Minding the other gap: A case for taxonomic distinctions in nanoethics

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Summary

Currently the focus of existing nanoethical reflection seems to be on either devices which have nanotechnologies embedded in them, or on the general effects of the production, use and disposal of nanotechnologies. In the former type of assessment, the devices are assessed, not the effects of using nanotechnologies in these devices. And in the latter type of assessment the effect of nanotechnologies in general is assessed and not specific nanotechnologies.

Due to these two types of assessments, three problems occur. First there is the non-specificity problem. When assessing a device, the detected issues could have little to do with the embedded nanotechnologies, and only a specific embedment of nanotechnologies is assessed. This distracts from the roles in the evocation of the issues that are attributable to nanotechnologies. Second there is the generalization problem. When looking at general issues, reflection is focused on the use of nanotechnologies in general instead of the effects of different nanotechnologies. This could result in generalizing the effects of certain nanotechnologies so that they seem applicable to all nanotechnologies. And third there is the speculation problem. There has been a lot of focus on uncertain foresights, which deflects attention from current pressing issues.

In this thesis I propose ways of distinguishing between different nanotechnologies in nanoethical reflection, and with these close the gap between the two types of assessment. I apply two distinctions – one distinction based on the method of production and one based on functionality – to the privacy and nanotoxicology case. In the privacy case, applying a distinction showed that the privacy issues are currently not nano-related, and the link between privacy issues and the field of nanotechnology relies on speculation. Applying the distinctions on the nanotoxicology case showed that there are types of nanotechnology that do not contribute to toxicological issues.

Applying the distinctions showed that they can be used as a critical instrument to show where the three problems occur in current ethical reflection. As a starting point for ethical reflection, the distinctions could prove to be a valuable heuristic instrument by allowing for nanotechnology-specific allocation of problems. This allows for setting the agenda for a better informed public and political debate, hence improving the quality.

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1. Introduction

The term nanotechnology was first used in 1974 as a reference to engineering material at nanometer level (Royal Society, Royal Academy of Engineering, 2004); it is a relatively new field that entails the creation and work with extremely small materials. Nanotechnology is usually defined as “the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometer scale” (Ibid, p. vii), and at the nano-scale refers to 100 nanometers or smaller.

This manipulation at nano-scale is rapidly gaining attention and the term nanotechnology is becoming well known. The reason the manipulation of materials at nano-scale is given attention, is because it brings new possibilities. Certain material properties at nano-scale are different compared to their properties at larger scale. Working at the nano-scale causes the surface of materials to become larger relative to the volume, which, in some cases, changes the chemical reactivity, the optical properties, the conductive properties and the magnetic properties (Ibid). The changed material properties allow for a wide range of applications.

Due to the wide range of possible applications, the emergence of the field of nanotechnology has not left other fields of science and engineering unaffected. Other fields are impacted by the incorporation of nanotechnologies in existing devices, but also by novel applications – such as autonomous nano-robots – that have, or could, become possible due to the small size of nanotechnologies. By allowing for the creation of smaller structures, the field of electronics has been impacted by, for example, the decrease in size of CMOS chips used in computers and on RFID chips. The field of biotechnology is also gaining attention, and is impacted by the new possibilities of molecular imaging and better targeted treatments due to nanotechnologies used in this field (Ibid).

The impact on these other fields is problematic. When technologies open up possibilities in other fields, it can be expected that the technologies will contribute to the rise of ethical issues within these fields. The issues are linked to the field of nanotechnology through both incorporation of nanotechnologies to miniaturize existing devices, and the more distinct applications of nanotechnologies. Some important issues include the impact on privacy due to the small size of RFID chips (van den Hoven and Vermaas, 2007), the divide occurring due to the lower level of access Third World countries have to nanotechnologies (Godman, 2008), issues related to human enhancement (Royal Society, Royal Academy of Engineering, 2004), issues related to military use, and issues related to the impact nanotechnologies can have on the environment and human health (Ibid).

The field of ethics that deals with the ethical issues related to nanotechnologies and its use is called nanoethics, it can thus be said to be a field of applied ethics. In a democratic society, one of the tasks – and quite an important one – of a field like nanoethics is to generate public debate. By investigating the ethical issues related to the use of nanotechnologies, ethicists can inform the non-scientific public, so that they are more able to partake in the policy making debate, and provide a guideline for policy makers to judge what solutions to the raised issues are morally acceptable (Beauchamp, 2003). Another purpose for nanoethics is formulated by the European Commission. The European Commission will ensure that ethical concern is integrated in Community funded research and development so that "ethical principles are respected and citizens' concerns and expectations are taken into account" (European Commission, 2007, p. 21). However, are current ethical assessments of nanotechnologies suitable for this purpose?

The focus of existing ethical reflection seems to be either on the devices which have nanotechnologies embedded in them rather than actual nanotechnologies, or on general effects that the emergence of the field of nanotechnology has. An example of the former is the assessment of devices like RFID chips. In this type of assessment the devices are assessed, not the effects of using nanotechnologies in said devices. Examples of the latter are risk issues and issues of transhumanism. In the assessment of these issues only the effect of nanotechnologies in general is assessed, but not the effects of specific nanotechnologies. This leaves a gap between device-oriented assessment and general ethical assessment. The gap could distract from the nano-specific insights that become visible when assessing nanotechnologies themselves. There is something missing in between general and device-oriented assessments, and if this gap proves problematic it needs bridging.

Although many issues appeared together with the emergence of the field of nanotechnology, there are many different ways in which nanotechnologies are used. There are different nanotechnologies, and besides being less than 100 nanometers in size, not every nanotechnology has the same effect on the evoked social and ethical issues: different applications make use of different features of different nanotechnologies. There have been claims that the field of ethics accompanying the field of nanotechnology is lagging behind (Mnyusiwalla et al., 2003), and that the field of nanotechnology had been growing a lot faster than the field of nanoethics.

The paper containing the claim also made a call for taxonomic distinctions – between for example nano-robots and nano-materials – and other ways to allow the lay public to better understand the role nanotechnologies can play in ethical and societal issues arising with the field of nanotechnology. Could differentiating between nanotechnologies provide better understanding of what nanotechnologies contribute to the ethical issues, and aid in preventing the problems that possibly come with having a gap between general and device-oriented assessment?

The existence of a gap between types of assessment could deflect attention from actual nanotechnologies by focusing on general issues and devices. When the deflection from actual nanotechnologies is problematic, this could indicate the need to investigate possible ways to bridge this gap. There being different types of nanotechnology and the lack of differentiation in the field of nanoethics cause the suspicion to arise that the answer might be found in differentiating between different nanotechnologies. This thesis aims to investigate what constitutes the gap between the literature on general issues related to nanotechnologies and the device-specific issues. As a possible solution, different ways of differentiating between nanotechnologies will be explored and evaluated on to what extent they are applicable in the process of dealing with the problems possibly caused by the gap in nanoethical literature.

This thesis will first explore the field of nanoethics by discussing what it does, what critiques there are on the field, the types of literature found, the problems with the literature, and the nature of the gap. The third chapter will continue on the results found in the chapter on nanoethics by looking at the technical aspects of nanotechnologies and formulating several distinctions based on method of production, functionality and material properties. These distinctions are evaluated on how likely they are going to be of use to ethicists and policy makers, and two are chosen to investigate further. In the fourth chapter of this thesis the chosen distinctions will be applied to cases in order to evaluate them. The distinctions will be applied to two cases: the loss of privacy case, and the nanotoxicology case. This all is done to lead to the conclusions in the fifth chapter. In the conclusion an attempt is made to answer the research question and sub-questions.

The research question and sub-questions are:

How could a taxonomy of nanotechnologies contribute to the ethical assessment of nanotechnologies and devices containing nanotechnologies?

- How can the current nanoethical literature be characterized, and how does it deal with different nanotechnologies?

- Is there gap between the general assessment and device-oriented assessments of nanotechnologies, and if so, to what extent is it problematic?
- What would a taxonomy of nanotechnologies look like, based on a representative sample of state of the art literature in this field?
- How might a taxonomy of nanotechnologies be used in nanoethics, and how does this use contribute to ethical assessments of nanotechnologies?

2. Nanoethics

Within the field of nanotechnology, there is a lot of conceptual confusion. Although many agree that there is a field of nanotechnology, the definitions of nanotechnology vary[1]. The difference in definitions lies in which size is regarded as nanotechnology (Moor & Weckert, 2004). Definitions of nanotechnology range from the original definition of building structures atom by atom (Drexler, 2004), to the definition of anything less than a thousand nanometers (Moor & Weckert, 2004). For this thesis I will use 'engineering done at 100 nanometers or less in one or more dimensions[2]' as the definition of nanotechnology. This definition is not as wide as regarding anything under a thousand nanometers as nanotechnology, but broader than only atom by atom manufacturing. Besides being somewhere in the middle of the range of definitions, it is also the definition most commonly used.

The field of nanotechnology is not completely clear about nanotechnology's definition, but how is the field of nanoethics doing? "Nanoethics is the ethics of nanotechnology" (Ibid, p. 301). It deals with nanotechnologies and the ethical issues they evoke. Dealing with the issues related to nanotechnologies is done by identifying the issues, looking at what effects in the form of risks or the crossing of moral boundaries the field of nanotechnology brings – or is expected to bring – with its emergence, and evaluating the possible routes and outcomes on their moral acceptability. The goal of nanoethics is the 'systematic ethical reflecting upon the production, use, and disposal of nanotechnologies, and providing a guideline for policy makers to judge what solutions to the raised issues are morally acceptable and desirable.'

Even though it is accepted that there is a field of nanotechnology, the acceptance of nanoethics as a field is problematic. It is clear now that nanoethics deals with moral issues brought forth by the production, use, and disposal of structures engineered at 100 nanometers or less, yet many doubt whether we really need a separate field of nanoethics (Lin & Allhoff, 2007). Many ethicists think that the issues evoked by nanotechnologies can also be dealt with in other fields of ethics, or by ethics in general, since nanotechnologies are mostly embedded in devices or technologies. Another argument is that nanotechnologies pose little or no new ethical issues in comparison with, for example, biotechnologies. The subject of debate is whether ethical reflection on nanotechnologies needs a new domain, and it is questioned

[1] Defining the term 'nano' was in the priority recommendations of the Nanotechnology Standards Panel formed by the American National Standards Institute (Borm et al., 2006).
[2] The amount of dimensions is the amount of directions in which engineering is done. RFID tags, for example, contain paterns in one or two dimensions. Structures made atom-by-atom are three dimensional.

whether issues related to nanotechnologies can be dealt with using standard ethical tools, tools already available in fields such as bioethics, or if there is a need to develop new tools for ethical reflection.

What could the criteria for requiring a separate field of applied ethics be? Aside from dealing with issues related to a different field of science or technology, a field of applied ethics should deal with issues related to that field of science or technology which are (relatively) new or unique to that field. If there are no specific issues for a field of science or technology, then I expect previously developed tools and principles to suffice for ethical reflection. In order to qualify for its own domain of applied ethics there thus need to be issues that mainly nanotechnologies evoke, are new with the emergence of the field of nanotechnology, or occur more frequent or severe in the field of nanotechnology than in any other field.

Some are not convinced the field of nanotechnology qualifies for its own domain of applied ethics. Marion Godman (2008), for example, argues that the issues nanotechnologies evoke are not novel to nanotechnologies. In other words, the issues nanoethics deals with are not caused by nanotechnologies alone, but also by other technologies, and the issues might not be new. This incorporates both arguments against the field of nanoethics. Nanotechnologies are, according to Godman, intertwined with other fields of science and engineering, and will therefore cause nanotechnologies "to act as an improver, multiplier and enhancer of already existing technologies" (Ibid, p. 3). This would cause nanotechnologies to be an extension of existing methods. If this claim holds, then the issues nanoethics deals with can also be dealt with in other fields of applied ethics. But, how does the field of nanotechnology qualify for its own field of applied ethics?

One of the reasons for having ethics of nanotechnology as a separate field is the impact of the anticipated possible future applications of nanotechnologies, such as nano-enhanced devices. With an ethics of nanotechnology, the potential future issues can be assessed through the evaluation of nano-specific foresights. It might be too late, given the high level of bureaucracy in today's society, to effectively govern[3] nanotechnologies, when they have not been properly assessed ahead of time. An example of this is the absence of regulation on nano-particles, while they have already been brought on the market in applications such as sunscreens, without enough being known about the safety of using these particles (Faunce et al., 2008). Toxicological issues related to nanotechnologies – such as the

[3] By governing I mean monitoring and controlling nanotechnologies, before and after exposure to the market.

damage to cell membranes that can be caused by buckyballs[4] (Service, 2004) – are becoming more apparent, and could have been anticipated before the nano-particle-containing sunscreens where allowed to enter the market. The field of nanoethics can identify such issues before they arise, and provide policy makers with tools to formulate nano-specific anticipative policies. These anticipative policies can, of course, not ensure complete and accurate intervention, but they could optimize preventive power or deal with the Collingride dilemma[5] in a better way.

There are, however, also similarities with existing fields of ethics. The problems with using these fields of ethics could be that the issues accompanying the emergence of the field of nanotechnology are expected to be, for example, more complex than the issues dealt with in bioethics. Parallels can be found between bioethical issues and nanoethical issues (Kuzma & Besley, 2008), but there is also a relatively new theme arising with the emergence of the field of nanotechnology, namely transhumanism. This higher level of complexness arises out of these transhumanistic issues, which could pass the limits of humanity and ethics (Ebbesen et al., 2006).

In bioethics a dominating approach to dealing with ethical issues is principlism. Principlism is the theory that there are several basic principles that all need to be met if possible, but if two or more principles conflict one may outweigh the other. Tom Beauchamp and James Childress (1996) formulated four principles for biomedical ethics. The principles are respect for autonomy, non-maleficence, beneficence, and justice. Could these four principles be used to deal with the issues raised by nanotechnologies?

Ebbesen et al. (2006) identified three groups of ethical issues related to nanotechnologies: risk problems, privacy problems, and problems of transhumanism. They claim the basic principles of autonomy, beneficence, non-maleficence, justice and integrity are at stake in these groups. To deal with the issues evoked by nanotechnologies a principlist approach could serve as a starting point. Ebbesen et al. (2006) claim that the principles formulated by Beauchamp and Childress (1996) suffice for several ethical issues related to nanotechnologies, but transhumanism issues evoked by nanotechnologies could prove too complex for current principles (Ibid). Ebbesen et al. thus make a case that a principlist approach using a modified set of principles could be used as a starting point to assess several problems that accompany the emergence of the field of nanotechnology.

[4] Buckyballs are molecules shaped like a ball with 60 carbon atoms. These buckyballs have unique conductive properties (Wolf, 2004).
[5] "when control of technological change is still possible, knowledge of eventual impacts (and how they will arise) is so limited that the direction to go is unclear" (Rip & Schot, 2002).

In this chapter three problems in the field of nanoethics will be identified and analyzed, and a solution to these problems will be sought. The solution will be sought in the direction of distinguishing between different nanotechnologies. Although some ethicists have touched on the topic of this thesis – Moor & Weckert (2004) explain several different applications of differently produced nanotechnologies – no thorough analysis has been made, and distinctions occur in the introductory paragraphs only to get the non-expert acquainted with the field of nanotechnology. Furthermore, differentiating to find the possibly different ethical impacts of different nanotechnologies have never been proposed as useful tools for the ethical reflection on nanotechnologies.

This thesis will attempt to go further than just touching on the topic, and aims to link ethical issues to the relevant technical aspects of the nanotechnologies involved. This could provide an argument for the field of nanoethics by showing how nanotechnologies play a unique part in the evoked issues, even if embedded in other devices/applications. The way of ethical reflection proposed in this thesis is not one that, like the principlist way Beauchamp and Childress (1996) have proposed, looks at a set of principles and evaluates if these principles are respected. It looks at the technologies themselves and identifies what exactly the issues caused by the nanotechnologies are. When identifying the technical aspects that need to be subject of ethical evaluation, more accurate application of the moral principles, modified or not, can take place.

In this chapter I will look at a selection of current nanoethical literature, and identify several types of nanoethical literature. I have identified non-assessing literature that comments on the field of nanoethics itself, literature that deals with issues related to the use of nanotechnologies in general, and literature that deals with issues related to the use of specific devices that make use of the properties of nanotechnologies. After the identification of the types of literature, I identify three problems in current nanoethical literature, and suggest that they might be prevented by looking at the specific nanotechnologies involved. By looking at specific nanotechnologies, I hope to discover a way of dealing with the three problems and a way of exposing nanotechnologies' role in the ethical issues.

2.1 Nanoethical literature

In order to find ethical literature representative for the field of nanoethics, a selection has been made from the journal NanoEthics. This journal publishes articles that focus on "philosophically and scientifically rigorous examination of the ethical and societal considerations and the public and policy concerns inherent in nanotechnology research and development."[6] Having the name NanoEthics, this journal that started in 2007 provided a logical starting point for the literature study. In the journal, articles were published that proved to be of direct use, or allowed for skimming the references for other useful articles. The first 48[7] articles published in the NanoEthics journal have been read, and those relevant – which were the articles on ethical implications related to nanotechnologies rather than policy issues – for this thesis have been studied further. This I expect to provide a representative selection of the literature available in the field of nanoethics.

Of course there has been written more nanoethical literature than the articles in the journal NanoEthics. As an attempt to ensure that the literature read represents the field of nanoethics, sources that have been frequently referred to in the articles in the journal NanoEthics have also been read. This complements the literature from the NanoEthics journal with other ethical literature, technical literature and ethics-related literature. In addition, scientific databases such as Google Scholar have been used to find relevant extra literature. With both the articles from the journal NanoEthics, and the often referred to literature from other sources, I expect to have made a selection of literature that gives a representative overview of the work published so far on, or related to, nanoethics[8]. The findings from the read nanoethical literature will be discussed below.

2.1.1 Non-assessing literature

First there is the non-assessing literature that aims at proposing ways in which to do nanoethics, critiques against the field of nanoethics, reasons to have the field of nanoethics, et cetera. An example of such literature is an article by Ibo van de Poel (2007). In his article he analyzes several positions about the field of nanoethics, and provides his way of doing nanoethics. The network approach he proposes allows for discerning ethical issues as they arise, provides ethical insights usable for steering Research & Development, and deals with ethical issues in their 'real world' context (Ibid). This is a nice example that discusses the field of nanotechnology and the ethics of nanotechnology, yet does not discuss any ethical issues.

Another example is the article called 'Cultural diversity in nanotechnology ethics' by Joachim Schummer (2006). In this article it is argued that nanoethical issues are perceived differently depending on used definition, culture, economic conditions, political conditions,

[6] See http://www.springer.com/philosophy/ethics/journal/11569?detailsPage=aimsAndScopes
[7] This is the amount of articles (excluding book reviews) that had been published during the literature study for this research.
[8] An overview of all nanotechnology/nanoethical articles read can be found in the appendix.

and ethical framework. For example, in cultures where surveillance cameras are already extensively used, the privacy issues emerging together with the field of nanotechnology will be perceived different than in more privacy-valuing cultures. This article sums up some factors that influence the nanoethics debate, and argues for a form of moral relativism. It is thus also an article on how to perform ethics of nanotechnology.

Both mentioned examples can be said to not discuss any ethical issues, but contribute on a methodological level. This type of literature provides tools for doing ethics, and does not evaluate issues that arise in nanoethics with the goal to provide insight into what would be morally acceptable or not. In this sense the non-assessing literature differs from the assessing literature.

2.1.2 General assessments

Second there is literature that discusses the potential danger of the use of nanotechnologies in general. Issues that recur in this literature are on inequalities due to the access to nanotechnologies (nanodivide), the use of nanotechnologies for good/bad, the gray goo[9] scenario, environmental health and safety issues, privacy issues, issues of human enhancement, et cetera. Here a division can be made in two different types of general assessments. The first, discussing the problems indirectly related to the technical aspects of nanotechnologies, and the second directly related to the technical aspects of nanotechnologies. Mainly the latter will be of importance for this thesis.

Although all ethical issues are related to social factors, I regard social factors as playing a bigger part in the evocation of indirect nanoethical issues. Not only can the indirect nanoethical issues be prevented or fixed by means of changing social actions, the consequences are also social. Direct ethical issues are caused due to, for example, uncertainties about nanotechnologies' material aspects and its impact. Here nanotechnologies' applications need to be dealt with, not the ways in which they are used.

An example of an issue indirectly related to nanotechnologies is the nanodivide (Godman, 2008). This nanodivide is the widening gap between rich and poor countries due to the unequal access to nanotechnologies. This goes for both financial benefits, and other benefits gained through the use of nanotechnologies; if a country has high access to nanotechnologies it is to be expected that they reap a high level of financial benefits, and with all the other benefits from this access, for example through biomedical nanotechnologies, the

[9] The gray goo scenario is a scenario published by Eric Drexler (1986) in his book Engines of Creation, which describes self-replication nano-sized machines that consume the entire world and turn it into grey goo.

quality of life of countries with high access is also expected to increase (Ibid). In this case there are technologies, namely nanotechnologies, that through the way in which they are accessed, cause ethical issues; there are thus the technical factors – the novel applications possible with nanotechnologies – which are used in such a way that they cause issues. Here the social factors can be seen as primary and the technical factors as secondary, since the issues arise due to a specific use[10]. A solution to this problem will most likely be social, such as stimulation of nanotechnology research in Third World countries.

An example of issues directly related to the use of nanotechnologies in general are the issues regarding toxicology (Service, 2004; Kipen & Laskin, 2005; Seaton & Donaldson, 2005; Roex et al., 2007; Schrader-Frechette, 2007). These toxicology issues are caused by the effect nanotechnologies have on the environment and the human health. It concerns emitted nano-particles with toxic properties. Emission of nano-particles can occur during the production, use, and disposal of nanotechnologies (Roex et al., 2007). Not a lot of research has been done on the effects nano-particles have on the environment, but about the health effects of nano-particles on living creatures more is known (Warheit, 2004). Several ways of exposure to nano-particles have been found during these studies: exposure to nano-particles can occur through breathing in nano-particles (respiratory exposure), nano-particles can be absorbed through the skin (dermal exposure), nano-particles can be swallowed (oral exposure), and nano-particles can be exposed to the body through biomedical applications (parental exposure) (Ibid). Several experiments have indicated negative effects of exposure to nano-particles, including research that showed the damaging effect of buckyballs to cell membranes in fish (Service, 2004). In these types of direct issues the focus is more on the material/technical factors. Although policy making attempts to regulate the use in order to prevent the negative effects to occur, in the discussion of the problem the social factors are still secondary and the technical factors primary; the direct problems might – at least in theory – be solved by a technological solution. Regarding toxicology, better ways of production, better designed products, and better ways of dealing with disposal can be developed.

The general nanotechnology assessment literature contains literature on the issues evoked by the use of nanotechnologies, either directly or indirectly. Although the border between direct and indirect issues can be vague, I regard the literature that discusses the issues directly caused by nanotechnologies to be of higher importance for this thesis. A convincing argument can be made that there are certain types of nanotechnologies that contribute more to

[10] There are similar issues in other fields, like the digital divide in the field of information technology (Brodie et al., 2000).

indirect issues – such as the nanodivide and military use, since they depend on highly technical factors – due to their novel properties, but the scope of this thesis is limited. For this reason the choice is made to limit the investigation to the issues directly caused by nanotechnologies only; I expect it to be more fruitful to investigate ethical issues which have primarily technical factors that cause them, because the link with nanotechnologies is clearer. Not limiting the investigation would leave too much room for debate about whether the discussed issues are novel to the field of nanotechnology[11].

2.1.3 Device-oriented assessments

The third type of literature found is the literature that looks at the devices or applications with nanotechnologies embedded in them, and the ethical issues related to these devices. An example of device-oriented assessments is the linking of certain nano-enhanced devices to privacy issues, by van den Hoven and Vermaas (2007). They claim that "nano-technology will give rise to a panoply of privacy issues" (Ibid, p. 284). Attention is paid especially to Radio Frequency Identification Chips (RFID). Although privacy is one of the general problems nanotechnologies are linked to, the paper by van den Hoven and Vermaas looks at how certain devices add to this problem.

By having nano-enhanced RFID chips, the chips decrease in size, and are hence enabling the evocation of new privacy issues or worsen existing problems. The moral reasons for privacy by van den Hoven and Vermaas (2007) are regarded as the prevention of information-based harm, prevention of informational inequality, prevention of information injustice, and respect for moral autonomy. RFID chips – and similar devices –allow for a move from larger, visible, central surveillance, to decentralized continuous surveillance; by having (almost) invisible nano-devices, people can be watched constantly. The third type of literature is thus focused on the function of devices in which nanotechnologies are embedded, yet pay little attention to the properties of nanotechnologies. The assessment is device-oriented, and results in an analysis of the role the devices play in the evoked issues. This could prove problematic because the assessment says little to nothing about the embedded nanotechnologies, yet because the devices contain nanotechnologies these nanotechnologies are associated with the problems caused by the devices, resulting in possibly wrong attribution of cause.

[11] For this discussion I recommend "But is it unique to nanotechnology?: Reframing nanoethics" by Marion Godman (2008).

2.2 Three problems

The literature on the ethics of nanotechnology is still quite scarce. By analyzing the nanoethical literature, I came across three problems, namely the problem of generalization, non-specificity, and speculation. The problem of generalization occurs in both the general assessments and the device-oriented assessments. Here the field of nanotechnology as a whole is associated with certain ethical issues without specifying the nanotechnologies involved in evoking the issues, thus creating a generalizing effect. One of the effects this can have is that the lay public perceives all nanotechnologies as the same, or to not even be aware that there are different nanotechnologies. A possible problem resulting from this could be the rejection of all nanotechnologies based on the effects of just one or a few nanotechnologies. Generalization also distracts from getting a clear image of the role nanotechnologies play in the evocation of the issues. For the gray goo scenario it is clear that it involves tiny robots that destroy the world, but not that not all nanotechnologies are able to play a part in the gray goo scenario; perception is limited because it is not clear that there are different nanotechnologies, of which not necessarily all contribute to the ethical issue. On the other hand, with toxicology issues it might not be clear that there are several ways in which nanotechnologies can impact human health or the environment; nano-particles can impact in the form of buckyballs, nano-tubes, et cetera. (Roex et al., 2007). This can deflect from the variety of ways in which nanotechnologies influence the evocation of the issues that are discussed in the general assessments.

The problem of non-specificity is found in the device-oriented assessments. Here attention is only paid to the device, not specifically to what the nanotechnology embedded in the device does. This assesses the device, not the role of nanotechnologies in the issues evoked by the device; it can be perfectly clear how a device evokes certain issues, but how exactly the nanotechnology embedded in the device contributes to the issues is not clear. Policy-wise this could mean that adequate policies can be formulated to deal with the assessed device, but not with the nanotechnologies that could have similar undesired effects when embedded in other devices; when assessing a device and not the embedded nanotechnologies, no nano-specific insight is gained, and no nano-specific policy measures can be taken. The general assumption by ethicists seems to be that nanotechnologies can make devices smaller, yet I suspect that, when paying closer attention to the type of nanotechnologies embedded in the device, more roles of nanotechnologies can be found. These roles can be reoccurring, so identifying them could yield nano-specific insights usable in during the assessments of devices embedded with similar nanotechnologies, hence preventing that the wheel is continuously reinvented.

Even though mainly present in device-oriented assessments, the exact role of nanotechnologies, or even the nanotechnology causing the problems, is also not always clear in general assessments; yet this is due to generalization, not due to looking at a device rather than nanotechnologies. In the gray goo scenario it is clear that it involves nano-robots that devour the world, but in problems of toxicology it is not always specified exactly what type of nanotechnologies cause the issues, or how the problems arise. The non-specificity problem thus occurs more in the device-oriented assessments.

The problem of speculation is found in both types of assessment. About the way in which certain nanotechnologies will develop little is known, and ethicists speculate[12] about possible applications of nanotechnologies. Although speculation can be used to detect problems that have not occurred yet, and by doing so allow for anticipating these problems, foresights are often uncertain. For example, the gray goo scenario is now, several years after being introduced and taken serious, regarded as unrealistic. Such speculation leading to uncertain foresights deflects attention from current pressing issues (Nordman, 2007); issues that are already of importance, such as toxicological issues, get less attention because of the focus on distant human-enhancement applications. Alfred Nordman and Arie Rip (2009) claim that the field of nanoethics is not lagging behind anymore as claimed six years ago, but is now heading in the wrong direction due to the focus on distant and uncertain applications. Speculation, I think, can certainly contribute to nanoethics in a valuable way, but in current nanoethical literature it is based too much on uncertain foresights; examples are the gray goo scenario and speculation about human-enhancement.

2.3 Prevention

Now I identified three problems in current nanoethical literature, but where to look for a solution to these problems? Some of the nanoethical literature from the two types of assessments already supplements each other by having a general problem and the assessment of a device related to this problem. An example of this is the are the issues regarding privacy to be linked to nanotechnologies (Moor & Weckert, 2004) and the assessment of RFID chips (van den Hoven & Vermaas, 2007); it is clear that there are privacy issues related to nanotechnologies as discussed in general assessments, and by the device-oriented assessments

[12] Speculation here seems to be based on scientific foresight, but there is also the phenomenon of ethicists getting carried away and coming up with implausible scenarios.

which devices evoke them. It is, however, not clear which type(s) of nanotechnology can be linked to privacy issues.

When looking at the assessments[13] of nanotechnologies in ethical literature, a gap is identifiable between the assessments of the general problems associated with the use of nanotechnologies and the assessments of nano-enhanced devices. Inquiring which nanotechnologies cause what type of issues quickly shows that a step is skipped between what problems are attributed to the use of nanotechnologies in general, and the use of nanotechnologies in specific devices. What is missing? And what can be gained from bridging this gap? The part that is missing is – keeping in mind that there are different nanotechnologies with different properties – an assessment of the different types of nanotechnologies; there is literature on what issues all nanotechnologies combined are linked to, and what certain devices are linked to, but little has been published on what issues can be attributed to which nanotechnology. I suspect it to be interesting to find out whether an addition to the ways of ethical reflection on nanotechnologies can aid in preventing/solving the three mentioned problems.

According to the International Risk Governance Council (2006) serious and realistic problems have been dismissed as science fiction due to scenarios such as the gray goo scenario. The combination of speculation and generalization can thus lead to uncritical acceptance or rejection of developments in the field of nanotechnology. This might not happen if there are relevant distinctions made between the different types of nanotechnology which is aptly communicated to the public, since it then becomes obvious that the gray goo scenario applies to one type of nanotechnology[14] rather than nanotechnologies in general, and that not all scenarios are as speculative as the grey goo scenario.

When making relevant distinctions, in effect, the speculative character of certain scenarios could become clear; there will, of course, necessarily always remain a degree of speculation. When differentiating between different nanotechnologies it will become clear what is possible with certain types of nanotechnology and what can realistically be expected in the future; it is better understood what effects the use of nanotechnologies has, and speculation about what the effects might be can be controlled. And, the speculation that does occur could tend to be more accurate, since the past path of the development of the type of

[13] Assessments will be understood, for this thesis, as an evaluation of a technology or device, where attention is paid to its possibilities, the possible problems that can flow forth out of its use or development, and whether steering in the production, use, disposal, or development is needed.
[14] Bottom-up created biological nanotechnology (Phoenix & Drexler, 2004).

nanotechnology can be used for to produce foresights; when only looking at nanotechnologies in general speculation is bound to run wild.

Not only is it likely that the path of development based on the technical advances can be extrapolated with a higher degree of accuracy, but the social forces that have driven or held back the development of a specific nanotechnology can also be used in the extrapolation of the possible paths of development. The absence, or re-occurrence, of social factors that have proven to be influential in the past, can help in the prediction of which direction certain nanotechnologies will tend to develop, and what their capabilities might become. Previous policies and the social factors that triggered the formulation of these policies can be analyzed. It can then be anticipated that, when a nanotechnology has an effect similar to a something that sparked the implementation of certain restrictions, the development of that nanotechnology has to develop differently in order to prevent similar restrictions. When engaging in speculative scenario sketching, it can be of importance to not only look at what is theoretically possible, but also anticipate social factors that can exercise restrictive force.

An example of taking into account social factors is anticipating regulation similar to that of asbestos. Certain nanotechnologies are said to have lung penetrating properties similar to asbestos, and hence can be perceived as similarly hazardous (van Amerom & Ruivenkamp, 2006). In order to anticipate possible obstacles in the form of objections and regulations, the past and current status of asbestos can be analyzed. Here the category of nanotechnologies similar to asbestos can be compared with the past and present of asbestos, after which the effects of social factors on asbestos can be used to produce foresight about possible social influences.

In addition to better control over speculation, using relevant distinctions can not only potentially prevent generalizing, but it also has the potential to prevent certain issues from being associated with nanotechnologies. Due to the nano-hype, the label ‘nano’ can be used to increase the chance to receive research funding (Schummer, 2007), and ethicists also seem to have made use of the nano-hype. Especially in the assessment of nano-enhanced devices, it often is not clear where microtechnology ends and nanotechnology begins. Since there are many definitions of nanotechnology, some use a definition that makes their research qualify for the label ‘nano’. When using relevant distinctions, ethicists can check the link between nanotechnologies and the ethical issues associated with them by analyzing the specific effects/impact a specific type of nanotechnology is likely to cause[15]. If specified that, for

[15] One of the IRGC’s (2006) recommended strategies also includes exploring the plausibility of the link between nanotechnologies and the scenarios in which they are used.

example, Lab-on-a-chip contain certain types of nanotechnology – these being, for example, casting, hot embossing, or injection molding in silicon, glass and polymer materials (Bhushan, 2004) – it can be checked whether that type of nanotechnology already is, or will become, available, or whether the projected use is possible at nano-scale. In Lab-on-a-chip applications there are parts that are now done at micro-scale (Ibid), and it is not yet clear if these parts can be done at the nano-scale. This 'mid-level' ethics prevents issues from being incorrectly associated with the field of nanotechnology.

Regarding the role nanotechnologies play in devices, when specifying the type of nanotechnology embedded in a device, the role can be attached to a type of nanotechnology. If, for example, a type of nanotechnology is found to have certain effects on the human neurological system, these effects can be taken into account in the assessments in future devices containing this type of nanotechnology.

Distinguishing between the types of available nanotechnologies and seeing which ethical issues they actually cause – or are able to cause – offers an additional way of ethically reflecting on nanotechnologies. I expect the additional way of ethical reflection on nanotechnologies to be able to contribute to nanoethics by possibly allowing the three problems found in nanoethical literature to be prevented/solved. It is, however, the question whether there are relevant distinctions to be made that can serve this purpose. If a relevant distinction is found, then it could potentially provide a tool that can be used in an attempt to bridge the gap and show that there are types of nanotechnology that evoke certain (types of) issues.

3. Distinctions

In order to provide a distinction useful for nanoethics, a strategy for finding a distinction is looking at the technical aspects of the different nanotechnologies and how they can be found back in the application of those nanotechnologies. The distinctions discussed in this chapter are inspired by a technical literature study. In this chapter I will list possible distinctions, and evaluate how they can possibly contribute to nanoethics. By doing so, I attempt to choose the most practical distinctions to investigate further.

Contrary to the literature on the field of nanoethics, there is a lot of literature available for the field of nanotechnology. For this thesis it was thus needed to make a selection. Where a search for nanoethical literature pointed to one specific journal and several books, the field of nanotechnology is too big to have a clear starting point for the literature study. In order to still select a sample of literature that is up to date, accurate, and accessible, several sources were used to get the literature study going. As a result, several handbooks and study books advised by experts, such as professionals and students, have been used, as well as review articles found through searching scientific databases to fill in the blanks left by the other literature. Even though the field of nanotechnology is too big to have a complete and detailed overview of what progress had been made, or is expected to be made, I suspect to have made a selection that can serve as a sufficient base for formulating technical distinctions that can prove ethically relevant. There are possibly more relevant distinctions, but the ones chosen in this chapter are the most obvious ones.

From the technical literature it can be concluded that there have already been developed nanotechnologies that are taken into use, both in industrial applications and consumer products. The ways in which nanotechnologies are applied vary widely. Currently nanotechnologies are used in applications such as additives for cosmetics and in computer chips. In the future, however, the use of nanotechnologies is expected to be in a wider range of applications and to fulfill more advanced functions. Figure 3.1 depicts a list of current and future applications[16] as expected by the International Risk Governance Council (2006). The applications depicted in figure 3.1 will be used to help evaluate the distinctions listed in this chapter. The white paper on nanotechnology Risk Governance has been referred to in many pieces of nanoethical literature read for the literature study. Besides that I conclude that the white paper on nanotechnology Risk Governance is reliable due to it being referred to often, I

[16] Here, however, it is difficult to say whether these future nanotechnologies are considered to be nanotechnologies when using the definition used in this thesis, or whether the term nanotechnology has been used rather loosely.

also expect the depicted applications to be a source of ethical issues due to the frequent reference in nanoethical literature. I must note that the future applications depicted in figure 3.1 are speculative, and consequently the discussion of these in this chapter, but this is unavoidable when discussing future applications.

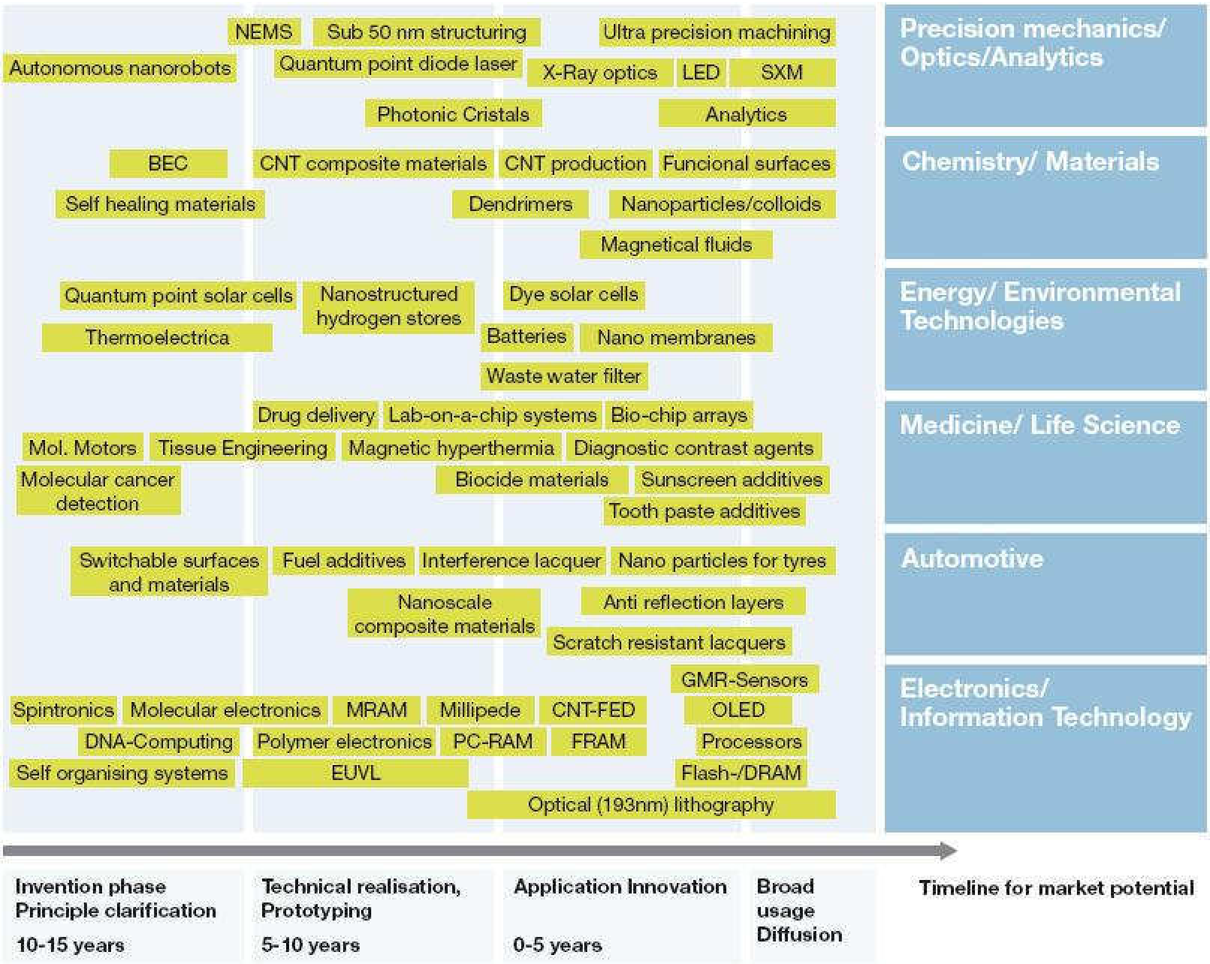


Figure 3.1: Current and future applications of nanotechnologies (IRGC, 2006).

Now that a set of applications of nanotechnology is chosen, there needs to be a list of criteria with which to evaluate the distinctions discussed in this chapter. These criteria have to be chosen in such a way that, if a distinction scores high on these criteria, the distinction is likely to be practically useful and ethically relevant.

The first criterion is that the categories of a distinction should not overlap. A distinction can seem important in theory, but if the nanotechnologies from the different categories of the distinction are used in the same applications, they probably do not evoke different ethical issues and consequently add little to nanoethics. In order to contribute to nanoethics, it is thus needed to have a distinction in which the categories are not used in the same applications. Meeting this criterion possibly allows for solving the generalization problem by showing that there are different categories of nanotechnologies that are not all used in similar applications. Clearly indicating that different categories relate to different uses of nanotechnologies – and likely also different ethical issues – could result in a situation in which the lay public does not see all nanotechnologies as the same.

The second criterion is that the distinction needs to be clearly identifiable in the applications of nanotechnologies. A distinction needs to be useable in such a way that, with using the distinction, it is visible what function nanotechnologies have in the application it is embedded in. By having a clear description of the category of the distinction, the role the nanotechnologies play in the ethical issues the device evokes, or the problem linked to the entire field of nanotechnology, should become clear and thus aid in solving the non-specificity problem: it is specified what the nanotechnologies do exactly. The distinction can aid in identifying the role by showing the relation between the present and expected future possibilities of nanotechnologies, and the functions of the device or general application of nanotechnologies. Other applications with nanotechnologies from the same category can then be assessed also (in part) by borrowing previous assessments in the same category of the distinction. In addition, by knowing the present and expected future role the nanotechnologies in a category can play, the speculation-problem can be controlled by limiting speculation because of the better targeted foresights regarding the role a specific nanotechnology is going to be able to fulfill.

The third criterion is that the ratio of occurrence of the categories of the distinction is such that the distinction is useful. Differentiating between certain nanotechnologies could contribute little to nanoethics if most applications of nanotechnologies fall into only one of the categories, and an insignificant amount of applications use nanotechnologies from the other categories of the distinction. The applied nanotechnologies should thus not all – or practically not all – fall into one of the categories of a distinction. This criterion has a function related to the practical use of the distinction rather than to solving the three problems. It is the case, however, that a practical distinction is needed to even allow the effects of having the first two criteria met to be noticeable.

The fourth criterion is that the distinction should have practical use in policy making. With practical use I mean that, not only should ethical issues related to the categories be identifiable using the distinction, but also that the categories of the distinction can be translated into policy. Policy guides actions to get desired outcomes, and a distinction needs to allow for category-specific guidance of actions; each category of the distinction should have not only its specific problems, but guiding actions – at least at the nano-scale – should be able to be taken to the specific problem causing nanotechnologies. Like the third criterion, this criterion does not aid in solving the three problems found in nanoethical literature, but is one to improve practical use. The use of a distinction should, for example, allow for targeted restriction or stimulation of research. With the distinction nanoethics should be better able to provide policy makers with tools for policy decisions regarding nanotechnologies.

Now that I formulated clear criteria, I will move on to the technical distinctions that have resulted from the technical literature study. I have identified several distinctions, a selection of which I will evaluate in this chapter. The distinctions were chosen on the basis of the technical features found in the sample of technical literature that I expected to be able to prove ethically relevant; by ethically relevant I mean that each category of the distinction has a different way of impacting the applications nanotechnologies from it are used in. In other words, the use of nanotechnologies from different categories should have different consequences that are identifiable in the evoked ethical issues.

The technical literature allowed for the identification of possible distinctions on three levels. First there are distinctions that relate to the way nanotechnologies are produced. In this type of distinction each of the categories represents a different way of producing nanotechnologies, and the nanotechnologies in each of its categories represent nanotechnologies that are produced in a certain way. Of these distinctions the distinction between 'top-down' and 'bottom-up' nanotechnologies will be discussed. Second there are distinctions based on what the nanotechnologies technically do. Of these distinctions the 'nano-materials/nano-patterned materials/smart materials/nano-devices' distinction and the 'newtonian mechanics/quantum mechanics' distinction will be discussed. Third there is a distinction based on the nature of the material produced. This is a distinction based on the technical aspects that make a material, such as the atom-distance, type of atom connection, and similar characteristics. The distinction discussed in this chapter is the 'metal/ceramic/polymer' distinction.

3.1 Top-down and Bottom-up

The top-down/bottom-up distinction is one based on the two possible methods of production. All nanotechnologies are produced through either top-down or bottom-up methods. The two categories refer to the fact that "*Bottom-up* methods arrange atoms and molecules in nanostructures" (Mijatovic et al., 2005, p. 492), and "*Top-down* methods are based on patterning on large scale while reducing the lateral dimensions to the nano-scale" (Ibid, p. 492). These methods thus work from opposite directions: one builds/arranges while the other removes/patterns material. This distinction is helpful for engineers because it indicates methods of production that are clearly different, as are the nanotechnologies produced by these methods. Within the bottom-up method several distinctions can be made as well, such as chemical assembly, biological assembly, self-organization, magnetic assembly, electric assembly, et cetera.

The top-down category shows similarities to the more conventional production methods. It can be said that top-down nanotechnology production resembles modes of production that have existed even before the first industrial revolution, but which are now executed on the nano-scale. What is done in top-down manufacturing is chopping away material and/or patterning material (Ibid): this can be said to be milling, drilling and coating at nano-scale. Some of the methods used in top-down manufacturing are cutting, etching, grinding and lithographing (Ibid). Figure 3.2 shows an example of a form of lithography.

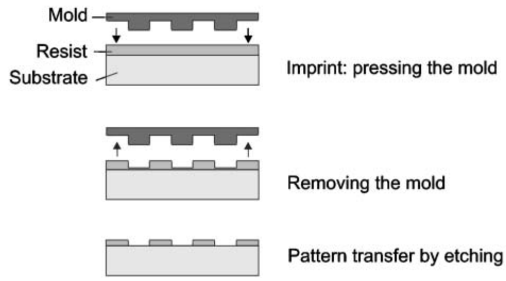


Figure 3.2: Nanoimprint lithography (Mijatovic et al., 2005).

The other method for nanotechnology production is the bottom-up method, and, as the name suggests, this method starts with small parts and assembles these parts into a bigger - or less small - structure. Bottom-up nanotechnology production currently involves either an assembly based on a chemical reaction, biological reaction, or assembly can occur through the intentional positioning of atoms or molecules (Ibid); this process is less controlled and largely relies on natural processes. Although the amount of different atoms is limited, the field of nanotechnology has opened up new possible combinations through manipulation at the nano-scale. Figure 3.3 shows the bottom-up fabrication of polymer tubes.

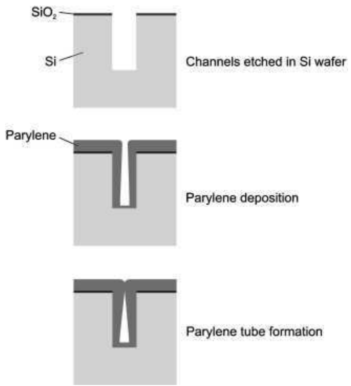


Figure 3.3: The fabrication of polymer tubes (Mijatovic et al., 2005).

Criterion 1 – Overlap

The downside of this distinction is that there are also hybrid methods of production that incorporate both top-down and bottom-up processes. An example of this hybrid production is the production of nano-tubes. Although it seems like a different category than top-down or bottom-up, a case can be made that hybrid

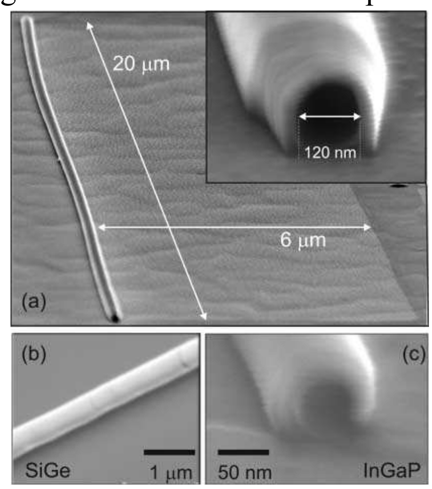


Figure 3.4: Nano-tubes (Schmidt et al., 2002).

methods of production belong to bottom-up methods. The main reason a hybrid is created between the two methods is to gain better control over the bottom-up assembly processes (Mijatovic et al., 2005). This higher level of control is achieved by using top-down techniques to create structures in which a bottom-up assembly can take place. Figure 3.4 shows how a nano-tube and the top-down created structure that determines the start point of the tube-forming.

The case is that when using a hybrid method of production, first a structure is created, and in this structure a bottom-up process takes place (Schmidt et al, 2002). There is thus first a product created using a top-down process. This structured material is not the desired end-product, but the nano-tube that is created in the structured material through a bottom-up process is. The nano-tube is thus the product of bottom-up processes, and the structured material is the product of a top-down process. Because of this, I do not regard letting one method closely take place after the other as a new method of production.

The overlap criterion is met, in the sense that there is no overlap between the two categories, and the effects of both remain analyzable separately. Even though the methods of production hybridize for the creation of certain nanotechnologies, the effect is that created through bottom-up production. When taking a look at figure 3.1 it can be seen that the current applications in the 'Electronics/Information technology' category contain chips. These chips are most likely all patterned with top-down techniques, and bottom-up processes only become a part in the last depicted phase of this category of applications. Applications such as fuel additives, anti-reflection layers, waste water filters, sunscreen additives, and functional surfaces all make use of the unique molecular combinations that can be made through bottom-up processes. Besides the 'Precision mechanics/Optics/Analytics' and 'Electronics/Information technology' categories, all the applications depicted in figure 3.1 contain bottom-up nanotechnologies. There is thus currently little overlap, and the overlap that is expected to occur will be limited.

Criterion 2 – Identifiable

Both categories can clearly be identified in the applications depicted in figure 3.1. The current use of nanotechnologies in 'Electronics/Information technology' is dominantly top-down. Only the applications expected to be used in 10 years here contain bottom-up nanotechnologies. The same goes for the precision 'Mechanics/Optics/Analytics' section, only here autonomous nano-robots and photonic crystals I expect to contain bottom-up nanotechnologies.

For bottom-up nanotechnologies the other categories apply. Besides possibly the functional surfaces, most applications seem to use bottom-up nanotechnologies. Within these uses of bottom-up nanotechnologies even the type of bottom-up method (chemical, biological, self-assembly, et cetera) can be easily detected in some cases.

The distinction thus meets this criterion to the extent that the categories are clearly identifiable in the applications such as depicted in figure 3.1. And, when the category in the applications is known, the capabilities of the used nanotechnologies are also known, leading to a better detection of the part nanotechnologies play in the ethical issues evoked by the application. For example, the 'Electronics/Information technology' category contains applications with top-down nanotechnologies. Here miniaturization is the main function of nanotechnologies, and these top-down nanotechnologies thus play a miniaturizing role. This role can be linked to privacy issues, since the decrease in size of electronic devices is linked to this.

Criterion 3 – Ratio of occurrence

In the applications depicted in figure 3.1, it can be seen that most applications use bottom-up nanotechnologies in all but the 'Precision mechanics/Optics/Analytics' and the 'Electronics/Information technology' categories. In the other categories, however, the applications are expected to be ready for the market later. The earliest applications that incorporated nanotechnologies were in the two top-down dominated categories. Besides certain small applications with bottom-up nanotechnologies (such as sunscreen additives), current applications of nanotechnologies only include top-down nanotechnologies.

The dominance of bottom-up nanotechnologies in the expected applications, however, shows the importance of this distinction. At the time bottom-up nanotechnologies start gaining in applicability potential, it is useful to distinguish so that the different types of nanotechnologies are separable. Between now and five years the increase of applications of bottom-up nanotechnologies will become better noticeable, and the ratio of top-down versus bottom-up nanotechnologies will change.

Distinguishing between bottom-up and top-down nanotechnologies thus meets the criterion of not having a ratio of occurrence such that there is one category of the distinction with an insignificant amount of applications. Although now the nanotechnology market is dominated by top-down nanotechnologies, this is expected to change.

Criterion 4 – Use for policy makers

This criterion is one where the distinction between top-down and bottom-up nanotechnologies scores high. Since the categories of the distinction refer to modes of production, it is easy to regulate the use, production, and research & development in either category; the development of the nanotechnologies in both categories can be guided so that they yield desired outcomes. Especially since criterion 2 is met, the usage of top-down technologies can be linked to certain issues and be governed, hence the distinction between top-down and bottom-up nanotechnologies meets the fourth criterion.

3.2 Nano-patterned materials/nano-particles/smart materials/nano-devices

This distinction differentiates between the levels of functionality that have been given to a piece of material or device through nano-technological processes. Each of the four categories is in a different level of functionality that nano-technological production has given the material or device. The higher the level, the more is possible with the nanotechnologies in that category.

The first and most basic category is the 'nano-patterned materials' category. Nano-patterned materials are the product of a piece of material on which a pattern has been made with dimensions of 100 nanometers or less. Patterning the material is a top-down process, usually a lithographic one. The materials themselves can have any size and be of any source, as long as the pattern applied to it has at least one dimension within 100 nanometers or less. This can, for example, create nano-patterned materials suitable for electric circuits on chips. Figure 3.5 shows the surface of a CMOS chip. New functionality, as opposed to the piece of material prior to the lithographic patterning, is thus gained through creating a pattern on the nano-scale that can be used for applications the non-patterned material cannot be used for. The function here can be providing patterns for guiding, for example, electric circuits or fluids in small volumes; materialistically there is no function fulfilled at nano-scale, but the pattern allows for guiding activity at nano-scale.

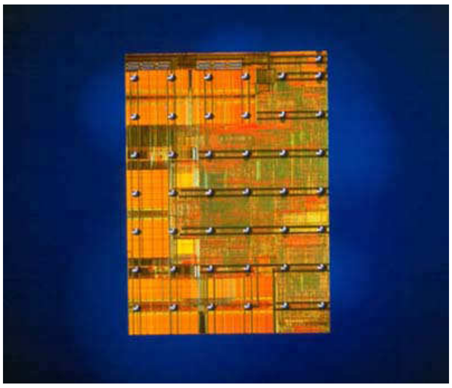


Figure 3.5: CMOS chip surface (Ratner & Ratner, 2002).

The second category basic level is the 'nano-particles' category. A nano-particle is a structure with dimensions at the nano-scale. Examples of nano-particles include nano-tubes (see figure 3.4), buckyballs, and other bottom-up created materials. These nano-particles are all created by assembling atoms or molecules. The applications that make use of nano-particles will use the properties of these particles that they gained from their change in surface to volume ratio. These properties are the changes in conductivity, magnetism, chemical reactivity, et cetera, that were not present above nano-scale. This category differs from nano-patterned materials in the sense that it is not the pattern that defines this category, but the properties that have been gained from working at nano-scale. Also, where nano-patterned materials are made from an already existing piece of material, nano-particles are built atom by atom or molecule by molecule.

The third category is the 'smart materials' category. Smart materials are materials "engineered at the nanoscale to perform a specific task" (Ratner & Ratner, 2002, p.60). Although smart materials are built out of nano-particles and/or nano-patterned materials, they have an added level of functionality due to the task they can perform. Where nano-patterned materials get their functionality from the pattern and nano-particles get their functionality from the new properties at nano-scale, smart materials can utilize either or both of these in creating a material that can react in a way the prior two cannot. The tasks the materials perform can be either static (not reacting to external forces) or dynamic (reacting to external forces) (Ibid). So far there have been developed smart materials that have the added function of self-healing, recognition, separation, encapsulation, et cetera (Ibid). Figure 3.6 shows a zeolite structure of molecules and atoms, which, because of its sift-like structure, is used as a catalyst.

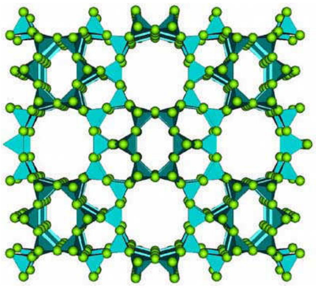


Figure 3.6: Zeolite structure (Ratner & Ratner, 2002).

The fourth category is the 'nano-device' category. Although there are several definitions available of what a nano-device is, some even overlapping with microtechnology (Wolf, 2004), I would like to define the category of nano-devices as the category that houses devices consisting of parts under a 100 nanometers. This definition excludes large devices that have nano-patterned materials embedded in them, and makes sure this category only covers nano-devices such as autonomous nano-robots and not virtually every other application of nanotechnologies. This category is distinct from the other three categories in that it goes one functionality level further because of being more like a conventional device but with dimensions at the nano-scale, not just a material. Where the other categories are lifeless, nano-devices can have a certain level of autonomy due to their mechanical or biological ability to function on their own, or with little external stimulation. In this category thus fall bacteria fighting nano-devices and self-replicating nano-bots, but not computer chips, catalysts, and applications alike.

Criterion 1 – Overlap

Given that the four categories of this distinction can be seen as different levels of functionality, there is a lot of overlap. Three of the four categories can contain nano-particles, yet there are differences in functionality. However, when granting that each category has its own level of functionality, there is no overlap in the application of the categories, which allows for analytic use. Materials that only have patterns with nano-scale dimensions are nano-patterned materials. When an application incorporates nano-particles without any specific task (besides being small) it falls into the nano-particles category. If the application incorporates nano-particles or nano-patterned materials formed into a material that has an added function (besides being small) it falls under the category of smart materials. And last, when a device is built with parts that are under a 100 nanometers it has an even higher level of functionality, and falls into the nano-devices category.

Although technically there is much overlap in the categories, there is not in the applications they are used for. As soon as a certain level of functionality is reached, a new category is entered. In the application of a nanotechnology it is not possible to mistake one category for the other, at least not when looking at the function the nanotechnology fulfills when stripped from the application.

From figure 3.1 the applications in the 'Electronics/Information technology' and 'Precision mechanics/Optics/Analytics' sections to currently contain only nano-patterned materials. Nano-particles can be found in sunscreen additives, particles for tires, magnetic fluids, et cetera for the use of their new properties nanotechnologies have at the nano-scale. Scratch resistant lacquers and fuel additives are examples of nano-particles assembled in such a way that they have self healing and catalyst properties respectively. And in the last phase depicted in figure 3.1 nano-devices such as molecular motors and autonomous nano-robots become available.

Criterion 2 – Identifiable

The criterion of being identifiable is met for this distinction. As shown during the discussion of the first criterion, nanotechnologies from each category are easily found back in the applications depicted in figure 3.1. Due to the different levels of functionality of the categories in this distinction, each category is identifiable in the applications.

The roles nanotechnologies play can be linked with the functionality of each category. In computer chips, as found in the 'Electronics/Information technology' section, the main role can be said to be miniaturizing: chips decrease in size due to the decrease in size of electric circuits. Nano-particles can be linked to other roles, as well as miniaturizing, due to the new properties gained at nano-scale. A difficult category is the ‘smart materials’ category. Smart materials can be, for example, self healing, catalyzing, separating, recognizing, and encapsulating. Due to the abundance of roles, it is hard to provide an overview of the roles smart materials can play, but it is identifiable that the functionality goes further than nano-patterned materials or nano-particles, and that there is not such a level of autonomy as in nano-devices. The role of nano-devices is currently hard to detect and limitless as well. They are scarce and far from being realized technically, but when they do hit the market they will have countless roles in applications. Even though the roles of smart materials and nano-devices are plentiful, this distinction does allow for separating them from the other categories, and the static or dynamic function of smart materials can be identified, as well as the degree of autonomy found in nano-devices.

Criterion 3 – Ratio of Occurrence

As seen in current applications, many already use nano-patterned materials, and nano-particles in the form of smart materials. Nano-devices, however, are only present in applications from figure 3.1 that are expected to be available 10-15 years from now (such as molecular motors and autonomous nano-robots). To indicate how far away the use of nano-devices in applications is, “the smallest mechanical machines readily available in a wide variety of forms are really on the millimeter scale” (Wolf, 2004, p.1).

Besides the lack of currently available applications with nano-devices, the distinction meets the criterion of not having all nanotechnologies in only one category. The nano-patterned materials, nano-particles and smart materials are already in full use, and there are applications for all three categories.

Criterion 4 – Use for policy makers

Since there is a technical overlap in the categories, it might be difficult for policy makers to incorporate the categories of the distinctions into policies. Although the categories might be workable for ethicists, in order to know where to intervene on a policy level it might be needed to re-label the categories of the distinction; it could prove difficult to monitor and control all categories separately. Solving this by re-labeling can entail a simple expansion or replacement with adding a functionality level to each category. For example, for nano-patterned materials this could be functionality level 1, for the nano-particles functionality level 2, for smart materials functionality level 3, and for nano-devices functionality level 4. If each category is labeled with a functionality level policy makers can accurately, monitor, control, and target policy interventions. Re-labeling the categories loses the information that is provided in the names of the categories, but for governing purposes it can prove easier to label a category since it is less confusing. Besides, labels can go accompanied with a clear description. This way there need not be loss of information when re-labeling for governance purposes.

3.3 Metal/polymer/ceramic

This type of distinction describes the types of material formed through nano-technological production. The material produced depends on the distance that the atoms/molecules are apart, the type of bindings, and the electron/ion distribution/ratio. The different materials come with different properties (and transitively different possible applications). At the nano-scale the properties of materials have been combined for new applications, such as polymers with conductive properties.

Criterion 1 – Overlap

It is difficult to say something about how the distinction can be identified in current and future applications, since the applications pictured in figure 3.1 need not necessarily use just one of the types of material or it is unclear which one is used. To judge the applicability, further investigation into the applications of nanotechnologies is needed.

In addition to it being unclear which type of material is used, it also is to be expected that a large part of the applications that use nanotechnologies can be made with several types of material. The overlap between the categories is thus expected to be large, hence the criterion of not overlapping significantly is poorly met by the 'metal/polymer/ceramic' distinction.

Criterion 2 – Identifiable

A note with this distinction is that it is mostly useful to separate bottom-up created materials. When making bottom-up materials, a kind of material is created, and when working with top-down the material is just patterned/reduced in size. This does thus not necessarily mean that it is a distinction not useful for nanoethics, but it will mostly be useful for bottom-up produced materials. A similar distinction is one between different molecules, such as nucleic acids, proteins, carbohydrates, et cetera.

Besides that the distinction is useful mainly to separate bottom-up produced nanotechnologies, it is also poorly identifiable within the applications depicted in figure 3.1. Not only is there an expected overlap, but due to this overlap it is also difficult to identify the role nanotechnologies play in current and future applications. The ‘metal/polymer/ceramic’ distinction thus poorly meets this criterion.

Criterion 3 – Ratio of occurrence

About the ratio of occurrence little can be said at this point. Due to the small amount of products that allow for identification of one of the categories of this distinction, it is not fruitful to state anything about the ratio of occurrence.

Criterion 4 – Use for policy makers

The distinction is, at this moment, poorly identifiable and expected to have a significant overlap between the categories of the distinction. Due to the poor score on the first two criteria, it follows that policies will be hard to make for the categories of this distinction. In general, all four criteria are poorly met, or not enough can be said about it due to the lack of available data on this distinction.

3.4 Newtonian mechanics/quantum mechanics

This distinction differentiates between nanotechnologies that follow the rules of Newtonian mechanics, and those that are small enough so that the rules of quantum mechanics apply. When the rules of quantum mechanics apply, different things are possible. Before reaching the quantum size, differences in properties such as mechanical frequencies, thermal properties, viscous forces, and frictional forces are possible (Wolf, 2004). The changes in properties after reaching quantum size are even more radical. New physical laws apply, which has consequences both at nano level and macro level (Ibid).

Criterion 1 – Overlap

The overlap between the categories I expect to be limited. Although there is too little known about the actual properties of nanotechnologies used in the applications in figure 3.1 to check if they belong to the Newtonian mechanics or the quantum mechanics category, the categories are significantly different and are expected not to overlap.

Criterion 2 – Identifiable

Due to the lack of in-depth technical data gathered on the applications depicted in figure 3.1, it is difficult to use the distinction and identify what the nanotechnologies in the depicted applications do. Expectedly, due to the radical change in properties after reaching quantum mechanical size, the role nanotechnologies play in applications will be clearly identifiable and put in the two categories. However, this distinction has been investigated too little to convincingly meet this criterion.

Criterion 3 – Ratio occurrence
The same as mentioned in the discussion of the previous criteria goes. Due to the unconvincing meeting of the second criterion nothing can be said about the ratio of occurrence.

Criterion 4 – Use for policy makers
If the previous criteria are not convincingly met, there will be little use for policy makers to copy the use of this distinction in policy making. This criterion is thus also not convincingly met. And, like was the case in the previous distinction, not enough data was present on the categories in this distinction to give a conclusive answer about the usability of this distinction.

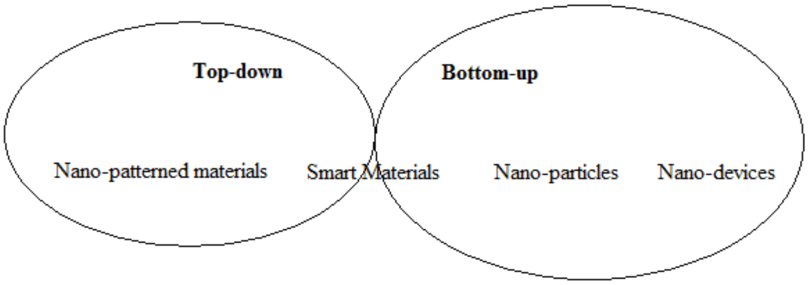
3.5 Chosen distinctions

When looking at the distinctions discussed in this chapter, it follows that the distinction between top-down and bottom-up nanotechnologies and the distinction between nano-particles, smart materials, and nano-devices will probably yield the most fruitful results when using them for the case studies in the next chapter. Both distinctions scored high on all four criteria, and hence lend themselves for further investigation.

The other discussed distinctions scored disappointingly on some or all criteria. The distinction between nanotechnologies abiding Newtonian mechanics and those abiding quantum mechanics is still premature and the field of nanotechnology has not yet developed far enough to formulate a useful distinction based on these categories. The distinction between ceramic, metal, and polymer nanotechnologies suffers mainly from the problem of overlap and identifiability. Having not met these categories is problematic also for the other two criteria.

Now why is it useful to investigate two distinctions and not just one? Are both distinctions not the same in some sense? When having just two categories like top-down and bottom-up that cover all nanotechnologies, it is to be expected that the categories from the 'nano-patterned materials/nano-particles/smart materials/nano-devices' distinction fall into the top-down or bottom-up category. The interesting thing about this combination of distinctions to investigate, is that nano-particles and nano-devices fall under the bottom-up category, nano-patterned materials fall under the top-down category, but smart materials can be either top-down, bottom-up or a combination of the two. See figure 3.7 for a visualization of this overlap. Because of this, the latter distinction is not just a more elaborate version of the former, and investigating both can yield interesting results.

In the rest of this thesis I will explore the distinctions between top-down and bottom-up nanotechnologies and between nano-patterned materials, nano-particles, smart materials, and nano-devices. These distinctions will be used to analyze two cases to evaluate whether they can aid in identifying the problems that the gap in literature brings, and to what extent they can be utilized to bridge the literature gap.



To illustrate what the two distinctions could mean in terms of linking them to applications, figure 3.8 shows a table with both distinctions, a selection of applications, and how which categories of the distinctions occur in the applications.

Two distinctions and applications

	Method of production		**Functionality distinction**			
Applications:	*Top-down*	*Bottom-up*	*Nano-patterned material*	*Nano-particle*	*Smart material*	*Nano-device*
Dye solar cells		X			X	
Waste water filters		X		X		
Sunscreen additives		X		X		
Tooth paste additives		X		X		
Lab-on-a-chip systems	X				X	
Anti-reflection layers		X			X	
Scratch resistant layers		X			X	
Processors	X		X			
Flash-/DRAM	X		X			
Optical (193nm) lithography	X					
Self healing materials		X			X	
Molecular motors		X				X
Molecular cancer detection		X				X
DNA computing		X				X
Self organizing systems		X				X
Autonomous nano-robots		X				X

Figure 3.8: A selection of applications from figure 3.1 and the categories of the distinctions they fall into.

4. Distinctions applied

Now that the distinctions to investigate have been selected, how to proceed in evaluating them? In this chapter the chosen distinctions will be evaluated through applying them to two cases. By first discussing the case, and looking at the extent to which the generalization, non-specificity, and speculation problem are present in the case, I expect the room for improvement in current nanoethical reflection to become clear. It will then be visible, after seeing how the distinctions can be used in these cases, whether they can aid in solving/preventing the three mentioned problems and how they might contribute to nanoethics.

When, during the application to the cases, a distinction allows for exposing the three problems and for adjustment of previous perceptions of nanotechnologies' roles and potential roles, then the evaluation results are positive. Both devices and general issues could be influenced by one, several, or all categories of a distinction. When only influenced by one (or not all) categories of a distinction, that distinction provides potential for solving the generalization and non-specificity problems because it allows for more specific and less general ethical reflection. On top of that, speculation can be controlled due to potentially more accurately extrapolated paths of development. If this is visible in the cases this yields a positive outcome of the evaluation.

The choice of cases with which to evaluate the distinctions requires clear motivation. In order to select relevant cases, I chose to select them on the basis of public perception and actuality. As Cobb and Macoubrie (2004) researched, there are several problems the public[17] associates with the emergence of the field of nanotechnology. The most important ones they found were economic disruption, losing personal privacy, nanotechnology inspired arms race, breathing nano-particles that accumulate in the body and uncontrollable spread of nano-robots (Ibid). Choosing the two problems that are regarded by the public as most important could show the importance of the contribution of the distinctions to nanoethics.

Regarded the most important by the public (with 33%) is losing personal privacy (Ibid). Due to the public's regardance of this problem as most important, this problem will be the first case discussed in this thesis. On privacy issues both general literature that discusses the issues themselves and device-oriented assessments are available. There is thus a body of

[17] Although Cobb and Macoubrie surveyed US public, such research in Europe (Siegriest et al., 2007) shows similar results regarding the risk perception of nanotechnology. A note here, however, is that perception of nanotechnology related privacy issues was not surveyed. Since in Cobb and Macoubrie's research this turned out to be most important, I expect this to be similar in European perception, but have not found literature to backup my expectation.

literature available, with a gap at the place where I expect using a distinction would aid in solving the three problems. The problem with choosing a second case in this manner was that the risk regarded as second most important (by 22%) was a nanotechnology inspired arms race, which is an issue that I regard more general and indirect[18] and have not included in the scope of this thesis. For this reason the third most important risk (19%), namely the breathing of nano-particles that accumulate in the body will be used as the second case to test the distinctions on. This is already a pressing issue, whereas the privacy scenarios focus on somewhat distant applications of nanotechnologies. In this chapter I will evaluate the distinctions using privacy issues and nanotoxicology issues.

4.1 Losing personal privacy

With the further emergence of the field of nanotechnology, a severe decrease in personal privacy is expected to take place (Weckert, 2009). The more a person is exposed to surveillance devices, the less privacy he has or "the *less* one's life is subject to being searched, the *more* privacy one has" (MacDonald, 2004, p. 1). Although nanotechnologies do not pose any fundamentally new issues, nano-electronics is expected to develop in such a way that information can be gathered, distributed and stored more easily; there are thus expected to be more practical privacy issues. This brings with it problems of not being able to know what data about a person is acquired, and problems of illegal access to this data (van den Hoven, 2008); new monitoring devices become almost invisible with nanotechnologies, and wrongdoers can, when having access to this data, for example, steel someone's identity.

There are at least two types of privacy issues accompanying the emergence of the field of nanotechnology. The first is caused by the decrease in size of devices so that they are nearly invisible. Decreasing in size is something that can be linked to nanotechnologies without giving it much thought, since the goal of the field of nanotechnology is to work at the smallest possible scale. The changing material properties are an effect additional to the decrease in size though, so this phenomenon has to be taken into account as well when reflecting on nanotechnologies.

The second type of privacy issues concern data-protection. These issues are not new[19], and similar for devices at a larger scale, but the almost invisibility of devices increases the

[18] I regard the nanotechnology inspired arms race as general and indirect because the case would include any type of nanotechnology, and a lot of different applications (computers, biological organisms, mechanical weaponry, et cetera.). Using it as a case study would thus not likely yield interesting results, because practically any nanotechnology can be harnassed in an arms race.

[19] Of course the decrease in size of devices is also not new, but engineering on the nano-scale could result in devices unnoticeable to the naked eye.

chance of wrongdoers abusing personal data. For this case I will look mainly at the decrease in size of privacy-endangering devices as something nanotechnologies have contributed to. Data protection issues are also important, but I chose to limit the scope of this thesis to size-related issues. I expect focusing on size-related issues is more likely to yield results that are nano-related, and I also expect the less novel data-protection issues to support the claim that there is no separate field of nanoethics necessary. By focusing on miniaturization I hope to be able to indicate the usefulness of the distinctions in an issue where nanotechnologies could clearly play a part.

In order to gather a collection of literature that allowed identifying the issues, devices, ethicist views, technical expert views and the nanotechnologies involved, privacy-related readings done for previous chapters were gathered and used as a starting point. From here, additional ethical literature was gathered by using databases such as Google Scholar and keywords such as 'privacy and nanotechnology', 'privacy and RFID', 'Smart Dust and nanotechnology', et cetera. In addition, technical literature on the mentioned devices was gathered using the same databases and the device names as keywords. With this collection of literature[20] both ethical and technical data was used while studying the privacy case.

4.1.1 The devices

Now how exactly can the nano-enabled miniaturization of electronic devices result in privacy limitations? One example is miniaturized surveillance. Cameras can be made so small that they are unnoticeable. However, I regard this as an unlikely and speculative scenario. First of all, it is true that progress has been made with nano-scale photoconductive film (Gutierrez, 2004), but I doubt whether this will become practical, or even possible, at the nano-scale. And secondly, with such applications it is likely that regulations will forbid its use, or even its production. On a European level, for example, the Data Protection Directive[21] from 1995 contains regulations for the gathering and movement of personal data. Measures are developed in the scope of this directive, and I regard it likely that this hinders privacy-endangering usage of nano-enhanced devices. However unlikely privacy-endangering use of nano-enhanced devices may seem, it remains the case that ethical reflection can be used as an aid in formulating restrictive policies for emerging privacy-endangering devices and technologies.

[20] An overview of all nanotechnology/nanoethical articles read can be found in the appendix.
[21] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31995L0046:EN:HTML

An example that I do regard as realistic, and in which nanotechnologies are likely playing – or are going to be playing – a role, is identification applications. These identification applications are available already in the form of Radio Frequency Identification (RFID) tags. RFID tags are tiny transponders that can be read with radio frequencies (Avoine & Oechslin, 2005). The most important feature of the tags is that they allow for "the identification of objects in an environment, with neither physical nor visual contact" (Ibid, p. 125). An example of how this can be used is in biomedicine is the implantation of an RFID tag to store information about a person's physical health (Boenink, 2008), which means that person has a readable health status everywhere without physical contact.

The way RFID tags are read is by having a reading transponder send a request to the RFID tag, which in return responds. RFID tags have to wait for a signal because they are passive, which means that they need the reading transponder to supply electrical or magnetic energy, because the RFID tag does not have its own source of energy (Avoine & Oechslin, 2005). The communication range is only several meters due to the regulatory limits put on RFID tags, although "non-conforming equipment could exceed these limits" (Ibid, p. 128).

Another type of device that can potentially impact privacy is Smart Dust. Smart Dust is the name used for a small system that can autonomously sense, compute and communicate (Warneke et al., 2001). This application finds its use mainly in monitoring applications. Smart Dust applications differ from RFID tags in that Smart Dust is more autonomous due to its own power supply.

The focus on RFID and Smart Dust tags excludes a lot of other devices from the analysis. I regard RFID and Smart Dust tags as representative for at least the start of possible nano-related privacy issues. Most other devices mentioned in the literature read serve similar purposes, and are based on similar nanotechnologies. I also left out novel devices such as nano-scale photoconductive devices, which could certainly start playing a role in the future. There is, however, not enough known about such applications to include them in this case analysis.

4.1.2. The issues

There are endless possible ways imaginable in which RFID and Smart Dust tags can contribute to a loss of privacy. A large part of these problems can be prevented by adequate laws and regulations, yet there will likely always remain ways to surpass these laws and regulations. To illustrate a way in which privacy can be lost when RFID technology and

Smart Dust are miniaturized to the level of being practically invisible, I shall elaborate an example that involves the use of technologies such as RFID and Smart Dust.

One example scenario that contains recurring elements from the scenarios sketched in the literature read for this thesis is that all consumer products in stores will be equipped with an RFID or Smart Dust tag. RFID tags are passive, and require to be read in order to get information from it, but Smart Dust is not, since it can be equipped with its own power supply. This adds some functionality to Smart Dust tags that RFID tags do not have.

To prevent others than the owners to read the tag, security measures have been developed (Avoine & Oechslin, 2005). This makes sure only the one placing the tag can read the data on it. If you buy a pair of pants in a store from a certain chain, all stores of that chain are likely to be able to identify that pair of pants as one bought from their chain. This in itself is something I expect – especially in European countries due to the Data Protection Directive – that consumers will be made aware of when this system is implemented, so then it becomes a conscious trade-off; consumers know that stores can trace the pair of pants, yet they do not care about that, or their desire to buy that pair of pants has the upper hand.

Even though outsiders cannot read what is on the tag due to security measures, it is possible to identify the type of tag. It is expected that there will be different types of RFID and Smart Dust tags, some of which are likely to be used for different applications (Ibid). This could result in outsiders being able to identify the tag in the purchased pants as a tag used in certain types of clothing. When identifying a combination of tags (e.g. clothing, food, and medicine) an amount of information about a person can be exposed to others, and privacy is lost. When using Smart Dust there are additional problems. Not only can the type of tags be accessed, the tag itself is also able to send information due to having a power supply. This could mean that the use of this type of tags can even move outside of the store.

This is one example of ways in which RFID and Smart Dust tags can contribute to a loss of privacy, and this can have undesired consequences or violate societal principles. Van den Hoven and Vermaas (2007) formulate four ways in which the privacy sensitive data extracted from, for example, RFID[22] tags can be used in a way that disadvantages the consumer. First is the prevention of harm due to the information given away about the consumer. Identity theft is one example, but junk mail-like practices could also result from the exposure of one's personal data. Second there is the loss of control over the information that

[22] Van den Hoven and Vermaas (2007) use the example of RFID tags. They do mention other devices, but focus on RFID tags because they see it as a 'core' technology in privacy issues related to tracking, tracing and surveillance.

is useful for companies. Companies would not need to use discount cards anymore in order to acquire purchase information, hence the consumer lost something that had value when it was private. Third is the unjust way in which information can be used. If insurance companies know about, for example, the collection of snowboards a person has, the health insurance policy is possibly made more expensive due to that person's expected hazardous past-time activities. Fourth there is the loss in moral autonomy. When a person knows he is now monitored he might live his life a certain way, yet if he knows others know certain things about him due to, for example, the groceries he does, that person is bound to live his life different. The exposure of some of this person's private data to companies or wrongdoers thus takes away a certain extent of control that person had over his life, making him less autonomous.

4.1.3 Three problems

The first problem, being the generalization problem, is one that is quite convincingly present in the privacy case. Privacy loss is associated with nanotechnologies in general, and although there are specific devices pointed at as causing the problems, both general assessments and device-oriented assessments do not distinguish between types of nanotechnology. Paul Litton (2007) for example, first discusses a loss of privacy due to nanotechnologies, then mentions "cheap, invisible devices that could be implanted in clothing and household appliances to gather and wirelessly transmit information" (Ibid, p. 24) which could have nanotechnologies embedded in them, yet does not mention the nanotechnologies involved. The same goes for all ethical literature on privacy issues read for this thesis[23]. This absence could lead to the reader inferring that all nanotechnologies come with privacy problems.

Closely connected to this generalization is the non-specificity problem. It is not explicitly discussed what part of the device carries the label 'nano', but just that applications like RFID and Smart Dust tags could have nanotechnologies embedded in them, and thus have a link between privacy problems and nanotechnologies. What role nanotechnologies play in the evocation of the privacy issues is not clear, and it is also not clear whether the privacy issues[24] are new and unique to nanotechnologies or not; the only thing clear is that nanotechnologies are linked to the miniaturization of devices. Although not all literature

[23] An overview of all nanotechnology/nanoethical articles read can be found in the appendix.
[24] Here I mean miniaturization issues, not data protection issues, because they are generally not seen as new in nanoethical literature, just of increasing importance due to the becoming increasingly unnoticeable of privacy-endangering devices.

mentions specific devices, the non-specificity problem is present in all the ethical literature read for this thesis.

A similar unclarity is seen with the amount of speculation that is involved in the scenario. When the exact role of the nanotechnologies in the device is not explicated, prediction could be based on expectations of the path of development of the RFID and Smart Dust tags, regardless of the used nanotechnologies' development path; from the literature read it is not clear whether the nano part of the envisioned RFID tags is technologically and economically feasible. Recent technical literature (Kamins, 2009; Wong et al., 2009) contradicts the claim that the nano part of the discussed devices, namely CMOS circuits, can be used in the envisioned way – by, for example, van den Hoven and Vermaas (2007), Litton (2007), and Rodrigues (2006) – and have implications on privacy additional to the impact of current devices.

All three problems with current nanoethical literature are thus present in the loss of personal privacy case. Nanotechnologies are generalized, the role of nanotechnologies is unclear due to the non-specificity problem in the case, and there is speculation, of which level and reliability is low or unknown. It will now be interesting to see how analyses with two of the formulated distinctions can aid in solving these problems.

4.1.4 Top-down and bottom-up

RFID and Smart Dust tags are based on CMOS circuits (Landt, 2005; Warneke et al., 2001). These CMOS circuits are made by applying several layers of coating, after which patterns are created using lithographic processes (Choi et al., 2001). Lithography is a top-down production method (Mijatovic et al., 2005). Currently, RFID and Smart Dust tags thus contain a top-down produced nanotechnology. It cannot, however, be claimed that bottom-up produced nanotechnologies will never play a part in privacy issues, but only that current and near-future privacy-endangering applications do not contain them[25].

Now that the category of nanotechnologies in current privacy-endangering devices is specified, what can be said about the role of nanotechnologies in these applications and the loss of privacy? The role nanotechnologies seem to play is that of miniaturization enabler. Knowing that it are the top-down fabrication techniques that could allow for the prefix 'nano'

[25] There is foresight about utilizing nano-wires – which is a bottom-up produced nanotechnology – in CMOS circuits because of their conductive properties (Gutierrez, 2004). However, these nano-wires are developed for use in CMOS circuits in computers, and it is not sure whether they will be technically and economically feasible for use in RFID and Smart Dust tags.

in the RFID and Smart Dust tags, it is unclear how much overlap there is between micro-[26] and nanotechnologies in the application sizes that are problematic. After all, it can very well be the case that RFID tags with CMOS circuits of micro dimensions cause similar – or the same – privacy issues. This is an important insight. Specifying the type of nanotechnologies provides insight in how nanotechnologies are different, or similar to, other technologies. In the RFID tags case this specification shows that the used nanotechnology's purpose is to miniaturize and that the difference with microtechnology is unclear in this case.

That microtechnologies might have a similar impact as nanotechnologies could prove that the privacy issues are not nano-specific, or that they have not become more severe with the emergence of the field nanotechnology. What this could mean is that ethically reflecting on microtechnology – or even other technologies – will suffice for nanotechnologies as well, and no new field of ethical inquiry is needed.

When specifying the category of nanotechnologies, not only the role becomes clear, but also the technical feasibility. Currently the lithographic processes can only be used to produce dimensions of 193 nanometers or more (Kamins, 2009; Wong et al., 2009). It is possible to create CMOS circuits with smaller dimensions, but this is currently not economical, and is expected to remain a laboratorial endeavor. Ethicists are thus using poor speculation, or are maintaining a broader definition of nanotechnology that overlaps with microtechnology. Ethicists claim that "RFID foreshadows what nano-electronics has in store for our privacy: invisible surveillance" (Van de Hoven & Vermaas, 2007), but it actually is uncertain whether the optical-insignificance boundary can be crossed with RFID tags. This could lead to an as less problematic perceived impact of the field of nanotechnology on society's privacy, because it becomes clear that privacy issues are not new or unique to nanotechnologies, as well as ethical reflection that is less deflected from current issues due to uncertain scenarios.

In the privacy case, distinguishing between top-down and bottom-up nanotechnologies could show the miniaturization role nanotechnologies play in the privacy-endangering devices, and call the link with nanotechnologies into question due to the issues also being related to different and less small technologies. In addition, exposing the speculative character – and moreover that it is contradicting expert expectations – has become possible due to the contradicting expert foresight about top-down produced nanotechnologies. This contradictory foresight exposes the link with nanotechnologies as being a speculative and uncertain one.

[26] Microtechnologies have dimensions between 100 nm and 500 µm (Wilding et al., 2006).

Distinguishing between top-down and bottom-up produced nanotechnologies, in this case, allows for questioning the link with nanotechnologies; theoretically it might be possible that nanotechnologies will become of practical use in privacy-endangering applications, but when looking at privacy scenarios and technological foresight, it becomes clear that if it does happen, it will be in the distant future.

4.1.5 Nano-patterned materials/nano-particles/smart materials/nano-devices

For this distinction certain things can be translated from the previous discussion of top-down and bottom-up produced nanotechnologies. Given that only top-down nanotechnologies are used in current RFID and Smart Dust tags, it is only necessary to look at nano-patterned materials and possibly smart materials. Current monitoring technologies such as RFID and Smart Dust tags are based on CMOS circuits (Landt, 2005; Warneke et al., 2001). The type of nanotechnology used in CMOS circuits, and that thus plays a role in privacy issues, is nano-patterned materials. Smart materials can also get their function from the top-down patterning at the nano-scale. These smart materials, however, get additional functionality[27] from the patterning, which is not present in CMOS circuits[28]. So, only nano-patterned materials are used in privacy-endangering devices. Here, again, I must note that I claim this to be for current and near-future applications, and am not excluding the other categories from playing a part in the distant future.

For the problem of generalization this means that apt communication about the actual nanotechnology type involved could lead to refraining from generalization. RFID and Smart Dust tags can be seen for what the devices do, but also nanotechnologies embedded in the tags become clear, as well as the nanotechnologies not embedded in the tag.

The information about the nanotechnologies embedded in the involved devices provides insight into the role of nanotechnologies in the privacy issues. Nano-patterned materials are the most basic type of nanotechnology, and are basically just applicable for decreasing the size of patterns in, for example, CMOS circuits. This insight provides clarity about the size-decrease enabling role nanotechnologies play in privacy issues, and that the decrease in size can be attributed to nanotechnologies, whereas the other functions cannot. The non-specificity problem can thus be solved to the extent that the role of nanotechnologies

[27] See chapter 3 for more detailed information.

[28] For Smart Dust I can imagine that smart materials will be used as an aid in power generation, but I have not found any literature that confirms my suspicion. Since I do not want to make ungrounded claims, I am leaving this out of my analysis.

is known due to the functionality of the nano-patterned materials, and can be separated from the other functions of the involved devices.

About the speculative nature of the privacy scenarios a lot can become apparent as well. Like mentioned before, with top-down there currently is no manipulation possible at the nano-scale on CMOS circuits that is economically usable in RFID or Smart Dust tags (Kamins, 2009; Wong et al., 2009). Such scenarios can be discarded due to their unlikelyness, and ethical reflective attention can be paid to other nanotechnologies and the issues they evoke. The same conclusion is reached as with the top-down/bottom-up distinction, also with regards to the need for an ethics of nanotechnology to deal with these issues.

The distinction between nano-patterned materials, nano-particles, smart materials, and nano-devices is thus applicable in a similar way as the distinction between top-down and bottom-up produced nanotechnologies. The generalization problem found in literature that discusses only the general emergence of the field of nanotechnology or mentions specific devices can be solved by showing that only nanotechnologies from one of the four categories currently contribute to the issues. Non-specificity found in literature that attributes effects of devices to nanotechnologies is solved by showing the role specific nanotechnologies can play, and discarding the attribution of other functions to nanotechnologies. This goes for RFID, Smart Dust and applications alike. Also speculation can be controlled due to the becoming apparent of unrealistic scenarios.

4.2 Nanotoxicology

The environment is a major concern these days, and nanotechnologies are expected to impact it negatively. Not only will nanotechnologies pose a threat to the environment, but exposure is also expected to have effects on human health. Largely the effects are uncertain or unknown, but the already available research data shows that there are new threats to the ecosystem and human health (Oberdorster et al., 2005; Kagan et al., 2005; Donaldson et al., 2004).

Nanotechnologies have already found their way into numerous applications like sunscreens, cosmetics, fuel additives and several electronic applications (Oberdorster et al., 2005). Although the applications are already plentiful, nano-particles are in some cases considered not to pose any additional risk to their bulk form (Faunce et al., 2008). Products are thus allowed to enter the market without prior extensive research that has shown the effects on the environment and human health.

Laws and regulations[29], for example, require manufacturers of materials to provide information for the materials they supply. In this information the properties of the material need to be listed. These properties include acidity, hazardous amounts of exposure, ways to handle the material, what to do when exposed to the material, et cetera. This seems like an adequate law-enforced measure to deal with materials that might be hazardous, yet with the emergence of nanotechnologies this requirement could prove to fail in serving its purpose of minimizing ecological and health damage. These requirements are for bulk material, meaning pieces of material way larger than materials at the nano-scale. When providing nano-scale material it would thus legally suffice for manufacturers to provide information for the bulk material (Oberdorster et al., 2005). Buckyballs, for example, could be accompanied with an information sheet for carbon, while buckyballs have proven to have different toxicological properties than regular sized and shaped carbon (Service, 2004).

The shape and size of nanotechnologies are expected to have not only desired effects, but through production, use and disposal, impact the ecosystem and human health in a negative way. Nanotoxicology has emerged as a new field (Oberdorster et al., 2005). And, although research is still being conducted, laws and regulations fall short when it comes to dealing with uncertainties regarding nanotechnologies (Faunce et al., 2008).

In order to gather a collection of literature that allowed identifying the issues, possible applications, ethicist views, technical expert views and the nanotechnologies involved, nanotoxicology-related readings done for previous chapters were gathered and used as a starting point. From here, additional ethical literature was gathered by using databases such as Google Scholar and the keywords ‘nanotoxocology’, ‘nanotechnology and environment’, ‘toxicology and nanotechnology’, et cetera. In addition, nanotoxicological literature was gathered by using the same databases and keywords. This collection of literature incorporates both ethical and nanotoxicological data, and allows for considering the ethical and technological aspects when discussing the nanotoxicology case.

4.2.1 The issues

How does the combination of a lack of regulation and the unknown risks result in new issues? Human beings, as well as the environment, have always been exposed to nano-sized particles in natural ways and through current industrial processes (Oberdorster et al., 2005). Why is it

[29] In Australia the Industrial Chemicals Act from 1989, in Japan the Chemical Substances Control Law (Law No. 117) from 1973, in the United Kingdom the Notification of New Substances Regulations from 1993 together with the Registration, Evaluation, Authorisation and Restriction of Chemicals, COMM from 2003, and in the United States the Toxic Substances Control Act from 1976 (Bowman & Hodge, 2007).

becoming an area of concern with the emergence of the field of nanotechnology? One reason is that the exposure to nano-sized particles is increasing; with the increase in production, use and disposal of nano-sized particles and products containing nano-sized particles, contact with human beings and the environment will occur more frequent (Ibid) and engineered nano-particles are smaller.

A second reason for the increased attention with the emergence of the field of nanotechnology are the new shapes created at nano-scale. The level of toxicity of nano-sized particles differs when shapes are different. Nano-tubes, for example, can have a width/length ratio that places them under the category of being a fibre. Small fibres like nano-tubes have been shown to cause fibre-shape related physical responses (Ibid). Tests with mice have shown carbon nano-tubes to cause inflammatory reactions in the lungs (Kagan et al., 2005). The new possible shapes thus bring additional toxicological properties.

Now why are small nano-sized particles more toxic than the same weight dose of regular-sized particles of a material? Besides the shape, surface area is also important. Nano-sized particles have a greater surface to weight ratio (Oberdorster et al., 2005). This allows for "greater biologic activity per given mass compared with larger particles" (Ibid, p. 824). Greater biologic activity can have effects such as antioxidative activity and being able to penetrate the blood brain barrier. These effects can be used for desirable applications. There are, however, also negative effects of the increased biologic activity, such as being toxic, inducting oxidative stress, and cause cellular dysfunction (Ibid).

So far there have been two types of research into the toxicological problems related to nano-sized particles: rodent studies and ecotoxicological studies (Ibid). The former type was conducted with the goal of finding out potential health effects of nano-sized particles, and the latter to find out the effects nano-sized particles can have on the ecosystem. During the studies on laboratory rodents, results showed the ways of exposure to nano-sized particles, the routes of distribution in the body, and the health effects experienced after the exposure to nano-sized particles (Ibid). The most important conclusions from these studies were that nano-sized particles do have negative health impacts, and that these are caused by the relatively large surface area and the shape of the nano-sized particles.

The ecotoxicological studies showed the impact nano-sized particles have on the ecosystem. Studies were carried out on several species that regulatory agencies see as "models for degining ecotoxicological effects" (Ibid, p. 827). Research showed that nano-sized particles such as nano-tubes can have negative health effects on species like the largemouth bass. Also, results on the way nano-sized particles move through the ecosystem provided insight into the potential negative effects of nanotechnologies. Figure 4.1 depicts the routes nano-sized particles can travel to, and through, the ecosystem.

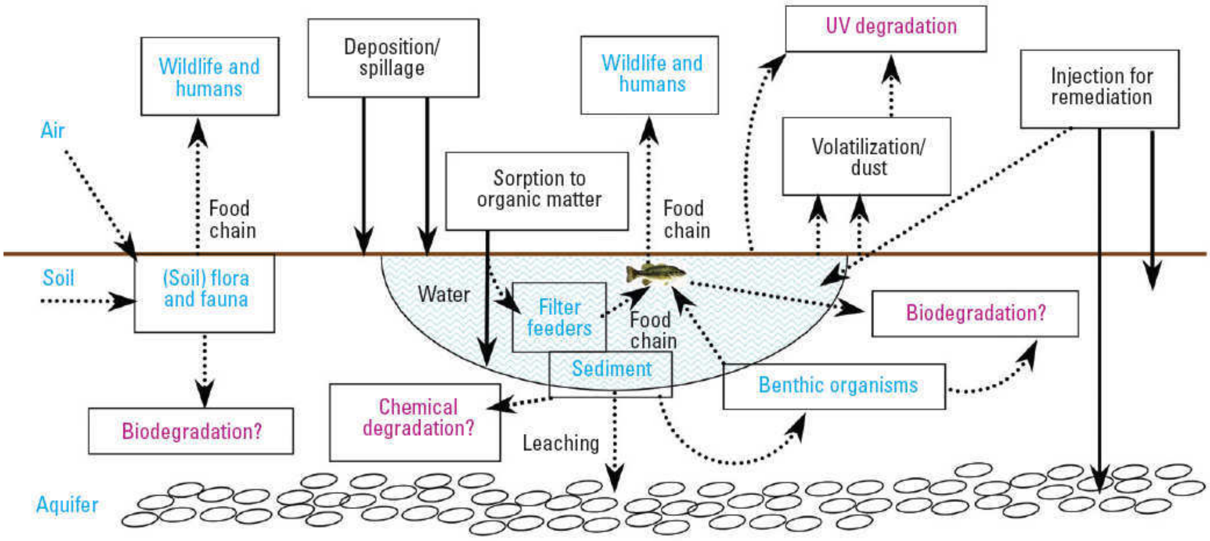


Figure 4.1: Routes of exposure, uptake, distribution, and degradation of nano-sized particles in the environment (Oberdorster et al., 2005).

Nanotoxicological literature indicates risks for human health and the ecosystem because of the use, production and disposal of nanotechnologies; besides the benefits there are several down-sides. There is, however, also a high level of uncertainty regarding several factors. It is currently not known how dangerous nanotechnologies exactly are toxicologically. This creates the dilemma of having an emerging field of nanotechnology, yet not knowing completely how and where to steer it into a desirable direction.

The risk perception of course results in problems with regulating nanotechnologies. Usage of nanotechnologies can be accepted knowing it might have negative impact on the environment and human health, or measures can be taken to deal with these risks. There is thus the dilemma of accepting the risks and carrying on use of nanotechnologies, or implement regulations to control the level of risk taken in use and research. This indicates that ethical reflection on the toxicological problems is difficult without adequate toxicological research, but also that ethical reflection can indicate where toxicological research is needed, or needed more.

4.2.2 Three problems

Now how can the problems of generalization, non-specificity and speculation be found back in the literature on nanotoxicology? The ethical literature on the topic was generally not very specific. Most general literature places a link between nanotechnologies and toxicological issues. It is, for example, mentioned that the use, production and disposal of nanotechnologies could result in tiny particles entering the environment or the human body, but it is not specified which nanotechnologies cause these risks. It is, however, clear that the size of the nanotechnologies causes the toxicological problems. This thus does not contribute to the non-specificity problem because it is clear how nanotechnologies contribute to the toxicological issues.

The problem of generalization of nanotechnologies is the problem that is most severe in the case of nanotoxicology. In the literature sometimes general claims are made such as "Whereas the potential health and environmental benefits of nanotechnologies have been welcomed, concerns have been expressed that the very properties that are being exploited by researchers and industry (such as high surface reactivity and ability to cross cell membranes) might have negative health and environmental impacts and, particularly, that they might result in greater toxicity" (Royal Society, Royal Academy of Engineering, 2004, p. 35). This general impression of toxic nanotechnologies that ethical literature contributes to is an effect of regarding any nanotechnology not only to be toxic when coming into contact with humans or the environment, but also to be hard to produce, use and dispose of without this exposure to humans and the environment happening. In ethical literature nanotechnologies are thus, at times, generalized as being a danger due to its toxicity and difficult handling.

Last there is the speculation problem. When discussing toxicological issues, the nanotechnologies contributing to the issues are known through nanotoxicological literature. The field of nanotechnology has reached a level in which the basic structures, such as nano-tubes, have been developed. These are the basic structures that are possibly in risk of being exposed to humans or the environment. There is thus no speculation needed as to what nanotechnologies can be problematic, or about how problematic nanotechnologies will behave in future applications, because the problematic nanotechnologies are known and have already been developed. The effect these problematic technologies have is, however, researched too little to confidently claim to have a good overview of toxicological effects of hazardous nanotechnologies. Here, for example, research is done on rodents (Oberdorster et al., 2005), after which results are speculatively translated to having similar effects on humans. Claims like this are used in nanoethical literature to speculate about the impact of products containing nanotechnologies on human health and the environment.

The generalization problem is present in nanoethical literature, as is the speculation problem to the extent that there are still uncertainties about the toxicological effects. Although the non-specificity problem is not present because nanotechnologies' role in the toxicological issues is the same in all applications, the generalization problem is present to a large extent. There are thus two of the three problems present in nanoethical literature that discusses nanotoxicological issues.

4.2.3 Top-down and bottom-up

What can the distinction between top-down and bottom-up produced nanotechnologies be used for towards solving the generalization and speculation problem? Ethical literature does not, or very little, mention specific nanotechnologies. So here attention is needed. The field of nanotoxicology can be defined as "science of engineered nanodevices and nanostructures that deals with their effects in living organisms" (Oberdorster et al., 2005, p. 824). The nanotechnological objects of study in nanotoxicology are thus nano-devices and nano-structures, which are bottom-up produced nanotechnologies[30]. Transitively this means that top-down nanotechnologies do not pose any new toxicological threats; top-down nanotechnologies are only as toxic as the material that is used, of which the silicon of CMOS circuits is an example. This is because with top-down manufactured nanotechnologies the surface area changes little, and only the pattern of the surface changes. Taking this into account in ethical literature would make it a reflection on bottom-up created nanotechnologies. This also follows from the sometimes mentioned examples such as buckyballs (Service, 2004) and carbon nano-tubes (Oberdorster et al., 2005), which are never top-down created nanotechnologies.

When specifying that only bottom-up nanotechnologies are – and should be – subject of nanotoxicological research, the role these nanotechnologies play in the new toxicological issues could also become clearer. Since for bottom-up nanotechnologies their properties are gained partly because of their relatively large surface area, it becomes clear that the change in ratio of inside to outside of a material is what causes the increased biological activity; the role bottom-up nanotechnologies play in the toxicological issues is to increase biological activity and hence, in combination with their cell-penetrating size, pose new threats to the ecosystem and human health. From this it follows that ethical issues related to toxicological effects are only caused by bottom-up produced nanotechnologies. This means that ethical reflection and political intervention needs to only concern bottom-up produced nanotechnologies.

Now the speculation problem, as present in the nanotoxicological literature, concerns speculation about the translation of animal test results into possible effects on humans. This is

[30] See chapter 3 for more detailed information.

not speculation about possible applications of nanotechnologies. To decrease uncertainty brought by this speculation, the distinction between top-down and a bottom-up produced nanotechnologies is of little to no help. A minor point where the distinction can prove useful is the exclusion of nanotoxicological scenarios that give a role to applications containing just top-down produced nanotechnologies. Top-down nanotechnologies do not pose new toxicological issues in their production, use, and disposal.

In the case of nanotoxicology the distinction between top-down and bottom-up produced nanotechnologies can aid in showing that not all nanotechnologies pose toxicological threats. The help in the speculation problem is limited however, since the distinction can only aid in excluding certain top-down nanotechnology scenarios from the more realistic scenarios. The non-specificity problem was not present to begin with since the effects of nanotechnologies in the toxicology case are clear.

4.2.4 Nano-patterned materials/nano-particles/smart materials/nano-devices

As discussed previously, nanotoxicological issues concern bottom-up produced nanotechnologies. This excluded nano-patterned materials[31]. The nanotoxicological issues occur during the production, use, and disposal of nanotechnologies. Since the aspect of the categories that matter are the higher surface-volume ratio attained at nano-scale, it has no use to discuss the categories separately from each other; different levels of functionality does not seem to matter, only the higher biological activity due to the change in surface-volume ratio.

Due to the functionality level being irrelevant for the nanotoxicological issues, the way in which the three problems can be solved is similar to how a distinction between top-down and bottom-up nanotechnologies can aid in solving them. Here nano-patterned materials represent top-down produced nanotechnologies, and the other three represent bottom-up produced nanotechnologies. However, it can become problematic that smart materials can also contain top-down nanotechnologies. In order to make it less problematic an additional distinction needs to be made between top-down created smart materials and bottom-up created smart materials so as to prevent confusion.

This distinction, as is, thus provides no further insight than the distinction between top-down and bottom-up nanotechnologies. The distinction has needless many categories for dealing with the three problems in ethical nanotoxicology reflection, of which the smart materials category is even problematic in this case. That the level of functionality of importance is the biological reactivity already found in nano-particles, is the main reason that

[31] See figure 3.7.

the top-down/bottom-up distinction is more convenient in the case of nanotoxicology. Although the nano-patterned materials/nano-particles/smart materials/nano-devices distinction can be of use in this case, it has needless many categories and one that only applies to this problem partially. Therefore it adds little to the previously discussed top-down/bottom-up distinction.

5. Conclusion

In this final part of this thesis I will discuss the conclusions I reached during the research. I will discuss the possible effects of using a distinction, as well as the two chosen distinctions and their possible contribution to nanoethics. Before doing this, it might be useful to shortly reflect on how use is already made of taxonomies in nanoethical literature. Now to what extent were the chosen taxonomies already used?

Especially in the ethical literature on toxicology, specifications of the types of nanotechnologies used were found. Specific examples of nanotechnologies were linked to the issues, yet it was not clear if just these nanotechnologies caused the issues, or if it was a problem applicable to all nanotechnologies. There are thus articles from which it is clear, and only the contributing nanotechnologies are reflected upon in some cases. Yet, in the nanotoxicology case, the talk of the specific nanotechnologies – nano-particles and nano-devices – went further in differentiating than the distinction between top-down and bottom-up produced nanotechnologies, because nano-particles and nano-devices are both bottom-up produced nanotechnologies. The differentiation did, however, not go as far as the nano-patterned materials/nano-particles/smart materials/nano-devices distinction. In the latter, the smart materials category proved problematic by having a part that can contribute, and a part that cannot because smart materials can consist of both top-down and bottom-up produced nanotechnologies. In the selected literature on the loss of privacy case, no specification regarding the type of nanotechnologies was done, but just the devices were mentioned. The lack of distinguishing in the loss of privacy case, and the incomplete way of distinguishing in the nanotoxicology case, could open possibilities for the three problems to occur.

Three problems were identified in ethical reflection, namely non-specificity, generalization and speculation. All three problems were present in the cases discussed in this thesis. The non-specificity problem was present to a lesser extent in the nanotoxicology case, but the loss of privacy case served as a good case to evaluate the distinctions on with regard to identifying this problem. It showed that, by providing an overview of possible nanotechnologies and their characteristics, both distinctions served their purpose of allowing for identification of the actual role nanotechnologies play in the evocation of ethical issues. Although using distinctions does not solve the problems, they are of use for detecting and preventing the problems. The becoming apparent of nanotechnologies' role allowed for the identification of the seemingly problematic practical overlap between nanotechnology and microtechnology in privacy-endangering devices; from current ethical reflection it is not clear whether the issues reflected upon are new – or unique – to nanotechnologies, and current technical literature contradicts speculation in ethical reflection by providing literature that suggests that nanotechnologies are not going to play a role in these issues in the near future. For the loss of privacy case I recommend a critical look to be taken at how different the contributions of microtechnologies and nanotechnologies are. Before suggesting a link nanotechnologies and privacy issues it should first become clear whether size matters beyond the micro-scale, and whether the problematic size is possible through nanotechnological production.

As far as the speculation problem goes, both distinctions indicate clearly defined categories, which lend themselves for a targeted analysis of how the nanotechnologies in a category have developed, and better informed foresight on how they are likely to develop, which allows for controlled speculation. But, although it did not show in the cases discussed, I expect the distinction of nano-patterned materials/nano-particles/smart materials/nano-devices to better allow for development path extrapolation. This, I think, is because of the distinction having more categories, but also due to those categories being four clear levels of functionality and not just methods of production. On the other hand, this could also mean that the distinction needs to be supplemented with additional categories once the field of nanotechnology develops further.

Both distinctions I expect to allow for serving as a critical instrument for detecting the three problems when looking at current ethical reflection and as a heuristic instrument when engaging in new ethical reflection. I expect there to be cases in which the top-down/bottom-up produced nanotechnologies distinction will prove more useful, and ones in which the nano-patterned materials/smart materials/nano-devices distinction can prove to be more useful. In certain cases the two distinctions might even prove to be usable complementary of each other.

The function of using a distinction largely relies on the contingency of the link with the case that is being assessed; I expect there to be cases in which the link with the case is of a different level of contingency for both distinctions. This became clear with the loss of privacy case, in which the link with the field of nanotechnology was more contingent than in the nanotoxicology case. In the loss of privacy case using the distinctions allowed for confirming the suspicion that the privacy issues are not necessarily, and thus contingently, related to nanotechnologies. On the other hand, in the nanotoxocology case, which has a less contingent relation to the field of nanotechnology, using the distinctions allowed for highlighting the division within the field of nanotechnology. The less contingent case thus allowed for more nano-specific insights when using distinctions. So, there can be cases in which a clear preference can be given for one of the distinctions, but how is using the distinctions different from not using the distinctions?

It can of course be claimed that the three problems can also be detected without the use of the distinctions. To an extent this is true. Yet without using a distinction it can become apparent that there is mentioning of nanotechnologies in general, but not how different the generalized nanotechnologies actually are; without using a distinction it can be detected where generalization takes place, but when using a distinction, suspicions about misplaced generalization can be confirmed or rejected. The same goes for the speculation problem, since it can become apparent that speculation is taking place, but when knowing the type of nanotechnology involved in the scenario the level of speculation can be determined. Using the distinctions as a critical instrument could thus aid in mapping the level of generalization and speculation, whereas a distinctionless analysis is likely to only be used to detect that there are problems, but not the level in which they are present. When looking only at devices, speculation can also be detected, but not nano-specific speculation, and generalization cannot be prevented if nanotechnologies are present in these devices.

The non-specificity problem, however, is of more importance when using the distinction as a heuristic instrument. Here the set of categories allow for the linking to specific possibilities of types of nanotechnology. This prevents that the functions a type of nanotechnology can fulfill in a device are assessed over and over in several devices, hence preventing the problem of reinventing the wheel. Compared to a device analysis, the knowledge about the specific type of nanotechnology can provide more accurate foresight; it is interesting to see what the expected future possibilities of a device are, but if the embedded nanotechnologies that are supposed to enable these future possibilities are not expected to develop towards being able to do so, the device foresight is of little use. On top of that, it could be checked whether the projected use of a device necessarily requires the embedment of nanotechnologies, or if – as possibly applicable with RFID tags and the use of microtechnology – similar effects can be accomplished by other means. Both as a critical and heuristic instrument, using the distinctions has benefits over not using the distinctions, but how will using the distinctions improve the field of nanoethics?

Since there is a lot of discussion regarding the use for a field of nanoethics, it would benefit the debate on the use for nanoethics if using one (or both) of the distinctions could allow for showing that nanoethics improves ethical reflection. Previous discussions have resulted in doubt about whether a field of nanoethics is needed, because the possibilities the field of nanotechnology opens up pose no novel ethical and societal challenges. The arguments for a field of nanoethics would receive a valuable addition if using the distinctions could separate the novel from the non-novel issues associated with the emergence of the field of nanotechnology; if this allows for showing that there are indeed novel issues, and that some non-novel issues are not convincingly associable with the field of nanotechnology, the need for nano-specific insights in ethical reflection becomes clear. If this is done, then I expect the novel ethical and societal challenges to become apparent, and hence the need for nano-specific ethical reflection. But how can the distinctions benefit nano-specific ethical reflection?

From the cases discussed in this thesis it can be seen that the distinctions aid in showing that, in some cases, different nanotechnologies can be linked to different issues, and that these different nanotechnologies might require a different way of ethical reflection. Applying the distinctions has shown the privacy issues to have a questionable link with nanotechnologies, whereas the nanotoxicology case exposed that it were the radical new properties of certain nanotechnologies that require attention. Having distinctions that allow for showing that there are really nano-specific problems indicates that there is at least reflection needed. That these issues can also be more specifically allocated than just to nanotechnologies in general indicates the need for a separate field of ethics; specific allocation is something that requires technical insight and nano-specific tools for ethical reflection. This specific allocation helps to set the agenda for the political and public debate on nanotechnologies.

Agenda setting is exactly where I expect using a distinction can contribute to nanoethics most. Applying the distinctions has shown the technical aspects of the nanotechnologies in the categories to matter for the role they play in the evocation of the ethical issues linked to nanotechnologies. Taxonomizing nanotechnologies, like attempted in this thesis, allows for showing the types of nanotechnologies responsible for each issue. When knowing which nanotechnologies can be linked to which issue, the public and political debate can be fed better (nano-specific) input. Using a distinction can thus be used as a means towards improving the accuracy of the public and political debate, as well as the rules and regulations that flow forth out of this debate.

The relation nanotechnologies have with nanoethics, is that nanoethics links issues to nanotechnologies, and can indicate problematic points where action is needed to yield desired outcomes. The role that the usage of the distinctions can play here is that they allow for giving more specifically targeted indications of points that need attention. Both distinctions can serve this purpose, however, using the distinctions does not aid in solving the issues, but it can aid in finding the troublesome nanotechnologies; the distinctions can serve as a heuristic instrument for the allocation of problems, and focusing the attention of ethical reflection. Heuristic value of using a distinction can also be found in its use for extrapolating a specific nanotechnology's path of development. This way speculation can be controlled and better informed when engaging in ethical reflection.

There were two distinctions evaluated in this thesis, which proved to both have their strengths and weaknesses. Being used separately or complementary, the three problems found in nanoethical literature can be detected or prevented by using one (or both) of the proposed distinctions. Doing so could make for a less general, more specific and less (better controlled) speculative ethical reflection on nanotechnologies. In addition, the use of one (or both) of the distinctions allows for better agenda setting by exposing the issues that are not caused by just nanotechnologies, by specifying which issues are caused by nanotechnologies, and which nanotechnologies are involved in the evocation of these issues. A result of this could be an improved systematic reflection on the production, use and disposal of nanotechnologies, providing better guidelines for policy makers.

I recommend ethicists to use – or at least keep in mind – both distinctions researched in this thesis. The case studies have not been extensive enough to give a clear preference for one of the researched distinctions. I expect it to be fruitful to take a further look at other cases as well. When taking a look at other cases I expect interesting results to come out of looking at how the distinctions can be used when nanotechnologies converge with information technology, biotechnology and cognitive science. I expect a taxonomy of nanotechnologies might be able to prepare nanoethics for the converging technologies debate by allowing for the identification of the effects nanotechnologies can contribute to the convergence.

One of the reasons the distinction between top-down and bottom-up produced nanotechnologies could prove more useful after further research is that this distinction is based on the methods of production, of which I expect there to not be any additional ones in the future. The distinction between nano-patterned materials/nano-particles/smart materials/nano-devices I regard as one that could require expansion once new applications of nanotechnologies are developed, which creates new levels of functionality: an example of such a category could be a living organism engineered at the nano-scale, which yields the additional category nano-organisms.

Complementary, the distinctions can be used as a set of tools to allocate both problems related to the production method, as well as the functionality level. As seen in the privacy case, there are cases in which it matters not how a device is produced, but only what the effects of its use can be. And the toxicology case showed that in some cases using nanotechnologies is not what causes the issues, but their material properties are. A toolbox containing both distinctions thus contains tools for accurately linking problems to either functionality or materiality. When having both distinctions at disposal, a look can first be taken at the relevant aspects of nanotechnologies, after which the appropriate distinction can be used.

Regarding the completeness of the distinction between top-down and bottom-up produced nanotechnologies, I recommend further research into the use of a further division. The nano-patterned materials/nano-particles/smart materials/nano-devices distinction is only in part a further categorization within the top-down and bottom-up produced nanotechnologies distinction. Investigation into a further division, of especially the bottom-up category, I suspect to be able to provide further benefits. The literature encountered during this thesis research did not sufficiently allow for such further division, but I expect this will be possible with the further development of the field of nanotechnology and its accompanying field of ethics.

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