

The Risk of Nanotechnology: A Challenge to the Insurance Industry

Adam Śliwiński* and Marietta Janowicz-Lomott

Department of Risk and Insurance, Warsaw School of Economics, Collegium of Management and Finance, Institute of Risk and Financial Markets, Poland

Abstract: Nanotechnology poses a challenge for the modern man. Aside from the many benefits that nanotechnological growth may bring, it exposes our civilization to an increasing number of new risks, creating hazards that are currently difficult to foresee. Nanotechnological developments may have a negative impact on the natural environment; some researchers claim that they may even jeopardize the very existence of humankind. Existence of defined threats opens up space for the functioning of insurance. Answering the need for nanotechnological risk management, the insurance sector should develop a strategy that would offer a reduction of risk aversion (especially among producers) and augment further development of nanotechnology-based production methods. However, this leads to questions whether nanotechnology-related risk is an insurable risk and whether it is technically feasible at this time to draft such an insurance offer. The present publication attempts to answer these questions.

Keywords: Nanotechnology, risk of nanotechnology, insurable risk, insurance industry, mutual insurance.

1. INTRODUCTION

Nanotechnology poses a challenge for the modern man. The discovery of nanoparticles has already revolutionized civilizational growth by impacting many aspects of human life. Nanotechnology, or controlled production and creation of atomic and molecular structures in nanoscopic scale, creates unimaginable opportunities in many disciplines including medicine, defense systems or clothing and food industries. Aside from the many benefits that nanotechnological growth may bring, it exposes our civilization to an increasing number of new risks, creating hazards that are currently difficult to foresee. Nanotechnological developments may have a negative impact on the natural environment; some researchers claim that they may even jeopardize the very existence of humankind. Therefore, nanotechnology-related risks should be deemed of utmost importance and require further studies and research. If we wish to further develop innovative production methods that will improve our functioning, the negative effects that may impact individuals or whole communities must not be overlooked. Nanotechnology indubitably fits these characteristics. As long as the current state of knowledge does not permit exact ascertainments as regards physicochemical properties relevant in specifying detailed nanomaterial compositions, it is highly unlikely that researchers would be able to establish the potential risk involved. A certain aversion

to risk and fear of potential consequences may inhibit growth of nanotechnology-based production methods.

Existence of defined threats opens up space for the functioning of insurance. Answering the need for nanotechnological risk management, the insurance sector should develop a strategy that would offer a reduction of risk aversion (especially among producers) and augment further development of nanotechnology-based production methods. By manipulating the risk connected to nanotechnology, it would be possible to further develop this area while providing protection against financial consequences of defined risk implementation.

However, this leads to questions whether nanotechnology-related risk is an insurable risk and whether it is technically feasible at this time to draft such an insurance offer. The present publication attempts to answer these questions.

The publication consists of four parts. Part one describes nanotechnology as a branch of science. Part two presents options of implementing nanotechnology-based methods in the industry. Part three discusses the hazards that nanotechnology poses for human health and the environment, and evaluates the insurability of risks connected to this production method (in the total lifespan of products containing nanotechnological materials).

In part four, authors advocate for applying mutual insurance specifics to risk management in conditions calling for nanotechnological use. The essence of mutual insurance creates opportunities for dealing with nanotechnological risk even in situations when no

*Address correspondence to this author at the Warsaw School of Economics, al. Niepodległości 162, 02-554 Warsaw, Poland; E-mail: asliwin@sgh.waw.pl

verified actuarial models enabling credible insurance contribution calculations exist.

The publication is based on authors' own research and analyses of literature pertaining to nanotechnological risk management, including studies of reinsurers and insurance companies (Allianz, Zurich, ACE, Munich Re).

2. NANOTECHNOLOGY - THE CONCEPT

Nanotechnology is a relatively young field of science which deals with controlled production and building of atomic and molecular structures at a nanoscale. One nanometer is one billionth of a meter, and the "nano" prefix comes from a Greek word for "dwarf" (νάνος). This unit of length is equal to five to ten atoms put in a line. One nanometer compares to a meter like a soccer ball compares to the planet Earth (Langner and Langner 2007). Nanotechnology operates on the level of atoms and molecules at the nanometric scale. It should be noted that today the size criterion is a key identifier of nanomaterial. Another important criterion is that a structure of nanometric dimensions must be human-made and that additionally it must display unique characteristics associated only with a very small size (Berger 2008).

The first area of application of nanotechnology is the production and usage of nanomaterials. The International Standards Organization has defined the term "nanomaterial" as a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate¹, and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm (GUS 2013). A similar definition appeared in the recommendations adopted by the European Commission in 2011. The definition of the European Commission allows that in specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50 % may be replaced by a threshold between 1 and 50 %. By derogation from the above, fullerenes, graphene flakes and single wall carbon

nanotubes² with one or more external dimensions below 1 nm should be considered as nanomaterials (Recommendation 2011/696/EU).

Many materials classified today as "nano" are in fact nothing new. For example, colourful stained church glass that were made in the Middle Ages contain nanoparticles of gold. (Opinion 2016/C071/05). Nanostructures also appear in nature, for instance in the microscopic structure of the surface of lotus leaves. Thanks to their structure and chemical composition lotus leaves never get wet - water droplets flow down a leaf's surface, collecting dirt at the same time (the so-called *lotus effect*). Similarly, metal-blue wings of a Morpho butterfly (occurring in South America) are coated with nanostructured scales. The highly sophisticated structure of the scales covering Morpho's wings causes light waves to reflect off their successive layers, creating an interference effect. This effect depends equally both on the length of the wave and on the observers' angle of view - therefore, the hue and its saturation change with different perspectives. This structure also makes the wings hydrophobic. Moreover, many substances and chemical processes display features specific to the nanoscale. However, only in recent years advanced tools were developed for the study and manipulation of matter in the nanoscale, which resulted in the actual creation of nanoscience (research) and nanotechnology (practical application).

The first visionary of nanotechnology was Richard P. Feynman, an American physicist who during a meeting of the American Physicist Society in 1959 gave a lecture entitled "There's plenty of room at the bottom"³ in which he presented a vision of the world where scientists, combining individual atoms of chosen molecules, can build any structures of the matter. According to him, the molecular effect should become the goal of science of the future (Waszkiewicz-Robak and Świdorski 2008). The term "nanotechnology" was first used in 1974 by Norio Taniguchi, a Japanese researcher, to define the manipulation of materials at the nanometric scale (Mazurkiewicz 2007). The issue of mechanical manipulation of the matter at the atomic level was raised again in the 1980s by the IBM

¹"Particle" in this definition means a piece of matter with defined physical boundaries, "agglomerate" means a collection of loosely tied particles or aggregates, where the resulting size of the external surface area is close to the sum of the surface areas of individual components and "aggregate" is defined as a particle comprising strongly bound or fused particles.

²Fullerenes and graphene are (together with graphite and diamonds) allotropic varieties of carbon. Carbon nanotubes are nothing but graphene sheets rolled into thin tubes with a diameter of 1 nm and length ranging from a few nanometers to several millimeters. Depending on the number of layers, we distinguish single and multi-walled nanotubes. (Mielcarek, Kruszynska and Sokolov, 2009).

³The full text of the lecture "There's Plenty of Room at the Bottom. An Invitation to Enter a New Field of Physics." <http://www.zyvex.com/nanotech/feynman.html>

company, where scientists⁴ constructed a tunnelling microscope (the first tool of nanotechnology) that allowed to observe conducting surfaces at the atomic level. This discovery proved that single atoms and molecules can serve to build structures. Afterwards an atomic force microscope was developed, which enabled the observation of insulator surfaces that had been inaccessible through tunnelling microscopes (Szczeplaniak-Lalewicz 2011).

Nanotechnology emerged as a separate field of science and practice in the second half of the 20th century. The actual novelty in nanotechnology these days is the fact that now we have a much better understanding of its mechanisms.

The key achievement of nanotechnology was the discovery of new nanomaterials such as spherical fullerenes (R. Curl, H. Kroto and R. Smalley, discovery in 1985, Nobel Prize in 1996) and carbon nanotubes - cylindrical layers of atoms with a diameter of a few nanometers and a length of up to a few centimeters (Iijima, NEC - Japan, 1991). Both of these nanomaterials demonstrate properties unseen at the macro level (Przygocki and Wlochowicz 2001). Fullerenes and nanotubes display unusual physicochemical features: they are as hard as diamonds, and at the same time they are flexible, elastic, tear- and crush-resistant; they are also very good heat conductors, which offers the prospect of wide use in many fields of technology. Fullerenes and nanotubes in the shape of tubes and polyhedrons are empty on the inside, therefore they may potentially be used as storage space for various substances (e.g. different medicines, flavorings), protecting them against the adverse effects of external factors (Szczeplaniak-Lalewicz 2011).

Nowadays there are a number of manufacturing techniques available. In terms of nanotechnology we distinguish the "bottom-up" manufacturing technique, which aims at building materials and devices at the nanoscale atom by atom, and the "top-down" approach, which involves arriving at a nanomaterial from a larger structure, among other ways, by mechanical forming processes. (Nanoscience 2004).

3. APPLICATION OF NANOTECHNOLOGY

For many years nanostructures were used only in chemistry and in physics. Currently, nanotechnologies

are or will be applied in the electrical industry, pharmaceuticals, precision industry, biomedicine, food sector and in other industries. It should also be pointed out that nanotechnology is still in the early stages of development and many of its most valuable commercial applications are still decades away. The products that involve nanotechnology and that are currently available on the market are usually gradually improved and their production process applies some form of nanotechnology-based materials and processes, e.g. simple compounds and composites used in sunscreens, cosmetics, paints and coatings, as well as stain-resistant clothing.

The next stage, estimated to begin halfway through the next decade, will also involve basic compounds in nanoscale and composites, however they will be of a much more complex nanostructure. A few years later, the first integrated nano-systems functioning like mammal cells are expected to appear. This stage will be associated with significant advances in robotics, biotechnology and information technology, as well as in designing devices at the atomic and molecular level, which should lead to improved understanding of the matter and control over it (Bowman and Hodge 2006).

The literature of the subject points out that in the future, nanotechnology might be used to build nanoscale robots, which will be used for precise manipulation of atoms in order to construct complex machine-robots (that will also be able to replicate independently) (Drexler 1990) (Drexler 2001).

Table 1 indicates the current and future (expected in the next few years) possible applications of nanotechnology.

First consumer products that applied nanotechnology appeared on market in the late 1990s. At the same time this industry is believed to be one of the most promising sectors. There are experts who claim that in the 21st century nanotechnology may affect the functioning of any company in the world by redefining current technology (Helmut Kaiser Consultancy 2015). Its global pace of development will differ by the industry and it is estimated to achieve a 8-21% growth per year over the next 15 years (Opinion 2016). The total nanotechnology market (sold products that use the achievements of nanotechnology) is estimated to rise from 110.6 billion USD in 2003 to 891.1 billion in the year 2015 (Table 2).

⁴Team headed by Heinrich Rohrer and Gerd Binnig, who received a Nobel Peace Prize in 1986 for their invention of the scanning tunnelling microscope.

Table 1: Current and Future Applications of Nanotechnology

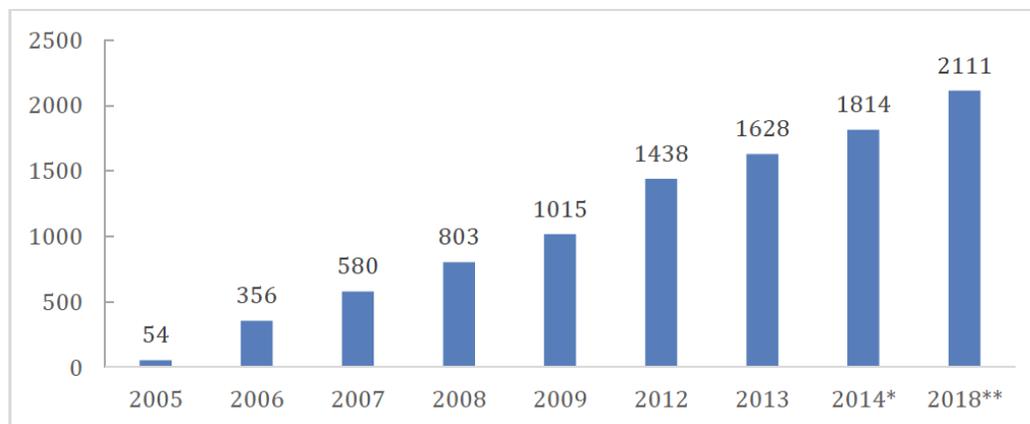
Field of life/industry	Possible application
Agriculture and food processing	<p>Food production – transforming DNA of seeds in a way that will allow the creation of plants with completely new properties, for example of a different colour, growing season, yield etc.</p> <p>Food modification - improved nutritious qualities of processed foods (dietary fiber, vitamins) or modified foods with reduced content of fat and sugar, which the body can absorb in the future as “smart” food (nanocapsules); these products will interact with consumers and change the colour, flavour or the nutrient content according to their preferences (for example using a microwave); such foods may also be able to sense whether a person is allergic to any of the ingredients and block it, or the packaging may release a dose of additional nutrients;</p> <p>Food preservation and storage - longer expiration dates, containers that retain freshness and provide protection against bacteria and UV radiation; biodegradable packaging, nanosensors informing about the location and authenticity of the merchandise, as well as about its “best before” date;</p> <p>New generation of fertilisers and pesticides;</p> <p>Nanosensors will enable plant growth, ensure an adequate pH level, proper nutrients, moisture level, pest control and disease protection – all subject to remote monitoring;</p>
Electronics	<p>Miniaturised semiconductors, memory cards and chips;</p> <p>The possibility of constructing increasingly powerful miniaturised devices;</p> <p>Optoelectronics;</p> <p>Biocompatible electronic systems;</p>
Cosmetics and chemicals Clothing	<p>Bactericidal, hydrophobic and antiallergic textiles;</p> <p>Increased effectiveness and absorption of active cosmetic ingredients;</p> <p>UV filters in sun creams;</p> <p>May replace preservatives currently used in cosmetics;</p> <p>Nanocapsules allowing to release a cosmetic at a desired moment;</p> <p>Accelerating the healing of wounds, alleviating skin diseases, acne, insect bites</p> <p>antibacterial wipes;</p> <p>Paints and varnishes, coatings (self-cleaning, antibacterial, more durable, more wear and tear resistant, waterproof);</p>
Military and security	<p>Soldier equipment – reduced weight, increased ballistic protection, ability to maintain an adequate temperature and humidity (suit), light weapons, locators and instant messaging in headgear, detection of chemical risks and protection against them, monitoring physiological functions (temperature, blood pressure, stress level etc.), automatic stiffening of sleeves and trouser legs if a limb is fractured or damaged;</p> <p>Improved protection of combat vehicles;</p> <p>Weapons (small explosives with greater firepower);</p>
Energy and the Environment	<p>Purification filters (e.g. for drinking water);</p> <p>More efficient and cheaper solar cells;</p> <p>Thermoelectric converters that may also recover heat, e.g. from internal combustion engines;</p>
Nanodrugs	<p>New drugs that demonstrate a bactericidal properties in 5 minutes after application and fungicidal properties in 15 minutes after use (they disrupt the water management in case of fungi, lead to energy disturbances in bacteria cells of bacteria and deprive viruses of their characteristics);</p> <p>Drugs in capsules – selective targeting of drugs at the diseased cells, thus reducing to a minimum harmful side effects of these drugs for the rest of the organism;</p> <p>Effective cancer drugs (using a nanogenerator instead of radiotherapy in order to introduce nanostructures that destroy diseased cells to the site affected by disease);</p> <p>Biomarkers; Medical devices – nanorobots; Environmental engineering for artificial organs;</p>
Medicine	<p>Materials for detecting bacterial contamination;</p> <p>Delivery of DNA into cells;</p> <p>Biological nanosensors for early diagnosis of common diseases (cardiovascular diseases or cancer);</p> <p>Replenishment of bone loss to accelerate fracture healing (rebuilding of the spinal cord successfully tested on mice);</p> <p>Implants biocompatible with damaged parts of the body.</p>
Other	<p>Glass coating preventing it from soiling, scratches or sweating;</p> <p>Construction - reinforcing steel and concrete;</p> <p>Better insulation materials;</p>

Own compilation based on (Czerwinska 2014), (Głód, Adamczak and Bednarski 2014), (Kachel-Jakubowska, Szymanek and Dziwulska-Hunek, 2015), (Patri, Majoros and Baker 2002), (Pike- Biegunski 2005b), (Pike-Biegunski 2005a), (Waszkiewicz-Robak and Świdorski, 2008), (Błaszczuk 2014).

Table 2: Nanotechnology Market in the World (USD bn)

Items	2002	2006	2010	2015	2018
World	110.6	299.9	516.9	891.1	1,055.1
NAFTA	82.9	179.9	258.4	409.9	473.61*
Europe	12.0	74.9	155.7	267.3	319.77*
Asia	11	32.9	77.5	169.4	191.73*
Other	4.4	11.9	25.8	44.5	52.32*

Source: (Helmut Kaiser Consultancy 2015) (Allied Market, 2019), * - results extrapolated assuming linear trend, based on the data from previous years.

**Figure 1: The number of products available on market that use nanotechnology.**

*estimated data based on the source, ** The result for 2018 has been estimated using linear trend assumption ($y = 255,55x - 188,96$; $R^2 = 0,9931$).

Source: (Vance *et al.* 2015).

The number of jobs in the field of nanotechnology in the European Union today is estimated at 300 000-400 000 (Opinion 2016).

Worldwide, there are over 4000 companies and research institutes engaged in nanotechnology. According to the records of the Project on Emerging Nanotechnologies (launched in 2006)⁵, there are around 2000 products using nanotechnology⁶ available on market (Figure 1)

Today's leading countries in the field of nanotechnology are the United States, Japan, China and Germany. Many countries (including the US, Japan, Germany, Australia, South Africa and Israel) have already developed national strategies for the development of nanotechnology and launched adequately designed support programs. Such

programs have been developed not only in countries that are leaders in the world of technology, but also in rapidly developing states such as Vietnam, Iran, Pakistan and Mexico. In 2006 such strategy was also drafted in Poland (MNISW 2006). By the end of 2011, the global value of funding research and development of nanotechnology reached 65 billion dollars, and by 2015 it will exceed 100 billion dollars (Harper 2011).

Not only does the nanotechnology increase marketability of textiles, cosmetics and consumer electronics, but also it has the potential to solve at least three problems of great social importance, such as: the energy crisis, effective medicine and the demand for clean water (Schmidt, 2007).

4. THREATS RELATED TO APPLICATION OF NANOTECHNOLOGY

To this day numerous laboratory tests have been carried out in order to establish in what manner nanoparticles affect living organisms (plants and animals) (Błaszczuk 2014). Unfortunately, it is not possible to deduce (even through extrapolation) the

⁵Products in the register must comply with three criteria: they are available for sale, they are identified as based on nanotechnologies either by the producer or by another source and this claim must seem to be justified.

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actual risk⁷ they pose for humans and their environment. There is insufficient data (Waszkiewicz-Robak and Świdorski, 2008) relative to:

1. possible biological consequences resulting of their application in the industry,
2. possible effects of overdosing a given substance ingested in the "nano"⁸ form, or accumulation of such substance in a living organism,
3. whether "nano" particles whose properties were not tested can migrate in the environment and become "omnipresent", leading to a situation in which humans are permanently exposed to them; it is a potential health hazard, because:
 - they may permeate physiological barriers and penetrate into human cells and brains,
 - their complex surfaces make them very chemically active, and as a result they may damage biological systems,
 - they may compromise defence mechanisms of living organisms.

Descriptions of most of the risks referred to above contain the word "may", because the impact of nanomaterials is still unknown or not fully researched. Interestingly, many research papers include a statement that there is no data to support the hypothesis that smaller particles are more reactive, and therefore more toxic. For this reason nanomaterials probably resemble ordinary substances – some of them may be toxic in certain circumstances, and some not. Since there is no one, commonly applied paradigm of identification of risks for nanomaterials, it is advised to assess risk connected with specific materials on a case by case basis (SCENHIR 2009). Below there is a list of sample issues that must be addressed when assessing risk connected with nanomaterials (OECD 2012):

- toxicological properties of chemical substance(s), connected to nanoparticles,

- substantially larger relative surface area of nanomaterials, which enhances their reactivity;
- larger surface area and high reactivity creates the possibility to absorb other substances (they may mask or support migration of other particles containing toxins that later accumulate in organs vital for survival),
- contamination and by-products connected with the manufacturing of nanomaterials.

What poses another challenge is the fact that producers and users may not be aware that nanoparticles were included in products and processes - there are no common reporting standards that would allow to precisely identify what type of nanoparticles can be found in a given product (Zurich 2014).

The threat that is most frequently mentioned in connection with nanotechnology is its impact on human health and the natural environment. The literature of the subject refers also to other threats (some of them being rather futuristic), although not as often. They include:

- the use of nanotechnology for military purposes - creating new weapons of mass destruction (e.g. using nanocapsules to carry chemical and/or biological weapons in the human body, in animals or in plants, developing new kinds of weapons), information warfare systems, creating "killing robots" or other general military applications of nanotechnologies (e.g. quicker and more efficient generation and improved storage of energy, self-repair capacities, smart materials, nanoimplants in a soldier's body (or in a machine) that may destabilize the world order (Altmann and Gubrud 2002)
- "nanoterrorism" – a result of a misuse of nanotechnologies by terrorist organizations (Czerwińska 2014) or creation of a weapon that will be invisible for currently existing devices (e.g. at airports). The greatest danger would be connected with engineering new viruses on the molecular level (Schmidt 2007). Another possible threat is using nanosensors to collect and gather classified information that may later be used for terrorist activities (Czerwińska 2014),
- limitation of personal freedom (following the use of nanosensors by government agencies, companies, private individuals etc.),

⁷We have assumed the following definition of risk is assumed in the context of nanotechnology: a social phenomenon defined as a state (states) and properties of subjects/objects considered in a given culture as negative, hence unacceptable and to be avoided; threat is conceived as being primary to risk and constituting a part of it. See more (Jastrzębska *et al* 2014).

⁸Reducing the scale allows to substantially reduce the intake (it is usually supervised in medicines, but for example in dietary supplements it is not the case), but lack of knowledge about all the ingredients and possible changes in properties of these substances during the processing on a "nano" scale may result in undesired effects, resembling symptoms of overdosing.

- humans becoming dependent on nanotechnologies (e.g. using devices instead of muscles that may lead to atrophy of natural body parts), machines replacing humans (creating the problem of excess of free time and insufficient activities),
- “Grey Goo scenario”⁹, an apocalyptic scenario in which self-replicating nanomechanisms get out of control, kill all living organisms on Earth and change the entire biosphere so that it becomes their copy; there are other “colourful versions” of this scenario leading ultimately to the destruction of humanity, including the “Green Goo scenario” - a vision in which nanomachines built exclusively from organic compounds also break free from the control of scientists (Drexler, 1990).

As long as the level of scientific progress does not allow us to establish which physical and chemical properties exactly determine the characteristics of nanomaterials, it will not be possible for the researchers to precisely assess the risk they carry. In this context the term “threat” should be used instead of “risk”. Risk assessment in nanomaterials is a complicated, time-intensive process that constitutes a great challenge for scientists, lawyers and also for the insurers. At the current stage of development of nanotechnology and given the threats that it poses, the question is whether the risk that may materialize as a result of the development of nanotechnology is insurable. Manipulation of nanotechnology-related risks may allow to further develop research in this area and at the same time to ensure protection against financial consequences of situations when specified risks materialize.

5. INSURABILITY OF RISK CONNECTED WITH THE DEVELOPMENT OF NANOTECHNOLOGY

Surveys indicate that a growing number of businesses apply nanotechnology in their production process. As a result they become exposed to threats that have so far been unknown and which may turn out to be considerable (Germano 2008). We can diagnose nanotechnology risk in two areas - the impact on people and the environment (Table 3).

Table 3: Parameters of Nanorisk

Human risk	Environmental risk
Toxicity	Persistence / bioaccumulation
Carcinogenicity	Aquatic toxicity
Mutagenicity	Other (e.g. microbial resistance)
Reproductive toxicity	
Other	

Source: (Zurich, 2014).

Given the above we can try to indicate which insurance products (according to our current knowledge) could be applied to nanotechnology (see Figure 2). Insurance losses can occur at any stage of manufacturing and use of nanomaterials. The Figure below illustrates how insurance protection can follow the life cycle of products containing nanomaterials (Baublyte *et al.* 2014).

Employees may be exposed to nanoparticles and nanomaterials at various stages of a product’s life cycle, such as research and development, production of raw materials, consumer product manufacturing and the end of the product’s life cycle, when it is disposed (Mullins *et al.* 2013). Consumers will have contact with nanomaterials when products reach the retail market. The exposure may increase if a consumer fails to observe the instructions for use of a product or if a product is damaged. All providers of such goods (i.e. manufacturers, wholesalers and retailers) may be held liable by their customers and other persons for losses resulting from the placing them on the market. In addition to losses resulting from employer’s liability and product liability, one must bear in mind possible losses resulting from environmental liability. They may occur not only at the stage of production and manufacturing (leaks) or use, but also as a result of accumulation of toxic waste on landfills.

It means that executives in businesses that apply nanotechnology may be exposed to threats connected with nanotechnology (D&O liability). Also instances of professional liability may occur involving physicians, construction industry workers, etc. (e.g. professional liability resulting from prescribing incorrect dosage or drugs).

Each of the above scenarios could result in the insurer’s liability for (Allianz, 2005):

- costs of soil and water pollution clean-up,
- costs of medical treatment (compensations etc.) and payments in the event of death of

⁹The term was coined by Eric Drexler, one of the pioneers of nanotechnology, who demonstrated in his later works that there is no need to create self-replicating nanomachines. Macroscopic devices may prove to be a better solution; they would synthesize any structures from atoms (including their own copies) (Dexler 2001).



Figure 2: Life cycle of a nanomaterial and possible areas of insurer's liability.

Source: (Baublyte *et al.* 2014).

- employees or other persons (customers and third parties),
- claims filed by shareholders and other stakeholders,
- other claims filed by injured persons,
- compensation for production downtime,
- costs of product recall,
- environmental risks (land and groundwater contamination),
- risk of health loss,
- third-party liability of manufacturers that use nanotechnologies,
- payments for employees who are at risk of exposure to nanoparticles at work.

Currently no insurance products exclude nanotechnology from their coverage, third-party liability insurance included. However, nowadays nanotechnology products are commercialized at a limited scale and potential consequences of their use are not well researched. The attitude of insurers is likely to change (or, as some claim, undergo a revolution) if nanotechnology becomes more popular. At the first instance the premium level for such a nano-insurance products could be relatively high. There would be also a special requirements or conditions impose by insurers before concluding the cover. One of the most important, in the opinion of authors of the paper, would be a right to recourse possible claims. It might be assumed that development of nano-insurance offer would be quite similar to the development of credit insurance where at the beginning premiums reached

the level of a few per cents. The premium level then has been reduced significantly together with further development of the products. The reduction has been connected to the development of the credit insurance market and in hence better risk analysis, more knowledge about an credit insurance portfolio.

However at that moment it seems that there is insufficient knowledge about the consequences of using nanotechnology on a massive scale. Only this is enough to give a negative answer to the question whether the nanotechnology risk is insurable. It is worthwhile, however, to consider what criteria should be met to make a given risk insurable. The key criteria are as follows (Rejda 2008):

1. repeatability of events – events must be repeatable (so that they can be statistically analysed)
2. randomness – events must be random, and their occurrence independent from the will of the insured person,
3. measurability of losses – a loss must be definitive and measurable,
4. reciprocity/solidarity – there must be a high number of entities exposed to the risk and they must be willing to join forces in order to establish a community of risk,
5. economic feasibility - insurers must be able to calculate an acceptable premium that will guarantee that their business is profitable in the long run.

It is clear that problems appear already with regard to the first item of the above list. It is possible that all of

us are at risk, but we are not able to correctly identify the threats or to give any calculations with regard to them. Accidents and individual claims that are frequently referred to in connection with nanotechnology seem to be the tip of the iceberg.

Complete evaluation of all the nanorisks is almost impossible because:

- production processes information limited (often patented)
- scientific support incomplete (traditional toxicological methods have to be extended, long-term and direct effects of NMs have not been sufficiently studied).

The insurers accepted most of major modern technological innovations, because usually they were a product of an evolution. However, their approach may differ with regard to the events that are revolutionary in terms of risk, and it is not possible to estimate the potential losses they may generate. It should also be stressed that the threats have not been investigated, and as a result we cannot exclude the possibility that we are dealing with so-called phantom (seeming) risks. What is more, the experience of the insurance sector in the field of insuring "technological inventions" can be negative. It is enough to mention the history of asbestos. For a long time asbestos showed no toxicity and was considered safe. However, asbestos microfibers enter the respiratory system causing severe damage to the lungs (asbestosis) that can lead to cancer. Despite the general ban on the use of asbestos in the 1990 net ultimate asbestos losses for the U.S. property/casualty industry have risen. They're now at \$100 billion (AM Best 2017).

What solutions should be applied if there are so many doubts connected with developing insurance products for nanotechnologies?

1. The insurance market must expand its expertise by gathering information from scientific research, participating actively in research projects in this area (in particular in those financed by the state budget), keeping its own statistics and closely follow the developments. The insurance companies can also engage in promotion of responsible practices in production and use of nanomaterials.
2. Those who are potentially at risk of liability may benefit from mutual insurance, which is a logical

insurance choice when statistical data is insufficient.

For many centuries the insurance services were developing without the support of mathematics and statistics (it is enough to mention the fact that the first tables of life expectancy were created in 1693 by Edmund Halley, and the first documented life policy had been purchased on 18 June 1583, exactly 110 years before¹⁰). In addition "all branches of insurance (...) are pioneered by the mutual companies, because the capitalists set up stock insurance companies only when they have a possibility for a secure and profitable investment in shares." (Ginwiłł-Piotrowski 1892).

Members of a mutual insurance company and their mutual liability may play a crucial role in the initial phase of development of nanotechnology. Moreover, experience suggests that mutual insurance companies are more willing to get involved in research activity. Also their involvement in activities financed by the public funds seems to be less controversial; in addition, it may allow to obtain public money to finance those activities of a mutual insurance companies that are connected with research and development of methods of nanotechnology risk management other than the insurance methods.

This brings us to another question – should we rather set up mutual funds or organize into mutual insurance companies? The latter option may prove to be impossible given the current formal and capital requirements under Solvency II Directive (2009/138/EC). Also, the renaissance of semi-insurance institutions should be noted, e.g. of mutual funds in the agriculture or mutual support funds, as well as platforms for "exchange" of risks that appeared thanks to modern technology – in particular through the Internet.

6. CONCLUSIONS

The development of nanotechnology is inextricably linked with the development of civilization. It was stated in this paper that new solutions employing

¹⁰The insurance policy was bought by a Deputy Mayor of London, who insured for life a certain William Gibbons. Under this policy the sum of 383 pounds, 6 shillings and 8 pence was to be paid if the insured died within one year. Unfortunately, the insured person died after 11 months. Business partners of the Deputy Mayor wanted to avoid the payment "... they made a dubious point that the insured did not die within twelve months, if we assumed that each month counted 28 days". The case was brought before a court that ruled that "months should be counted according to the calendar" and the due compensation was paid out (Robertson 2011).

nanoparticles bring about numerous improvements in everyday life. At the same time however they increase the possibility that the humankind experiences a materialization of currently unknown risks. In this situation works connected with nanotechnology may continue only with the support from the insurance industry. One of the basic functions of insurance is to protect against materialization of certain risks; hence, the insurance business may help to minimize the risk connected with the use of nanotechnology. Currently, in order for nanotechnologies to enter into common use entrepreneurs and customers buying nanoproducts must secure financing for the basic production processes and also for instances when certain losses occur that are not directly connected with the manufacturing process. Since insurance products grant protection against consequences of occurrence of certain losses connected with nanotechnology, they may help to reduce the level of risk aversion among the entrepreneurs and the final users of nanoproducts. Protection against materialization of certain risks, for instance against environmental losses, might incentivize entrepreneurs to invest in nanotechnology and to apply nanotechnology-based methods in their business activity. Nanotechnology-related risks are relatively new. If they materialize, their consequences may be potentially catastrophic. In this situation insurance companies are faced with a particularly difficult challenge of developing a comprehensive insurance offer that will impact the future development of nanotechnology and its application in mass production and everyday life. However, there are no verified actuarial models that describe the risk connected with nanotechnology. Also, such models are difficult to construct because there is insufficient data on nanotechnology losses. The time series that we have at our disposal are too short to provide a basis for reliable calculations. Mutual insurance companies should be mentioned when analyzing the capacity of the insurance industry. Their business model creates a possibility to handle the nanotechnology risk even without verified actuarial models to calculate reliable premium amounts and, consequently, to estimate adequate technical and insurance reserves. To sum up, the popularization of nanotechnology depends on the measures taken by the insurance industry. This situation creates an opportunity for the industry to be innovative and to support the civilizational development. To live up to this challenge, the insurance industry may come up in the near future with relevant offers and actively join efforts targeted at minimizing the risk related to the development of nanotechnology.

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