DOKTORI ÉRTEKEZÉS

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RISK POLICY IN THE DESIGN OF ENVIRONMENTAL LIMIT VALUES

Challenges of the regulation of Polycyclic Aromatic Hydrocarbons (PAHs) in ambient air

A KOCKÁZATPOLITIKA SZEREPE A KÖRNYEZETI HATÁRÉRTÉKEK ALAKÍTÁSÁBAN

A policiklusos aromás szénhidrogének környezeti levegőbeni szabályozásának kihívásai

Témavezető: dr. Hronszky Imre

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Ph.D. Thesis

Imre Olivér Kozák

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Table of contents

List of figures and tables

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“Raising awareness creates change.”

(Fritz Perls)

Foreword

Starting originally in the 1950s, nowadays the field of environmental protection arrived to the status when its importance is globally recognized. The integration of environmental concerns into economic growth and development policies has emerged as a priority concern of modern environmental policies since the 1970s (Speck et al., 2001). Fundamental research programs are ongoing, international developments had been started, governmental, non-governmental and private organizations investigate the state of the environment. Both the number of persons in environmental related positions and students in environmental related programmes are increasing (Valkó and Gál, 2000). As Farkas (1994a) describes, general awareness of environmental issues related to economical growth is present and people are willing to sacrifice for a better environment. As we can see in Galántai (2004), environmental concern is present even in space programs. However, environmental habits in professional and private life still vary on a wide scale depending on the level of development and culture. In the developed Western societies, environmental protection is an organic part of everyday life, however, in less developed countries this attitude waits for implementation as needs of development for high quality of the economy precedes needs for a better quality environment (Farkas, 1994a). The main attitude, sustainability, had been interpreted to ensure growth, development and the fulfilling of needs (Hronszky, 1998).

Air pollution is one of the *major* environmental problems of cities of heavy traffic and industry, consisting of both inorganic and organic pollutants. (Moser and Palmai, 1992). As Tarr (1996) describes, air pollution as a concept, is relatively new, and before World War II, smoke was viewed as the primary cause of atmospheric contamination. He describes that among the leading causes of urban smoke were industries, commercial establishments, residences, railroads and tugboats, in short anything that utilized wood or coal as fuel. According to Hays (1998), the regulation of air pollution on the global scene dates back to the environmental Act of 1970 in the USA. Then the passage of the 1977 amendments to the Clean Air Act (first instituted in 1963) came after seven years of intense experience with the workings of the 1970 law. Despite the complex detail, the clean air effort consists of two elements: standards and implementation. The identical issue is how clean the air should be. Almost any environmental quality program desires to clean up the air, water or land, or to prevent its degradation. The focus is, however, as Hays (1998) explains, on *the degree of cleanness*. To be effective, the general concern must be translated into an operating procedure, a performance standard or an acceptable practice for all groups (individuals, corporations, government). While to the public, a standard represents a

higher qualitative level of living, to the polluter it represents a cost, which reduces both original profit of a private corporation and original budget of a public enterprise.

Inorganic pollutants, like CO, CO_2, NO_x, SO_x, are usually present in high concentrations, their short and long-term effects are well described, and a relatively well working regulation system had been developed over time (in Europe and CEE, mostly based on charges and taxes, Speck et al., 2001). However, organic air pollutants are usually present in much smaller concentrations, their effects are not so precisely explored and unfortunately, their regulation is not as efficient as desired.

Nowadays, one of the most important organic pollutants in urban surroundings is the group of Polycyclic Aromatic Hydrocarbons (PAHs). PAHs have a similar chemical structure to the building blocks of DNA; therefore, they can easily bond into the DNA chain during cell replication resulting in mutant DNA strains and development of cancer. Because of this mechanism, even very small amounts of PAHs can result in cancer, therefore even the relatively small concentrations of PAHs in urban air is considered dangerous. At least 20% of the EU population will succumb to cancer, therefore for the Health and Safety policy objectives of EU it is clearly important to ascertain whether this incidence can be decreased by improvements in our environment.

As the use of PAH in the chemical industry has undergone a severe change and very strict health and safety regulations are in place[1], but urban traffic, domestic and industrial heating remain as the main sources of PAH contamination. However, urban environmental regulation of PAHs is still in development and shows important differences when one compares the different regulation systems of different countries. The easiest way to control PAH contamination is the use of environmental limit and target values and by far this is the most frequently used method.

Regarding our field of study from the perspectives of history of science and technology, the history of environmental regulation started with a very noble initiative in the fifties: to extend scientific knowledge to this new area so exact statements can be made. Environmental movements promoted precaution and safety, while other parties wanted to allow only such regulation to take place, which is based on precisely defined values. These latter directions had a

[1] For example PAHs are banned to use in cosmetic and other public products in Europe since the 70's. See the 76/779/EEC EU Council Directive „ restrictions on the marketing and use of certain dangerous substances and preparations". The Directive lists PAHs in Appendix *Point 29 Carcinogens List 2 Category 2* and *Point 30 Mutagens List 4, Category 2* and bans these materials as „may not be used in substances and preparations placed on the market for sale to the general public in individual concentration equal to or greater than […]". The objective of this European directive is to either restrict or prevent the marketing of substances or products which may adversely affect public health or the environment. The manufacturer is obliged to comply with the restrictions for the use of the chemicals mentioned in the directive. The Authorities inspect factories and analyse all finished products for compliance with this directive.

political background, to delay control over by 10-20 years because huge financial interests of the industry. PAH related environmental concern is no different by these means, and is found at the meeting point of this two very different worlds: natural sciences, which tries to be as objective as possible, and policy making, loaded with social values. Both areas have their own rules and disciplined methodologies and only vague explorations have been made to leave the secure terrain of either of these domains. Although EU management have made steps in this direction to advance a high level of protection, the current environmental protection system for PAHs is still taking its form. It is still characterized by the learning process on how to deal with the above two radically different approaches, and in the same time, on how to implement the learning into legislation and industrial practice.

Introduction

The current Thesis discovers the current place of limit and target values in environmental regulation, presenting different types of legislative and non-legislative possibilities available for the regulation; exploring regulative possibilities offered by limit values and evaluating the design process of these limit values. The Thesis presents the related international analytical results regarding polycyclic aromatic hydrocarbons (PAHs), also introducing the national (Hungarian) status of pollution. It examines what factors are considered in the design process of PAH limit values, what are the consequences of these factors and what other factors should be considered during this design process to establish limit values that are in line with the original objectives of environmental regulation. It also shapes the possible scenario for the recent future of regulation possibilities.

The content of the Thesis follows a certain curve, of which the first part (the first two chapters) presents the status of knowledge about environmental limit values and PAHs. The second part (the third and fourth chapter) applies the methods and attitude of history and sociology of technology, to formulate new results in the area of PAH regulation and to shape its future.

In detail, the chapters consist of the following subtopics:

The first chapter begins the investigation starting from the side of environmental policy making and deals with limit values in environmental regulation. It details the possible legislative and non-legislative environmental regulation tools, and places limit values in this context; then count the possible types of environmental limit values. Investigates the design process of environmental limit values, analyses the future possible roles of limit values in regulation and investigates the trends of environmental regulation of the EU. Finally, this chapter presents the available technical solutions to reduce emissions of polluting materials.

The second chapter approaches from the side of environmental natural sciences and investigates polycyclic aromatic hydrocarbons. It elaborates the major sources of emission, describes the environmental and health effects of PAHs and details the most important physical and chemical properties. Then this chapter summarizes the available data about PAH pollution in the world and in Hungary, the former based on literature data, the later based on own research data.

The third chapter enters to the gray field between natural sciences and policy making, by discovering uncertainties in the environmental regulation of PAHs. First, it introduces the difficulties in the regulation of PAHs, then presents the relating concepts from risk management about uncertainties. The chapter analyses the role of knowledge and ignorance in PAH regulation and shows alternatives to deal with the situation. In addition, new notions are defined to

introduce a new theoretical background to make suggestions on improving PAH regulation based on limit values. Finally, the chapter investigates the change over time of limit values.

The fourth chapter deals with different approaches at the meeting point of natural sciences and policy making and investigates ways of the forming PAH regulation in Europe by establishing possible scenarios. It presents the initial assumptions and criteria for the development of the scenarios, and then presents four general scenario alternatives. Then, building based on the three previous chapters, predicts the most likely scenario in the environmental regulation of polycyclic aromatic hydrocarbons.

Problem Outline

Targets of the research

The primary target of the research is to discover the current environmental regulation of PAHs and to identify the key points of issues. Then secondary objective of the research is to develop a model in a multidisciplinary approach, that makes possible the design of environmental regulation measures, that will result in reduction of PAH emission and in consequence the improvement of the status of the environment.

The reconstruction of the process of formation of knowledge can bring new insights and can help us understand the limitations of natural-sciences, and can reveal which non-scientific, 'non-objective' factors play an important role in knowledge formulation, as it is presented by Hronszky (2003). Therefore, during the analysis of the above topic, we invest a considerable effort into the understanding on how the knowledge is shaped, which factors are considered in an implicit and others in an explicit way during the formation of PAH limit values. The Thesis will therefore examine the design process of environmental limit values from natural scientific and socio-natural scientific point of views. A specific methodological objective of this study is to explore the borderline area of engineering and social sciences, to link factors that are usually rarely investigated together, by using the approaches and attitudes of history of technology and sociology of technology. Therefore, during the research we also examine our own engineering work in a reflexive, self-investigating way.

The main question to answer in the Thesis is how shall we improve the regulation system of PAHs to be more effective?

To cover the subject in detail, we have to focus on the following areas:

- what are the environmental regulation tools used for PAH control, what is their place in current environmental legislation, how these tools are designed?
- why is it required to regulate PAH emission – what are the environmental and health effects, does the environmental concentration of PAHs demand legislative measures?
- how the design process of PAH regulation tools can be seen from a social sciences perspective, what points can be revealed to improve the design process?
- how do we foresee the near future of PAH regulation?

As environmental regulation in Hungary is part of the larger network of the European Union environmental regulation system, we focus mainly on Hungary and the EU, with giving insight on the worldwide context.

The particular multidisciplinary approach of the topic requires an approach that branches-out to the different areas of sciences. To reach the targeted goals, beside the investigation of the relevant literature of each area, the different particular methods of investigation have to be incorporated as well. In the domain of environmental policy, the live policy practice and current regulations were the primary sources. In the area of technical environmental protection, the determination of concentrations, and the discovery of environmental and health effects can be established using laboratory experiments and literature data. The exploration of the borderline of these areas and the inclusion of non-natural scientific point of views can be done using discourse and reflexive self-analyses with the attitudes of history of technology and sociology of technology. It has to be emphasized that to successfully reach the targeted research objectives, not only the information and data available from the different disciplines has to be combined but the different working methods and approaches have to be harmonized. Therefore, the current topic of analyses requires besides technical knowledge and expertise a large degree of openness towards the area of social sciences.

Methodological context of the research

The field of PAH regulation lies between the natural scientific science of chemical analyses and the social science of policy making, having radically different approaches on how to manage error in building their knowledge base.

From the point of view of natural sciences, classifying molecules as harmful and hence ban from general usage, scientific evidence has to be given to prove the harmful nature of the molecule. From this point of view, when knowledge is produced in natural science, the main approach is to avoid Type I statistical error[2]. In other words to avoid the incorporation of a statement into the knowledge body which is found false later. This is because natural science is a cooperative system, the knowledge structure of natural science is based on trust – one researcher trusts the other that his/her data and conclusions are valid, therefore he/she can use them as the starting point of his/her own work. Therefore, the error of accepting a false statement as true has to be avoided by all possible means. To commit the error of rejecting a statement (assume it is false), which is true in reality, is of course a great value loss, however, it does not danger the operation of the whole system of natural scientific knowledge and has no effect on the reputation of the

[2] *Type I statistical error* = the error of rejecting the null hypothesis given that it is actually true (banning a molecule as harmful which is actually not harmful).

Type II statistical error = the error of failing to reject the null hypothesis given that the alternative hypothesis is actually true (classifing a molecule as not harmful which is actually harmful). (Kemeny and Deak, 2000) They outline that the smaller the information content of the sample (small number of cases, high variation), the bigger the probability of accepting the null hypthesis, if it is not true in reality.

scientist. The industry also approaches environmental protection calling upon natural sciences, to avoid all financial expenses and technological investments that are not 100% justified.

Policy making has different goals set as target as the normative point of view defends the founding values of humans and their environment, and is surrounded by the context of value choice (Schwarz and Thompson, 1990; Hays, 1998; Farkas, 2002). Other times, policy rules are designed to implement societal norms (Brown and Zaepfel, 1996). This normativity incorporates the attitude of being subjective, saying that this normativity is important to us but maybe not for others. Therefore, to avoid Type II errors, we take the risk of accepting a false positive, in other words, based on current knowledge we implement control over a polluting agent, which in reality might not be dangerous.

The above renders a difference between the two sides, as in contrary to policy making, the resistance to subjective point of views and the differentiation between facts and values is a general characteristic of science (Popper, 1934, cited in Farkas, 1994b). However, as Tickner (2000) explains, the convention of guarding against Type I errors can create a bias toward the null hypothesis, usually stated as “no effect”. While type I error rate is traditionally set at 5 percent (“the finding is so strong that there is less than a 5 percent probability that the result would have been seen by chance alone”), the Type II error rate is often set at 20 percent. This means, that 20 of the time a real phenomenon will be missed because the data were not strong enough to demonstrate convincingly its existence (Kriebel et al. 2001 cited in Tickner, 2000). While having certainty before accepting a casual theory is central of experimental science, this level of certainty is often difficult to achieve in the complex, uncertain world of environmental science and can work against policy making.

In this gray area, it is vital on how we can fill with content this certain area where we move in the interest of two different approaches on building knowledge. How can we fill it with knowledge coming from natural sciences (scientific research, industry)? How can we build knowledge approaching from social sciences (policy making, governments, NGOs)? What can we do when we face difficulties building up knowledge from one area or both? These questions will be answered trough the methodological approach of our research, which itself is a learning curve on how to deal with the task of combining so radically different interests, when there isn’t one *good* solution.

1. Limit Values in Environmental Regulation

1.1 Different tools of environmental regulation

Environmental policy became one of the focus areas of governmental functions in recent years. Politicians discovered that dealing with environmental protection can be at the basis of their success, and both the corporate sector and individuals are aware that the different industrial and communal activities must respect the environment. Different tools were developed to orientate the actors of the society towards an *environmental friendly behaviour*. These tools include environmental *legislation*, *economic pressure* and the use of *management tools* to motivate the actors for self-regulation. Of these different apparatuses, environmental legislation was the first to appear on the national and international scene, and still, it is the most developed form of the above.

The primary duty of environmental protection is to maintain our and our descendants' health and survival by assuring the appropriate life conditions, and the protection of the good state of natural and artificial surroundings. Therefore, environmental protection cannot be solely a defensive system, but has to assure the foundations of an environmental development, that in parallel of guaranteeing avoidance of environmental damages, also shapes it with regard the above necessities. Therefore, we understand by the term *environmental regulation*, all the interconnected system of actions that assures reaching the above goal.

With regard to the methods of environmental regulation, we differentiate between primary and secondary regulatory tools. The object and goal of *primary regulatory* tools is the protection of the environment itself, hence we have a public act especially created for the protection of the environment. However, the object and goal of *secondary regulatory* tools is not the protection of the environment directly, but, trough its nature and indirect measures, the law takes into consideration the environment.

The possibilities of primary and secondary regulatory tools can also be grouped along different criteria. Beside legislation, we can also regulate environmental matters trough other tools, which are often called *speculative tools*, for example, environmental management systems in this case. Then, regarding the time and place of the object of the regulatory tool, we can make a difference in the following way: the goal of *preventive* regulation is to avoid a certain negative environmental effect in the future, and in time, it regulates before the environmental damage would happen. The *preventive and reparative* tools regulate for the time and space of the environmental damage itself, and their main purpose is to avoid further damage and pollution.

The *reparative and preventive* tools provide criteria afterwards the environmental effect has happened for the remedy of polluting effects that already took place.

We assume that all human activities have an effect on the environment in some extent. Corporations, industries use the environment in an intensified way in space and time; therefore, a general emphasis to *motivate* their actions towards behaviour takes into account environmental effects. There are several ways to motivate these environmental actors, which are presented on *Figure 1.*

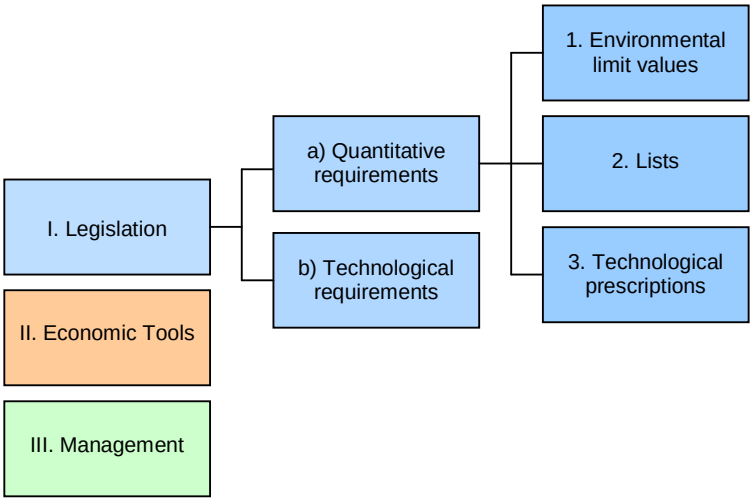

Figure 1. General tools implying environmental friendly behaviour.

The following three groups are easy to establish: regulation by *legislation* (acts, decrees, directives), by *economic tools* (taxation system, fees, allowances), and *management tools* (environmental management system). (These groups are called as “direct regulation”, “economic instruments” and “suasive instruments” in Szlávik (1996)).

Legislative tools have a direct effect on the polluters, by banning or restricting their actions. Economic tools create a financial situation with special taxation systems, grants and benefits that creates a financial benefit for the environmental players. In many countries for example, the taxation for hybrid engine cars (fuel coupled with electrical traction) allows a lower final prices of these vehicles compared to fuel engine cars, and both automotive manufacturers and end users are more financially interested in replacing ordinary vehicles with hybrid engine cars. Then management tools encourage the voluntary use of operational systems of the enterprises that regard environmental change as a benefit, and targets the operation of the enterprise towards profitability coupled with respect to the environment (Kósi and Valkó, 1999). En example for

such management systems is the Eco-Management and Audit Scheme (EMAS) of the EU, or the ISO 14001:2004 international standard on environmental management systems.

Inside the group of regulation by legislation, requirements regarding the allowed utilization of the environment can be separated into further two groups (Bandi and Perecz, 1998):

- quantitative requirements;
- technological requirements.

Quantitative requirements can be imposed for actors with environmental effects:

- environmental limit values;
- lists;
- application and safety prescriptions.

Technological requirements only accept the fulfilment of the prescriptions when a given technology is used. In contrary with quantitative requirements, they do not contain limit values for certain substances, rather they protect the environment by forcing the compulsory use of environmentally friendly or clean technologies. Such a requirement can be that the nearest available waste deposit settlement should be used, or the most efficient technology must be used during waste burning. Requirements for the usage of the *Best Available Technology* (BAT) go even further, which prescribes for the given company the compulsory use of the best advanced technology from those that are available on the market already and economically available and used in the industry. However, this regulatory tool is more complicated to implement in the practice because the available best technology can be different from area to area depending on the local conditions. It is very important to emphasize that technological requirements do not contain limit values but they assure to avoid environmental damages by the use of an environment friendly or clean technology.

Lists, as their name implies, contain environmental requirements in a listed form. As experience shows, public opinion is the most sensible to lists related to nature protection, like lists of the protected bird species.

Application, protective and safety measures are implemented for activities with a high-risk accident. In this case, the uses of the prescribed work method and safety equipment are compulsory. These measures can prescribe the use of safety and security circuitry in the technology, which can even stop the functioning of the production line in a severe case.

Limit values impose a limit on the concentration of certain substances, and they mainly consider the quality of the environment. The aim is that the quantity of the polluting material should not pass the concentration or cumulative limit defined in the public act. In case the limit passed,

sanctions are in place for the subject with polluting activity, like obligation to pay a fine, or in severe cases, obligation to terminate the activity.

Limit values have a very important place in regulation system, and we present how they are defined in Hungary, according to Bandi and Perecz (1998). They also demonstrate that Hungarian law has not been using technological prescriptions but almost in every case put in place limit values. We will meet more and more technological prescriptions as the change has begun in the last few years, however, limit values will probably remain at the basis of environmental regulation.

Streffer et al. (2003) highlight that the notions of *threshold values* and *limit values* should not be confused. Threshold values belong to processes in the nature and link the action and the resulting effect with a certain natural relationship, as it can be seen in *Figure 2*. However, limit values are artificially created values; they link the action and the resulting effect in a context important for us: they determine a "limit" defined by us. Unfortunately, public opinion does not always differentiate between these two notions. Therefore, we have to emphasize, that in case of limit values, we talk about out *arbitrary values* that have been fixed by us, which can be linked or not linked to natural phenomena.

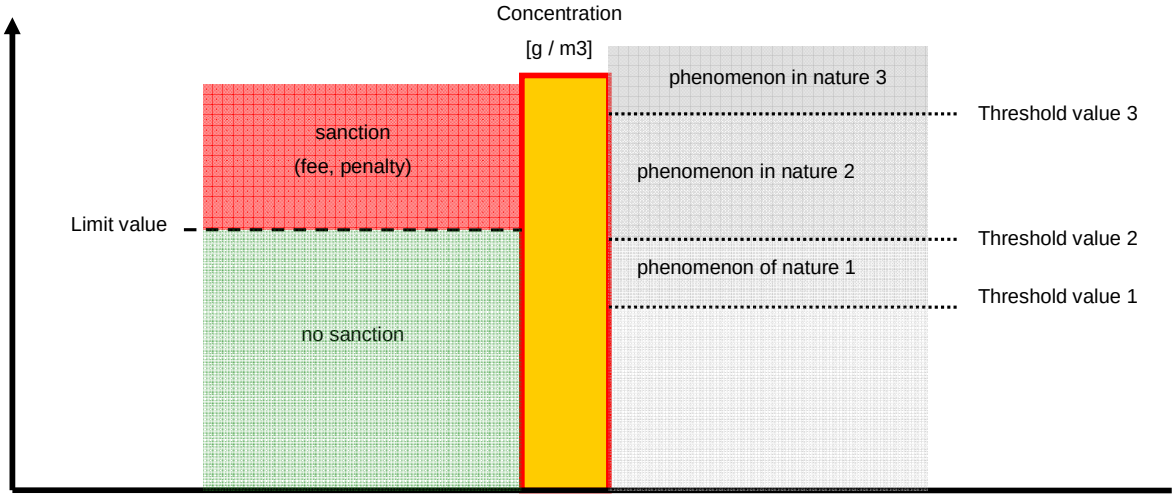

Figure 2. Limit values and threshold values.

As limit values have an important status in Hungarian law, let us review briefly their notions, usage and application area based on the *"Act LIII of 1995 on the General Rules of Environmental Protection"*[3], which describes limit values in detail in section 35:

[3] Hungarian terminology: "1995. évi LIII. törvény A környezet védelmének általános szabályairól."

"In order to protect and conserve environmental components and protect against impacts that endanger the utilization of the environment, emission and pollution standards shall be established in accordance with the contents of this Act.

In the course of establishing the standards specified in Subsection (1), the actual and desirable target state of the environment shall also be taken into consideration."

The act differentiates between discharge limit values (= utilization, stress), emission limit values and pollution standards, which are defined in Section 4[4]:

Discharge limit values: "level of discharge to the environment or any natural resources as stipulated in a legal regulation or an official decision that – relying on available scientific data – is likely to cause damage to the environment if exceeded".

Emission limit values: "level of emission to the environment or any natural resources as stipulated in a legal regulation or an official decision that – relying on available scientific data – is likely to cause damage to the environment if exceeded".

Pollution standards: "level of pollution of any component of the environment – as stipulated in a legal regulation – that, if exceeded, may, on the basis of the current scientific knowledge, result in environmental damage or health impairment".

Later, Section 87 distinguishes from each other the following limit values, depending on the specific features of the environmental component to be protected or the type of contamination; standards may be defined according to the following types: general, regional, local, individual, pertaining to protective zones, for ecological, health and planning reasons or for use in emergency situations. [5]

The act describes in detail discharge limit values (utilization limit values), emission standards (emission limit values) and pollution standards (pollution limit values) in Section 88:

"The extent to which environmental components may be utilized and the quantity, quality and concentration of substances and energy that may be released into the environment shall be determined in view of the objective set forth for the preservation or restoration of the environment or affected environmental component."

Emission limit values:

"An emission standard may be established for:

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[4] Hungarian terminology: "Igénybevételi határérték", "Kibocsátási határérték", "Szennyezettségi határérték". In the current text we used the already available English translation in the literature for the definitons. However, we belive that the following terms would discribe better these notions: "utilization limit values", "emission limit values", "pollution limit values".

[5] Naturally, beyond the reach of the Act, certain areas of expertise can use their own specific limit values. As an example, in environmental air protection, health and ocology air pollution limits, the short and long period air quality limits, or limits applied to soil concentrations are also in use. (Moser and Pálmai, 1992)

a) some product (product standard);

b) the quantity of an emission that is typical of some technology or pollutant (technology standard; which may be an emission concentration or a specific value for the quantity of input, production and energy production etc.);

c) the quantity of a pollutant or energy that may be emitted in the given area by the polluting source (area standard);

d) in a total quantity for a specified area, branch of production or group of polluting sources."

Discharge limit values (utilization limit values):

"A utilization standard may be established:

a) for the admissible level of utilization with respect to some use of the environment (the extent of potential environmental change, the total quantity of a natural resource that may be extracted or the amount that may be extracted in a certain unit of time);

b) for the admissible extent of the abstraction or use of an environmental component that may be utilized in some area;

c) in a total quantity for a specified group of exploiters or users."

The Act explains in the next section that "emission and exposure standards shall be determined – in addition to contamination standards – in due observation of the current and proposed state of the environment or a specific environmental component and the most efficient response and the best available techniques in respect of activities defined in specific other legislation. When introduced, adequate and sufficient time shall be allowed for preparations." The expected joint impact of natural processes and certain environment-loading factors shall also be taken into consideration when the standards are being established and the standards shall be established by the Minister in decrees – issued jointly with the concerned ministers – or by the environmental protection authority in cases specified in decree.

Beyond the legislative regulation, certain fields of expertise can have further limit values. For example, in air protection the following limit values are used in practice:

Human-health air pollution limits[6] represent the quantity based on the status of the science and technology, which does not cause any permanent loss in health or injuries, and which has to be respected in order to protect human health with the described methods and during the specified period in the given environmental law.

[6] Hungarian terminology: "*Légszennyezettség egészségügyi határértéke*"

Ecological air pollution limit[7] is a level of air pollution, which when surpassed, can result in damaging the Ecological system.

Air quality limit[8] is the concentration or quantity of the air pollutant materials, which when present for the specified period of time, results health loss or injury.

Short period air quality limit value[9]: the largest allowed concentration of air polluting materials during 60 minutes or 24 hours. The objectives of the short period air quality limits are to prevent the formation of acute health or environmental damage, the evaluation of the level of the most important environmentally polluting effect, the determination of the magnitude of the allowable industrial polluting sources and the foundation of the measures of the environmental authorities.

Long period air quality limit value[10]: yearly limit of the environmentally air polluting materials. The objectives of the long period limits is to prohibit the development of chronic health and environmental losses, the characterisation of the air quality of certain areas, the evaluation of the results of the air purity related measures, trend-evaluations.

Soil level concentration[11]: the quantity of solid, liquid or gas phase materials at the determined height above the ground.

Target values can be defined as a special form of limit values. As we have seen above, limit value necessities a kind of negative action on the polluter and usually are linked to threshold value, and the regulator justifies the limit value by a link in nature ("we must respect this and this limit, otherwise this and this disease will appear", etc.). However, it can be that either we cannot show a justifiable link in nature, or we do not want to penalise the polluters, and we implement a softer form of the original limit values. In this case, to emphasise the difference, we talk about *environmental target values*. However, these values are still arbitrarily chosen by the policy maker and can have the same types and forms as the original limit values. Later in the thesis, when we talk about limit values, we will consider both the original meaning of limit values and the softer target values, and we will point out the difference only when it is necessary to specifically talk about target values.

Finally, we have to be aware that sometimes limit values are linked to other legislative forms. This alone would be an extensive topic, therefore we will not discuss these possibilities in detail, but we mention that Fodor (2000) demonstrates the link between emission limit values and the

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[7] Hungarian terminology: "*Légszennyezettség ökológiai határértéke"*

[8] Hungarian terminology: "*Levegőminőségi határérték"*

[9] Hungarian terminology: "*Rövid idejű levegőminőségi határérték"*

[10] Hungarian terminology: "*Hosszú idejű levegőminőségi határérték"*

[11] Hungarian terminology: *"Talajszinti koncentráció"*

Best Available Technology, which is one of the most common links for limit values one can find in current environmental legislation.

1.2 Process of the design of limit values

Unfortunately, we could not find analyses about the design process of environmental limit values. Therefore, we modelled the process based on our own experience and available theoretical literature (Farkas (1994a), Pinkau and Renn (1998)) and discuss accordingly. Farkas explains that the development of environmental regulation should track the general pathway of beginning with the environment, and its problems, matters and plans come into interaction with certain political considerations. From these specific legal responses can be drawn which lead to codification (see *Figure 3*).

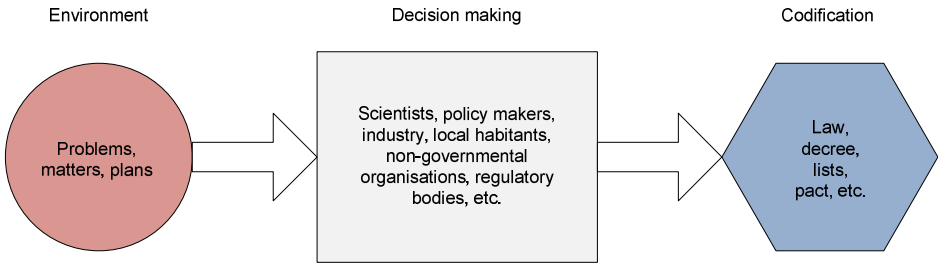

Figure 3. General pathway of development of environmental regulation.

The development of limit values also follows this way; the detailed steps of the procedure are presented on *Figure 4.*

At the commencement part, people became aware of a certain environmental change, usually negative, and hence started to talk about a certain environmental damage. The need for the environmental regulation of these compounds appears.

The second part usually starts by adequate authorities initiating the process of establishment of a limit value for this compound. Early models supposed that policy making itself is a rational process, however it turned out, that it is more value laden, and both rational and social factors play a role in the process (Farkas, 2002). In this model, we map this bi-nature in the following way.

Regulators turn to natural scientists of different disciplines, to analytical chemists, to chemical engineers, biological chemists, experts in health protection (Hronszky, 2002a). The scientific basis for limit values usually looks like the following (based on Wiedmann, 1999): Environmental experts analyse the environment with a natural and technical science approach, and characterize a compound, or a series of compounds or effects that can be responsible for the

change, especially if the situation related to chemical-biological reactions. Scientists analyse the compound, try to describe its possible reactions and effects in the environment, run model reactions. They construct dose-response (also called dose-effect) curves for biological effects; develop mathematical relationship models for reversible and irreversible effects. (We present dose-response curves more in detail in *Chapter 1.3*, page 29). They analyse exposition possibilities and finally characterise risk.

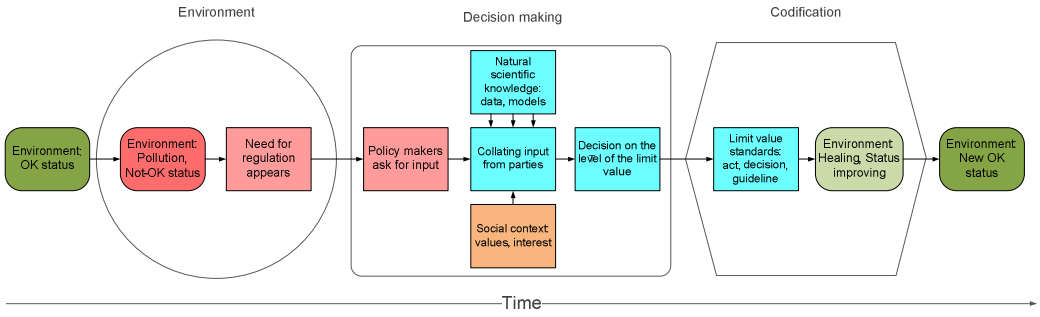

Figure 4. Model of the design process of environmental limit values.

Social values, personal interests are usually also taken into account, either in an implicit or explicit way. In an implicit way social factors are always taken into account, because the risk variable, by its nature, is value laden – determining what damage is and what is not, is choice being made along values. An explicit way involves other players directly into the decision making process, and non-governmental organisations, nearby habitants, industrial players, future users, can all bring into account their needs and values. In some countries, this happens in an institutionalized form, by organising official debates and round tables, or this can be also made with informal conversation.

The input from both science and social context are usually collated by the policy makers but there are also examples for official multidisciplinary groups who match the different input. This area became of major interest in recent years and extensive literature is available in environmental policy on how we can or should organize the matching of inputs of these different sides. However, in the usual process, natural scientific knowledge is much more extensively taken into account and shapes the step “Collecting input from parties” (three arrows) (the “objective” attitude of natural sciences is shown in blue on the figure, while the “subjective” attitude of social context is shown in orange).

After the matching of available input, a decision is being made on what the limit value should be, based on the reasoning provided by the concepts of natural science (heavily) and social values and interest (a little). The decision is either directly made by the policy maker; or it can be made by an external body, whose decision is adopted by the policy maker.

In the third part, codification can take even several years after the decision was made. Regulators formulate a law, decree or decision which can be reviewed, then has to be accepted by a legislative body or just issued by a local or central administration (ministry, city hall). In the ideal case, after the codified legislation becomes current, environmental players start to react and the environment starts to heal and finally reaches a new satisfactory state. The codified limit value is usually based heavily on natural-scientific knowledge and bears the attitude of being "objective".

To see a practical example, let us follow the development process of limit values of PAH regulation in the European Union. After the 70-80s, increased traffic and industry led to significantly higher emissions of organic air pollutants. Many academic and legal research laboratories started to measure and report PAH concentrations in various forms, and the need for regulation appeared, which was formally announced in the *White paper on Growth, Competitiveness, Employment* (1993). EU administration first called for scientific reasoning about PAHs. Science and technology platforms had been established to reply to the need of PAH measurement, and even our laboratory[12] participated in such a project to map current PAH concentrations across Europe. After more than a decade of research, results, techniques, methodologies had been summarized in *Ambient air pollution by Polycyclic Aromatic Hydrocarbons (PAH). Position Paper* (27 July 2001). This position paper had been reviewed and commented by several players of the society, and based on the conclusions of the position paper and the feedback from other parties, a regulation proposal had been established (*Proposal for a "Directive of the European Parliament and of the Council" relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air* (16 July 2003)) and different suggestions about a possible limit value had been summarized and a decision has been made about it in the *Opinion of the European Economic and Social Committee on the 'proposal for a "Directive of the European Parliament and of the Council" relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air' (30 Apr 2004)*. Then, the limit value has been officially legalised in the *"Directive of the European Parliament and of the*

[12] The Hungarian measurement was carried out in the laboratory of BUTE General and Analytical Chemistry Department by us. Results are published in detail in Kozák et al., 2003 and Ötvös et al., 2004. See page 6 for full reference details.

Council" relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (15 Dec 2004). Nowadays (2008), member states are rolling out their local regulative measures in regard of the Directive, and in 3-5 years, we can probably see, how these limits established in the standards can be respected by the industry.

1.3 Dose-response curves, deterministic and stochastic effects

It is frequently assumed that deterministic (non-stochastic) and stochastic[13] effects can be differentiated between by their different dose-response curves, which have been extensively studied for quantitative assessment for the biological impact of ionizing rays (radiation) (IAEA-WHO 1983, Kamrin et al. (1995), Young and Sussman Yalow, 1995, Pinkau and Renn, 1998, Streffer et al., 2003). Ionizing rays and PAHs are both assumed to have carcinogenic effects, and as ionizing rays have already been widely studied, we present the theoretical basis of the dose-response curves based on the available literature for ionizing rays.

Simplified dose-response curves of the two types are demonstrated in *Figure 5*. For deterministic effects, a threshold dose has to be exceeded before the described effect can be induced. Once this threshold is crossed, the number of persons affected, but primarily the severity of the effect, increases with increasing dose. Here, a multicellular mechanism operates, that is, many cells have to be damaged for effects to become manifest. Acute damages and late radiation damages of tissues and organs are assigned to this category. For stochastic effects, it is not the severity of such effects but the probability of their incidence increases with increasing dose, and this occurrence follows a stochastic distribution. Experimental observations and reflections about the mechanism make us assume that induction of these effects is a unicellular process, which starts from one single damaged cell. As we lack experimental or epidemiological data in the lower dose range, we assume that there is no threshold dose and that the dose-response relation is a liner one for low doses. Induction of hereditary defects and induction of malignant diseases (leukaemia and solid tumours) is assigned to this category. (Pinkau and Renn, 1998).

[13] Stochastic = „A stochastic event is based on random behavior. The occurrence of individual events cannot be predicted, although measuring the distribution of all observations usually follows a predictable pattern. These patterns can be described by statistical means. An example is the decay of radio active material, where a clump of matter has a measurable and thus predictable half-life time. It is impossible, however, to mark an individual atom and predict when it will decay and emit radiation. The latter process is a stochastic event." (What is Life, 2008).

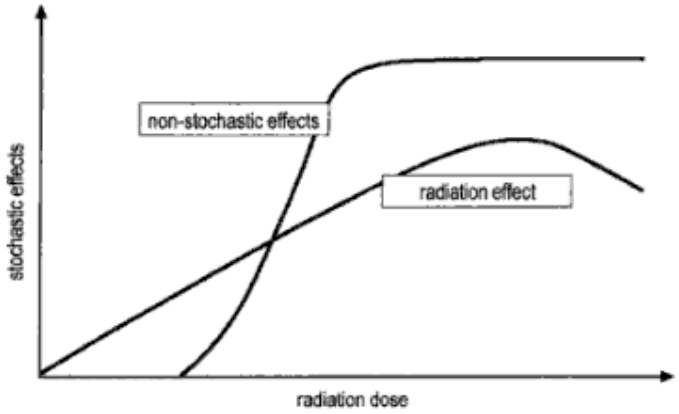

Figure 5. Basic types of dose-response relations of exposure to radiation[14].

As presented by Streffer et al. (2003), without any doubt, mutations as a direct result of stochastic events feature a linear dose-effect relationship, which can be expressed as an exponential relationship between (radiation) dose and mutagenic effect. In graphs with linear x- and y-axes, an exponential dose-effect relationship in the lower dose range appears as a straight line as illustrated in *Figure 6*. A linear relationship like that is regarded as characteristic for stochastic effect (unicellular).

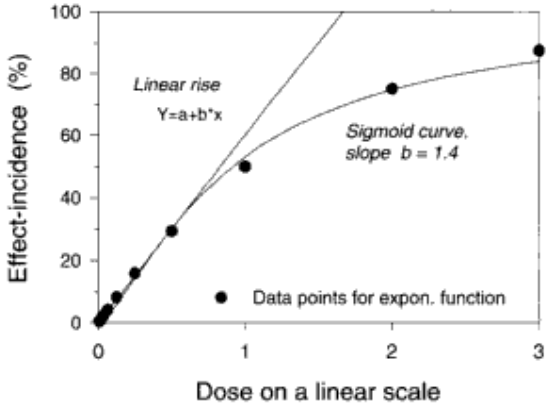

Figure 6. Lower dose-range: linear rise and sigmoid curve dose-effect relationships[15].

On the other hand, in the same linear notation for both X-Y axes (see *Figure 7a*), non-stochastic effects (multicellular) are described by S-shaped curves that do not rise from zero-dose but, quite visibly, from a threshold dose.

In cases of malformations that can be triggered by mutations and of radiation-induced cancer, mutations are the initial, stochastic event, followed by non-stochastic processes resulting in

[14] Picture cited from Pinkau and Renn, 1998.

[15] Figure cited from Streffer et al., 2003.

malformations and tumours. Dose-effect relationships for such processes are well represented by sigmoid dose-response curves over a logarithmic dose axis (see *Figure 7b*).

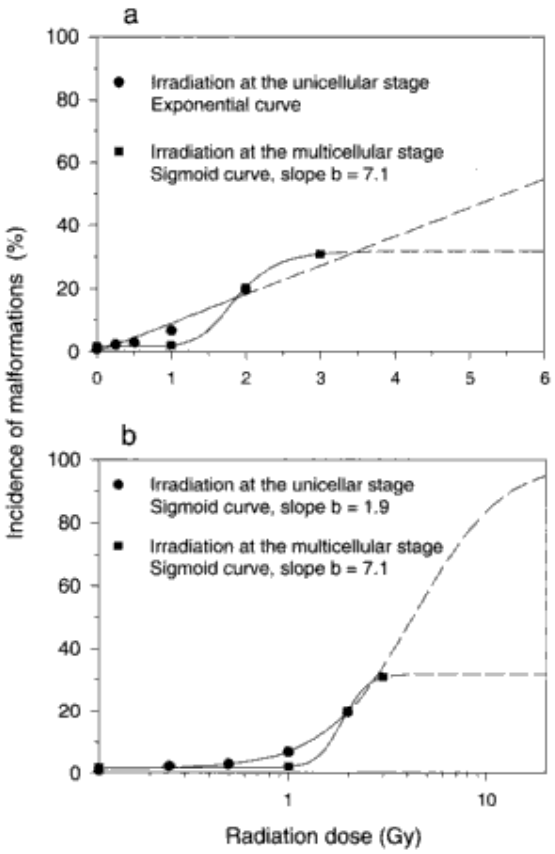

Figure 7. Linear-scale and exponential scale dose-effect curves.
Irradiation of unicellular and multicellular embryos[16].

Similar exponential effect one also observes for mutagenic chemicals, as it can be seen on *Figure 8* (Donnelly et al. 1998 cited in Streffer et al. 2003).

[16] Source: Müller et al., 1994 cited in Streffer et al., 2003

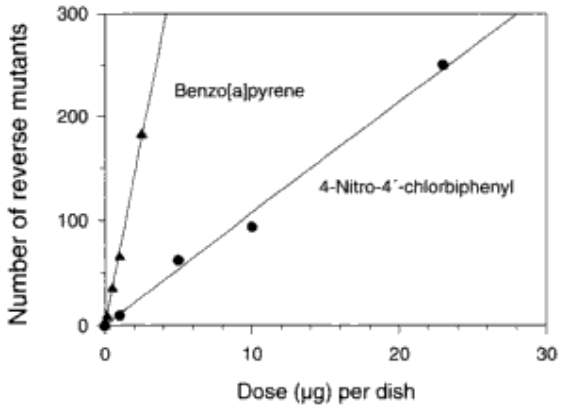

Figure 8. Linear dose-effect function of experimental results with mutagens[17].

For both non- and carcinogenic evaluation, a mathematical model has to be developed based on the experimental data of dose-response curves[18]. Two different types of mathematical models are applied in practice, one is called threshold-model, the other is non-threshold model (*Figure 9).*

The threshold model is based on the premise that repeated exposures to a chemical are needed before a threshold of exposure is reached and disease, cancer or death follows. The non-threshold model is based on the assumption that even one molecule can be a causing-agent and leads to cancer. This latter type of model is also referred as a "one-hit" model.

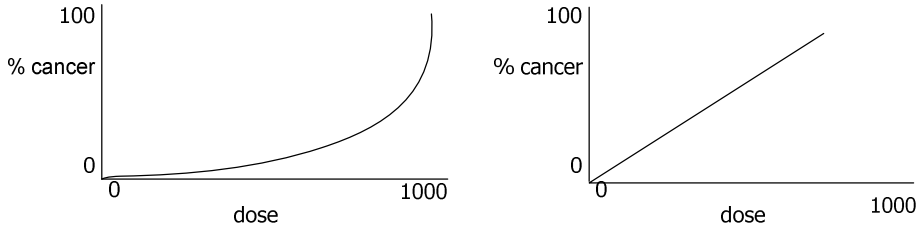

Figure 9. Threshold and non-threshold mathematical models[19].

For both threshold and non-threshold can be used but for non-carcinogenic molecules, almost in all cases a threshold model is used, and for carcinogenic molecules, a non-threshold model is used. Kamrin et al. (1995) explains that scientists assess non-carcinogenic and carcinogenic toxicity differently, in response to public fear about cancer. This is because people want to know if even one in a million individuals will get cancer from exposure to a suspected carcinogen.

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[17] Figure cited from Streffer et al. (2003).

[18] By a mathematical model we understand a set of equations that mimic a real situation and predict what will happen under different circumstances.

[19] Figure cited from Kamrin et al. (1995).

For non-carcinogenic molecules, usually a clearly visible threshold level can be observed (as seen above). Most commonly, the *No Observed Effect Concentration* (NOEC[20]) (sometimes also called No Observed Effect Level, NOEL) is chosen among the threshold levels and this is proposed for the regulators to be used as a limit value, but sometimes the Lowest Observable Effect Level (LOEL)[21] , or No Adverse Effect Level (NAEL) is used. In fact, as different effects can be determined, these different effects will have different threshold levels, and therefore different limit values with different sanctions can be established. As an example, there can be a threshold level of immediate death, a (smaller) threshold level for adult respiratory disturbance, a (smaller) threshold for child respiratory disturbance, and for each threshold, a limit value can be codified with different sanctions.

For carcinogenic effects, unfortunately scientists do not know what will happen to humans exposed to the low doses found in the environment. Therefore, models are developed to apply information gained in animal studies to the human condition; and these data are extrapolated to humans (Schlüter et al., 1999; ACS, 1998). The choice of model will have a strong influence on the outcome of the toxicity assessment, because when scientists apply different models to identical data, they will get different results. For cancer in the small dose-range, these usually can be linear, quadratic or linear quadratic (Pinkau and Renn, 1998). According to Kamrin et al. (1995), scientists in regulatory agencies usually use non-threshold models for carcinogenic bioassays. As Pinkau and Renn (1998) explains, there is no definitive scientific proof for this assumption yet, it is rather based on plausibility considerations. The idea that one single transformed cell may lead to cancer or solid tumours is based on the assumption (supported by experimental results) of a monoclonal growth of a tumour. Often, identical expression of the same specific gene products are found in each cell. They also explain that sometimes the hypothesis is put forward that low radiation doses may stimulate repair processes in the genome; current experimental studies are not useful here because of fundamental statistical problems and because of the multitude of other factors influencing the frequency of cases of cancer.

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[20] NOEC = No observed effect concentration and NEC = No effect concentration. NEC is a risk assessment parameter that represents the concentration of a pollutant that will not harm the species involved, with respect to the effect that is studied. There is not much debate on the existence of an NEC but the assignment of a value is another matter. Current practice consists of the use of standard tests, where groups of animals are exposed to different concentrations of chemicals and different effects such as survival, growth or reproduction are monitored. These toxicity tests typically result in a No Observed Effect Concentration (NOEC). A proposed alternative to NOEC is the use of so called ECx – concentrations, or the concentrating showing x % Effect (e.g. an EC5 in a survival experiment indicates the concentration where 5 % of the test animals would die in that experiment). (However any other value for x other than zero means an effect is accepted, this is in conflict with the aim of protecting the environment.) (See Calow, 1998)

[21] LOEL = scientists look for the smallest does that causes any detectable effect. This smalles dose is called LOEL (Kamrin et al., 1994).

1.4 Trends in environmental regulation

When we analyse the direction of the development of environmental regulation in the World, we can observe the same major trends in most cases (Hays, 1998); although we might observe that a certain country or state is at a different step of the general pathway. Some of the major steps usually are: incremental environmental knowledge, cost-benefit and comparative risk investigation, shift to forces of market and private economy, structurisation of politics, which can be described as the moving ahead in incremental steps from the well-established directions of the decades since World War II. As Hays (1998) explains, the evolutionary direction is the linear continuation of political forces and strategies within the context of increasing complexity of environmental knowledge.

To describe trends in the EU environmental regulation, we outline the major ideas introduced first in the White Paper 'Growth, Competitiveness, Employment', which initiated a completely new attitude regarding the environment. These ideas cascaded into later Framework Programs (5 and 6-7) and into the environmental action programs (as these programmes are and will be shaping the future also for the environmental regulation in Hungary, we analyse this more in detail).

The White Paper[22] on *Growth, Competitiveness, Employment* (1993) called for a new development model for the future. The document clearly concluded that the development attitude in practice (which is still very alive in 2008) resulted in a negative balance in the use of natural and human resources. This economic model is characterised by the not well exploited use of human potentials and the extensive use of natural resources, which contribute together to the gradual decrease of life quality. This is because the economic and industrial conditions did not favour the better use of existing human resources but encouraged their replacement by financial capital and the use of extensive energy and raw material resources. The White Paper underlined that the economic development model of the EU has to deal with the challenge of improving life quality with decreased air pollution and use of environmental resources. The joining to the EU of the countries with high environmental awareness in 1995, Austria, Finland and Sweden also gave a boost to the conceptual change in the general attitude in the EU about dealing with

[22] A *white paper* is usually a report or guide that addresses problems and how to solve them and are used to educate readers and help people make decisions. They are present both in politics and in businesses. Commission White Papers are documents containing proposals for Community action in a specific area. In some cases they follow a Green Paper published to launch a consultation process at European level. When a White Paper is favourably received by the Council, it can lead to an action programme for the Union in the area concerned. Examples are the White Papers on *Completion of the Internal Market* (1985), on *Growth, Competitiveness, Employment* (1993) and on *European Governance* (2001). More recently, the White *Paper on Services of General Interest* (2004) and that on a *European Communication Policy* (2006) have also moulded the development of Community policies.

environmental issues and highlighted the gap between local and central environmental legislation in both directions.

Fortunately, the EU recognized in time that in order to imply a change in current trends and environmental practices, it needed to change extensively the former approach, when almost solely limit values were used as the basis of regulation. With introduction of Framework Programme 5[23] (1998–2002), a development of a widened set of tools for environmental protection was encouraged: legislation, economic tools, horizontal supporting tools, financial supporting mechanisms. The most important – market based – economic tools can be:

- environmental fees
- promoting the concept of environmental responsibility
- application of voluntary agreements in line with the rules of the market
- encouraging financial reform for the protection of the environment.

Among environmental regulation tools, therefore FP6 (2002-2007) and FP7 (2007-2013) encourages a wider set of market based tools, like environmental fees and motivation for financial reform. Instead of "direct regulation", voluntary agreements are in favour. FP6 had as *Thematic Priorities* "Sustainable Development, Global Change and Ecosystems" and "Citizens and Governance in a Knowledge-based Society" to promote the development of sustainable development and public participation. In FP7, such topics can be developed in the Cooperation Specific Programmes Energy, Environment (including climate change) and Socio-economic Sciences and Humanities.

The Fifth Environmental Action Programme (5th EAP, 1993-2000) formed the environmental agenda for the previous decade. It's major underpinning principles are: the integration of the environmental dimension in all major policy areas is a key factor as environmental protection targets can only be achieved by involving those policy areas causing environmental deterioration; then only by replacing the command-and-control approach with shared responsibility between the various actors, e.g. governments, industry and the public, can commitment to agreed measures be achieved. It sets a new direction by stating that, for the improvement of the mechanisms of the market, environmental aspects have to be integrated more efficiently into the own procedures of the EU organisations and the results of the EU developments should be evaluated regarding the environment.

[23] The *Framework Programmes for Research and Technological Development*, shortly *Framework Programmes* or abbreviated FP, are funding programmes created by the European Union in order to support and encourage European research or, more specifically, the European Research Area (ERA). The detailed objectives and actions vary from one funding period to another.

The Sixth Environment Action Programme of the European Community (6th EAP, 2002-2012) sets new standards by focusing on the following areas, identifying four priority areas of environmental issues:

- Climate change
- Nature and biodiversity
- Environment and health
- Natural resources and waste.

The 6th EAP promotes full integration of environmental protection requirements into all Community policies and actions and provides the environmental component of the Community's strategy for sustainable development. The link is made between environment and European objectives for growth, competitiveness and employment. Regarding the environment, the 6th EAP focuses action around the development of seven Thematic Strategies in the field of soil and the marine environment (in the priority area of biodiversity), air, pesticides and urban environment (in the priority area of environment, health and quality of life) and natural resources and waste recycling (in the priority area of natural resources and waste). The Thematic Strategies constitute the framework for action at EU level in each of the concerned priorities. More interesting to our topic of discussion are the established strategic approaches by the 6th EAP to meet the environmental goals and objectives and priority actions on international issues. The strategic approaches include among others: the development of Community legislation and its effective implementation and enforcement, the integration of environment protection requirements in other Community policies and the promotion of sustainable production and consumption patterns, improving collaboration with enterprises and informing individual consumers, enterprises and public purchasers about the environmental impact of processes and products.

The 6th EAP ensures full consideration that the Community's environmental policy-making is undertaken in an integrated way and to all available options and instruments, taking into account regional and local differences, as well as ecologically sensitive areas, with an emphasis on (cited from the 6th EAP):

- "developing European initiatives to raise the awareness of citizens and local authorities;
- extensive dialogue with stakeholders, raising environmental awareness and public participation;
- analysis of benefits and costs, taking into account the need to internalise environmental costs;
- the best available scientific evidence, and the further improvement of scientific knowledge through research and technological development;

- data and information on the state and trends of the environment."

It is interesting to see, that beside the integrated approach, when setting targets, how 6th EAP sets the objective. "The Programme aims at emphasising climate change as an outstanding challenge of the next 10 years and beyond and contributing to the long term objective of stabilising greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Thus, a long term objective of a maximum global temperature increase of 2 °Celsius over pre-industrial levels and a CO_2 concentration below 550 ppm shall guide the Programme. In the longer term this is likely to require a global reduction in emissions of greenhouse gases by 70 % as compared to 1990 as identified by the Intergovernmental Panel on Climate Change (IPCC)". As we can see, the 6th EAP sets its goals by defining relative targets compared to previous states of the environment and setting absolute limits by using limit values. Note, that the mid-term review of the 6th EAP was adopted by the Commission on the 30th April 2007 and confirmed that "the 6th EAP remains the correct framework for Community action in the field of the environment up to 2012".

The environmental regulation in Hungary is shaped by the Hungarian Environmental Act, enacted in 1995, which relies heavily on the 5th action programme, 'Towards Sustainability'. The Hungarian Environmental National Programmes are based on EU recommendations as well (Szlávik, 2000). The Hungarian situation is also shaped by the Sofia Initiative, which were set up by high level officials from Central and Eastern Europe (CEE). The Sofia Initiative partly encouraged the use of economic instruments, to provide incentives for behavioural change, generating revenues to finance environmental investments and support the transition to sustainable development (Klarer et al., 1999). The reason behind the Sofia initiative is that emission charges and non-compliance fees are very exentsively used in CEE countries, including Hungary. To work towards a more economics – management tools in CEE countries, still remains after 2000, but the proportion of legislative tools is still much higher. Therefore, we can observe the move towards combination of legislative tools with other tool, as originally defined by Klarer et al. (1999).

In summary, we can observe that there is a shift toward integrating the diverse legislative tools with each other (for which combining limit values with the prescription of BAT is a clear example (Fodor (2000)), and with other environmental motivation tools (changing the economic context in favour of environmental protection, encouraging environmental management). Still, legislation is and will be at the core of environmental protection.

1.5 Future of environmental regulation based on limit values

According to Speck et al. (2001) the environmental effectiveness of economic instruments was low in the recent future in CEE countries and air pollution regulation is mostly based on charges/taxes, and the system regulation system was developed further in this direction.

Several factors can require prescribing the allowed quantity of environmental load in the form quantitative, numerical levels. First, standards expressed in numerical levels are technology independent and can be applied to any kind of activity. Another great advantage of limit values is that they can be easily verified, whether someone conforms to the regulation or not. We believe that the widespread popularity of limit values in environmental regulation is because of these two very important practical advantages. In addition, these two properties also allow for public participation in the development with relatively small knowledge about related technologies, especially with the help of non-governmental organisations (Carmin, 2003).

However, these advantages have a price on the other hand. Because of their nature, chemical limit values should be determined for every molecule with effect. Of course, we can combine some groups of molecules, based on their chemical structures, function groups, nature of damage, etc. but practice has to decide whether grouping is accurate or not. For example, in case of Polycyclic Aromatic Hydrocarbons (PAH), because the number of molecules is between 50-100, scientists estimate their quantity with 16-20 very dangerous molecule and regulation in many countries prescribes a limit using only 1 single molecule. However, it has been not demonstrated how the blend ratio, the effect, the quantity, health and environmental effects of the other molecules vary compared to the molecule in the standard.

What is more, Streffer et al. (2003) underlines, that current environmental prescription do not cover the synergetic and extinguishing effects (combined effects) of two or three molecules present next to each other, and the amplifying and weakening effect of environmental conditions (see also ACS, 1998). For example, the long term health effect of the carcinogenic molecules combined with high or low concentrations of carbon-monoxide (because both are related to high traffic, they are present in parallel). Alternatively, in windy regions, molecules travel further away from the source (i.e. road), and different near-road emission concentrations should be implemented for a windy and a non-windy region (because, as we demonstrated in the previous section, the limit value is based on the estimation of the environmental effect, which is different in this two cases). Alternatively, the intake of a carcinogenic molecule can be intensified in high temperature – high humidity weather conditions (in a rainy summer). The physical-chemical form of hydrophobic compounds also plays a major role in their bioavailability (Farrington,

1991). The set up of limit values for such combined effects is particularly difficult according to Streffer (2003).

We also experienced in our laboratory analyses works that practice can show orders of magnitude of difference when comparing the analyses results of certain chemicals, depending on which method was used for the measurement, which laboratory carried out the measurements or from which country came the data. This renders difficult to decide whether an environmental actor complies or not to a certain limit value standard.

Experience shows, that public opinion is only concerned by some of the chemical effects, usually about the most important, most polluting chemicals, like the air polluting nitrogen-oxides, sulphur-dioxide or carbon-monoxide. This is maybe because it is difficult to discuss a large number of different chemicals during the negotiation process (it is estimated that about 5 000 000 chemicals are in use and about 200 000 are commercially available). Still, awareness and precaution attitude could be implemented with the help of public participation (Várkonyi, 2007).

We should not forget that too loose limit values do not encourage economic actors to use environmental friendly or clean technologies; they rather keep in operation existing polluting technologies and pay the small fees. Too rigorous environmental limit values usually define conditions that Eastern-European companies cannot fulfil, simply because they do not own the necessary technological or economic background to take action. As an alternative solution for the latter problem is to implement small changes (Vigh (2001), described later in detail). While the core of the technology can only be changed usually with high oncost and with the agreement of the owner of the licences, actually a very large part of production losses and harmful emissions origin not from the core of the technology and can be reduced with smaller oncost. Small quantity emissions related to the technology can seem unimportant alone, but their cumulative effect can be significant and their reduction can be the basis of a significant reduction of pollution.

We present in a former study of ours (Kozák and Kozák, 2001), and discuss in detail in the next chapter, that EU recognised in time that to change current industrial trends, a wider set of tools is required compared to the action plans of former years, which were based almost only on regulative tools, and inside that on limit values. Therefore, beginning from the 5th Framework Programme, the EU enlarged its set of environmental tools, and beside environmental regulation, a set of economic tools, horizontal financial supporting tools, and other financial mechanisms are present (Glatz, 1998).

In parallel, the trends of natural sciences and sociological-sciences show that the practice of best available technologies will replace more and more the practice of environmental limit values (Bandi and Perecz, 1998 and Renn, 1998). In other words, the existing theory and attitude on environmental limit values needs to undergo an important change of the methodology in order to reply to the changes of most recent needs. A possibility to improve current limit value methodology can be a more integrated approach of considering risk factors in environmental regulation of limit values, which we present later.

In summary, we can say that limit values are a very practical tool in environmental protection and for this reason, they will be extensively used in the future, too. However, they also bring along certain complication for legislation. First, as biological and chemical complexity increases, their justifiability becomes more complex, and their initial virtue becomes a disadvantage. Then for stochastic effects, the use of limit values can be regarded as more subjective, as there is no clear threshold observable could be justified as a limit on the dose-response curves. Therefore, the arbitrary nature of limit values is more expressed for stochastic effects (i.e. radiation, carcinogenic chemicals).

1.6 About technical solutions aimed to reduce environmental pollution

Although the EU and other regulatory bodies push hard the use of BAT, usually these are difficult to implement as they require change in the core of the technology, and we can expect technological change only on the long term (usually more than 4-5 years). This is particularly true to Hungary and other CEE countries, where the political change in the 1990 brought change in the economics, and advanced technological output, the core technologies of the 1950-1990 era remained in function. This is mainly because Hungary and other CEE countries were during the history of industrialization, and are still a place, where new capital comes from foreign countries; and lacking the funds to delays changes in the manufacturing processes (see Németh, 1999).

To understand what actually can be an alternative on the short term (up to 3-4 years), we present a summary of the approach presented by Vigh (2001).

Industrial production, traffic, energy making and the agriculture all emit harmful substances (side products of finished products) into the environment, which create harmful effects not only near the source of emission, but diffused in the longer distance. Either in their original form or often modified, they threaten the entire environment and finally human life. Moser and Palmai (1992) classify technological solutions to avert environmental damages:

- reduction of harmful emissions, elimination of the emitting source, change of procedures to pollution free technologies,
- prevention of travel and conversion of polluting materials,
- use of safety equipment at the site of emission.

It is evident, that the most valuable solutions are in the first group, as these methodologies really protect the environment, they really prevent the introduction of pollution materials into the environment. Therefore, these technologies are often called waste-reduced or waste free technologies.

Up-to-date handling of environmental issues require more and more that polluted air, water or solid waste are not just treated at the end of the process line, but are minimized by using applications in processes that minimize emission of polluting materials, or even more avoid releasing polluting materials. On the global market of the chemical and petrochemical industry, the processes of the new factories are usually designed with minimal emission of harmful substances. Even in Hungary, many environmentally well designed plants were built recently.

Chemical substances which are persistent, bioaccumulative and/or toxic (PBT) should not be released into the environment. Therefore, producers or users need to avoid the usage of such substances or limit the use to such applications were no emissions can occur (Ahrens et al., 2003). Substitution of hazardous substances by less hazardous alternatives appears to be a straightforward approach when enterprises consider management and reduction of chemical-related risks (Lohse et al., 2003). However, for PAHs, the main sources of (air) emissions are combustion processes; no emission reduction can be achieved by the substitution of chemical products (Ahrens et al., 2003), therefore a different ways of working is necessary.

Vigh (2001) summarizes an interesting approach for loss and waste reduction. During the design of the manufacturing sites, for an efficient environmental friendly technology, the first step is the identification of sources of losses and waste. This is done trough a detailed mass-balance of the general process and of the sub processes. When the instrumental setup of the plant does not allow building a precise mass-balance, the best possible estimation has to be used. Experiences from other manufacturing sites or knowledge on the given technology can both be handful for this. Losses and waste identified in the mass-balance can be of two types: real losses of the technology itself and losses because of imprecision of the estimations, calculations and measuring equipment. It is important to differentiate between these ‘imprecision’ losses from real losses of the technology. Real losses also constitute from two parts; there is a constant loss coming from the setup of the technology itself, while a part that comes from the variation of the weather/surrounding condition changes over time (like high environmental temperature increases

losses of evaporation, or a rainy period results the dryer needing more time to dry the materials because of the decreased ability of water uptake of air).

According to Vigh, the following most important sources of losses and wastes should be considered:

- inventory and measurement of incoming raw materials and intermediate materials
- estimation of the quantity of leftovers
- estimation of the quantities of materials leaving the equipments, the manufacturing sites and establishments
- changes in quantity of the materials to be treated in the technology
- pollution in the raw materials
- changes of quantities inside equipments
- losses from blowing off, rinsing
- leaking of valves, including safety equipments
- discharge, overcharge and leaking of equipments
- losses of start-up, shut down and emergency shut down
- environmental effects, like high temperature during summer, rinsing effect of rain, increased fuel consumption in snow
- losses during stocking

The most important task is the accurate identification sources of losses and wastes. Most manufacturing sites can only account and measure with the third of the total losses and wastes. Revision of the accounting system and after the possibly necessary post-investments in the technology, this ratio can be pushed below 10%. During the exploration and determination of non-accountable losses and wastes with eliminate able sources can be also identified.

Changing the core of the technology can be carried out usually only with important investments and oncost, and in case of licensed processes, with the agreement of the licence owner. However, the largest part of manufacturing related losses and wastes usually do not come from the core of the technology itself; hence can be reduced more simply, with smaller investments and oncost. Reduction of the emission of small losses and wastes related to technology usually is the basis of significant results in overall emission reduction.

2. Polycyclic Aromatic Hydrocarbons and their Regulation

2.1 About PAHs

2.1.1 Sources of PAHs in the environment

Polycyclic aromatic hydrocarbons (PAH) include many individual pollutants that affect the air quality of the cities around the world (Fertmann et al., 2002). PAHs are emitted into the atmosphere from both anthropogenic and natural sources (Simonich and Hites, 1995). Anthropogenic sources are generally referred to sources that produce energy such as domestic heating, engine exhaust (traffic), incinerators, and natural gas (Mastral et al., 2003). Natural sources are usually volcanic eruptions and biomass burning. Most of the PAHs are produced from combustion of fossil and non-fossil fuels through pyrolysis and pyrosynthesis mechanisms (Kiss et al., 2001). Another source of PAHs is from small particles of unburned components of fuel (Mastral et al., 2003; Larsen and Baker, 2003).

PAHs are highly volatile and can be easily released into the environment. After entering into the atmosphere, volatile PAH compounds remain in the gas phase while non-volatile compounds (five or more rings) are adsorbed onto plant species and/or solid particles. Medium volatile PAHs are distributed between gas and the adsorption phases where ratios depend on chemical and physical properties of PAHs, environmental conditions, and the nature of the phases (Thomas, 1986; Viskari et al. 1997; Holubek et al., 2000).

Several PAHs are hazardous to living organisms due to their mutagenic, carcinogenic teratogenic, immunosuppressive and/or neurotoxic properties (Gruszka, 2000). These PAHs are being included in the EU priority pollutant lists. Therefore, it is important to monitor and regulate the presence of PAH in ambient air.

2.1.1 Environmental and health effects of PAHs

The health effects that can be caused by exposure to PAHs are presented based on the Cancer in Illinois Resources (2008). PAH health effects mainly depend on

- how much has entered the body,
- how long one has been exposed to PAHs, and
- how the body responds to PAHs.

These effects may be either short-term or long-term. It is not clear that PAHs cause short-term health effects. Other compounds commonly found with PAHs may be the cause of short-term

symptoms such as eye irritation, nausea, vomiting, diarrhoea, and confusion. Long-term health effects of exposure to PAHs may include cataracts, kidney and liver damage, and jaundice. Repeated skin contact to the PAH naphthalene can result in redness and inflammation of the skin. Breathing or swallowing large amounts of naphthalene can cause the breakdown of red blood cells. Studies of workers exposed to mixtures of PAHs and other compounds have noted an increased risk of skin, lung, bladder, and gastrointestinal cancers. The information provided by studies is usually limited because the workers were exposed to other potential cancer-causing chemicals besides PAHs. Although animal studies have shown adverse reproductive and developmental effects from PAH exposure, these effects have generally not been seen in humans yet. Generally speaking, we can say that the PAH molecules have analogous chemical structure to the building blocks of the DNA chain and initiate mutation. In *Figure 10*, we can see a representation for the DNA spiral disrupted because of in-bound PAH molecules. The demonstration of the chemical pathway of PAH metabolism leading to cancer can be found in

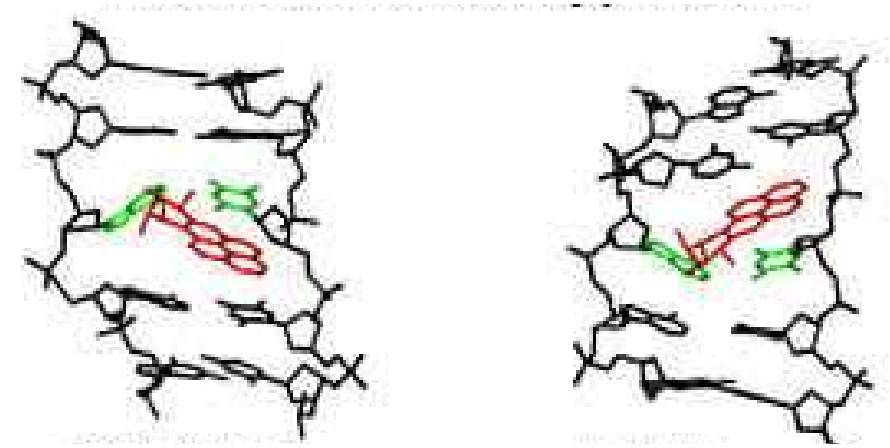

Figure 10. DNA spirals disrupted by an in-bound PAH molecule.

For a detailed introduction of PAH-induced carcinogenesis mechanisms, see the comprehensive study of Luch (2005) and Orgoványi (2004).

The proportions of different PAHs detected in different emissions and workplaces sometimes differ widely from each other and from PAH profiles in ambient air. Nevertheless, the profiles of PAHs in ambient air do not seem to differ very much from one area to another, although large variations may be seen under special conditions. Furthermore, the carcinogenicity of PAH mixtures may be influenced by synergistic and antagonistic effects of other compounds emitted together with PAHs during incomplete combustion. It should also be recognised that in ambient

air the carcinogenic 4 to 7-ring PAHs (representing the majority of PAHs) are preferentially attached to particles and only a minor fraction, depending on the temperature, exists as volatiles. A few studies indicate that the toxicokinetic properties of inhaled Benz-a-pyrene (BaP) attached to particles are different from those of pure BaP alone. Virtually nothing is known about other PAHs in this respect.

Attempts to derive relative potencies of individual PAHs (relative to BaP) have also been published, and the idea of summarising the contributions from each of the selected PAHs into a total BaP equivalent dose (assuming their carcinogenic effects to be additive) has emerged (Heinrich et al 1994). There are doubts, however, about the scientific justification for these procedures. An extensive survey of human and laboratory animal studies, carcinogenesis and risks about PAH effects can be found in Air Toxics NEPM – PAHs Health Review (May 2003, made for the request of the Australian Government).

WHO (World Health Organisation) presented an excess lifetime cancer risk, expressed in terms of the BaP concentration and based on observations in coke oven workers exposed to mixtures of PAHs. It was emphasised that the composition of PAHs to which coke oven workers are exposed may not be similar to that in ambient air. The working group also considered some recent animal data but concluded that the occupational epidemiology data should serve as the bases for the risk estimate.

The WHO adopted the lung cancer risk estimate calculated by the US Environmental Protection Agency. The US EPA based its calculations on extensive studies of coke oven workers in Pennsylvania. The US EPA used a linearised multistage model. The unit risk for BaP is estimated to be 8.7×10-5 (ng/m³)-1. The corresponding concentrations of BaP producing excess lifetime cancer risks of 1/10 000, 1/100 000 and 1/1 000 000 are 1.2, 0.12 and 0.012 ng/m³ respectively.

One can be exposed to PAHs in many ways. Air can be contaminated by PAHs and levels of PAHs in urban air may be 10 times greater than levels found in rural areas. Beside the most important air exposition, one may be also exposed to PAHs in soil near hazardous waste sites or near areas where coal, wood, gasoline or other products have been burned. Low levels of PAHs have been found in some drinking water supplies in the United States. In the home, PAHs are present in tobacco smoke, smoke from wood burning stoves and fireplaces, creosote-treated wood products, and some foods. Barbecuing, smoking, or charring food over a fire greatly increases the amount of PAHs in the food. Other foods that may contain low levels of PAHs include roasted coffee, roasted peanuts, refined vegetable oil, grains, vegetables, and fruits. A

variety of cosmetics and shampoos are made with coal tar and therefore are a container of PAHs. The PAH compound naphthalene is present in some mothballs[24].

2.1.2 Chemical and physical properties of PAHs

The simplest PAHs, as defined by the International Union on Pure and Applied Chemistry (IUPAC), are phenanthrene and anthracene. Smaller molecules, such as benzene and naphthalene, are not formally PAHs, although they are chemically related. They are called one-ring (or mono) and two-ring (di)aromatics, and naphthalene is routinely discussed and analysed with PAHs.

Properties of PAHs are presented based on Fekete et al. (1993). Polycyclic aromatic hydrocarbons are molecules three or more aromatic rings (see *Figure 11*), even up to seven-member rings, but those with five or six are most common. PAHs composed only of six-member rings are called alternant PAHs. Certain alternant PAHs are called "benzenoid" PAHs. The name comes from benzene, an aromatic hydrocarbon with a single, six-member ring. These can be benzene rings interconnected with each other by single carbon-carbon bonds and with no rings remaining that do not contain a complete benzene ring.

PAHs are easily soluble in fats and are difficult to dissolve in water. Under atmospheric conditions, they are solid, have boiling points between 300-600ºC and have low vapour pressure. The most important physical properties of some PAHs are presented in Table 1.

[24] For biological effects, it is interesting to know, that the „PAH World hypothesis" is a biological hypothesis that proposes that the use of polycyclic aromatic hydrocarbons (PAH) was a means for a „pre-RNA World basis" for the origin of life. As yet it is untested, though in 2007, the Cassini spacecraft found the presence of heavy negative ions of tholin in the upper regions of Titan's atmosphere.

Table 1. Physical properties of PAHs.

IUPAC- name	Molecular formula	Molar mass [g/mol]	Boiling point [ºC]	Solubility [mg/l]	Ring No.
Naphthalene	$C_{10}H_8$	128	218	30	2
Acenaphtene	$C_{12}H_{10}$	154	279	3.47	
Fluorene	$C_{13}H_{10}$	166	293	1.98	3
Phenanthrene	$C_{14}H_{10}$	178	338.4	-	
Anthracene	$C_{14}H_{10}$	178	340	0.073	
Fluoranthene	$C_{16}H_{10}$	202	383.5	0.26	
Pyrene	$C_{16}H_{10}$	202	393.5	0.135	
Benz-(a)-anthracene	$C_{18}H_{12}$	228	437.5	0.014	4
Chrysene	$C_{18}H_{12}$	228	441	0.002	
Benz-(a)-pyrene	$C_{20}H_{12}$	252	492.5	-	
Benz-(b)-fluoranthene	$C_{20}H_{12}$	252	481.2	-	
Benz-(k)-fluoranthene	$C_{20}H_{12}$	252	481	-	5
Dibenz-(a,h)-anthracene	$C_{22}H_{14}$	278	535	-	
Indeno-(1,2,3-cd)-pirene	$C_{22}H_{12}$	276	534	-	
Benz-(g,h,i)-perylene	$C_{22}H_{12}$	276	542	-	6

Being apolar compounds, PAHs are easily soluble in apolar compounds; their most important solvents are hexane, cyclohexane, pentane and chloroform (aqueous solubility decreases approximately one order of magnitude for each additional ring). They can be present in water in high concentrations when bond to the surface of floating particles. Molecules with more than 4 rings adsorb onto solid small particles. They can degrade in sunlight due to the UV-components of sunlight (physical degradation), but only a few soil bacteria are able to decompose PAHs (biodegradation).

Because of their delocalised electron system, they are easily excited by fluorescent light, and therefore most PAHs are fluorescent, emitting characteristic wavelengths of light when they are excited (when the molecules absorb light). The extended pi-electron electronic structures of PAHs lead to these spectra, as well as to certain large PAHs also exhibiting semi-conducting and other behaviours. Although their UV-coefficient is small, PAHs possess very characteristic UV absorbance spectra. These often possess many absorbance bands and are unique for each ring structure. Thus, for a set of isomers, each isomer has a different UV absorbance spectrum than the others. This is particularly useful in the identification of PAHs.

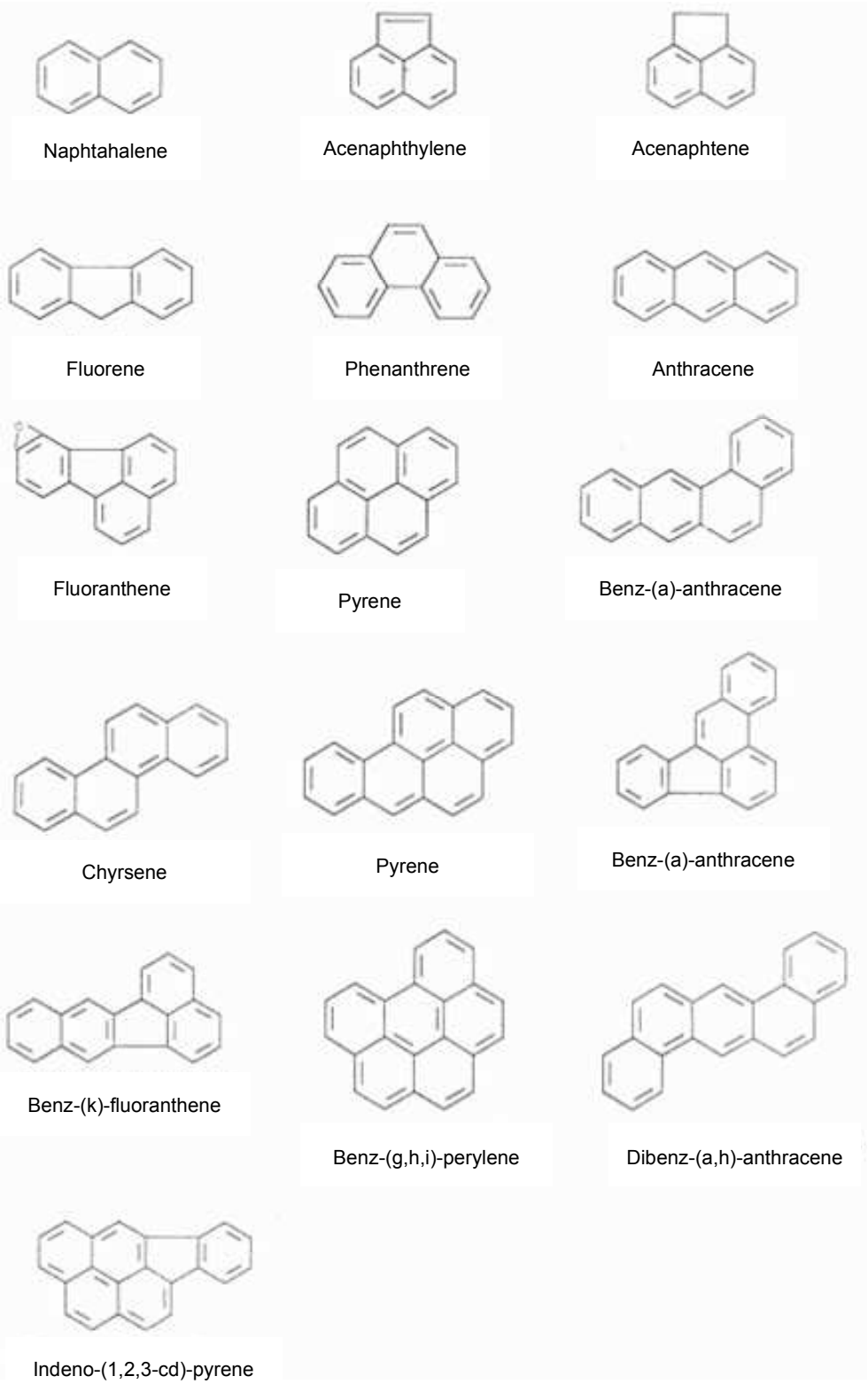

Figure 11. Molecular structure of PAHs

2.2 Concentration of PAHs in the environment

There have been many efforts lately to monitor systematically PAH concentration in the environment. Vegetation samples are used to identify sources of pollutants in order to determine the regional and global pollution trends (Simonich and Hites, 1995). Vegetation samples are easier to collect than air samples, which also make them economical to monitor the quality of air. Over the last two decades, there have been many studies assessing atmospheric fallout by analyzing moss samples (Oehme et al., 1985; Ruhling et al., 1987; Markert et al., 1996; Milukaite, 1998; Sucharova and Suchara, 1998; Faus-Kessler et al., 1999; Gerdol et al., 2002). Mosses do not have a root system; therefore, the uptake of pollutants occurs only from the atmosphere (Wegener et al., 1992; Kunlst et al., 1995). Mosses have been used for both active and passive monitoring of pollutants in the atmosphere (Wegener et al., 1992, Steinnes et al., 1992). In active monitoring, plants that gave grow under standard conditions were exposed to pollution for a limited time (usually about several weeks) (Wegener et al., 1992). This monitoring is independent of the natural conditions of plant growth and gives an assessment of pollution in urban or industrialized area of the atmosphere.

2.2.3 PAH concentrations in the World

Total PAH concentrations

Menichini (1992) has conducted comprehensive studies on the results of international PAH analysis projects. More than 90% of the release of PAHs was from two sources: traffic and domestic heating; industrial pollution was presented as a possible third source for PAH release. Menichini made the comparison in the following ways: PAH profiles (proportion of different PAHs), concentration of a given PAH, “spy-PAHs” (transportation of PAH released from a given source).

In Los Angeles, the correlation between vehicle traffic and PAH concentration was very strong. In New Jersey, PAH concentration showed a remarkable correlation with coal burners, and in the summer, with vehicle traffic. It was observed in Paris, that fuel engines affected more the PAH concentration in the summer (72 %) than in the winter (42 %) of the total PAH release, while PAH pollution related to domestic heating was 30 % in the winter and only 2 % in the summer.

Ciccioli, et al. (1996), conducted measurements to map the pollution of different regions. The observed areas were grouped into four categories: large cities, suburbs, forests close to large cities, areas away from habited places.

Samples were collected from Rome, Milan and Naples, while suburban samples were from Montelibretti (close to Rome) and from a suburban town of Madrid. Forest were examined at Castel Porziano (in the Apennines, close to Rome), Storkow (30 km from Berlin) and from Alta Floresta in Brazil. Samples were also collected from Sagarmantha National Park (Nepal, close to Mount Everest) and Terra Nova Bay (the Antarctic).

It is clear from the measurements, that the concentration of nitro-PAHs is the highest close to the largest cities, and decreases towards areas away from cities. The pollution was the highest in Milan, where the traffic is the heaviest, and both coal, wood and oil combustion is significant, and it can be concluded, that the main emission source of the nitro-PAHs is the same as for the PAHs that is the energy sector and traffic. Concentration values in Storkow were surprisingly low. This fact can be explained by less vehicles circulating on the roads of the former Eastern Germany then in the more developed Italy. Pollution in Brazil is possibly from forest burns, and the lowest concentrations in Nepal and the Antarctic are due to the lack of human activity in these rural areas.

It has been observed, that concentrations also vary according to the season and the part of the day. The direction of the wind also has to be taken into account. The warm, sunny days of summer favour photochemical reactions, and this is why concentrations can be high in the neighbouring forests of Rome, because of the extremely high pollution of the Italian capital. The lowest concentrations ever were from Nepal from the period after monsoon.

Chovanec et al. (1994) determined the concentration of chlorinated organic compounds, PAHs and heavy metals from river sediments and mosses (Fontinalis antipyretica) of upper-Austria, from the rivers Danube and Traun near to Linz. This area has been chosen because Linz is one of the largest industrial centres in Austria, and many plants are located along the rivers. The lowest concentration was measured at sampling site A, which was the uppermost location on the river, without any industrial activity. In the area of location D, where the concentration was higher, the number of industrial plants are higher, however they were at distance that can explain, therefore the PAH concentration were possibly diluted. Near to sampling sites C and B, an important paint industry and a hydropower plant can be found, and the concentrations were the greatest at these sites. Probably the concentrations of location C were also diluted compared to location D.

The research group of Chovanec also conducted measurements of the Danube in Slovakia, the concentrations ranged between 26-4690 µg/kg in 1991, and between 86-8794 µg/kg in 1992.

Most frequent PAH molecules

Menichini (1992) concludes that the magnitudes of concentrations are known. benz-(a)-pyrene was found in concentrations of 1-50 ng/m³ in Europe and of 1 ng/m³ in the USA. Concentrations of other PAH molecules was measured in between 1-50 ng/m³ in Europe, 0,1-1 ng/m³ in the USA and in Australia, 1-10 in Japan and 10-100 in India and at two locations of New-Zealand. These great differences are possibly due to the various sampling methods and sampling sites. With the help of values of such a wide range, it is impossible to make direct comparisons between cities and standards should be established: sampling parameters, factors for choosing the sampling sites, required minimal number of samples, shortest allowed period of monitoring, PAH molecules to be analyzed. The source of variations is usually known (traffic, weather); however, winter conditions only offer a rough basis for comparison. Menichini highlights that the authors should describe extensively the sampling conditions, the description of the sampling site and the possible sources for PAH release in the area. He also presents the results of the survey of Pits, et al., in 1985, who have found a high concentration of nitro-PAHs in the basin of Los Angeles, especially those of molecular mass of 247 (ex. 2-nitrofluoranthene, 2-nitropyrene).
Provini, et al. (1989), took sediment samples from the Italian Lake Varese, and fluoranthene was found in a concentration of 100-200 µg/kg. Baker has concluded similar measurements in the USA at Lake Superior. He has identified the following molecules: Fluorene 4.2-7.7 µg/kg, Fenantrene 62.1-98.2 µg/kg, Fluoranthene 36.5-153.2 µg/kg, Pyrene 21.5-88.3 µg/kg, Benz-(b)-fluoranthene 104-319.4 µg/kg and Benz(k)fluoranthene 49.1-196.7 µg/kg.
Chovanec, et al. (1994), summarizes the concentrations of PAHs from various locations. They have identified 13 different PAHs, like Benz-(a)-pyrene (13.9 µg/kg), Benz-(b)-fluoranthene (49.6 µg/g), Benz-(k)-fluoranthene (20.06 µg/g) and Fluoranthene (107.1 µg/kg)[25].

PAH concentrations in biomonitoring

The PAH concentrations measured in our study to PAH levels in mosses and other forms of vegetation collected from different regions around the world is compared in Table 2.

Table 2. Total PAH concentrations in vegetation samples in different regions of the World.

Region	Samples	Bio-Monitoring	Total PAH, µg/kg	Reference
Finland	*Fontinalis antipyretica*	Active	5.4–48.2	Roy et al. (1996)
Finland	*Pleurozium schreberi*	Active	120–480	Viskari et al. (1997)

[25] 1000 µg/kg = 1 µg/g, in other words µg/kg is a 1000x smaller unit than µg/g.

Finland	*Pleurozium schreberi*	Active	166–404	Viskari (2000)
Poland	*Hylocomium splendens*	Active	828–3573	Orlinski (2002)
Austrian	*Fontinalis antipyretica*	Passive	232–479	Chovanec et al. (1994)
Sweden	*Hylocomium splendens*	Passive	39.0–730	Knulst et al. (1995)
Sweden	*Pleurozium schreberi*			
Northeastern USA	Maple leaves	Passive	220–1600	Wagrowski and Hites (1997)
Northeastern USA	Pine needles	Passive	370	
Czech Republic	*Hypnum cupressiforme*	Passive	-0.3–16733	Holoubek et al. (2000)
Northern Italy	*Tortula muralis*	Passive	0.2–1.5	Gerdol et al. (2002)
South-Central Poland	*Hypogymnia splendens*	Passive	587–622	Migaszewski et al. (2002)
Hungary	*Hypnum cupressiforme*	Passive	1567–10450	Ötvös et al. (2004)

The comparison of PAH concentrations in *Table 2* demonstrates that the different plant species can give different amounts of bioaccumulation of PAHs. Hypnum cupressiforme accumulates hydrocarbons at the highest concentration than other vegetation species (Table 2). This accumulation in Hypnum cupressiforme has the same order of magnitude in Hungary and Czech Republic regions (Table 2) even though emission sources of hydrocarbons are different in these two countries (Holubek et al., 2000). The uptakes of PAHs by Hypnum cupressiforme rather than the emissions in these regions may result in the observed values in Table 2. Hypnum cupressiforme is a dense mat forming species and can accumulate PAHs more effectively compared to other moss species. Similar observations were found in absorption of metals from atmospheric deposition (Sucharova and Suchara, 1998; Ross, 1990). Additionally, Hypnum cupressiforme contains biflavonoids, phenyl-substituted aromadendrin derivatives, and kaempferol in its structure (Sievers et al., 1994), which may have a greater affinity for PAH compounds than the other mosses. However, to understand fully the possible differences in the accumulation of PAHs in the moss species, atmospheric deposition data and moss-growth of the region should be investigated.

Inhalation of PAHs compounds

Minoia et al. (1997) proposed a new sampling strategy to determine the daily inhaled quantity of PAHs in urban air. The individual environmental samplings took place in two different seasons (winter and summer), for persons living in four different urban areas with different traffic density. The mean ± S.D. value of Benz-a-pyrene was 0.37 ± 0.15 ng m−3 in winter and 0.12 ± 0.07 ng m−3 in summer. Assuming 18 m3 as the daily inhaled quantity the estimate of the BaP inhaled quantity was 6.66 ng/day in winter and 2.16 ng/day in summer.

2.2.4 PAH concentrations in Hungary

Recently, we made the first time a passive investigation of atmospheric PAHs deposition by analyzing moss (Hypnum cupressiforme) samples collected at 29 regions in Hungary. The concentration of total amount of PAHs and 16 individual PAHs were chosen to be included in the study according to the EPA directives. The reasons to investigate this profile of individual PAHs according to EPA are:

- more information is available on these PAHs than on the others;
- they are suspected to be more harmful than some of the others, and they exhibit harmful effects that are representative of the PAHs;
- there is a greater chance that one will be exposed to these PAHs than to the others;
- in addition, of all the PAHs analyzed, these were the PAHs were previously identified at the highest concentrations at hazardous waste sites.

The list of the individual PAH compounds of the study is the following:

- acenaphthalene
- acenaphthene
- anthracene
- benz-(a)-anthracene
- benz-(a)-pyrene
- benz-(b)-fluoranthene
- benz-(ghi)-perylene
- benz-(j)-fluoranthene
- benz-(k)-fluoranthene
- chrysene
- dibenz-(ah)-anthracene
- fluoranthene
- fluorene
- indeno-(123-cd)-pyrene
- phenanthrene
- pyrene

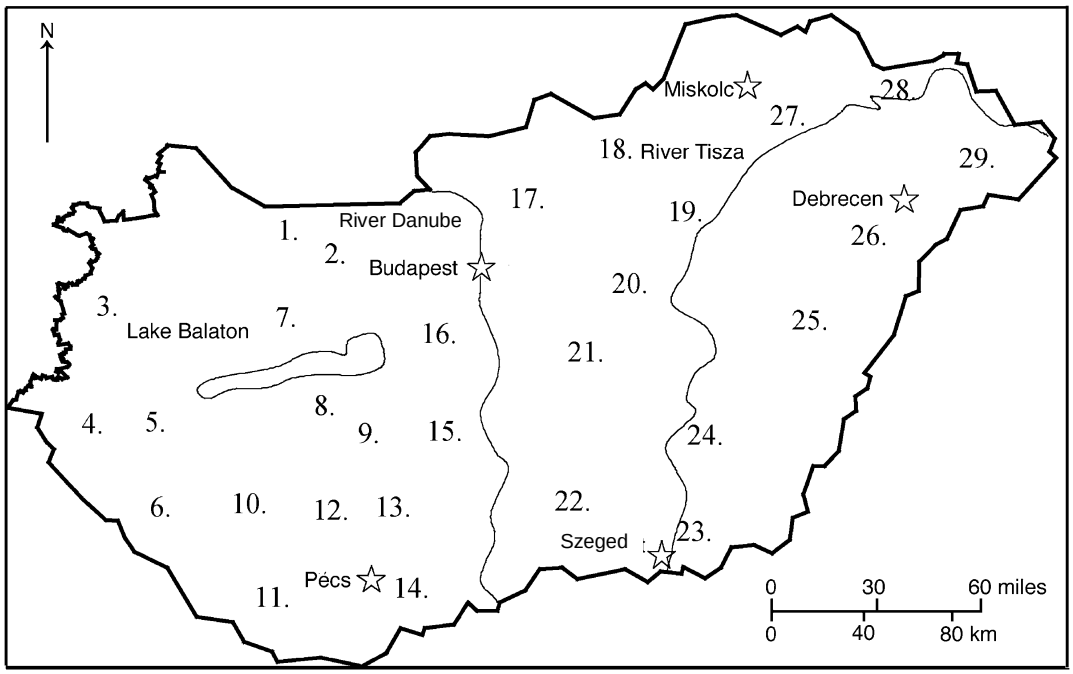

Figure 12. Moss sampling sites for PAH analyses in Hungary

Concentrations of PAHs in Hypnum cupressiforme at different sampling stations (see *Figure 12*) were usually influenced by urban, industrial and traffic activities of the area. At most of these sites, a good correlation between PAHs levels and traffic volumes was found. Incomplete combustion of fuel was thus the dominant source contributing to the atmospheric deposition of PAHs in moss samples. No relationship between PAHs and metal pollution in moss samples in Hungary was found, which reflects differences in emission sources and atmospheric transport pathways of metals and organic pollutants. In comparison with other moss species and vegetation around the world, Hypnum cupressiforme accumulates the highest concentration of PAHs from the environment. The uptake of PAHs is probably much higher in Hypnum cupressiforme than other species, which results in higher values. Based on relationship of octanol-air partition coefficients of the various PAHs to the bioconcentration factors, most of the compounds prefer aerosol particles over the surfaces of Hypnum cupressiforme at a particular site of the studied region. In future work, additional determination of the deposition rates of PAHs, which also account the growth rates of vegetation, must be carried out to gain insight into PAHs deposition.

The total concentrations of PAH ranged from 0.1567 to 10.45×10^4 µg/kg with a mean value of 1.87×10^4 µg/kg dry weight. The samples were analyzed for individual low and high molecular weight PAH compounds. The concentrations of identified PAHs mainly resulted in low

molecular weight PAHs (up to 3 ring compounds). Heavy PAHs (more than 3 ring compounds) were less than 1% of the total concentrations of PAHs. Low molecular weight PAHs of our study are mostly in the gaseous form and can travel a long distance away from the road. High molecular weight PAHs can easily adsorb onto particles and probably settle near the road. Sampling stations were away (300 m) from the road traffic and possible industrial sources, which resulted in low atmospheric deposition of high molecular weight PAHs in the samples of our study. Decreases in the concentrations of PAHs in moss samples were also found with increasing distance from the road in previous studies (Hauutala et al., 1995; Orlinski, 2002; Viskari, 2000). Naphthalene, acenaphthalene, phenanthrene, anthracene and fluoranthene were dominant PAHs in Hypnum cupressiforme samples. The heavy PAH compounds benz-(a)-pyrene, indeno-(123-cd)-pyrene and benz-(ghi)-perylene were not identified in Hypnum cupressiforme samples of the studied region, the highest concentrations were of Benz-(b)-fluoranthene, whereas the lowest concentrations were Dibenz-(ah)-anthracene. Details concentration data and interpretation can be found in our papers Kozák et. al. (2003) and Ötvös et al. (2004).

2.3 Regulation of PAHs

2.3.1 PAH regulation in the World

The most important international reference points in environmental regulation are the WHO (World Health Organisation) and the USA regulations.

General international awareness implied the control of PAHs in the late 1980s, when the IARC (International Agency for Research of Cancer, a WHO organization) characterized their carcinogenity in 1987 and in parallel WHO has examined the issue of PAH health risk on a number of occasions and has published the Air Quality Guidelines in 1987. The IARC summary on carcinogenity was reviewed in 1997, while WHO guidelines were updated in 2001, and last updated in 2005. The PAH related PM10 fraction guidelines are 20 μg/m³ annual mean and 50 μg/m³ 24-hour mean. For PAHs, the WHO guideline is PAH 1.0 ng/m³ years as ng BAP/m³.

The USEPA (US Environmental Protection Agency) (1990) has classified PAHs with BaP indicator species as a B-2 pollutant that means a probable human carcinogen with sufficient evidence from animal studies but inadequate evidence from human studies. The OSHA (U.S. Department of Labour, Occupational Safety & Health Administration) regulates PAHs in the regulation *about Coal Tar Pitch Volatiles (benzene soluble fraction)* and the general industry limit in ambient air is 0.2 mg/m³. Emission pollution is controlled in the US by the Clean Air Act (CAA) (1990). The CAA requires EPA to regulate emissions of toxic air pollutants from a

published list of industrial sources referred to as "source categories." As required under the Act, EPA has developed a list of source categories that must meet control technology requirements for these toxic air pollutants. The EPA is required to develop regulations (also known as rules or standards) for all industries that emit one or more of the pollutants in significant quantities. PAHs are included in the group of Polycyclic Organic Matter[26], and member states have their own PAH air emission limit values as average acceptable ambient air concentrations, either as 1, 8 or 24h averages or annual averages, detailed in ATSDR (1995). The concentrations are defined mostly for benz-(a)-pyrene, benz-a-anthracene, but can also be defined as coal tar pitch volatiles. We find examples for both very low levels - BaP 0.00 μg/m³ 24 hour average in Virginia – and very high levels - naphthalene 10000.0000 μg/m³ 8-hour average in Connecticut; but most concentration limits are between 1-10 μg/m³.[27]

Other worldwide limit concentrations usually are around the 0.1 – 5 ng/m³, like a New Zealand authority considered that a criterion of BaP 0.30 ng/m³ (annual average).

2.3.2 PAH regulation in the EU

There is at present no EU level ambient air quality limit value for PAH compounds. The Directive 2004/107/EC "relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air" (2005) does not impose strict air quality limits, but foresees mandatory monitoring where concentrations exceed 1 ng Benz-a-pyrene (BaP) /m³ (=0.001 μg/m³) annual average (target value). Members states started to implement locally the directive both on national and regional levels, see for example in Scotland "The Air Quality Standards (Scotland) Regulations 2007 (S.S.I. 2007/182)", which implements the same concentration for BaP. Note, that in the UK the Air Quality Objective for PAHs based even lower targets in turn on the recommendations of the Expert Panel on Air Quality Standards (EPAQS), for an annual air quality standard of 0.25 ng BaP /m³. Some Member States set guide or target values, in Netherlands PAHs limit value is 5 ng/m³, and Benz-a-Pyrene guideline value is 0.5 ng/m³ Years as ng BaP/m³. Italy has a legally enforceable ambient air quality standard of 1.0 ng BaP/m³ and Sweden has a guidance value of 2 ng/m³ for fluoranthene. As far as designing a network to monitor compliance with a potential BaP limit value is concerned, the macro-scale

[26] The Act defines this group as "Includes organic compounds with more than one benzene ring, and which have a boiling point greater than or equal to 100 º C".

[27] The zeros in the decimals show the precision required. For example, in the case of 10000.0000, a value of 10000.00007 is over, but 10000.00004 can be considered as equal to 10000.0000.

setting criteria described in Annex VI of Council Directive 1999/30/EC for the protection of human health are also applicable to PAH.

PAHs are also covered by the Persistent Organic Pollutant (POP) Protocol under the United Nations Economic Commission for Europe's Convention on Long Range Transboundary Air Pollution (UN ECE CLRTAP). Under the Protocol, emissions of four PAH compounds have to be reported annually; in addition, emissions of PAH in 2010 may not exceed the levels of 1990 (or any other base year between 1985 and 1995). The European Community is a party to the Convention and therefore has to fulfil the obligations of the Protocol after ratification.

While not directly controlling PAHs, nevertheless it is likely that a number of Directives indirectly influence emission or concentration in ambient air on a longer term. These include the directives: arising from the Auto Oil programme, on the

incineration of wastes, the IPPC directive (96/61/EC), the air quality framework directive (96/62/EC) and its first daughter directive -1999/30/EC (Council Directive relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air, OJ L 163, 29.6.1999, p.41) which addresses particulate matter. The objectives of this legislation cannot be met without the control of the emissions of particulate material from a very wide range of sources, many of which are sources of PAH. It is likely that measures to meet the objectives of the daughter directive will reduce PAH emissions also. Vehicle emissions regulations ('EURO IV': Euro 4 (2005) for any vehicle - 98/69/EC (and 2002/80/EC), and 'Euro V': Euro 5 (2008/9, proposed) for any vehicle) will, in time, further reduce particulate emissions too; this will result in further PAH reductions. However, the particular effect of these measures is hard to predict.

2.3.3 PAH regulation in Hungary

The environmental regulation for polluting substances in Hungary in the recent past has been fee/penalty centric (Farkas, 1994a), and there was a need for the re-evaluation of health limit values. Although the 1995 Act brought fresh air to the regulation system (which is still current as of 2008), as Klarer et al. (1999) demonstrated, the wished changes by that time was to implement a systematic air-emission charges-airload charges system to reduce heavy pollution and to generate revenues. Therefore, the mainly administrative nature still reigns as of 2008 and to assess PAH regulation in Hungary the air quality measures listed by the Ministry of Environment were examined.[28]

[28] List of the existing and planned regulations in Hungary about stationary sources for ambient air pollutants („A helyhez kötött légszennyező forrásokra vonatkozó hatályos és tervezett jogszabályok jegyzéke) (2004-04-07 17:23:35)"

PAHs are regulated in Hungary by current governmental directive 14/2001, which deals with setting limits for a range of atmospheric pollutants. The directive sets the health limit for Benz-(a)-pyrene as 0.001 µg/m³ as 24 hours average[29], and sets the technological emission limit as 0.1 mg/ m³ when the emission flowrate of the compound is 0.0005 kg/h.

Unfortunately, the above described 2004/107/EC directive has been only partially implemented yet (as of May 2008) for PAHs. Some aspects of it appear in the governmental directive 21/2001 sections 7, points 7, 8 and 11 (the original directive was modified in the governmental directive 36/2006 (II. 20.) to implement some of the 2004/107/EC directive's measures)[30]. The directive says when the current limit values for Benz-(a)-pyrene are exceeded (7) or the current target values are exceeded (8) local action programs have to be developed to reduce emission to conforming concentration levels, or if the limit values or target values are respected, the state of the environment has to be maintained (11).

An interesting regulative measure in Hungary is the *"1998 Protocol to the 1989 convention on long range transboundary air pollution on persistent organic pollutants"* It has been revised and reinforced by parties of the convention (Hungary and neighbouring countries) in September 2003. The protocol accounts all important areas of the industry where a high level PAH emission is foreseen as probable, and enforces limit values for the technologies and prescribes the use the best or preferred available technologies. These areas include mobile (traffic) and stationary sources. Although, as we have found in our work, traffic data correlates most with background PAH concentration, it is interesting to see, which industries are included in this regulation. Technologies that are expected to contribute to a great extent to PAH emissions:

incineration (including co-incineration, of municipal, hazardous or medical waste, or of sewage sludge); sinter plants; primary and secondary production of copper; production of steel; smelting plants in the secondary aluminium industry; combustion of fossil fuels (in utility and industrial boilers with a thermal capacity above 50 MWth[31]); residential combustion, firing installations for

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source: http://www.ktm.hu/index.php?pid=9&sid=47&hid=381

National provisions communicated by Hungary concerning Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air.

source: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:72004L0107:EN:NOT

[29] 0.001 µg/m³ = 1 ng/ m³

[30] Altough it would be interesting to include the full text of the directive in the Appendix, due to size restrictions we recommend to read it on-line. The directives are available online at:

14/2001: http://www.kvvm.hu/cimg/documents/14_2001_K_M_E_M_FVM.doc

21/2001: http://www.kvvm.hu/cimg/documents/21_2001_Korm.rendelet_a_leveg_vel_kapcsolatos_egyes_szab_lyir_l.doc

[31] MWth = megawatt thermal (to differentiate from MW, megawatt electrical)

wood (with a thermal capacity below 50 MWth); coke production; anode production; aluminium production using the Soederberg process; wood preservation installations.

3. Analysis of the Environmental Regulation of PAHs

3.1 Difficulties in PAH regulation

When looking at PAH regulation in the world, we can see a varying picture, both in approach, both in levels.

The general approach in the USA is to control emission as much as possible. We can observe that there is no uniform PAH regulation, but every member state has its own codification. Most of the members states in the US implemented emission limit values, with varying levels, sometimes with differences of orders of magnitudes. As Vari explains (in Pataki, 2008), the decision making processes, the operation of companies and the state is very different from any European approach. The most different is the unbelievable (by European standards) degree of control in regulation. All alternatives are possibly developed to the finest detail, because every conflict immediately started to be resolved by legislative bodies. Therefore, Vari concludes, they somehow try to "pass down responsibility to legislation", but because of over-regulation, the system becomes inflexible. This can be observed also for PAH limit values, which are the most developed among all the countries in the World, and they were codified well ahead of European countries.

Among all the current regulations for PAHs, the EU directive is going in the best direction as it integrates many important aspects for a better control. The regulator understands that PAHs are carcinogenic and assumes that even small concentrations would bear a risk for humanity; BaP to be having the most evidence to be carcinogenic; therefore the dose-response curves show stochastic effects. The EU directive approaches by prescribing the use of BAT and targets to decrease the environmentally harmful effects as much as possible. Therefore, instead of limit values, the reach of a target value with a target date is set in the directive: member states have to do all possible actions to reduce immission PAH concentrations below 1 ng/m^3 by 31 Dec 2012. In the understanding of the directive, "target values would not require any measure entailing disproportionate costs. Regarding industrial installations, they would not involve measures beyond the application of best available techniques, [...] and in particular would not lead to the closure of instllatations."

However, the target values in the EU directive had been developed taking the same way as the limit values in other regulations. Scientific bodies had been asked to determine and measure the effects and suggest a target concentration. Unfortunately, the differences and uncertainties of the measurement methods and the not well characterized nature of the carcinogenic effects (effect-

models) had been ignored largely. The target date also imposes different economical and technical challenges to member states with different level of industrial development. In the end, we see that the form of the regulation in the EU directive is different from other countries and has a much better approach. Although, it imposes a softer regulation compared to limit values, this regulation had been developed using the same considerations, as limit values in other countries, i.e. assuming that concentrations and effects can be well determined.

The legislation for PAHs in Hungary is less developed compared to both US and EU practice, both in approach and attitude. Limit values are implemented in the same way as for inorganic and organic compounds, and slowly following the EU directives.

To have a better overview on the actual levels of PAH limit values, let us build a short summary list to be able to have a general overview. The following PAH limits can be found:

- WHO recommendation (1997-2001-2005) (immission):
  - 1.0 ng/m³ yearly average BaP
  - 20 μg/m³ yearly average PM10
  - 50 μg/m³ 24h average PM10
- USA: (1990-1995-2xxx) (emmission):
  - Different in every State
  - Virginia: 0.00 μg/m³ 24h average BaP
    Connecticut: 10000.0000 μg/m³ 8h average Naphthalene
  - Generally in other states: 1-10 μg/m³ BaP, BaA or other molecule
- Other countries in the World
  - Mostly: 0.1 – 5 ng/m³ - adopting WHO recommendation (immission) or copying USA (emission)
  - ex. New-Zealand: 0.30 ng/m³ yearly average BaP (immission)
- EU countries (immission):
  - EU recommendation: when over 1 ng/m³ BaP detected, monitoring afterwards (2004/107/EC)
  - UK 0.25 ng/m³ BaP
  - Netherlands: 5 ng/m³ total PAH, 0.5 ng/m³ BaP
  - Sweden: 2 ng/m³ fluoranthene (recommendation)
  - Italy: 1 ng/m³ BaP (limit value)
- Hungary (emmission):
  - 14/2001 governmental directive
  - 0.1 mg/ m³ BaP emission, if mass flow rate of the technology 0.0005 kg/h

– (0.001 µg/m³ as 24h average BaP, but health safety limit value, not environmental)

While the use of PAHs in products and processes are well controlled, their environmental regulation has still to overcome several issues: we can observe a huge difference in both approach and values among the limit values of the different countries. Nielsen et al. (1999) also conducted a comparative study of available limit values earlier, and comparing The Netherlands, Germany, US-EPA, WHO and Denmark, he presents a similar diversity in PAH limit values.

Although PAHs are carcinogenic, and regulation has to consider the carcinogenic nature (as it is done in current EU regulation), this fact only cannot explain all these variations. What can be in the background of such a varying picture for PAH regulation? As we have seen in *Chapter 1*, limit values are still one of the most widely used institutional mechanisms. As they are uniform, they can address many non-economic factors in the same time (Kozák, 2002). Uniformity for limit values means they can be applied industry wide for any kind of production process, as is the case for PAHs. However, once a limit value had been codified, because they are idiosyncratic, they are slowly adapted and inflexible when regulation needs change (Voice (2004)). Although this inconvenience, available limit values (and other legislations) had an overall positive effect, and levels had been reduced linked to regulation (Nielsen et al. 1999)[32]. (The reduction of PAH levels demonstrated by Nielsen was linked to the necessity of the reduction of inorganic compounds. These compounds had a severe limit value codified and then technologies were modified.) In summary, we believe that limit values, as an environmental tool, are in general a good choice for the above practical reasons.

Therefore, let us investigate the process of the formation of the regulation, especially for limit values. As we have seen in *Chapter 1*, the formation of a certain environmental regulation system can be regarded as a decision-making process. Based on available knowledge about the molecules, the health effects, the regulator makes a decision, on what and how he regulates (see *Figure 3* on page 26 and *Figure 4* on page 27). To our supposition, in this process of the development of PAH limit values, there are two critical areas, both related to the 'providing knowledge' step in the middle. One is the inclusion of natural-scientific knowledge; the other is

[32] "Measurements made in the period 1992-94 (Miljøprojekt 285, 1995) indicated, that the levels of PAH and mutagens was reduced during period. It was estimated that explanations could be the increased use of catalytic converters and the introduction of an improved diesel fuel. The measurements in this project confirm, that a significant reduction of PAH and mutagens took place during the period 1992-1996. The reduction of the PAH-concentration has been estimated to about 35%. It is concluded that 2/3 of the reduction is due to the use of the improved diesel quality and 1/3 to the increased use of catalytic converters." Cited from Nielsen et al. (1999).

representing social values and personal interests. We investigate the scientific knowledge in the following *Chapter 3.2* and the importance of social context in *Chapter 3.3* (page 72).

3.2 Dealing with shaky scientific knowledge

3.2.1 The concepts of incertitude, uncertainty and ignorance in risk analysis

In the scientific knowledge provided for the decision-making, the key elements are risk calculations, as experts consider risk in either an implicit or an explicit way to justify the codification. Let us investigate risk calculations. A risk factor (R), in its most simplified model, can be regarded as a function of probability (P) and function of outcome (O).

$$R = P \times O$$

This way limit values reflect some kind of an environmental outcome, in this case damage, that is imposed by a certain probability[33], in other words with a certain likelihood to happen. Obviously, experts will legislate limit values for high-risk cases in a more severe way, and with low risk, in a less severe way. Namely, for environmental damages those outcome is considered more harmful, or for damages that occur with a higher probability. Consequently, during the implementation of the risk concept in the definition of limit values, we should handle both probability and outcome, in an explicit, intentional way, as these are at the basis of risk calculations, and hence the decision making process. For PAH limit values, probability can be translated as environmental *Concentrations* of PAH molecules (higher concentration ~ higher probability to inhale PAHs) and damages or outcomes as *Effect-models.*

$$R_{PAH} = \text{Concentration}_{PAH} \times \text{Effect-model}_{PAH}$$

Health regulation risks assessments are based on good knowledge, as the probabilities/concentrations are of a firm basis (it is well known how much and who uses these chemicals) and the effect-models are well defined (cancer and other health effects are well described for these working environments).

We believe that the problem lies in the shaky nature of the information available for these risk calculations and we investigate in detail this area. Several models have been developed to

[33] According to Audi (1995), the main interpreations of probability include the *classical*, *relative frequency*, *propensity*, *logical* and *subjective* notions. Here we use probability in the relative frequency interpretation, where probability attaches to sets of events withinga "reference class". This kind of interpretation (together with the classical and propensity interpretation) are sometimes called "objective", "statistical" or "empirical" , since the value of a probability (here) depends on what actually happens, or on what actual given physical situations are disposed to produce. Kemény and Deák (2000) uses the following definiton:" Those variables, which are not constant, but can have a value different from case to case, and it can be determined with which likelyhood their value falls into given limits, are called probability variable".

characterize the situation for shaky knowledge. We found the concept of Stirling (1999) very effective to describe the properties of PAH regulation, therefore we present in detail his approach. A very similar theory was developed by Funtowitz and Ravetz (1990) earlier, which we outline shortly at the end of this sub-chapter.

Stirling points out in this concept of 'Risk', 'Incertitude', 'Uncertainty' and 'Ignorance'[34] that while a mathematical apparatus for risk calculations is already available, they can only be used if our knowledge about likelihoods and outcomes are accurate. However, many situations provide only unspecified information of these factors, hence the multidimensional risk factors, and so the limit values can become inaccurate for the decision making process. Along the quality of knowledge - firm based knowledge, shaky knowledge and without any firm basis of knowledge - , he sets up four distinct regions on how to approach risk, which are demonstrated on *Figure 13*. (A more detailed diagram of the concept can be found in Stirling (2003), which is presented in *Appendix*

[34] We propose the following translation of these knowledge areas for the Hungarian wording: „kétséges tudás", „bizonytalan tudás", „tudatlanság".

A.2 page 104).

The differentiation enables us to identify the issues relevant in the calculation, as Stirling (1999) explained, by using appropriate approaches for these situations. The alternative analyses are designed to allow improved decision-making by enabling consideration that is more complete for either probabilities or outcomes and their implications. In the case of *uncertainty*, when our knowledge is based on a poorly defined likelihood, fuzzy logic and sensitivity analysis can be applied to improve our knowledge. When *ambiguity* is present, that is the outcomes are poorly defined, scenario analysis can provide an effective way to get a better knowledge of the problem. Finally, when both likelihood and outcomes of a technological risk are inadequately expressed, we talk about *ignorance.* In this latter case, the suggested approach for handling the situation is precaution.

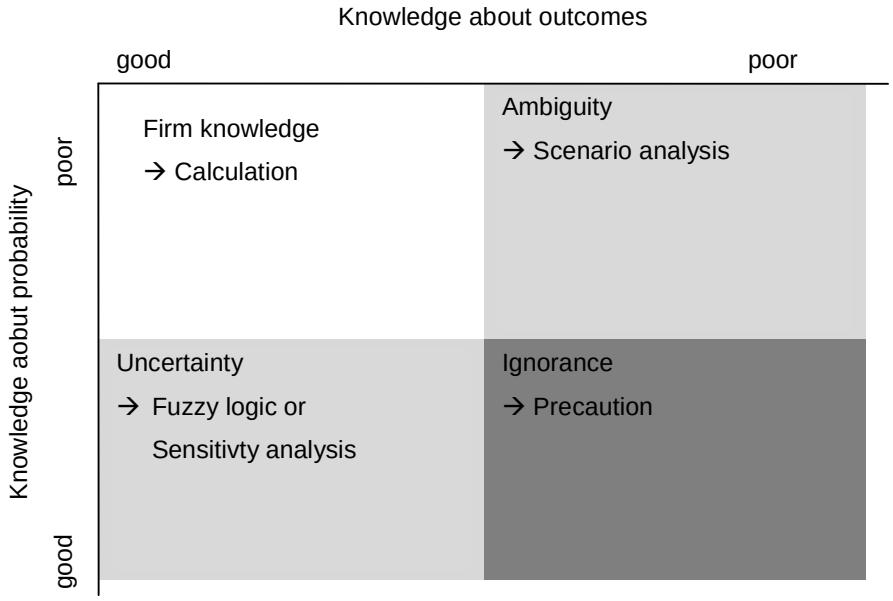

Figure 13. Stirling's diagram of 'Incertitude', 'Risk', 'Uncertainty' and 'Ignorance'.[35]

Scenario analysis can be defined as a process of considering alternative possible outcomes (scenarios) in order to analyzing possible future events (Fahey and Randall, 1998)[36]. In this case,

[35] We decided to swap the placement of scenario analysis and fuzzy logic/sensitivity analysis compared to the original figure of Stirling, as we believe this way the figure discribes better in what kind of knowledge situation these tools are used. Stirling uses these tools interchangeable in the figure presented *Appendix A.2* page 6).

[36] For more detailed introduction on scenario analyses see Marsh, B. (1998): Using Scenarios to Identify, Analyze and Manage Uncertainty (see page 6 for full reference details).

we know the probability very well; however, we only have vague information about the event that will happen with the well-determined probability.

McKone and Deshpande (2005) demonstrate, for the management of solid waste in major cities, how fuzzy logic can be efficiently used in environmental protection, when probabilities cannot be characterized for proper risk assessment. As they describe, *Fuzzy logic* deals with the situation when no mathematical apparatus is present to get information about a given phenomenon, or we don't have the necessary resources to establish such a model (financial, time or computing power), however general experience is available and everyday verbal description can be given, like "small" infection, "mild" pH or "very" probable. In contrast to classical sets, fuzzy sets include objects with partial membership, for example, a soil contaminated by a citric acid solution and with a pH of 6.5, can be described as "little bit" acidic soil, "almost" neutral soil, and "not at all" basic soil.

Sensitivity analysis explores how in response to variations in key parameters and their interactions the outcomes or impacts of a course of action would change. In other words, how different sources of variation in the input of a (mathematical) model can be linked the uncertainty (i.e. variation) in the output of a model, either qualitatively or quantitatively (Saltelli et al., 2008; SEC(2005) 791). A well known model for example to handle such a situation is the Monte Carlo analysis, in which we look at the distribution functions of the input parameters, as derived from the estimation (Saltelli et al., 2008).

These analyses methodologies can be transformed to special forms replying to the needs of the given area, like for evaluating GMOs Substantial Equivalence is used (~sensitivity analysis) (Karner, 2004), or SWOT analyses to determine the role and place of environmental protection for an organisation (~scenario analysis) (Kósi and Valkó, 1999).

In the fourth area, both our knowledge about probabilities and damage (outcome) is poor; we do not exactly know *what* we want to avoid and we do not exactly know *how likely* that unknown thing might happen. Therefore, we are prepared for the combination of several damage alternatives, with unpredicted, surprise type probability (Tickner, 2000)[37]. The common methodology to deal with ignorance, as explained by Stirling (1999), and Brown and Zaepfle (1996), instead of risk assessments, is *precaution* that should be applied throughout the

[37] It is important to make a distinction between the following similarly sounding notions: prevention and precaution. *Prevention* is the application of measures pre-damage that increase the possibility of avoiding damage; in this case the knowledge about damage (outcome) is well difined, i.e. we know what we want to avoid.

The related *precautionary principle* is only wagualy defined in the literature, but mostly understood as a European guideline for regulation adoption of the "precautionary approach as an explicit formal element in the design of conventions, treaties, legislation, institutions or other statutory instruments associated with the management of technological risk" (cited from Stirling, 1999).

elaboration of the regulation. The precautionary approach directly deals with the problems of multidimensionality, incommensurability and ignorance. It recognises multiple perspectives and it is open to alternatives and shifts from the basic idea that science can always reliably assess and quantify all aspects of risk (Stirling, 1999; COMEST 2005).

Earlier, Funtowitz and Ravetz (1990) also presented the context when we have to deal with high systems uncertainty (available knowledge for probabilities is poor, in other words, knowledge weakness is high), and in the same time stakes of our decisions are high (knowledge weakness of outcomes is high). They define this area as *post-normal science* (see *Figure* 14).

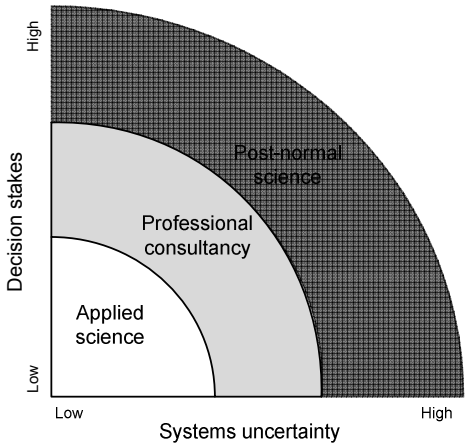

Figure 14. Uncertainty-stakes diagram of Funtowitz and Ravetz[38]

The areas on the two diagrams are analogous: the area of *Calculation* can be linked to *Applied science*, the areas of *Scenario analyses* and *Fuzzy logic + Sensitivity analyses* to *Professional consultancy*, and finally *Precaution* to *Post-normal science.*

These considerations show that in typical "post-normal" research, the source of information of the above techniques should originate not on the calculations, but on expert opinions and public participation (Fischer, 2000). The revolutionary idea of Stirling is that instead of avoiding 'no-knowledge' situations, we handle these in a new way. This way, concerning probability and damage, framing decisions about the different aspects and dimensions of risk, is necessary based on a social discourse.

3.2.2 The role of ignorance in environmental regulation

We can group the limit values into different categories: to a category where the limit value corresponds to an environmental event those risk is calculable, thus the knowledge on both the

[38] Figure cited from Funtowith and Ravetz (1992).

probability and the outcome are accurate, and to a category of environmental events those risk is only estimateable, which should be regulated separately. *Figure 15* explains how limit values can be separated into two groups, using the concepts of Stirling (2003) (the first category is white and the second category is shaded light and dark gray).

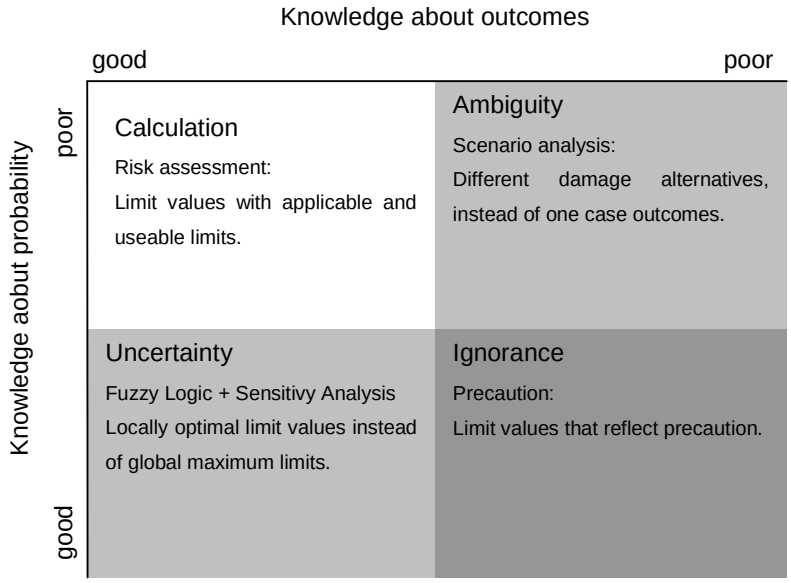

Figure 15. Considering risk in regulation of limit values
Firm risk (white) vs. estimateable risk (gray) areas

Most likely, the limit values that belong to the first group of limit values that bear a calculateable risk factor can be more easily obtained with natural scientific calculations, and limit values of the other group require longer trial-and-error periods. In the group of limit values whose risk is only estimateable, we can make further distinctions, according to *Figure 15*: limit values of an environmental event those risks probability are not well known; then those with a risk referring to an outcome barely shaped; and finally environmental events, where both probability and outcome are only estimated using special techniques.

In risk calculations of environmental limit values, the main factors corresponding to *probability* and *outcome* are *concentration* and *effect-models* (the effect-model can be the dose-response curve itself for non-stochastic effects, and mathematical models for stochastic effects, as seen in Chapter 1.3). Therefore, Stirling's concept can be applied in the following way for the risk assessment of environmental air pollutants (see *Figure 16*).

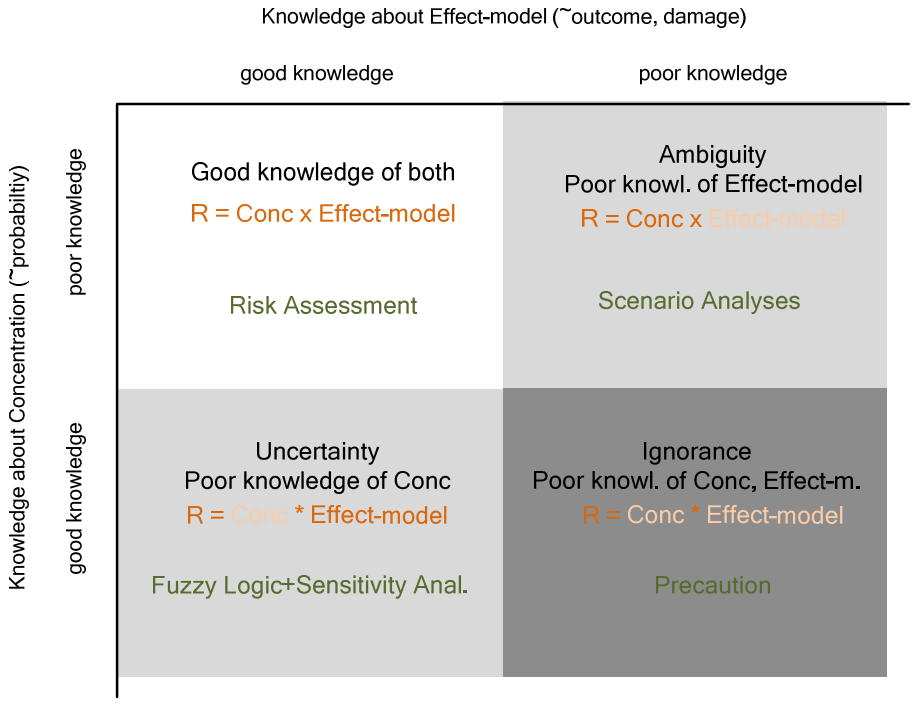

Figure 16. Concept of poor and firm knowledge of risk calculation with Concentration and Effect-levels.

The figure helps us to understand the current situation of the regulation of the air pollutants. For the most important inorganic and organic pollutants, usually both concentration information and effect-model information are of firm basis of knowledge, consequently risk assessments can be carried out and regulation can be based on the results of the assessment studies.

Limit values for the classical inorganic polluting compounds can be classified to the first group: CO_2, SO_2, NO_x. For these compounds, routinely applied analytical methods around the world are in practice and long-term health-effect experiences are available, which allow exact knowledge on the probability and the outcome of effects related to these compounds (see Act LIII of 1995 on the General Rules of Environmental Protection of the Hungarian Parliament). These limits are well established and rarely modified.

When the limit value is based on risk calculations where originally the knowledge of the probability were uncertain, regulators arrived to limit values that consisted of local optimum values, instead of the original global maximums based on mathematical relationships. Where the knowledge about outcomes left the regulators in ambiguity, the final limit values usually reflect the preparation for different alternative damages. Cyanide shows an example for this latter. Cyanide is classified as “priority pollutant” under the Clean Water Act, and outcomes were well described with different well-established dose-response relationships (Annachhatre and

Amorkanev, 2000; Boening and Chew, 1999). However, new situations, see continental scaled disasters, present new areas of outcomes that are not defined in current regulations (Ferguson, 2000), and we find ourselves in the area ambiguity. With the help of scenario analyses, experts advise the design of different limit values for different situations, as normal operation and emergencies.

As we can see from these examples, for certain compounds, scientific knowledge is well established and provides a firm bases for the development of limit values, while for some other cases, the regulation needs to undergo a procedure of redesignment. In the case of ignorance, the limit values will not function, and will trigger a continuous need for revision of the codified levels.

3.2.3 Precaution in the environmental regulation of PAHs

However, in the case of the organic air pollutants – PAHs –, both concentration data and effect-models are of shaky basis of knowledge.

Determination of PAH concentration in urban air is technically difficult, and different analytical techniques were developed to estimate concentrations. The presented levels can differ in orders of magnitude depending on the equipment, climate and procedure used during measurements (see *Chapter 2.2*, page 49). Because of the particularly low levels of PAH concentrations, there are different approaches to measure PAH concentration on the "market of analytical chemistry". Two accepted indirect monitoring methodology for example, as we have already seen, are the use of snow samples along roadside and the biomonitoring by accumulation on moss samples (Kozák et. al., 2003; Viskari et al. 1997). Unfortunately, these two methods produce incomparable PAH concentration values between the two methods, and because of the many different forms of snow and mosses in the environment, results are often difficult to interpret even when talking about snow sample or moss sample results only. Then the other available methods in the EU and Hungarian prescriptions are difficult to use and sometimes impossible to implement due to the local concentration ranges and setups (hence the use of indirect methods with mosses and snow samples had been developed). Unfortunately, none of the methods found in literature is accepted currently as a standard way to determine PAH concentrations, as all of them have their weaknesses. Direct methods are influenced by different meteorological conditions, which may cause air pollutant variations to be larger than changes in daily and yearly emissions (Nielsen et al., 1999). Indirect monitoring then suffers from practical problems, such as snow samples can be used only in countries where there is a sufficient yearly-snowfall, while moss requires the necessary climatic conditions to grow (temperature, humidity, shadow). This

results in the fact that the concentration of PAH measurements are accurate only for some relative comparison, with excessive inter- and extrapolation between methods and concentration ranges. What is more, when looking at the concentration values we can see that even when the same analytical techniques are used, the published concentrations can vary in orders of magnitude, depending on time of year, analytical equipment or the way samples were taken (Virender et al. 2001; Kozák, 2003). Our general experience shows that the best is to compare only intra laboratory PAH result data, and comparison of data carried out in different laboratories has to be made with great precaution. As a result, risk assessments are also of shaky basis and could be used only on a "what if" basis to develop regulation.

The side of outcomes for PAHs is also troubled with shaky knowledge. Types of diseases are characterized; PAH molecules bind through their epoxides to the guanine of DNA chain and cause cancer on the long term (summarized previously in Kozák et al., 1999.). However, due the large variety of these molecules, and to the lack of dose-response experiments, there are only vaguely defined effect-models available. We do know that these molecules are carcinogenic, but we hardly know an exposure of which concentrations will cause a skin cancer in 5 years, for example. In general two kinds of investigations are used to assess environmental exposure (Sublet, 1994), toxicological studies and epidemiological studies. In toxicological studies, animals are dosed with a hazardous substance and then response to the agent is measured by evaluating different physiological parameters. Epidemiological studies are conducted using humans as the study population, but such studies for PAHs are only available as indirect data (nobody inhales PAHs intentionally). As summarized in the PAH Position Paper (2001), many data has been established for inhalation of Benz-(a)-pyrene, and/or chrysene and/or Benz-a-anthracene for laboratory animal experiments (golden hamsters, rats, mice). Trend analysis for incidences of both respiratory tract tumours and upper gastrointestinal tract tumours showed a statistically significant tendency for the proportion of animals with either tumour type to increase steadily with increased dose of BaP in 10 to 60 week experiments. However, in other studies, an increased mortality was observed due to the development of large, multiple tumours in the lungs during 10-20 months exposure times. However, we do not have sufficient evidence for midterm exposure times of 3-5 years (a typical period for studying and/or working in a certain location, i.e. in a PAH polluted environment) and long-term periods of 10 years or more (a typical period for example for the children of a family to grow up in a given environment). What is more, laboratory analyses data about PAH exposure effects for humans is virtually not available, and we can base our logic for human effects only on careful extrapolations of the laboratory animal experiments. In fact, we only have evidence for the wording based on current PAH risk

assessment for health and work protection, and can say that presumably the presence of PAH contamination in urban air is strongly possible to be harmful on the long term.

In fact, we do not know accurately nor the effect-models, nor the probabilities necessary for a firm basis of risk calculation, and these data have to be used only for a precautionary approach.

Although the available PAHs concentration values cannot be used for precise risk assessment studies, they are serviceable as indication values of general trends for applying precaution. For example, we have found (Kozák et al., 2003) a considerable correlation between the PAH concentration determined with the help of moss samples and daily vehicle traffic. We also found that heavy PAH molecules (4-5-6 aromatic rings) were present in the moss samples at levels close to the detection limit, hence levels of heavy PAHs are negligible in areas far away from the sources (traffic, heating, industry). This suggests that the environmental regulation for PAH should focus on the light PAH molecules (2 or 3 rings) and regulating traffic related PAH emission is quite sensible.

In summary, the main difficulty for developing a regulation excessively based on risk assessment in the case of PAH emissions is the fact that PAH concentrations in air are hard to determine by means of environmental analytical chemistry, second, the required dose-response relationships/models necessary to shape the possible health and environmental effects are missing or incomplete.

3.3 Social values and interests

3.3.1 Limit values designed on natural-scientific basis

Beside the shaky nature of scientific knowledge of risk calculations, one also have to deal with social values and interests during the decision making process of limit value formation.

From the development process perspective of regulation, we see that during the design process of environmental and health safety regulations, a number of factors are taken into account like scientific, economical, cultural, social, political and technological factors. However, as we have seen, in recent years, scientific reasoning is gaining more and more importance. For example, in the domain of food safety, scientific risk-based policy is overtaking the cultural and political debate about food, and countries are creating policies based on risk, not on culture (Fletcher, 2004). The authors' personal experience shows that in the case of environmental regulation the risk-assessment results – scientific factor – are also becoming the weightiest factor.

We agree that the design process of limit values can originally being based on natural scientific reasons, but the conscious involvement of socio-natural scientific factors would significantly

reduce the time necessary to arrive at final levels of the environmental limit values. Then, when they have accomplished their main purpose, motivate actors to modify their technology and produce less of the compound under discussion. An important socionatural-scientific approach, beside the economical, psychological, managerial and other factors, could be the use of the above-described knowledge-areas in the classification of limit values, to determine where we are knowledge wise, and only use natural-scientific knowledge to extent that it is reasonable.

As we have seen in Chapter 1, the Hungarian Act on environmental protection clearly defines that the primary goal of environmental limit values is the prevention of environmental pollution, to control and terminate polluting activities and finally the remediation of polluted areas and the reestablishment of the previous state of the environment (Bandi and Perecz, 1998). Current limit values in the legislation have been articulated for these three goals: *preventive* limit values target to reduce the possibility of environmental pollution of hazardous and non-hazardous activities; general limit values have the objective to control and terminate polluting activities; while *remediative* limit values identify to which state has the concentration of the polluting material to be restored in order to eliminate the pollution at the give area.

For chemical limit value determination based on natural science, as the damages and losses of private and natural properties are fixed in the regulation, risks should be taken into account both for the description and for the assessment of the damages and losses (Krimsky and Golding (1992)). For this reason, current limit values are mostly bonded to environmental threshold values. Threshold values characterize the response of the environment in regard of certain processes and changes. For example, in case of hazardous materials, the threshold value of the environment can be determined with the help of indicator species: at what concentration level changes the life mechanism of the given indicator organism, or in a higher concentration area, at what concentration level will die the half of the population of the given indicator species in one hour. Usually microorganisms or low-evolution level spiciness with high number of individuals in the population, with a fast reproduction rate are chosen for these experiments. Then, limit values are determined by legislative bodies as they convert threshold values into limit values. However, at the beginning, the threshold values, which are the basis of limit values, were determined by academic personnel and researchers of laboratories and research institutes. Therefore, current limit values are in fact bonded to natural scientific laws, they originate on a natural-scientific basis.

Farkas (1994a) explains based on the results of modern knowledge and science sociology, that technical rules are in fact social constructions, consequences of social conflicts and agreements. This can be seen also in environmental protection, as we have to determine what is polluting and

harmful for the environment, in other words we have to set the borderline between pollution and non-pollution: the limit between pollution and non-pollution concentrations.

What is more, the circle of affected public has extensively enlarged because of the social-scientific value changes, and public opinion cares much more about the status of the environment. For example, instead of the allowed maximum concentration levels, local optimum levels come to the front (Fischer, 2000). Furthermore, because of the incertitude in the development of the limit values, the subject of the formation of winner-looser groups formed resulting of the regulation and the management of these groups are increasingly important.

Chemical limit values determined by theoretical experts in the offices that have not been tested and verified in real-life situations, although firmly based by science, can have several not foreseeable consequences. Therefore in the future, beside estimated risk levels, other, social-economic factors should be included in the development process, especially for widely applied limit values.

One has to face many factors of incertitude during the selection of chemical limit values, whose effect in human activity is often impossible to predict (Hronszky, 1998). Only model experiments and assessments can provide useable data for the analyses of happenings, whose validity has to be evaluated by “industrial scale” conditions.

It has been underlined also by other sources that behind the incertitude of current limit values can be several other sources. Fischer (2000) also clearly explains, is that current chemical regulations mostly are based solely on natural-scientific facts, instead of taking into account socionatural-scientific factors during their development. Then, the damage related to the notion of the limit value is often vaguely determined, the notion of damage that we relate to exceeding the limit value. Furthermore, the notion of damage rarely includes local specific factors, while they do depend on a large extent on local factors. Therefore, it can often happen that something is considered as an environmental damage at one place, and not at the other.

We have to note here, that instead of quality values and limit values, the global tendency is to move towards the use of best technology solutions (Bandi and Perecz (1998); Streffer et al., 2003). However, when we choose a technology, our choice is also value laden and is a choice of directions. Then, when introducing a new technology, during the introduction and application of a new technology many factors of incertitude has to be considered (Hronszky et al., 1994), because during the use of the given technology, social, economical, regulation values and interest conflicts, which increase even more the incertitude.

The above considerations underline, that the notion of determining knowledge of risk calculation should be applied both in theory and practice as new needs and interests had risen in the field of

environmental limit values. Hronszky (1995) clarified earlier that quantitative risk analyses and the parallel consideration of "surprise" (the many sorts of risks) is urging to be applied. Preparing for the unknown is increasingly important in today's environmental regulation, when newer and newer and yet unknown technologies, applications are born with strong, unforeseeable impact on the environment. Therefore, it seems to be rather justified, that it is increasingly necessary to include error-friendly alternatives during the development of regulation models.

These natural and sociological factors together are evaluated by socialconstructivist models (see Bijker et al., 1987). Instead of the constructivist only models, which only deal with the calculable and predictable science, bringing in socialconstructivist approach will be preferred more and more, as we have to deal with more and more with situations where exact science delivers poor results. However, it is recommended to maintain the balance between the two approaches (Farkas, 1996). The acceptance of the above-described theoretical and practical approaches, based on the advanced ideas of history of technology, can facilitate more efficiently the development strategies of environmentally friendly new technologies.

3.3.2 Change over time of limit values

The non-inclusion and not enough conscious involvement of social values and local interests into the decision making step results in a feedback-adjusting process, with which these factors are being taken into account in an implicit way.

The process of the design of limit values presented in *Chapter 1.2* seems to be rather scientific and methodologically well established. However, practice shows that limit values at this step are not finished, but they are adjusted on a longer-term trial-and-error basis, when the introduced level of the limit value or the sanction is not well applicable in real-life situations, the regulator modifies them. Given that the level was too easy to acquire, and their accomplishment did not result in a better environment, the regulator can propose a level that is more severe and is more likely to assure a better quality of the environment. Another example for social context change is the development of analytical technologies for a given compound, and the limit of detection and the limit of quantification are lower (referred as "LOD" and "LOQ" in analytical chemistry publications), regulators also lower the maximum allowed concentration of the compound. However, it can also happen, that the defined level of limit was too hard to acquire and the actors were not interested in modifying their technologies because it would require a financial investment from their part that is impossible to accomplish. Consequently, the regulator usually

sets the limit value to a new level that is more sensible for the actor to respect. In both examples, the limit value differs from its original level developed by natural scientific deductions.

These modifications can prolong the appearance of the finally usable limit values with years or even tens of years, as the regulations can usually be modified only on a yearly basis, and the reply of the actors varies on the time level of years accordingly, which is illustrated on *Figure 17*. The dotted lines and the gray letters in the box of natural-scientific knowledge symbolises the nature of shaky knowledge, the placement and the dotted line the non-implicit inclusion of the social context knowledge.

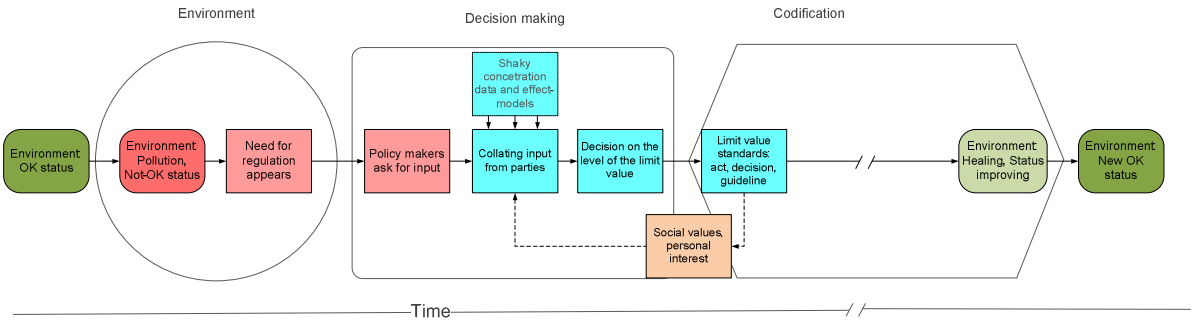

Figure 17. Feedback-adjusting process of limit values.

Therefore, the described situation demonstrate a design process that originally was really based on the facts of natural science, but is followed by an extended trial-and-error procedure to find *the* level of a limit value that is possible to accomplish and is motivating for the actor to modify its technology at the same time. However, the limit value is still regarded as an entity based on a scientific basis. While the trial-and-error phase in the design process involves *non-natural scientific factors*, but in an implicit manner. These non-natural scientific factors can be the economical influences, the reaction of the actors to a new regulation, the managerial factors or the public debates of technology (Hronszky, 2002b). The explained pathway for certain compounds results in “working” limit values that are useable in real-life. However, while limit values of a certain compound that work in certain industries, can be not usable in other industries. Certain limit values are defined because they are easy to investigate but in fact have very small relation with the quotidian problems of environmental protection and therefore they do not reach the original purpose, i.e. to improve the status of the environment. What is more, the list of compounds is also very long that have an environmental impact and should have been limited, when the available capacity of researchers to develop dose-response curves is

constrained – usually from a group of molecules, only the 2-3 molecules are analysed in detail, which are believed to be the most important.

It is understood that communication can play an important role in this refining process. Farkas (1994a) describes based on several case studies that the general main obstacle in the resolution of environmental conflicts is the lack of efficient communication channels between players of a certain case. The communication can be biased between a polluting company and the local habitants, between technical experts and the legal professions, experts and farmers, central and local administration, environmental movements and investors. The situation could be improved by developing and teaching techniques of conflict management. Another aspect beside communication channels is the amount of information. Mansell and Silverstone (1996) described in detail the phenomenon that more information that is scientific available to non-scientists actually renders the selection of technical systems more complex and less predictable, while Farkas (2002) describes that rational knowledge is not necessarly a positive resource in policy making. This can be an explanation on why more and more environmental information available - thank to the better and better communication technologies – results the in feedback-shaping part of the design process longer.

Beside communication, another issue is that these corrections can be even changes of an order of magnitude – the background of these large steps of adjustments is often the availability on the market of new, more precise analytical technologies, or the understanding of new, only recently considered processes. Such changes make life of the industry even harder, as the situation becomes unforeseeable on the long term, and they cannot develop their long-term goals and strategies, when needs and prescriptions change significantly.

3.3.3 Efficiency of environmental limit values

Among the many environmental regulation tools there are many successful ones, which are respected by environmental actors who modify their activities, upgrade their technologies in order to reduce their pollution. There are other regulation tools however, which are currently in practice, but the change in activities and technologies due them are minor, compared to successful tools. These also define theoretically important measures, they would prevent important environmental pollutions, however the status of the environment does not change related to these tools for different reasons. To be able to differentiate among the many environmental tools for these criteria, we introduce a new notion.

We define the *efficiency of an environmental regulation tool* as their capability of changing the status of the environment. A highly efficient environmental regulation tool causes a significant

change in the status of the environment, while a low efficiency environmental tool causes a small or no change in the status of the environment in the desired direction. The primary goal of environmental legislation is the improvement of the status of the environment. Resulting of this, the goal is the implementation of environmental limit values that are efficient, in other words, that bring a change in the status of the environment.

As described earlier, the goal of precaution is to prevent harm, and it forces to defend from possible harm, but it not for preventing progress. Fesus and Hronszky (2005) describes, that preventing possible environmental and health related harm can slow down or even close innovation processes and cause harm in financial or in technological terms to some producers who already made investments in the technology.

To overcome this limitation, we suggest using *motivation limit values*. We define motivation limit values as such that targets to reduce emission instead of targeting to set up objective limits that mirror some characteristic of a natural scientific phenomenon. We also define motivation limit values as such that will change over time, as needs and possibilities change of the regulators and polluters. Motivation limit values are defined based on a discussion between regulators and polluters, taking into account the needs of regulation and the performance possibilities of the emitters. The concentration level set by a motivational limit value will 'motivate' the pollution emitters to modify their technology to emit less, instead of keeping their technology unchanged and paying fees.

The concept of the motivation limit value is based on the idea that we are honest to engineers of the industry and say that our knowledge for risk assessments is poor and we cannot back up our environmental policy with results of firm risk assessment. However, from health/work regulation we know that the presence of PAH in outside air can be dangerous – carcinogenic – therefore it is required that on the long term the concentration of PAHs in outside air should be minimized. The innovative idea of motivation limit values is the incorporation of the feedback-adjustment process into the decision-making – codifying step of the design process of the limit values. This way, the time elapsing until the status of the environment starts to improve can be shortened significantly.

The approach of environmental target values is a similar, but the basis of target values usually are still scientific considerations, like the PAH target values of the EU. What is more, as target values are not obligatory and do not imply immediate negative measures on the polluters, their real life impact is variable. Therefore we suggest to use limit values (which have a financial or legislative consequence on the polluter), when a major environmental concern is present, like for PAHs.

We often hear the argument on why PAH emitting technologies are not banned completely, and BAT is used instead. Worst-case scenario can be applied for both knowledge and ignorant situations. This implies that new technologies that we are ignorant about (both probabilities and possible effects) should not be introduced (like GMOs), or for compounds, that we know to be harmful, should be replaced by BAT. (Like the US and EU halts exports of the neurotoxic commodity quicksilver (mercury) because it is used later by small-scale gold-miners to separate gold from sand (Hogue, 2008)).

However, in the case of decrease of PAH emission, this concept is not applicable as PAH emission is due to long existing well-established technologies that cannot be stopped from one moment to the other so we cannot stop PAH emission immediately to zero. Such a radical message would not get across from policy makers to the industry. Instead, an explicitly normative approach could be applied, a normative educating of people. We consider working with the industry/economics on a cooperative way, make them understand that PAH emission should be minimized on long term, but instead of radically imposing on them to set PAH emission to zero, we imply limit values that are also suitable for them, in a win-win situation of somewhat keeping the business but also reducing emissions. The step-by-step application also prefers the revision of the technological process for reduction of small amounts (see *Chapter 1.6*, page 40), which is much more probable to happen than the change of the core of the technology.

Furthermore, this attitude in the design process of PAH limit values can also help engineers to carry out a "special kind of risk management", as emphasized by Molnar (2005), and hence to develop socio-critical approaches and act as critical responders through a reflective, co-evolutionary learning process, emphasizing objectives that fulfil the requirements of these co-evolutionary aims.

In summary, instead of setting up limit values based on dubious risk assessment results, it is more advisable to develop limit values that consider the current level of technological and economical performance of the urban vehicle industry. On the long term, the goal is not to determine and prescribe a limit value that represents some kind of an absolute standard related to health dose-response curves, but to motivate the industry to reduce PAH emission. These motivating limit values then can be adjusted as the performance of the industry changes over time.

3.4 A new model for the design process of PAH limit values

In view of the above considerations a more effective regulation for PAH can be based on limit values, however we have to be aware of the shaky basis of our scientific foundations, and we

have to apply precaution. On the other hand, we have to incorporate social values and interest in a more explicit way, by characterising the majority of the social factors at the decision making part. Therefore, our initiative can be different from what we have seen in the regulation until now, notably the measurement of the current and desired state of the environment; not the codified limit value will assure the positive change, but the design process itself will assure an efficient regulation.

To deal with the shaky basis of scientific knowledge, we suggest that instead of a global approach, local knowledge has to be incorporated; therefore, every country/region should develop an analytical method that can be robustly used in their region. Probably the data between the methods will not be comparable; however, the status of the local environment can be monitored. As we cannot structure knowledge in the step “Collating input from parties” from natural-science side, we have to accept that we have structure the situation from the side of social context.

The new suggested design process is presented on *Figure 18*. Until the step of 'policy-makers ask for input', the design process remains the same. However, scientific knowledge is considered as Precaution, and because the shaky basis of this knowledge, social context is considered in an emphasized way to allow a better structurization of this interdisciplinary area of where science and social context shapes together the situation. We have to accept, that our choice will be value laden and will reflect local interests, however, this will result in a better status of the environment.

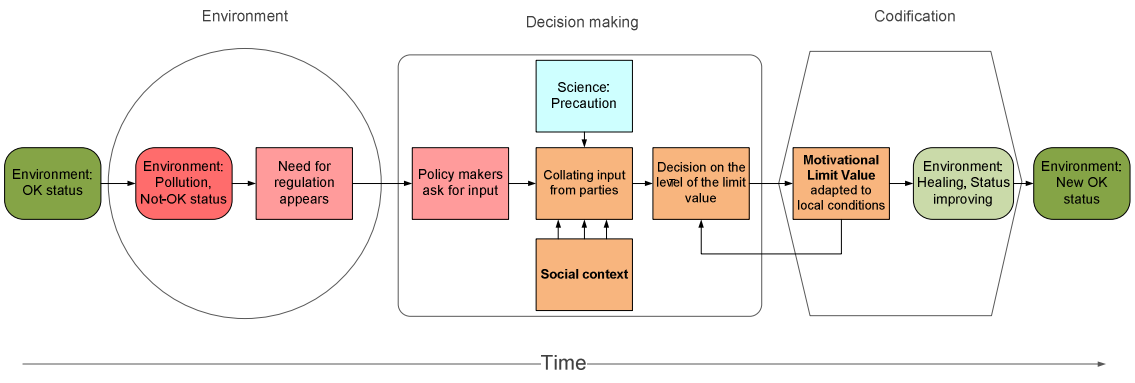

Figure 18. Design process of PAH limit values based on precaution and emphasized social context.

Our experience shows, as we also come from such a background, it is very difficult for natural scientists to accept this new methodology. Next, the limit value is determined therefore not on

the shaky knowledge of natural sciences, but considering local technical conditions and economical possibilities, more individual interests. These limit values therefore are not valid globally and can be codified only locally. The level of the limit value should be implemented in way that motivates local polluters to modify their technologies, hence initiating an improvement in the status of the environment. This level should be reviewed periodically by the decision makers to assure that the status of the environment improves continuously, in other words, PAH concentration is reduced constantly.

4. Politics of Chemical risk – Scenarios for a Regulatory Future of PAHs

4.1. General scenarios

4.1.1 Choices are to made

What kind of regulatory future would be possible to handle given the current situation? To answer the questions, we base our considerations on our experience gained through the research project on determining background PAH concentration on national level in Hungary and the conclusions of the 1995 Amsterdam workshop on chemical risk summarised in their book *The Politics of Chemical Risk: Scenarios for a Regulatory Future* (Halffman & Bal 1998). We chose to use the suggestions of this meeting because since then even after the serious critics and debates that followed it, the conclusions of Bal and Halffman stand as a respectable alternative to explain regulation related to chemical risk. The conclusions of the Amsterdam workshop are also evaluated and combined with ideas from the discussions carried out at the Fellow Meetings in at IAS-STS Graz.

Bal and Halffman (eds.) present four basic scenarios for health and safety regulations for the industry, named as 'International experts', 'European risk consultation', 'European coordination of assessment' and 'Europe as a translator' and we match an adequate alternative from these scenarios for urban air PAH regulation. We have to underline, that the discussed scenarios are *not predictions*, but possible sketches. As each scenario has its own advantages, dynamics; as choices are to made, and *possibilities to explored*, there is no one best way. This is a very important element of the discussion, as it happened several times during the Fellow Meetings (in IAS-STS Graz) that we have noticed that instead of choosing among values and giving way to certain preferences we simply try to find the best applicable scenario for PAH regulation again.

To allow a better understanding of the topic, before passing to the scenario analysis itself, we introduce the reader to the assumptions and criteria used to develop the general scenarios and briefly describe the four general scenarios.

4.1.2 Assumptions for the scenarios

Before we actually can begin to talk about the scenarios, we have to agree to certain assumptions about the regulation system and the situation in general.

First, we have to state, that although on the long term we try to avoid the use of chemicals, now chemicals and the related regulation are present in production processes and they seem to stay for a longer time. While chemicals are heavily used for almost more than two hundred years in the industry, the regulatory framework of the chemicals is incomplete: new chemicals are and will be produced revealing new problems, old chemicals can bring up new-unexpected problems and the regulatory world will continue to develop and run into familiar and unfamiliar obstacles. Then we have to assume that the basic tensions in the regulation are still unsolved, the centrality of chemicals in the production processes is long lasting and even when we base the regulation on the general reduction of emissions, we have to point out chemicals and make priority list for chemicals to be used and not used.

Our second assumption is focus on the EU level of regulation. The perspective of EU is particularly important, as EU will remain the primary source of change, be the central place for tensions, the policy developed in the EU will influence national policies and the EU policy is more than the sum of the national regulation systems when considering the European countries.

Third, we also assume that the science-policy boundary is at the backbone of the regulation. We believe that regulation is only feasible when there is a boundary between science (risk assessment) and policy (risk management), as expert assessment can be challenged, separation of the work experts vs. policy makers is a requirement and expert choices are value laden because of political dimensions. The question is to what extent should choices be delegated to experts and how and when should they be reclaimed by political institutions. There are several reasons to maintain a division between science and policy: the agenda of political institutions is limited, experts can help to focus discussions on political choices, political institutions function at higher costs, political conflicts are present, but experts alone can develop uncontrollable technocracies (loss of pragmatic control, loss of pragmatic check of negotiations, delegitimaiton of regulation). The question is not whether there should be a boundary between expert and policy institution, but about the *attribution of responsibilities* across this boundary and the *organization of disputes* about the attribution process.

4.1.3 Criteria for the scenarios

During the development of the scenarios a new set of certain criteria were set up allowing four different possibilities for the regulatory future. The first criterion is the nature of expertise. It can be either global with objective expression of health and environmental sciences and with uniform-global expertise that can also be transferred across local contexts. When expertise is local, it is a national phenomenon and is tied to social, cultural and political development and/or

institutions. The other organizing criterion is the way the boundary is organised between risk assessment (science) and risk management (policy). When the boundary is strict, influence from risk management to risk assessment should be avoided, while we allow a pragmatic attribution of issues when the boundary is flexible. The four possible scenarios are presented on *Figure 19.*

		Nature of expertise	
		Global	*Local*
Organisation of boundary	*Strict*	**I.**	**III.**
	Flexible	**II.**	**IV.**

Figure 19. Criteria used for the organisation of scenarios.

4.1.4 Four possible scenarios

The first scenario, called *International Experts*, describes the combination of strict boundary and global expertise – in other words chemical risk assessment is regarded as a scientific issue. Experts are not necessarily come from the member states, but are strictly isolated from political issues. Research is carried out at national level but controlled by a central agency. In this scenario, expertise and science are regarded as identical.

Scenario two, *Consultation at EU Level*, combines a flexible science/policy boundary with global expertise, resulting in risk assessment as a consultation between member states, supported by expert assessments. The risk assessment process itself is an exchange of views at several stages with public consultative rounds, including country representatives, interest groups and the wider public. Explicit and public route of the decision making to assume the political basis of experts is important.

EU Coordination of Assessment, the third scenario, is imagined along a strict boundary and local expertise. Risk assessment is harmonized, but kept at a national level, with the help of negotiation of experts. The objective is to harmonize, in other words to smooth the differences between regulatory approaches of the different states. A committee of experts at the EU level tries to align and eliminate national differences. Though negotiators accept the blurred boundary, expertise is regarded as scientific.

Finally, scenario four, *Europe as a Translator,* is imagined when the boundary between science and policy is kept flexible and expertise is local. The situation is very interesting, as the starting point for the debates is the differences in regulatory styles-views of risk. The objective is not to

eliminate the differences, but to find correspondence and indicate the differences. The central issue of the debate is the boundary between risk assessment – risk management.

4.2. Possible scenario for the future in PAH regulation

The first and the second scenario assume that expert knowledge and natural scientific knowledge are the same. However, the knowledge provided from natural scientists for policy makers is already a reshaped knowledge, a knowledge that has already been reformed. Therefore right from the beginning of risk assessment, this knowledge brings this double nature, on one side physical-natural reality, and on the other side, a social construction, and both are included in the same entity. There are a multitudes of dangers around the World, some of these are been chosen and are evaluated and handled. They want to avoid, prevent or at least minimize these. Therefore, risk is already a danger transformed by people. However, the notion itself is normative, as we talk about something that does not exist now, but about something that will possibly happen in the future. Therefore we think that if we want risk assessment to be reasonable as much as possible, we suggest that the risk accessor should align with the risk manager, as in our view risk assessment is carried in an autonomous way, but not completely independently from risk management.

During the discussion of PAH regulation, we have observed a serious problem: when we do not make a clear distinction about which area of regulation we are talking about, we often lose ground during reasoning. Therefore, we find it important to frame three different areas of PAH regulation: PAH usage of the industry, PAH emission into the air from combustion processes and finally the area of background PAH concentrations. Although the diverse nature of these fields, of course we can use observations across these different areas, but let's focus on PAH emission of combustion sources and narrow further down our analysis to urban environments. This seems reasonable, as we have seen before, the pattern of PAHs from our previous studies suggests local sources rather than long-range transport of contamination in the air. Possible local sources are of industrial, urban, and traffic activities and the results indicate that the incomplete combustion of fuel is largely responsible for the air quality of the studied areas (Kozák et al., 2003).

Unfortunately, practices from the heavily expert based PAH regulation of industrial use cannot be brought directly to urban air PAH regulation because of technical difficulties. As we have seen, for most chemicals, the ground of the regulation is risk assessment, where major factors for risk assessment are *Concentration* (probability) and *Effect-models* of PAHs. However, we have serious complications to determine both PAH concentration and effect-levels in urban air (Kozák, 2004).

Consequently, we arrive at scenario 4, Europe as a Translator, where local knowledge is combined with a flexible boundary between science and policy. However, we have to consider that this scenario assumes the existence and development of one of the other scenarios and it can be a priority for further development, but cannot take over the role of existing decision-making institutions (Halffman & Bal, 1998). According to the contributions of McCutheon and Sedee at the same Amsterdam discussion, regulatory practices are generally between scenario 2 ("European risk consultation") and scenario 3 ("European coordination of assessment") and more close to scenario 3 than 2, but preference is given to decentralize risk assessment from "Brussels" on the long term (Halffman & Bal, 1998). Altough we believe that scenario 2 and 3 are not close to what we believe to be plausible in current environmental regulation.

Delegating expertise to the local level is also an advantageous way for the inclusion of local needs, which take into account un-pronounced social values as presented by Fischer (2000), who explores in detail the - often strained - interaction between technical environmental experts (global knowledge) and citizen participants (local knowledge). It is interesting to see, that the inclusion of local interests in economic and management tools had also started – for example, the implementation of the Local Agenda 21 program (see Szlávik and Turchany, 2002)).

For the inclusion of citizen participants, *non-governmental organisations* (NGO) are effective to bring public participation into practice in Western Societies. However, Carmin (2003) explains that patterns suggest that specialized NGOs may be instrumental in promoting public participation in local environmental policy and planning processes in states that historically have not had nonprofit sector (like Hungary and other CEE countries). What is more, in Former Soviet Central Asia, states have inherited severe environmental problems from the Soviet Union, alongside a range of social and political structures and poor economic performance (Farmer and Farmer, 2001). Here, NGOs are often fragmented and have short-term planning and limited impacts of governments. Environmental NGO activity is complicated by the presence of quasi-NGOs with official government support and, in some cases, by the direct participation of NGOs in election processes. Therefore, the future development of NGOs in CEE and former Sovet Union Countries should not necessarily be viewed within Western models.

Finally, we underline again that there is no 'one best way' and therefore we had to make choices along values and preferences, decide which factors are more important for us and which are put aside. Our personal experience shows that this situation is very hard to accept for the participants during the debates as when we have to decide between local and global expertise and between a strict and flexible boundary – between risk assessment and risk management –, our regulation system will be unavoidably value-laden.

Conclusions

Environmental limit values are artificially created possibility-frameworks for pollution. Nowadays they are mainly determined by the status of scientific results and expert community, and on the long term, the emphasised involvement of other factors is necessary to maintain their efficiency in improving the status of the environment.

A way to improve dramatically the development of limit values, instead of shaping the existing considerations, is the intended involvement of new factors into the design process. These factors should origin from the area of socio-natural sciences, beside the already existing natural scientific factors (trough public participation or negotiation for example; with the inclusion of non-governmental organisations).

The design of environmental limit and target values of PAHs are rendered more difficult compared to that of inorganic pollutants by the difficult analytical circumstances and the with difficulty predictable long-term effects/severe extrapolations. Limit values can be classified into two main groups concerning risk calculations: the first group involves limit values with a firm basis for risk calculations, while the other group assembles limit values whose risk calculations are without a firm base in a certain way. By applying the concept of Stirling, we can understand that instead of deriving the regulation on questionable results of risk assessment, it is more appropriate to use precaution for developing urban air PAH limit values; for example, the vehicle industry to diminish PAH emission step by step with accordingly adjusted limit values.

We detail the findings of the Thesis in the following points:

- Limit values are a specific form of quantitative legislation and are one of the most widely used tools of environmental regulation and probably will be even more used in the future due to the advantage they present with their ease of implementation and ease of control. During the development of environmental limit values, most importantly natural scientific factors are considered, and the non-natural scientific factors play a role during the adaptation period after their implementation.
- During the design process of the environmental limit values of PAHs risk factors are based on poor knowledge of both concentration (i.e. probability) and effect-models, while they are considered as being based on firm knowledge. Due to this, limit values only adapt to a level that both improves the status of the environment and accurate for environmental actors during a long period after their implementation.
- Environmental limit values can be grouped in the following categories by the firmness of the knowledge:

- limit values based on risk calculations
- limit values based on poor knowledge of probabilities, but based on firm knowledge of outcomes (limit values considering several alternatives of outcomes);
- limit values based on firm knowledge of probabilities, but based on poor knowledge of outcomes (limit values considering local optimum values instead of global maximum levels);
- limit values based on poor knowledge of both probabilities and outcomes (applying precaution during the development of limit values).

- The effectiveness of environmental tools are defined as to what level they improve the status of the environment after their implementation.

  Motivational limit values are defined as values that after their implementation polluters are interested to modify their technology instead of paying fees. Motivational values can also be developed based on non natural scientific factors.
- Current PAH limit and target values are low efficient tools because after their implementation they have to adapt to a level that both improves the status of the environment and is accurate for environmental actors, happening during a long period of time. Motivational PAH limit and target values can be developed with the conscious involvement of non natural scientific factors during their development, with the primary goal of improving the status of the environment right after their implementation, instead of conforming to the natural scientific models developed during the risk calculations.
- Due to the special characteristics of PAH concentration measurements and analyses of effects, the scenario of *Europe as a translator* is suggested, when local expertise is combined with a flexible boundary between science and policy.

During the research of the thesis a new methodological approach towards PAH regulation had to be applied. The complex field of PAH regulation is shaped from one side by the attitude of natural sciences and the industry, requiring a normative regulation based only on exact scientific statements, to avoid extra cost and activity. On the other side, social context requires a regulation that respects values of the society and its environment, avoiding all possible situations that can harm people or their environment. It is vital in this story that how we can fill with content this gray area. Then, if we cannot fill it with firm knowledge from the side of natural sciences, we have to be able to structure the knowledgebase from the other side. In other words, to define what the final goal is of and how to reach the normative regulation. Our approach to deal with this complex area is to exploit all available natural scientific knowledge, but without bonding

ourselves to the ideology that these are only meaningful if they are nearly hundred percent hard confirmed statements of science.

Endword

This study was aimed to reveal the importance of the procedure how limit values are designed for environmental policy. The first part of the paper presented the usual way of the design process of limit values, and PAHs were presented from environmental, chemical and regulative aspects. The second part described how concepts of risk can be applied in environmental regulation to classify limit values in a new way and how this relates to PAHs. Finally, we reviewed the possible regulatory future for PAHs in the EU.

According to the knowledge of the author of the Thesis, the relevant accessible literature of environmental policy, techno-chemical analytics and science-technology-society (STS) studies do not link knowledge from the above areas to improve the efficiency of environmental protection.

The Thesis provides a comprehensive analysis the status of environmental policy and techno-chemical analytics along the inner criteria, then stepping outside of their own frames, along the criteria of history of technology - sociology of technology. In order to draw conclusions, the Thesis introduces new notions to establish new theoretical concepts and solutions that can be applied to the practice.

Beside the general investigation of the different areas, the Thesis focuses on the environmental regulation of PAHs, which are in the centre of interest of science and public opinion, and provides guidelines for the practice.

To understand the importance of our work, we have to acknowledge that policy makers often mistakenly view science as an incontrovertible source of knowledge on which to base policy decisions. However, in the context of environmental risks, it is much more useful to think of science and policy as dynamically informing each other: science provides important information on which to base policy, and public policy outlines critical societal research and knowledge needs. As environmental science faces the increasing challenges of more complex risks with greater ignorance, the nexus between science and policy becomes even more important. It is very beneficial to understand, how science can better inform policy, without sacrificing objectivity, its primary characteristic.

Environmental limit values belong to the area of policy rules. Here, a synthesis is shaped among natural sciences, technology, policy and society, therefore it sounds very unreasonable to investigate these areas individually. In the case of a well-established and well working policy rule, we can observe a special synergy. Risk factor (variable) itself is a special type of variable,

which combines both natural scientific and social context characteristics. This is because the definition of damage will be always a decision about values of the society, even though one can precisely define its value. For example, for carcinogenic effects, we can measure death, different stages of lethal diseases, or healable tumours. Choices have to be made, which have policy consequences as wide areas of public will be affected differently with differently written regulations.

However, in the case of PAH limit values, policy is still being shaped, and this synthesis is not achieved yet. The picture is heavily characterized by the approach of natural sciences. However, as most of the basic requirements for proper laboratory analyses are missing, it is difficult to tell the knowledge that should be used to initiate a decision. In this story, it is vital, how we can fill with content this gray area. If we cannot fill it with firm knowledge from the side of natural sciences, we have to be able to structurize this area from the other side; in other words, to tell, what our final objective is in normative regulation.

Therefore, we introduce motivational limit value, which in its immediate appearance has a character of natural sciences, and in its real essence concentrates policy, social context and natural scientific characteristics.

To arrive to here, we had to make three very important steps in this complex area of PAH regulation. First, we acknowledged that current regulation, based on natural scientific reasoning, is not fulfilling its task. Then, we departed from natural sciences, to investigate our own work and understand where the limits are of the current knowledge basis, literally saying, we got to know what we do not know. Finally, we provided an approach on how to integrate considerations from the opposite side, to reach the final objective, the improvement of the status of the environment.

Further research will focus on to develop a framework to describe the degree of poorness-firmness of knowledge, which can enable a better characterisation of the according risk-area and hence to more easily choose the necessary tools to deal with poor knowledge. Later, other shaky areas of environmental regulation can be evaluated with the tools and attitudes of history and sociology of technology, similarly to PAHs.

During the research of the Thesis, another interesting area for further research revealed, notably, how non-sociological factors, like degree of development, environmental awareness, scientific development and influence can determine the methods and level of regulation of pollutants, of which the measurement is highly technology and knowledge intensive. In parallel, the analysis of the evolution and forming of PAH regulation can be very interesting by applying different models used to describe evolution from history of technology or sociology of science (see

Farkas, 1994b). Chemical analytical theories for PAH measurement are just being developed nowadays and many analytical approaches developed by different scientific groups compete with each other on the “scientific market”. Applying the naturalism and cognitive characteristic of Kuhn’s approach (Farkas, 1994b; Kuhn, 1962, Hronszky, 1997) can be also very fruitful to understand how social factors influence the outcome of this competition and which chemical analytical theory and why will be accepted for the long term.

We believe that focusing on the above process of the design of limit values will lead us finally to more useful and more efficient environmental regulation and thus to a better environment.

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Appendices

A.1 Resolution of abbreviations

ACS = American Chemical Society

BaP = Benz-a-pyrene

BAT = Best Available Technology or Best Available Technique

BUTE = Budapest University of Technology and Economics

CAA = Clean Air Act (in the USA)

CEE = Central and Eastern Europe

EAP = Environmental Action Programme

EU = European Union

FIT = Florida Institute of Technology

FP = Framework Programme

LOEL = Lowest Observable Effect Level

NOEC = No Observed Effect Concentration

NOEL = No Observed Effect Level

PAH = Polycyclic aromatic hydrocarbon

POP = Persistent Organic Pollutant

A.2 Other figures

Detailed figure of Stirling's concept

Stirling developed further the diagram representing probabilities and outcomes, and defined several sub-areas of risk calculations, and beside precaution, lists other approaches to deal with the situation in the area of ignorance.

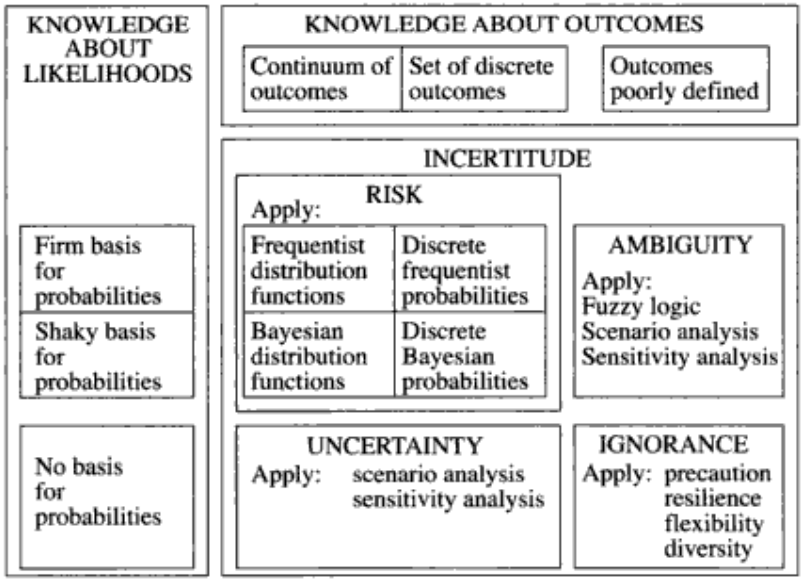

Figure 20. Dimensions of incertitude: an emerging scheme.[39]

Although he uses scenario analyses and sensitivity analyses interchangeably, we believe that scenario analysis necessities firm knowledge of probabilities (we know that something *will* happen, and its probability, just we don't exactly know what will happen), and sensitivity analysis and fuzzy logic necessities firm knowledge of outcomes (we know what will happen, just we need tools to characterize the probability of these happenings).

[39] Figure cited from Stirling (2003).

Risk management diagram from Wiedmann

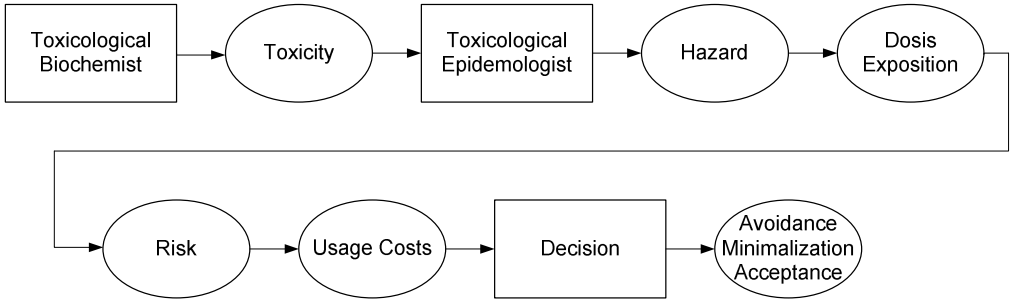

Figure 21. Structure of risk management[40]

[40] Cited from Wiedmann (1999)

A.3 One page summary in English

Environmental limit values represent the core of current environmental legislation and remains widely used beside the other tools of environmental regulation in the future. Therefore, their proper design is of outmost importance in being able to reply to the ever-changing needs of environment protection. While current limit values are usually based on concepts of natural science, we focus on how limit values can be improved by the intended involvement of socio-natural scientific factors in their design process. Risk assessment results are at the backbone of environmental limit value formation. Current environmental risk assessment procedures are heavily based on the regulation of the application of chemicals, which in turn is largely related to concentration data and dose-effect relationships of health effects.

Among urban environmental pollutants, the group of Polycyclic Aromatic Hydrocarbons (PAHs) is one of the most important organic pollutants. Although PAH usage in the chemical industry has undergone a severe change and now very strict health and safety regulations are in place, urban traffic, domestic and industrial heating remain as the main sources of PAH contamination.

The environmental regulation of PAHs is still in development and shows important differences when comparing the regulation systems of different countries. The variability roots in the shaky scientific knowledge of risk analysis used in the design process of PAH limit values. The available concentration data of environmental PAHs is weakened by incertitude and the dose-effect models are blurred uncertainty because of effects are long-term and severe extrapolations are needed. Therefore, the possible outcomes and probabilities are less definable than in the case of usage of chemicals, and in consequence, the way of handling ignorance plays a substantial role for setting environmental limits; and precaution should be applied. This way, the design process has to be modified and instead of natural scientific knowledge, social context has to be used to structurize policy making. Developing motivational limit values for PAHs can be an alternative that allows including the social context and as a result improves the status of the environment, and therefore is a more effective environmental tool for PAHs. These particular circumstances of PAHs make the suggestion of a scenario for PAH regulation in the EU complicated, as we have to decide between a strict or flexible boundary between risk assessment and risk management and between local and global expertise in accordance to the specific needs of this area; resulting in a regulation system that is always value-laden.

Keywords: environmental limit values, risk assessment, polycyclic aromatic hydrocarbons, ignorance, uncertainty, environmental policy

A.4 One page Hungarian summary - Egy oldalas magyar nyelvű összefoglaló

A környezetvédelmi határértékek a környezeti szabályozás egyik legfontosabb eszközét képezik manapság. Ezért a megfelelő kialakításuk nagyon fontos ahhoz, hogy a környezetvédelem gyorsan változó igényeinek meg tudjanak felelelni. A jelenlegi határértékek általában természettudományos alapokon vannak kialakítva, a jelen munkában arra összpontosítunk, hogy hogyan lehetne a határérékeket jobbá tenni társadalomtudámányi tényezők tudatos bevonásával a kialakításuk során. A kockázatszámítások a határérték kialakításban kulcsszerepet játszanatk. A jelenlegi kémiai anyag felhasználás szabályozásban használt kockázat számítások koncentráció adatokon és egészségügyi mérték-hatás modelleken alapulnak.

A városi környezeti légszennyező anyagok között a policiklusos aromás szénhidrogének (PAH-ok) a egyik legfontosabb szerves légszennyezők. Mivel a PAH felhasználás a vegyiparban jelentős korlátozáson esett keresztül a közelmúltban, és szigorú egészségügyi és biztonsági szabályok vannak érvényben, a PAH kibocsátások legfontosabb forrásai a közlekedés ill. a háztartási és ipari szervesanyag tüzelés.

A PAH környezeti szabályozása még kialakulóban van, és az országok szabályozási rendszerei között nagy eltéréseket figyelhetünk meg. Ez az eltérés a tudományos tudás bizonytalanságában gyökerezik. A rendelkezésre álló környezeti PAH koncentráció adatok bizonytalansággal terheltek, míg a hatás-görbék a hosszútávú kétes események és a nagyfokú extrapolációk miatt gyengén meghatározottak. Emiatt a valószínűségek és az események gyengébben meghatározottak mint a vegyipari PAH felhasználás esetében. Ezért a PAH határértékek kialakításában a tudatlanság kezelésére elővigyázatosság alkalmazásával kell eljárni. Ezért a PAH határértékek kialakítási folyamata során a természettudományos tudás helyett a társadalomtudományi tudást kell felhasználni szabályozás kialakítási folyamat struktúrálására. A motivációs határértékek jó altenatívát jelenthetnek ebben a szituációban, elősegíthetik a környezet állapotának javulását, és így hatékony környezeti szabályozó eszközök lehetnek.

A ezek a nehezítő körülmények a PAH szabályozás jövőjének a leírását bonyolulttá teszik, mivel választanunk kell a markáns és a felxibilis kockázat számítás-kockázat management határvonal között, valamint a helyi és a globális szakértés között, vagyis a választások miatt a szabályozási rendszer mindig az értékek által áthatott lesz.

Kulcsszavak: környezeti határértékek, kockázat vizsgálat, policiklusos aromás szénhidrogének, tudatlanság, bizonytalanság, környezeti politika.

A.5 English language abstract and title - Angol nyelvű kivonat és cím

Title:

Risk Policy in the Design of environmental Limit values. Challenges of the regulation of Polycyclic Aromatic Hydrocarbons (PAHs) in ambient air

Author:

Imre Oliver KOZAK

Abstract:

The environmental regulation of PAHs is still in development and there are important differences between the regulation systems of different countries. The variability originates in the shaky scientific knowledge of risk analysis used in the design process of PAH limit values. The available concentration data is weakened by incertitude and the dose-effect models are blurred uncertainty. Therefore, the possible outcomes and probabilities are poorly defined, and in consequence, the way of handling ignorance plays a substantial role and precaution should be applied. This way, the design process has to be modified and instead of natural scientific knowledge, social context has to be used to structurize policy making. Developing motivational limit values for PAHs is an alternative that allows including the social context and as a result improves the status of the environment on the short term.

Keywords:

environmental limit values, risk assessment, polycyclic aromatic hydrocarbons, shaky knowledge, ignorance, uncertainty, environmental policy

A.6 Declaration - Nyilatkozat

I the undersigned, Imre Oliver Kozák, declare that this Ph.D. Thesis is my own work and that I used references only mentioned in the Thesis. I have marked all citations, either presented in orignal form or rephrased, and presented the source of information.

Alulírott Kozák Imre Olivér kijelentem, hogy ezt a doktori értekezést magam készítettem és abban csak a megadott forrásokat használtam fel. Minden olyan részt, amelyet szó szerint, vagy azonos tartalomban, de átfogalmazva más forrásból átvettem, egyértelműen, a forrás megadásával megjelöltem.

Budapest, 2008. július 1.

……

Signature / Aláírás