Nanoethics

From Utopian Dreams and Apocalyptic Nightmares towards a more Balanced View

Bert Gordijn

1 Introduction

Nanotechnology is a rapidly developing field of technology that seems to have the potential of great upsides and excessive downsides. Thus far, there has been a strong tendency in the debate on nanotechnology to focus on either the first or the latter. Accordingly, assessments of nanotechnology tend to radically diverge. On the one hand, optimistic visionaries promise truly utopian states of affairs, e.g. solving the problem of hunger in the world or expanding our maximum life span. On the other hand, pessimistic thinkers draw worst-case scenarios in which, for instance, nanotechnology has exceptionally disruptive effects on societies or swarms of nanoassemblers devour the whole biosphere. The utopian views follow from one-sidedly focusing on the potential benefits of nanotechnology, whereas the apocalyptic perspective results from giving exclusive attention to worst-case scenarios.

These radically diverging assessments that have thus far dominated the debate on nanotechnology seem to a lack common ground. This situation holds the risk of conflicts and unwanted backlashes. Hence, the present state of the debate on nanotechnology calls for the development of a more balanced ethical view. This contribution will first briefly describe the field of nanotechnology. Next, the present state of the ethical debate of this field will be described as overshadowed by utopian dreams and apocalyptic nightmares. Finally, a method will be introduced to develop more balanced ethical views on nanotechnology. Thus, the focus of this paper is on the *methodology* and not on *normative analysis*.

2 Nanotechnology

2.1 Terminology and basic idea

Nanotechnology is a rapidly developing new field of research.[1] In the literature, both a fairly broad as well as a rather narrow concept of nanotechnology are employed (vgl. Moore, 2001; Peterson, 2003; Stevenson, 1994; Stix, 2001). The first signifies any technology smaller than microtechnology. In contrast, the latter stands for the technology to program and manipulate matter with molecular precision and to scale it to three-dimensional products of arbitrary size (Foresight Guidelines, 2000).[2]

The basic idea of nanotechnology, used in the narrow sense of the word, is to employ individual atoms and molecules to construct functional structures. In his lecture "There is plenty of room at the bottom", held on December 29th 1959 at the annual meeting of the *American Physical Society* at the *California Institute of Technology*, the famous physician Richard Feynman already speculated on radical forms of miniaturization (Feynman, 1961).[3] His reflections, however, were not

---

[1] The prefix *nano-*, derived from νάννος (Greek for dwarf), signifies a unit, viz., 10^{-9} (one billionth). Thus, one nanometer is one billionth of a meter. One nanometer (nm) is one thousandth of a micrometer (µm) and one millionth of a millimeter (mm).

[2] Other terms are also used to denote the narrow concept of this technology are *molecular engineering* (Drexler, 1981), *molecular manufacturing* (Ashley, 2001; Drexler, 1992; Freitas, 1998a & 2000b) and *molecular nanotechnology* (Drexler, 2001; Fahy, 1993a & 1993b; Kaehler, 1994).

[3] "The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom. It is not an attempt to violate any laws; it is something, in principle, that can be done; but in practice, it

taken very seriously at first. Both practically and theoretically, significant progress in the field of nanotechnology started only in the eighties.

2.2 Practical development

A significant practical development was the fast progress in microscopy.[4] At the beginning of the eighties, Gerd Binnig and Heinrich Rohrer, working at the IBM research laboratory in Zurich, developed *scanning tunneling microscopy*. This new technique can provide an image of the atomic arrangement of a metal or a semiconductor surface.[5] Thus, using this new technique Binnig and Rohrer could, for the first time ever, "map" the arrangement of individual atoms of metals and semiconductors. In 1986 Binnig and Rohrer received the Nobel Prize for their achievements.

The a*tomic force microscope* represents a further development in microscopy. It enables images of materials inaccessible to the scanning tunneling microscope, for instance insulators, organic materials, biological macromolecules, polymers, ceramics and glasses.[6]

Finally, it was discovered that scanning tunneling microscopes could also be used to manipulate nanoscale objects (Foster et al. 1988; Hansma et al. 1988). For instance, in 1990, Eigler and Schweizer, two IBM scientists, were able to shape the three initials of the logo of their employer from 35 individual xenon atoms (Eigler & Schweizer, 1990).[7] It is expected that further developments in microscopy will be highly significant for nanotechnology (Bunk, 2001).

2.3 Theoretical development

A significant theoretical development in the eighties was the research done by Eric Drexler (1981 & 1986). His work provided a theoretical basis for the field. Besides, it brought nanotechnology to the attention of a broader public. Drexler argues that the laws of physics do not forbid the possibility of pre-programmed maneuvering and goal directed management of individual molecules. In addition, he elaborates on the future development of technical means and methods to arrange matter at the nanoscale. Finally, Drexler also discusses the various fields of application for future nanomachines (Drexler, 1981 & 1986).

In discussing future nanotechnological manufacturing, Drexler comes up with the idea of the assembler: „a molecular machine that can be programmed to build virtually any molecular structure or device from simpler chemical building blocks" (Drexler, 1986, 285). This nanoscale construction device can position molecules in every which way, thereby facilitating, for example, chemical reactions. Through precise sequences of manipulations, a computer-steered assembler could thus – molecule by molecule - assemble any chemically stabile structure that it has been programmed to construct.

---

has not been done because we are too big." (Feynman, 1961).

[4] Feynman (1961) already pointed out the importance of better microscopes for the further development of nanotechnology.

[5] First, a finely sharpened metal tip is positioned extremely close to a conducting sample surface. At this small distance, electrons can tunnel between the tip and the sample surface, thereby producing a measurable current. When a bias voltage is applied across the tip-sample junction, a tunneling current of electrons starts flowing with an exponential dependence on the separation between tip and sample. During image acquisition, the tip is scanned across the surface. A feedback mechanism usually adjusts the tip height in order to maintain a constant current. This tip height signal is displayed as the resulting image. Hence, by detecting the delicate changes in tunneling current as the tip scans the surface, a two-dimensional image with atomic resolution of surface features results (Bachmann, 1998; Foster et al. 1988 and Hansma et al. 1988).

[6] As in scanning tunneling microscopy, again a sharp tip is used to map surface morphology. But an atomic force microscope can sense a diversity of forces, for example Van der Waals, electrostatic, magnetic or capillary forces. Thus, this new technique works without requiring a current.

[7] The tip of the microscope can be used to attract an individual atom on a surface sample. This atom can then be pulled across the surface to another place with great precision.

According to Drexler, the development of universally applicable assemblers is essential for the further development of nanotechnology. Assemblers could obviously also be programmed to replicate themselves. From a commercial point of view, this would have the interesting advantage of being able to manufacture products in a feasible time frame. After all, if accomplished by only one assembler, constructing a car in a molecule-by-molecule way could take ages. If, on the other hand, millions or billions of assemblers could work together, things would look far more optimistic (Drexler, 1986).[8]

2.4 State of the field at present

In the meantime, the field of nanotechnology has developed considerably. Current research is not exclusively focused on achieving assemblers.[9] Instead, research is directed towards the production of a wide array of different nanoscale structures.[10] The fabrication techniques of these structures can be divided into two approaches: “top-down” and “bottom-up” (Bachmann, 1998; Freitas, 1999; Pool, 1990; Roukes, 2001; Whitesides & Love, 2001).

The top-down techniques that are used to manufacture nanoscale structures are mostly extensions of methods already employed in small-scale assembly at the micron scale, for example, photolithography. By further miniaturization, the nanodimension is entered (Ashley, 2001). In this way, further miniaturization of microelectronics could result in nanoelectronics (Lieber, 2001).

Bottom-up fabrication methods for manufacture are studied within synthetic chemistry, which is, almost by definition, the science of producing nanoscale structures. They are also inspired by phenomena such as crystal growth and self-assembly. In a certain way, many bottom-up methods try to imitate regularly occurring processes in nature. Living nature, for example, constantly shapes complex macroscopic structures from individual biomolecular elements.

It is widely expected that, if nanotechnology were to be further developed, a whole range of products could be produced more rapidly, cheaper and better. After all, manufacture would be done in a molecule-by-molecule way, meaning that all features of the product and all aspects of production could be programmed and would be under control in ways that are unknown up to now (Herzog, 2002; Miksanek, 2001).[11] Conformingly, many countries have set up programs to financially support further development of nanotechnology (Bachmann, 1998; Ball, 2000; Randal, 2001).[12] Moreover, investing in the further development of specific nanotechnological projects is also rapidly getting more interesting for private companies (Ball, 2000).

---

[8] Moreover, since universal assemblers and more specialized nanomachines would use raw materials in an extremely efficient way, production would probably be relatively inexpensive. In addition, production would also be extremely clean. Having resulted from a controlled atom-by-atom construction strategy, nanotechnologically manufactured products would have extraordinarily high quality as well as new and interesting properties. Consequently, they would lack the flaws that traditionally assembled products demonstrate up to now (Drexler, 1992).

[9] In Drexler’s vision of nanotechnology, assemblers play a crucial role (Drexler, 1981 & 1986). Many other authors from different disciplines concur with Drexler in holding that it is possible to develop assemblers (Dewdney, 1988; Fahy, 1993a; Freitas, 1999; Herzog, 2002; Merkle, 1992 & 1996). As to the timeframe and the specific way in which the first nanomachines will be manufactured opinions obviously differ. However, there are also skeptics who deny that the production of self-replicating universal assemblers will ever become possible or practically feasible (Ashley, 2001 & Smalley, 2001).

[10] For example, buckminsterfullerenes, nanotubes, nanoparticles, nanocapsules, molecular motors, a variety of biomolecules, “quantum dots” and “quantum wires” (vgl. ETC, 2003; Kricka & Fortina, 2002; Mnyusiwalla, Daar & Singer, 2003).

[11] Also, in science fiction literature, nanotechnology is regularly regarded as the key technology of the 21st Century (Collins, 2001; Miksanek, 2001).

[12] For example in the USA, the *National Nanotechnology Initiative* (NSET, 2000; CRNNI, 2002; http://www.nano.gov/; accessed 30.08.2002) was a few years ago. In 2001, US government spending for nanotechnology totaled 463 million dollar. Japanese government expenditure pulled ahead of the United States in 2002. The European Union comes at the third place (ETC, 2003). In many other countries, e.g. South Korea, Taiwan, Australia, Brazil and China nanotechnology is financially supported (ETC, 2003; Mnyusiwalla, Daar & Singer, 2003). Globally, government spending surpassed one billion American dollars. Almost 2,5 billion was spent in 2002 (ETC, 2003).

3 Utopian dreams and apocalyptic nightmares

The present state of ethical debate about nanotechnology seems to be dominated by utopian dreams and apocalyptic nightmares.

3.1 Utopian dreams

During the 17th century, the idea was developed that utopian ideals, such as control of the natural environment, a perfect society, life without disease and pain, prolongation of life as well as enhancement of man and his characteristics could be achieved through the further development of science. All that was needed for that would be to organize science in a correct way and to work with effective methods. This modern idea became a source of great enthusiasm.

Many contemporary views on nanotechnology can be placed in this tradition of scientific utopianism, which started in the 17th century. Over and over again, it is argued that, if only nanotechnology were to be fully developed, a large part of the world's current problems would be solved and a whole array of ideals would be achieved. A few examples of the utopian perspectives of nanotechnology are given.

To begin with, molecule-by-molecule manufacturing would be self-sufficient and dirt free. After all, molecular manufacturing techniques would not result in any chemical pollution whatsoever. Leftover molecules would be recycled. What is more, molecular manufacturing would enable environmental restoration at the molecular level. Unwanted chemicals could be detected and inactivated. Hence, we will be able to reverse existing environmental degradation.

Next, molecule-by-molecule manufacturing could create unprecedented objects and materials. For example, new nanotechnologically manufactured strong lightweight materials will enable easier access to space and space resources. Nanoelectronics could come up with computer chips that would be billions of times faster as a result of the smaller components.

Using molecular manufacturing techniques, we will be able to produce inexpensive high-quality products. For example, storage batteries, processors, personal computers, lap tops, cell phones and display devices could become strikingly inexpensive.

Molecular manufacturing could also be used to fabricate food rather than growing it. After all, food is simply a combination of molecules in certain configurations. Hence, the problem of hunger could be effectively solved by efficient molecule-by-molecule mass production of food.

Finally, it is also in medicine that nanotechnology is said to work miracles (Freitas, 1999). There are numerous astounding promises in this context. Molecular manufacturing will provide low-priced and superior equipment for medical research and health care. These improved tools would be available far and wide. Medical nanomachines will be programmed to travel through our bloodstream to clean out fatty deposits. Hence, they would reduce the probability of cardio-vascular diseases. Medical diagnosis and drug-delivery will be transformed. Moreover, preventive medicine will be greatly improved by having nano-robots within our bodies that could provide a defense against invading viruses. Thus, nanotechnology has been hailed as the solution to many medical problems.

It is even expected that it will contribute to the enhancement of man (Drexler, 1986, Freitas, 1998b; Kaku, 1997; Kurzweil, 1999). Not only will it be possible to overcome contemporary diseases, pain and other unpleasant bodily symptoms. Over and above, nanotechnology will enable us to enhance all our human capabilities and properties (Freitas, 1998b).

With regard to the enhancement of the human body, it is expected that nanotechnology will enable the construction of stronger and enhanced tissues and organs. For instance, cells specific to certain tissues or organs could be reconstructed and be made immune against all known pathogens, thereby making our present immune system obsolete (Kurzweil, 1999).

The cryonics community has also enthusiastically embraced nanotechnology. Cryonics means freezing people who have been declared legally dead and waiting until technology is advanced enough to reverse cause of death as well as the freezing damage (Merkle, 1992). Here, nanotechnology is expected to produce real miracles in reversing all the adverse configurations of molecules in the frozen organism after it has been thawed out (Merkle, 1994a & 1994b).

Also, nanotechnology would enable an almost infinite improvement of our mental capacities. It would, for example, be possible to enhance our memory as well as all our data processing capacities.[13] However, with regard to enhancing the human mind the scenario of '*uploading*' is the *non plus ultra*. Uploading involves transferring the contents of the human brain to a computer. Special nanomachines would scan the brain atom-by-atom. Next, the neural networks of the brain would be implemented on a computer (Bostrom, 1999).

Nanotechnology is finally also expected to lead to social advances. Freitas (1998b) thinks that the huge achievements of nanotechnology, especially nanomedicine, will make people more content and peaceful. It will be a great deal easier to live together in ideal harmony with perfect bodies and flawlessly functioning brains.[14]

3.2 Apocalyptic nightmares

Besides utopian outlooks, catastrophic scenarios have also heavily influenced the debate on nanotechnology. Severe disruption of many different aspects of society and politics is one of the nightmare scenarios that have been sketched in connection with the further development of nanotechnology. For example, rapid developments in molecular manufacturing and the concomitant inexpensive manufacturing could cause severe economic disruption. The economic upheaval could involve the sudden abundance of low-priced products, rapidly changing employment patterns (e.g. unexpected redundancy of a variety of jobs) and the problem of copying of designs.

Moreover, molecular manufacturing might also invite premeditated misuse in warfare or terrorism. First, all kinds of conventional weapons could be constructed more rapidly. Next, new nanoweaponry and could be made in huge numbers, low-priced, extremely powerful. Hence, traditional arms control would be far more difficult and competing states could enter a troublesome and unsound arms race that would be extremely difficult to end.

Also, infinitesimally small surveillance devices such as nanoscale tracking devices, nanosensors, nanocameras and nanomicrophones could enable dictatorial observation and control of subjects in a way that is totally unprecedented. Nanotechnology would enable total surveillance of entire civilian populations without them even noticing it.

Nanotechnology could also have the potential to cause extensive environmental damage. For example, destructive nanomachines might enter the food chain thereby disturbing entire ecological systems or nanomaterials such as nanoparticles could escape into the air and turn out to pose asbestos-like health treats.

Some of the most serious risks of nanotechnology have been brought to the attention of the public by Bill Joy, co-founder and scientific leader of *Sun Microsystems*. Joy is especially worried about the research with regard to assemblers. After all, these nanomachines will have the worrisome capacity of self-replication. Without this kind of assemblers it is hardly imaginable how molecular manufacturing could ever become practically feasible. After all, without the ability of self-replication, all assemblers needed for nanotechnological production would have to be built one by one, which would definitely be too expensive. In this case, however, practical feasibility and commercial viability would involve grave dangers. Technical faults, for example problems with the software of the onboard

---

[13] In this regard, Freitas (1998b) gives an instructive example: "Consider that a nanostructured data storage device measuring ~ 8,000 micron^3, a cubic volume about the size of a single human liver cell and smaller than a typical neuron, could store an amount of information equivalent to the entire Library of Congress. If implanted somewhere in the human brain, together with the appropriate interface mechanisms, such a device could allow extremely rapid access to this information." (Freitas, 1998b).

[14] "But perhaps the most important long-term benefit to human society as a whole could be the dawning of a new era of peace. We could hope that people who are independently well-fed, well-clothed, well-housed, smart, well-educated, healthy and happy will have little motivation to make war. Human beings who have a reasonable prospect of living many "normal" lifetimes will learn patience from experience, and will be extremely unlikely to risk those "many lifetimes" for any but the most compelling of reasons." (Freitas, 1998b).

computer of an assembler, could cause unbridled self-replication. In that case, since the newly produced assemblers would also start replicating themselves, the total number of assemblers would grow exponentially. If these uncontrolled assemblers used a wide variety of raw materials as resources for self-replication, they could devour the whole biosphere in an amazingly short while. The biosphere would, so to speak, be transformed into gray goo – hence, the terminology of *gray-goo* scenario (Joy, 2000; see also Bostrom, 1999; Drexler, 1986; Service, 2000).

Another danger has to do with the fact that many private companies will try to develop and produce assemblers.[15] After all, the perspective to put them on to the market will seem lucrative for many. Hence, it will be difficult for central governments to retain control over the development of assemblers. Therefore, there will always be the danger of abuse of assemblers by criminals and terrorists, for example, to develop weapons of mass destruction (Joy, 2000). For example, one could construct special nanomachines to destroy computer systems or certain resources of the opponent. Of course, nanomachines could also be designed to attack the enemy directly. This apocalyptic scenario, in which destructive nanomachines are being used for warfare or terrorist purposes, has also been called the *black-goo*-scenario (Bostrom, 1999).

4 Toward a more balanced ethical view

The dominance of the drastic opposition of utopian dreams and apocalyptic nightmares in the debate on the future perspectives of nanotechnology holds the risk of undesirable conflicts and unnecessary backlashes. Hence, the present state of debate on nanotechnology calls for the development of more balanced ethical views. In response to this important challenge, a six-step method is here presented. With the help of this method, a fine-grained and rational assessment can be made as to the ethical desirability of further developing research in a specific field of nanotechnology.

4.1 Step one: what specific field of nanotechnology is to be assessed?

Up to now, broad and sweeping statements about nanotechnology as such have dominated the debate. However, for an ethical analysis to be sound and discriminating, it should be focused more specifically on a particular field of nanotechnological research, instead of generalizing in an all-encompassing way (cf. Peterson, 2003). Thus, more detailed and better-informed ethical research is needed. Nanotechnology is by no means one single effort. Rather, it is a complex of countless different projects with a huge variety of goals. Hence, different fields of nanotechnological research can be distinguished that will not necessarily demonstrate identical or even similar ethical aspects, for example: 1) materials and manufacturing, 2) nanoelectronics and computer technology, 3) medicine and health, 4) aeronautics and space exploration, 5) environment and energy, 6) biotechnology and agriculture and 7) security.[16] Evidently, the ethical assessments of developments in these fields are likely to differ as the objectives and the ethical problems encountered will be different.[17]

4.2 Step two: what are the objectives of that specific field of nanotechnology?

Having specified the nanotechnological field to ethically be assessed, the next step is to focus on the objectives that the research in that field aims to achieve. Ideally, we should first discuss our

[15] In contrast, the nuclear, biological and chemical technologies that were used in the 20th century to build weapons of mass destruction were largely developed in government laboratories for military purposes (Joy, 2000).
[16] Probably, an even more fine-grained distinction of fields will be needed.
[17] For example, it makes a huge difference whether one reflects on the ethics of nanotechnologically manufactured memory enhancing neuro-implants, filters with nanopores for the recycling of water or nanodevices for surveillance purposes.

needs, fundamental purposes and social ends in order to move on to make choices about ways of achieving these goals, for example by further developing certain fields of technological research. However, this is not always the case. What is more, technology often seems to develop in a seemingly autonomous way. However, it remains imperative to reflect about the goals that we try to achieve in developing certain technologies. Technology development should be directed towards a good or an end. Otherwise, technology is developed for its own sake, isolated from any human good. This would obviously be undesirable. After all, science and technology should serve man and not the other way round.[18]

4.3 Step three: are these objectives ethically desirable?

After having specified the nanotechnological field to be assessed as well as having detected the objectives of that field, it should be asked whether these objectives are ethically desirable. After all, if the objectives that are aimed for with the further development of a certain research area are ethically undesirable, it does not make sense to continue this research from an ethical point of view (Gordijn, 2004).[19]

4.4 Step four: will further development of the field of research contribute to the realization of these objectives?

If the objectives are ethically desirable but not achievable or very unlikely to be achieved by advances in a specified field of research, it seems pointless to push the research forward (Gordijn, 2004). Of course, it is not possible to predict advances in science or technology in detail and with certainty (Popper, 1982). Nevertheless, in many cases it will be possible to give a broad assessment of the probability of achieving certain objectives in a specified field of research on the basis of the corpus of existing scientific literature.[20]

---

[18] A specific field of nanotechnological research can have different objectives. Let us take the example of nanomedicine to illustrate this thought. Up to now, there have been two distinct groups of objectives that are connected with further development of nanomedicine. On the one hand, there is a group of more traditional objectives such as improved prevention of pain and disease, better diagnosis and superior therapy (Alivisatos, 2001; Bachmann, 1998; Chemla et al. 2000; Jordan et al. 2000; Randal, 2001; Reichert et al. 2000; West & Halas, 2000; Wolfe, 2002). On the other hand, there are different objectives that have to do with the enhancement of certain human properties, for example the improvement of memory, perfection of our sensory qualities and advance in our cognitive skills (Drexler, 1986, Freitas, 1998b; Kaku, 1997; Kurzweil, 1999).

[19] It is essential to realize that not all objectives that a certain field of nanoresearch aims to achieve are necessarily ethically desirable. Moreover, objectives that seem attractive at first sight can sometimes turn out to be less so after a more thorough enquiry. To illustrate this point, again an example from nanomedicine is given. Whereas the more traditional group of objectives of nanomedicine, such as prevention, diagnosis and therapy, are by and large desirable, the desirability of enhancement of human properties – though *prima facie* attractive - turns out to be questionable after more analysis. First, it is not really clear what kind of changes of human properties would count as an improvement. The criteria to demarcate changes that involve an improvement and those that are neutral or - worse - that entail deterioration are lacking. Second, development and clinical application of enhancement techniques could result in a huge amount of medicalization, making perfectly normal properties and features seem pathologic and in need of medical attention. Third, it is questionable whether enhancement can be seen as having priority given the scarcity of resources in health care. Fourth, it should be asked whether it is wise to focus on medicine where it concerns enhancement of man. Using medicine as the vehicle for improvement of our properties will have the effect of focusing exclusively on improving only a select fraction of our properties, such as outer appearance, motoric, sensory and cognitive skills. Other properties that are not readily improvable with nanomedical means, for example, wisdom, spirituality, social abilities, empathy, moral and emotional skills, will unavoidably be neglected.

[20] Again focusing on nanomedicine as an example, it can be said that it is very likely that there will be progress in achieving the goals of better diagnosis and new therapeutic options given the advances that have been made already in drug targeting (Alivisatos, 2001; Bogunia-Kubik & Sugisaka, 2002; Davis, 1997; Mehnert & Mäder, 2001; Moghimi et al. 2001; Randal, 2001; Taton, 2001; West & Halas, 2000; Woolley, 2001Wüsthof, 2002),

4.5 *Step five: what are the ethical problems connected with further development of the field of research?*

The next step involves determining the ethical problems that are connected with the further developments in a specified nanotechnological field. Ethical problems connected with further development of nanoresearch are not necessarily the same in different fields of nanotechnological inquiry. For example, present research on nanotechnologically manufactured coatings of prostheses to improve their biocompatibility can hardly be said to pose the same ethical questions as, for instance, projects focused on producing perfect mosquito nets to reduce the problem of infectious disease or research on new nanochips that can read individual genomes in a feasible timeframe. Thus far, unfortunately, ethical problems have been mostly discussed on a very general level. As a rule, problems have not been linked to specific fields of nanotechnological enquiry.[21] In order to give an idea of the ethical problems that have been discussed in debate on nanotechnology up to now, the most important problems are here presented without pretending to give a complete sketch.

Risks: Up to now, the ethical debate on nanotechnology has been dominated by discussions about risks. A few examples are risks of disruption of the basis of economies (Peterson, 2003), environmental damage (ETC, 2003; Mnyusiwalla, Daar & Singer, 2003), an unstable arms race (Joy, 2000), the gray goo scenario (Bostrom, 1999; Drexler, 1986; Joy, 2000; Service, 2000), the black goo scenario (Bostrom, 1999) etc.. Against this backdrop, the environmental pressure group ETC has proposed that governments worldwide proclaim an instantaneous moratorium on commercial fabrication of new nanomaterials. Moreover, they want to start a transparent and global process of assessment of the various implications (for example for the environment, society and health) of the technology (ETC, 2003). Other less radical authors have called for an early and honest assessment of all the risks and unintended consequences of nanotechnology (Colvin, 2003; Foresight, 2000; Kurzweil, 2003).[22]

Equity: From a global justice point of view, the risk that the rise of nanotechnology will only be advantageous for rich countries, leaving developing countries behind, should be avoided. Therefore, it is imperative that a strategy be developed as to how the development of nanotechnology can be organized to both improve the lives of people in industrial states as well as advance living standards of those in developing countries. Also within individual countries and societies a sharp

---

diagnosis (Alivisatos, 2001; Chemla et al. 2000; Randal, 2001; Reichert et al. 2000; West & Halas, 2000; Wolfe, 2002), prostheses and implants (Alivisatos, 2001; Bachmann, 1998; Murphy et al. 1994; Taton, 2001) and cancer therapies (Alivisatos, 2001; Jordan et al. 2000; Randal, 2001; Schattenfroh, 2000). With regard to the other objective of nanomedicine, the enhancement of man, no such progress is known from the scientific literature up to now. Hence, the likelihood that a further development of nanomedicine will contribute to the goal of improving human properties will be assessed as being considerably lower.

[21] Some authors, however, have made a difference between present or near-term nanotechnology and more advanced molecular manufacturing. The ethical problems of these two stages of nanotechnological research have been noticed to be are clearly different in character and in scope (Kurzweil, 2003).

[22] In the context of reflecting on risks and risk management in nanotechnology, there has also been a lot of thought about the precautionary principle. In European thinking and regulation, the principle has become more influential than among U.S. regulators. A problem, however, is that there are a lot of different interpretations and formulations of the principle, making it a bit complicated as an analytic or a policy tool. In its strongest formulation the principle calls for complete scientific evidence of absolute safety before permitting new technologies to be accepted. This, however, would clearly be a very radical position. After all, complete scientific evidence of absolute safety of any technology whatsoever will not be possible to provide on principle. Moreover, it seems important to recall an important danger of relinquishment of all nanoresearch. If decent nations would delay nanotechnology development or relinquish nanotechnology all together, they would give the lead to other perhaps less law-abiding states and organizations (Peterson, 2003). Therefore, total relinquishment clearly would be too radical. Hence, if we do not want to radically stop all kinds of progress in technology, it seems necessary to accept some level of connected risk. Therefore, it would seem to be wiser to apply a norm of proportionality, stating that in technology development the risks should be in proportion to the expected benefit. That is to say that, *summa summarum*, the expected benefits have to measure up against the risks. Obviously, this would only be a necessary condition for responsible technology development and not a sufficient one.

nano-divide between the well off and the underprivileged ought to be prevented. It would clearly be problematic from the viewpoint of equity, if further development of nanotechnology would disproportionately benefit the higher echelon of society. In that case existing gap between haves and have-nots would only widen (Langdon, 2003).

Privacy: The extreme miniaturization that nanotechnology facilitates would be enormously advantageous for further developing espionage and surveillance gadgets (Mnyusiwalla, Daar & Singer, 2003; Peterson, 2003). It is not hard to imagine infinitesimally small tracking devices, nanocameras and nanomicrophones registering virtually everything we do without us even noticing it. Evidently, this idea poses the question of whether, and if so how, we will be able to defend our privacy.

Playing God: From a religious point of view, it could be argued that fully advanced molecular manufacturing would demonstrate a problematic attitude towards God's creation. After all, it would involve a fairly fundamental reshaping of creation in order to comply with human ideas and directives. Taking God's creation apart in the most extreme form and putting it together in a molecule-by-molecule way is likely to offend those who believe that the structure of creation is already pervaded by divine rationality and heavenly benevolence.

Approach to nature: In a way that would not necessarily have to be based on religious premises, a similar argument could be constructed around the attitude to nature that is involved in molecular manufacturing. Constructing our surroundings in a molecule-by-molecule way demonstrates an invasive and instrumental approach to nature that could be seen as conflicting with the idea of respect for nature (Langdon, 2003). The idea that nature has finality and some kind of moral meaning is a very old tradition in western philosophy. It can be found already in the philosophy of Plato, Aristotle, the Stoics, the Neoplatonists and Thomas Aquinas. More recently Goethe, in his theory of colors, criticized Newton for having forced light through prisms, thereby demonstrating a wrong approach to nature and thus coming up with biased results as to the real essence of light.

4.6 Step six: are these ethical problems surmountable?

After having determined the ethical problems that are connected with further developments in a specified nanotechnological field, analysis should decide whether they can be dealt with or not. After all, if it happens that the ethical problems are not surmountable, it seems ethically objectionable to favor further developments of the research (Gordijn, 2004).

To exemplify this last step, an example is given that concerns risk management. To reduce the risks of the further development of techniques of molecular manufacturing using assemblers the Foresight Institute has issued the so-called "Foresight Guidelines on Molecular Nanotechnology" (Foresight, 2000).[23] These guidelines contain a set of "Development Principles" as well as "Specific Design Guidelines". Among the first are prohibitions such as the statement that artificial replicators must not be capable of replication in natural environments (Foresight, 2000) or directives reminding developers that they should attempt to consider systematically the environmental consequences of the technology and limit them to intended effects (Foresight, 2000). Among the "Specific Design Guidelines" are directives focussing on ways to device designs to prevent self-replicating devices running amok such as complete dependence on artificial "vitamins" not available in any natural environment or programming termination dates into devices (Foresight, 2000).[24]

[23] The Foresight Institute is a non-profit organization "to guide emerging technologies to improve the human condition" (http://www.foresight.org/; accessed 30.10.2003).

[24] Also others have focused on measures to prevent the gray goo scenario. Moreover, all experiments with self-replicating nanomachines would have to be confined to hermetically isolated laboratories. A further measure to protect us against scavenging assemblers would involve the construction of automated protective shields. They would consist of a global immune system of specialized nanomachines that would search the earth's surface and the atmosphere for dangerous self-replicating nanodevices (Bostrom, 1999). Unfortunately, the development of such protective systems would probably be more difficult and accordingly take a longer time than it would take to produce dangerously destructive nanomachines. Thus, the global community would be unprotected against self-replicators during a certain time span. During this stretch of time, adequate regulation would be the only way to prevent misuse of nanotechnology (Bostrom, 1999 & 2000). See Freitas (2000a) for a first elaborate

5 Conclusion and outlook

Hardly ever has there been such a discrepancy between opposing evaluative judgments as can be observed in the debate on nanotechnology. However, both the radically optimistic as well as the thoroughly pessimistic ideas seem to be founded on a somewhat one-sided and narrow approach in ethical assessment. Nanotechnology is a complex endeavor that consists of many different projects with a huge variety of goals. Hence, different fields of nanotechnological research should be distinguished. After all, these fields will not necessarily demonstrate identical or even similar ethical aspects. Up to now, most of the debate has been too emotional, too general and quite decontextualized.

In order to improve ethical assessments of nanotechnology, a six-step method has been presented. Use of this method results in a rational and systematic assessment of the ethical desirability of further development of a specific field of nanoresearch. Due to the complexity of nanotechnology, it will be necessary to create interdisciplinary groups for ethics research. These, in turn, would need adequate funding. Therefore, it would be a good idea to devote a certain percentage of the government spending for nanotechnology to ethical research such as we have done in earlier attempts to address the ethical, legal and social implications of the human genome research (Mnyusiwalla, Daar & Singer, 2003; Kurzweil, 2003).

6 List of references

Ashley S, Nanobot Construction Crews. *Scientific American* 2001; 285(3): 76-77.

Bachmann G, *Innovationsschub aus dem Nanokosmos*. *Technologieanalyse*. Düsseldorf: VDI-Technologiezentrum, 1998.

Ball P, Nanotechnology. Molecular Movers and Shakers. *Nature* 2000; 408(December 21-28): 904.

Bostrom N, *The World in 2050*. 2000 (http://www.nickbostrom.com/2050/world.html; accessed 30.08.2002).

Bostrom N, *Transhumanismus FAQ*. 1999 (http://www.transhumanism.org/translations/german/FAQ.htm#3-4; accessed 30.08.2002).

Bunk S, Better Microscopes will be Instrumental in Nanotechnology Development. *Nature* 2001; 410(March 1): 127-129.

Collins GP, Shamans of Small. *Scientific American* 2001; 285(3): 78-83.

Colvin VL, Testimony to the U.S. House of Representatives Committee on Science, Full Science Committee Hearing on The Societal Implications of Nanotechnology, April 9, 2003 (http://www.house.gov/science/hearings/full03/apr09/colvin.htm; accessed 28.11.2003).

Committee for the Review of the National Nanotechnology Initiative (CRNNI), Division on Engineering and Physical Sciences, National Research Council, *Small Wonders, Endless Frontiers. A Review of the National Nanotechnology Initiative*. Washington, D.C.: National Academy Press, 2002.

Dewdney AK, Nanotechnology: Wherein Molecular Computers control Tiny Circulatory Submarines. *Scientific American* 1988; 258 (1): 100-103.

Drexler KE, Molecular Engineering: An Approach to the Development of General Capabilities for Molecular Manipulation. *Proceedings of the National Academy of Sciences USA* 1981; 78(9): 5275-5278.

Drexler KE, *Engines of Creation. The Coming Era of Nanotechnology*. New York: Anchor Press/Doubleday, 1986.

Drexler KE, Peterson C & Pergamit G, *Unbounding the Future: The Nanotechnology Revolution*. New York: William Morrow, 1991.

Drexler KE, *Nanosystems: Molecular Machinery, Manufacturing, and Computation*. New York: John Wiley and Sons, 1992.

---

technical analysis of various aspects of the *gray-goo*-scenario. Freitas uses the terminology of *global ecophagy*. It is, for example stated that assemblers could be equipped with a very rare chemical element without which it would not function (Bostrom, 1999).

Drexler KE, Machine-Phase Nanotechnology. *Scientific American* 2001; 285(3): 66-67.
Eigler DM & Schweizer EK, Positioning Single Atoms with a Scanning Tunnelling Microscope. *Nature* 1990; 344(April 5): 524-526.
ETC, The Big Down: Technologies Converging at the Nano-scale. 2003 http://www.etcgroup.org/documents/TheBigDown.pdf; accessed 30.10.2003).
Fahy GM, Molecular Nanotechnology. *Clinical Chemistry* 1993a; 39(9): 2011-2016.
Fahy GM, Molecular Nanotechnology and its Possible Pharmaceutical Implications. In: Bezold C, Halperin JA & Eng JL, (Eds.), *2020 Visions: Health Care Information Standards and Technologies*. Rockville MD: U.S. Pharmacopeial Convention, Inc.,1993b: 152-159.
Feynman R, There's Plenty of Room at the Bottom. In: Gilbert HD (Ed.), *Miniaturization*. New York: Reinhold, 1961: 282-296.
Foresight Guidelines on Molecular Nanotechnology (Original Version 1.0: February 21, 1999; Revised Draft Version 3.7: June 4, 2000) (http://www.foresight.org/guidelines/current.html#Preamble; accessed 30.10.2003).
Foster JS, Frommer JE & Arnett PC, Molecular Manipulation using a Tunneling Microscope. *Nature* 1988; 331 (January 28): 324-326.
Freitas RAJr, Exploratory Design in Medical Nanotechnology: A Mechanical Artificial Red Cell. *Artificial Cells, Blood Substitutes, and Immobilization Biotechnology* 1998a; 26(4): 411-430.
Freitas RAJr, *Nanomedicine FAQ*. 1998b (http://www.foresight.org/Nanomedicine/index.html#NMFAQ; accessed 30.08.2002).
Freitas RAJr, *Nanomedicine, Volume I: Basic Capabilities*. Georgetown, TX: Landes Bioscience, 1999.
Freitas RAJr, Some Limits to Global Ecophagy by Biovorous Nanoreplicators, with Public Policy Recommendations. *Zyvex preprint* 2000a (http://www.foresight.org/NanoRev/Ecophagy.html; accessed 30.08.2002).
Freitas RAJr, Nanodentistry. *Journal of the American Dental Association* 2000b; 131(11): 1559-1565.
Gordijn B, *Medizinische Utopien. Eine ethische Betrachtung*. Göttingen, Vandenhoeck & Ruprecht, 2004 (forthcoming).
Hansma PK, Elings VB, Marti O & Bracker CE, Scanning Tunneling Microscopy and Atomic Force Microscopy: Application to Biology and Technology. *Science*, 1988; 242(October 14): 209-216.
Herzog A, Of Genomics, Cyborgs and Nanotechnology: A Look into the Future of Medicine. *Connecticut Medicine* 2002; 66(1): 53-54.
Joy B, Why the Future doesn't need Us. *Wired* 2000; 8.04 (http://www.wired.com/wired/archive/8.04/joy.html); accessed 30.08.2002).
Kaehler T, Nanotechnology: Basic Concepts and Definitions. *Clinical Chemistry* 1994; 40(9): 1797-1799.
Kaku M, *Visions. How Science will revolutionize the 21st Century*. New York: Anchor Books/Doubleday, 1997.
Kricka LJ & Fortina P, Nanotechnology and Applications: An All-Language Literature Survey including Books and Patents. *Clinical Chemistry* 2002; 48(4): 662-665.
Kurzweil R, *The Age of Spiritual Machines. When Computers Exceed Human Intelligence*. New York: The Viking Press, 1999.
Kurzweil R, Testimony to the U.S. House of Representatives Committee on Science, Full Science Committee Hearing on The Societal Implications of Nanotechnology, April 9, 2003 (http://www.house.gov/science/hearings/full03/apr09/kurzweil.pdf; accessed 28.11.2003).
Lieber CM, The Incredible Shrinking Circuit. *Scientific American* 2001; 285(3): 51-56.
Mehta M D, On Nano-Panopticism: A Sociological Perspective. No date (http://chem4823.usask.ca/~cassidyr/OnNano-Panopticism-ASociologicalPerspective.htm).
Merkle RC, The Technical Feasibility of Cryonics. *Medical Hypotheses* 1992; 39: 6-16.
Merkle RC, The Molecular Repair of the Brain. Part I. *Cryonics* 1994a; 15(1): 16-31.
Merkle RC, The Molecular Repair of the Brain. Part II. *Cryonics* 1994b; 15(2): 20-32.
Merkle RC, Nanotechnology and Medicine. In: Klatz RM (Ed.), *Advances in Anti-Aging Medicine. Vol. I*. Larchmont, New York: Mary Ann Liebert, Inc., 1996: 277-286 (http://nano.xerox.com/nanotech/nanotechAndMedicine.html; accessed 30.08.2002).

Miksanek T, Microscopic Doctors and Molecular Black Bags: Science Fiction's Prescription for Nanotechnology and Medicine, *Literature and Medicine* 2001; 20(1): 55-70.
Mnyusiwalla A, Daar AS & Singer PA, 'Mind the Gap: Science and Ethics in Nanotechnology. Nanotechnology 2003; 14: R9-R13 (http://www.utoronto.ca/jcb/pdf/nanotechnology.pdf; accessed 28.11.2003).
Moore A, Brave Small World. Biotechnology and Nanotechnology may give Rise to a Completely New Industry. *EMBO Reports* 2001; 2(2): 86-88.
National Science and Technology Council, Committee on Technology, Subcommittee on Nanoscale Science, Engineering and Technology (NSET), *National Nanotechnology Initiative: The Initiative and Its Implementation Plan*. Washington, D.C., 2000.
Peterson C, Testimony to the U.S. House of Representatives Committee on Science, Full Science Committee Hearing on The Societal Implications of Nanotechnology, April 9, 2003 (http://www.house.gov/science/hearings/full03/apr09/peterson.htm; accessed 28.11.2003).
Pool R, A Small Revolution Gets Under Way. *Science* 1990; 247(January 5): 26-27.
Popper K, *The Open Universe: An Argument for Indeterminism*. London: Hutchinson, 1982.
Randal J, Nanotechnology getting off the Ground in Cancer Research. *Journal of the National Cancer Institute* 2001; 93(24): 1836-1838.
Roukes M, Plenty of Room, Indeed. *Scientific American* 2001; 285(3): 42-49.
Service RF, Is Nanotechnology Dangerous? *Science* 2000; 290(November 24): 1526-1527.
Smalley RE, Of Chemistry, Love and Nanobots. *Scientific American* 2001; 285(3): 68-69.
Stevenson RL, Nanotechnology: The Next Opportunity for Biotechnology. *American Biotechnology Laboratory* 1994; 12(13): 18-20.
Stix G, Little Big Science. *Scientific American* 2001; 285(3): 26-31.
Whitesides GM & Love JC, The Art of Building Small. *Scientific American* 2001; 285(3): 33-41.
Winner L, Testimony to the U.S. House of Representatives Committee on Science, Full Science Committee Hearing on The Societal Implications of Nanotechnology, April 9, 2003 (http://www.house.gov/science/hearings/full03/apr09/winner.htm; accessed 28.11.2003).