in each field, the costs involved in the development and production should be balanced against the potential benefits. There may be applications where the use of nanotechnology increases the costs to such an extent that the benefits would be outweighed.

And there may also be application areas where the alleged benefits seem doubtful. Food technology, for example, is concerned with the development of products designed to help the consumer prepare foodstuffs and alleviate the consumption of valuable ingredients: so-called "convenience food". But here, critics warn about the loss of a natural diet through the practice of technical processing and concentration of certain fashion ingredients and the offensive advertising of them, as shortly later real benefits of these products are negated in new nutrition studies. The question, whether a balanced and healthy diet cannot be achieved without high technical expenditure and the costs associated therewith, was put even before nanotechnologically altered foodstuffs were introduced.

6.2.4 Considering alternatives

The debate so far leads to the following ethical demand: In cases where there is doubt as to the harmlessness of a product, where potential risks for health and environment must be suspected with regard to the production process, or the use or disposal of the product concerned, it is necessary to examine whether alternative products or techniques are suitable substitutes and if so to give them priority.

The comparison with the use of gene technology in agriculture shows that this criterion was not respected: Genetically modified plants are still being cultivated, although they have been demonstrated to have more negative effects on the biological diversity than conventional plants.[42]

[42] Farm Scale Evaluations, www.defra.gov.uk/environment/gm/fse/index.htm

6.2.5 Justice

In an increasingly globalised world, the aspect of justice is of crucial importance. The provision of drinking water is one of the largest health challenges of humankind. The broad use of nanotechnological methods for sterilizing and filtering water could offer a better chance of survival for millions of people. This is why safe new technologies should be rapidly and widely implemented.

Similarly with drugs for treating malaria, tuberculosis and HIV/AIDS, these new technologies should be made available at a fair price especially to financially weak countries in order to supply the people without insisting on expensive patent protection or compulsory licensing common in industrial nations.[43] However, the technologically less developed South must not become the testing ground for new risky technologies from the North.

There is not only the issue of equality of distribution, but also of equality of participation: Does the public participate sufficiently in decisions about a new technology which will certainly have a great impact on its future life? In this discourse, what are the roles of agents such as the scientific community, industry, non-governmental organisations, surveillance agencies, and legislators? Considering the advancing globalisation, are the Southern countries sufficiently involved in this kind of communication?

6.3 Ethical aspects of nanomedicine

In the field of diagnostics, nanomedicine certainly offers the opportunity to identify health risks at an early stage and to subsequently implement suitable therapeutic treatments. But, as in genetic diagnostics, the use of nanotechnology may also further increase the gap between predictive diagnostics and possible therapies available. The increase in knowledge of existing hazards and risks may cause alarm and turn any "healthy" person into a "potentially sick" one. Comparable to genetic diagnostics, impacts on health and life insurances as well as prospects in the job market are conceivable.[44] In the case of chronic diseases, for instance, nanochips

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[43] Cf. also: UNESCO (ed.): The Ethics and Politics of Nanotechnology, 2006, www.unesco.org/shs/ethics

[44] Ethical considerations of genetic diagnostics are published by the working group „Ethische Fragen der Gentechnik" of the Protestant Church of Westphalia in the series "Materialien für den Dienst in der Evangelischen Kirche von Westfalen", issue 5/2004, http://www.kircheundgesellschaft.de/umweltreferat/documents/materialien_gendiagnostik.pdf

could be implanted in patients enabling permanent monitoring and consequently speedy intervention when threatening conditions arise. But where is the threshold between a reasonable control of metabolic processes and the "transparent human being"?

An important question in the field of nanomedicine is whether all patients will benefit from the new diagnostic and therapeutic procedures or whether they will be offered only to a financially strong clientele. Already today, the costs for many medical procedures are not covered by health insurances and the patient is then required to pay the costs (partly) himself. By broadly using new nanotechnological devices, this trend towards a two-class-medicine could increase. Conflicts already existing in the current field of medicine must also be taken into account: Patenting leads to an increase of test costs (for example, breast cancer gene tests). Pharmaceuticals important for use in Southern countries (for the treatment of HIV/AIDS, for instance) are available only after tenacious negotiations and intense public pressure, at prices which are affordable to these countries, allowing a widespread use in the population. With regard to the innovations expected from nanomedicine there is, furthermore, the question how fair access to vital procedures can be internationally guaranteed.

6.4 Ethical aspects of nanobiotechnology

"The nanotechnology, biotechnology, information technology, and cognitive science research fields and technologies will converge increasingly in the future. Expectations of the results that might be achieved by means of implementing converging technologies range from healing paraplegics to developing new therapies and artificial organs and significantly extending life expectancy whilst retaining an equal or better quality of life. In the long term, more and more functions of the human body might be taken on by products and procedures resulting from converging technologies. One day, we might even be in a position to improve the mental and sensory capabilities of humankind. Fundamental ethical issues arise in conjunction with these kinds of development, since they have a bearing on human self perception."[45]

The ethical evaluation of a new technology cannot provide definite answers to questions that have partially not even yet been asked. There are reports on the op-

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[45] Bundesministerium für Bildung und Forschung (ed.): Nano-Initiative Action Plan 2010, Bonn/Berlin, 2006 [BMBF (ed.): Nano-Initiative – Aktionsplan 2010, Bonn/Berlin, 2006]

portunities of nanotechnology which sound like science fiction, describing a world inhabited by self-replicating intelligent robots and technically optimized humans. Nanotechnology is "highly visionary" and its visual anticipations of possible futures play an important role in the discourses of science, economy, and the mass media, as well as in their mutual interactions and interdependencies.[46]

Some descriptions of these options for a nanotechnologically-optimized future seem rather euphoric. Critical analysis, however, reveals that they are based on a conception of animated nature that has been considered to be wrong: With regard to the development of genetic engineering, there was an attempt to schematically classify living organisms according to the dogma "one gene, one piece of information, one function". By the end of the 20th century, this idea of genetically determined living organisms had already become outdated. The genome turns out to be a dynamic structure with various regulatory potentials whose way of functioning is far from and not even approximately understood at the beginning of the 21st century. Due to the findings of proteomics, it is now uncontested that various protein structures also play a central role in the life of organisms.

Accompanying the development of nanobiotechnology, a reductionist view of nature has regrettably reappeared. Hereditary information does no longer constitute the kind of information that will ultimately help us to control nature, both animated and non-animated, and to change it according to our own ideas. The world of nanotechnology is composed of single atoms or small molecules. Scientists use natural biological structures as a matrix and subsequently build up hybrid nanostructures from biological and non-biological materials.

Future vision sees the human being as a creator composing a new world by means of these ultrafine particles and possibly even creating new life from atoms.[47] By combining inorganic materials with cell cultures, synthetic life forms are already being compiled. A key objective in nanobiotechnology is to provide bacteria and cells with new properties by means of micro sized structures and in this way to construct artificial organisms obliterating the distinction between animated and

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[46] Andreas Lösch: Antizipation nanotechnischer Zukünfte: Visionäre Bilder als Kommunikationsmedien, in: Alfred Nordmann, Joachim Schummer, Astrid Schwarz (ed.): Nanotechnologie im Kontext. Philosophische, ethische und gesellschaftliche Perspektiven, Berlin, 2006, 223-242 (223f.). According to Lösch, futuristic images serve as a means of communication in and between the fields of science, economy, and the mass media. As these images are continuously being modified in mutual dependence, dominant themes, of varying contexts, present themselves periodically.

[47] Cf. especially Eric K. Drexler: Engines of Creation. The Coming Era of Nanotechnology, New York, 1986. Cf. also notes 37 and 38 cited above.

inanimated nature. There are already speculations about the possibility of creating enhanced humans and human-machine-systems.

In nanobiotechnology, living beings are thus reduced to machines once again – or machines are elevated to the level of humans, depending on the point of view taken. This new combination of a scientific reductionist and mechano-technical view of the world poses a particular ethical challenge. In this nanobiotechnological world, there will be no dispute any more whether the world came into existence by evolutionary processes or by "intelligent design". In the future, "intelligent design" will possibly be taken over by nanorobots.[48]

In 2004, the ETC Group, a non-governmental organisation, advocated a moratorium committed to introducing nanobiotechnology, analogous to the moratorium at the beginning of genetic engineering, but this call was not echoed. The organisation continues to warn about ongoing research carried out in the border area between nanotechnology and biotechnology virtually unnoticed by the public.[49]

Although in this application field of nanotechnology, imagination certainly plays a more important role than the issue of real feasibility, the development of nanobiotechnology should be carefully observed und accompanied by ethical evaluation from the very beginning. The example of genetic engineering development shows that ethical assessment must not lag years behind scientific progress.

It seems essential to distinguish between real feasibility on the one hand and highly exaggerated promises and utopias on the other hand. The detection, at the end of 2005 and beginning of 2006, of the scientific fraud perpetrated by the South Korean stem cell researcher Hwang, has led to a far more sober discussion about the potentials and ethical problems of embryonic stem cell research. Another "hype", for example, the promise of generating functioning organs from embryonic stem cells by combining nanotechnology and tissue engineering in the near future, should be prevented.

In the field of medicine, the benefits and risks of a therapy based on nanoparticles must be carefully considered in advance and continuously monitored by ethics commissions. In the history of medicine, medical innovations often failed until a successful therapy could be introduced. New therapies, however, should neither be rashly administered to patients nor should the existing hazards be underestimated, as was sometimes the case using genetic therapy.

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48 In the Netherlands, the nanotechnologist Cornelis (Cees) Dekker was a prominent figure in the centre of discussions about the idea of intelligent design.

49 NanoGeoPolitics: ETC Group Surveys the Political Landscape, ETC Group Special Report – Communiqué No. 89, 2005, www.etcgroup.org

Particular attention should be given to approaches which can be used for eugenic purposes as well. In nanobiotechnology, the transition from an ethically justifiable therapy to an "enhancement" of human beings may seem to be flowing as in the field of genetic therapy. Here, ethical assessment has a special responsibility of its own.

7 Conclusion

Nanotechnology is a new cross-sectional technology which already influences our daily life and health, but whose impact will significantly increase in the future. The critical study "Late lessons from early warnings" should be extended to include several new examples of environmental and health hazards caused by nanotechnological applications whose risks were not recognized and met in time. It is, therefore, essential to assess diligently the technological consequences and to investigate the risks involved with appropriate scientific and financial support – on the basis of an ethics of responsibility.

Public attention should not only be drawn to the wide range of potential applications and future options, but intensive social risk communication should take place as well. It is important to seek a dialogue not only with well-informed agents from the fields of science, technology, industry, but as well as authorities and non-governmental organisations. But the broad population must be provided with balanced information, too. When preparing information material, risk communication and the discussion of ethical considerations should be given sufficient room in addition to the description of future technological opportunities. Only then is there a guarantee that this technology will be implemented in an appropriate way. Here, theology is obliged to make its contribution as well as philosophy and ethics.

Public perception concerning nanotechnology must not only be drawn to the wide range of potential applications and future options, but intensive social risk communication should take place as well.

The publication presented here gives a comprehensible survey of the great variety of nanotechnological applications particularly focussing on potential health and environment hazards. It points out to existing deficits with regard to both the assessment of technical consequences and the regulation of the application of the new technology. It concludes by developing ethical criteria of evaluation based on a Christian point of view.

The Working Group of Commissioners for Environmental Affairs of the Protestant regional churches (AGU) has a basically positive attitude towards research and innovation, but, in view of so many open questions related to possible risks, it warns about being too euphoric. The use of nanotechnological applications should be based on the precautionary principle. When developing new procedures, the risks of nanoparticles to health and environment must be assessed carefully and taken sufficiently into account. This is essential for medical and biotechnological applications as well.

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