Strategic Approach for Safe Chemical and Energy Industries

Hazardous Substances Council

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KNOWLEDGE INFRASTRUCTURE FOR SAFETY AND HAZARDOUS SUBSTANCES FOR THE NETHERLANDS OF 2020

AGS

The Hazardous Substances Council of the Netherlands (AGS) has been instituted, by law, in 2004. The AGS advises the government and parliament with regard to policy and regulations concerning the prevention and mitigation of major accidents with hazardous substances.

Preface

As a follow-on to the advisory report 'Safety Requires Knowledge', that urges necessity and urgency in strengthening the 'Safety and Hazardous Substances' knowledge domain, the Hazardous Substances Council (AGS) focused on the strategic level within the knowledge infrastructure. The relevant knowledge areas in the Netherlands were identified and the scope of the research and education has been documented. An external commission of experts from various universities provided support to the AGS' Knowledge Infrastructure Advisory Workgroup. Furthermore meetings were held with experts from the business community, government and knowledge institutes concerning societal and technology trends, as well as about related knowledge issues.

With this advisory report, the AGS provides insight into the knowledge areas that are relevant in preventing disasters involving hazardous substances and for limiting the consequences of any disaster that may nevertheless occur. The size of the chemical industry and transport of hazardous substances in the Netherlands, the degree of spatial densification and the expected developments in areas such as new energy carriers, deserve investment in knowledge infrastructure in the area of safety and hazardous substances. The AGS considers the decreasing volume of research, the present focus in education and the fragmented focus on safety within the university domain to be a cause for concern.

The AGS recommends that the government and Parliament take the initiative to invest in this knowledge infrastructure and, together with the business community, ensure that knowledge development in the area of safety does not stagnate, that students – particularly process technologists, chemists, urban designers and civil engineers – are thoroughly educated in the area of safety and that the Dutch research programme in this domain be formulated in an international context.

This advisory report is aimed at the strategic level of the knowledge infrastructure. Furthermore it can be used in support of ongoing initiatives to strengthen this infrastructure at the operational and tactical level. These actions have been initiated in part pursuant to the advisory report 'Safety Requires Knowledge' issued previously.

The AGS consulted many people in preparing this advisory report – experts from knowledge institutes and universities, government and the business community. The Advisory Council thanks all who contributed for their commitment and effort. Collectively we are of the opinion that knowledge development in the Netherlands in the area of safety and hazardous substances must not be allowed to come to a standstill.

Chairman,	General Secretary,	Chairman Working group,
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Summary

BACKGROUND

Knowledge has played an important role in the establishment and growth of the chemical industry in the Netherlands. The direct and indirect contribution of the chemical industry to the gross national product is substantial and is expected to grow even further. At the same time, this domain involves activities that carry risk. Not only to its employees and industry sites, but also to the environment surrounding company premises and transportation corridors. Conditions for responsibly handling hazardous substances in areas of increased spatial densification include an adequate knowledge base and strategic knowledge development. Due to the growth of the chemical industry and the transportation of hazardous substances, the large-scale introduction of new substances such as LNG and hydrogen combined with an increase in the population density of the Randstad[1], the demand for knowledge will acquire greater significance.

The Hazardous Substances Council (AGS) notes that it is apparently difficult in actual practice to maintain the required knowledge about safety and to evaluate it on a continuous basis. For example, due to serious accidents, more has become known in recent years about the 'drift' phenomenon in large organisations. It is precisely during times of few accidents, that the safety margin is gradually reduced through organisational and technical changes that are designed to produce efficiency improvements and cost savings, but that can ultimately lead to a catastrophe. The damage resulting from accidents is ultimately much greater (costlier) than the cost savings – which were the goal in the first place. This once again became apparent fairly recently during an explosion in a reputable company[2]. Incidents show us time and time again that the focus on safety must never be relaxed.

In business, not only management, designer and builder must be safety-conscious, but the operational personnel responsible for running the daily processes as well. Furthermore, policy, laws and regulations, and inspection and enforcement must be aimed at stimulating and facilitating a continuous focus on safety. This is expressed for example in planning and risk evaluation as part of the land use planning process, the licensing process and in disaster preparedness and emergency response.

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1 The Randstad is a conurbation in the western Netherlands consisting of its four largest cities (Amsterdam, Rotterdam, The Hague and Utrecht).

2 The report of the BP U.S. Refineries Independent Safety Review Panel. J.A. Baker III et al., January 2007. This report was prepared as a result of the accident at the BP refinery in Texas City, USA in March 2005. Also see E. Hollnagel et al. Resilience Engineering, Ashgate Publ. Ltd, ISBN-10:1-7546-4641-6, which describes the 'drift' phenomenon – the shift in safety margins as a result of which safety is compromised – that occurs when efficiency and cost reduction measures are pursued.

MOTIVATION FOR THE ADVISORY REPORT

In 2006, the AGS noted that there was a pressing need for improving the failing knowledge infrastructure concerning the handling of hazardous substances ('Safety Requires Knowledge', December 2006). Stakeholders from the business community, government and knowledge institutes supported the conclusion that in order to achieve a symbiosis between living and working in a densely populated area such as the Netherlands it is necessary to invest in knowledge infrastructure in the area of safety and hazardous substances. The Cabinet, in its response, supported the conclusions and advice issued by the AGS. The AGS was assigned the task of further defining the knowledge domain and to indicate the knowledge areas requiring strengthening at the strategic level.

In this advisory report, the AGS describes the relevant knowledge areas in the safety and hazardous substances domain and the Netherlands performance in relation to the development of new knowledge during the past decade in comparison with other countries. The trends related to the chemical industry and energy carriers and in society and technology are also described. Based on these trends, long-term knowledge needs were identified. An overview of the strengths and weakness of the strategic knowledge level within the current knowledge infrastructure emerges from this. In addition to knowledge development, this also involves education.

The issue concerning which knowledge areas should be strengthened as a means of restoring the eroded expertise in the Netherlands was studied on the basis of the notion that research and education at the university level can cross-fertilise. The principles of safety deserve a position in the basic education programmes for engineers and chemists, including future expert decision-makers. This is why a focus on safety as part of the curriculum of these education programmes is also part of this advisory report.

SAFETY AND HAZARDOUS SUBSTANCES KNOWLEDGE DOMAIN

An extensive palette of academic disciplines contributes to the prevention of disasters involving hazardous substances or limiting the consequences of such disasters. This includes typical beta as well as gamma disciplines. The Advisory Council has created insight into the safety and hazardous substances knowledge domain. There are three sub-domains: hazardous properties of substances, system safety and process safety. These sub-domains are analysed in further detail in this advisory report and their relevance to risk analysis and risk management is clarified.

NATURE AND SCOPE OF DUTCH RESEARCH COMPARED TO OTHER COUNTRIES

Dutch research activities in this knowledge domain, measured on the basis of the number of publications, was less than could be expected during the past decade given the degree of spatial densification in our country and the scale of the chemical industry and transportation of hazardous substances.

Another important observation is that in the Netherlands, there is no balance among the three sub-domains. For example, the focus on the hazardous properties of substances and system safety is weak. The United States and the United Kingdom are leading in the entire knowledge domain. Furthermore, in these countries there is a balanced focus on the different sub-domains due to years of attention to safety in this area by government and professional associations.

A survey of current research (2007) in the Netherlands produces a disturbing image. Research groups have disappeared or are about to disappear and research is limited to sub-areas and lack an integral approach. The current trend of promoting project financing instead of the structural financing of strategic research is expected to worsen the existing fragmentation. To counteract this fragmentation it is important to develop a strategic plan for the knowledge infrastructure.

CONCLUSIONS

The current inadequate financing and programming of research in the Netherlands are unable to produce the critical mass required to maintain existing knowledge and to evaluate and further develop it. Furthermore, there are insufficient safeguards to ensure the quality of the basic education programmes in this domain and for translating international and other knowledge into national policy.

It appears that the Netherlands will miss the opportunity to link up with European developments leading to a joint research programme in this knowledge domain. A critical mass of Dutch strategic research is required to harmonise methodologies and participate in international research.

In view of Dutch growth ambitions in the chemical industry and transportation sector, further spatial densification and the switchover to other energy carriers, further development of knowledge concerning the involved risks and how to manage them is indispensable for government as well as the business community. Furthermore, striving for greater safety and transparency, changed perceptions of the allocation of responsibility, inspection and enforcement will require the further development of knowledge by government as well as business. The AGS concludes that a strategic plan is required for this knowledge domain to enable knowledge development, prepare a road map and enable top-down control. The recommendations explore this in further detail.

RECOMMENDATIONS

The AGS recommends that the government and Parliament – partially in cooperation with business – strengthen the strategic top layer of the knowledge infrastructure for safety and hazardous substances, safeguard the critical mass and independence of knowledge development and the focus on the safety ‘discipline’ within university education programmes. The AGS motivates its recommendations on the basis of the added value created for government as well as business.

1. The AGS recommends that steps be taken to create a critical research mass in the Netherlands as a means of safeguarding the university focus – research and education – on safety. To accomplish this the foundation of a number of knowledge areas identified in the advisory report needs to be strengthened. This concerns natural sciences as well as social sciences that address fundamental issues, as well as the further development of knowledge in support of design and engineering. The AGS estimates that a threefold increase of university research is required in these areas. It is necessary to involve researchers with broad insight into national and international developments in this effort. This is important to promote the desired interaction among sub-domains to be able to effectively study the various issues identified in this advisory report.

This critical mass requires a certain minimum of fixed public financing for fundamental research to safeguard the independence of the research and the focus on the subject for a longer period of time. AGS recommends that the government and Parliament enter into discussions with the 3TU Federation[3] on this subject. The AGS has discussed the social relevance with this federation. The federation has indicated that additional financing should be allocated to this knowledge domain.

Furthermore, the AGS recommends that steps be taken to ensure that a focus on safety in the curriculum of relevant universities – including that for process technologists, chemists, civil engineers and urban designers – be better safeguarded.

2. The AGS recommends that steps be taken to ensure that a fixed percentage of the ongoing public/private research programmes be spent on safety and hazardous substances. In this regard it is important that there be a cross-fertilisation among the various research programmes. The AGS has incorporated a proposal of the *Association of the Netherlands Chemical Industry* (VNCI) to earmark a percentage of the current public/private funding of dedicated research programmes related to the chemical industry (such as the research programme *Advanced Chemical Technologies for Sustainability* (NOW-ACTS) and the innovation programme of the Regiegroep Chemie *(Chemical Industry's Coordinating Body)*) for research into safety. The AGS recommends that the government and Parliament embrace this initiative and furthermore that they use the public funding of dedicated research programmes of several Ministries to join these initiatives (i.e. the Ministry of Housing, Spatial Planning and the Environment, Ministry of Transport, Public Works and Water Management. Ministry of the Interior and Kingdom Relations, Ministry of Social Affairs and Employment, Ministry of Health, Welfare and Sport and the Ministry of Economic Affairs). This clustering of public and private funding of will promote cross-fertilisation within this knowledge domain.

This proposal assumes that the critical mass – financed from public funds – for strategic knowledge development described above exists within the Netherlands, as no research proposals could otherwise even be formulated.

3. The AGS recommends that a public/private coordinating body be created to administer the percentage earmarked for safety from public as well as private funds for current research programmes. This coordinating body could look after the tasks outlined under the aegis of the NWO *(Netherlands Organisation for Scientific Research*). The NWO has stated it is prepared to facilitate this coordinating body. The AGS perceives several opportunities for linking the coordinating function for this knowledge domain to existing bodies from an organisational perspective. A separate ambassador function for this domain is of key importance, for the very reason that attention for this subject diminishes when safety is not an issue and apparently it cannot take off without encouragement. Aside from government, the AGS in particular sees an important role for the business community and for universities.

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3 The three leading universities of technology in the Netherlands - Delft University of Technology, Eindhoven University of Technology and the University of Twente - have joined forces in the 3TU.Federation

Background and Challenge

The Dutch economy is in part driven by the chemical sector. The interests of this sector must be kept in balance with other social interests. The ability to deal with current and future challenges and to be able to provide the necessary education requires a certain knowledge base and strategic knowledge development. This is explained in further detail below.
The definition of the problem and the relationship with previous advisory reports of the Hazardous Substances Council (AGS) are also described in this chapter.

Importance of a well-embedded chemical industry in the Netherlands
The chemical sector and the related transportation sector for chemicals and energy carriers make a substantial contribution to the gross national product. Facilitating industrial activity and the transportation and storage of substances with hazardous properties in an environment that also accommodates living and recreation, nature and agriculture at the same time requires that hazards be identified and properly assessed. Knowledge about safety and hazardous substances is required to manage risks to the maximum possible extent and to ultimately arrive at a balanced assessment of the costs and benefits of the measures designed to effectively and efficiently manage risks. The benefits include the safety of employees, civilians and the environment, and the continuity of business processes.

The prognosis is that production and transportation volumes in the chemical sector will increase further. Sales as well as production volume in the Dutch chemical industry have risen sharply in recent years. In 2007 sales climbed to €50 billion, an increase in revenues of 7% in comparison to 2006. The export (including transhipments) grew by 11% in 2006 and 13% in 2007. The contribution to the gross national product in 2007 was over 2.9% (2006: 2.3%)[4]. In addition to these growth forecasts for the chemical industry, population density is projected to exhibit a relatively significant increase over the next twenty years, particularly in the Randstad[5]. This means that the need for knowledge about safety and hazardous substances in the Netherlands will become even more significant in the future.

Continued focus on safety
Pursuant to serious accidents abroad – for example in the space programmes sector and in the chemical industry in the United States – more has become known about the so-called 'drift' phenomenon in large organisations. It is precisely during times of few accidents, that the safety margin is gradually reduced through organisational

4 Facts and figures about the chemical industry in the Netherlands 2007. VNCI, 2008.
5 Regional population and household forecast 2007 – 2025 of Statistics Netherlands and the Planning Office for the Living Environment.
See www.regionalebevolkingsprognose.nl

and technical changes that are designed to produce efficiency improvements and cost savings, but that will ultimately lead to catastrophe. The damage resulting from accidents is ultimately much greater than the cost savings – which is what it was all about in the first place.

Safety requires continuous effort and continuous renewal and knowledge development is needed to be able to better identify risks and promote safety awareness in companies and government. As such, not only management, designer and builder must be safety-conscious, but operational personnel, from the highest to the lowest ranks, responsible for running the daily processes as well. Furthermore, policy, laws and regulations and inspection and enforcement must also be focused on stimulating and facilitating a continued focus on safety in companies and during transportation, and should contribute to the responsible treatment of risks in society. This is expressed in the form of planning and risk evaluation as part of the land use planning process, in the licensing process and in fighting disasters. Not only the business community, but government and civilians as well require knowledge to be able to make responsible decisions in the proper context and take the proper actions. Proper implementation of safety is important in terms of promoting confidence in government and the business community, for image and for the investment climate.

Incidents show us time and time again that the focus on safety must never be slackened. This is why a proper knowledge infrastructure is required for the safety and hazardous substances knowledge domain.

The Netherlands is a densely populated country that after the Second World War built up an important position for itself in the chemical process industry and in the transportation of hazardous substances. This combination makes it necessary – ahead of other countries – to develop new insights designed to integrate social and economic interests. The Netherlands consequently made a significant contribution to research into new risk analysis methods during the seventies and eighties. The risk-based approach became an important element in Dutch laws and regulations. Competent authorities today are consequently accountable to Dutch citizenry about the risks related to external safety. As a result – on the surface – everything appears to be cut and dried.

Changing conditions

However, conditions change, expertise erodes, existing issues change – such as the need for better risk analysis methods in support of the continually increasing degree of spatial densification – and new issues constantly emerge, such as the use of new energy carriers. The chemical sector perceives opportunities for growth and its ambition is to double its contribution to the gross national product over the coming ten years and to significantly reduce the use of fossil fuels[6]. Innovation is the basis for a healthy, sustainable and strong chemical industry for tomorrow. That is the position of the Regiegroep Chemie *(Chemical Industry's Coordinating Body)* and this requires 'a further expansion of high-quality technological knowledge, strong collaboration among knowledge institutes and business and increased space for industrial activity'. The Cabinet is contributing approximately €50 million to plans related to research and innovation as well as to promoting enrolment in beta education programmes. Safety does not yet occupy a prominent position in these initiatives.

6 Regiegroep Chemie Business Plan, 2006.

Example of changed conditions

Hydrogen is an energy carrier that is expected to be increasingly used in addition to fossil fuels such as oil and gas. The Platform Nieuw Gas *(New Gas Platform)* (part of the Energy Transition Taskforce) expects that around 2020, approximately 25% of buses for public transport in large cities will run on hydrogen. By that time, the first hydrogen fuelled cars for personal use will be on the roads. The expectation is that by 2050, 40% to 75% of cars will be fuelled by hydrogen. Furthermore, the homes in new residential districts can gradually be equipped with hydrogen fuel cell installations[7]. The use of hydrogen in comparison to fossil fuel has a number of advantages. The key advantage is that it does not generate any greenhouse effects and pollution during the combustion process. But hydrogen also has some treacherous properties: mixed with air it is highly flammable and highly explosive. Furthermore, it tends to corrode metals. Consequently it cannot just be transported unlimitedly through natural gas pipelines without any risks. Quite a few uncertainties will have to be eliminated before hydrogen can take a fully fledged position beside traditional fuels. Indeed, there already exists a great deal of knowledge about hydrogen, however, that knowledge pertains to the safe industrial use of hydrogen. Very little research has been done in relation to its use in cars or homes. The conditions under which hydrogen can be introduced on a broad scale within society must be identified. On this basis, the government can develop policy and regulations that will contribute to the safe introduction of a 'hydrogen economy'.

This example makes it clear that it is important for the knowledge infrastructure to have the capacity to respond to the changes that will develop in the future. Government and business must be able to access this infrastructure for answers to their knowledge questions. This is why it is important to have an understanding of the strengths and weaknesses of the current knowledge infrastructure and to know which knowledge areas are important in terms of the current and future demand for knowledge. The AGS addresses these issues in this report.

Previous advisory reports

Previous AGS advisory reports on the knowledge infrastructure are:

- Space for Expertise, 2004 (available in Dutch only)
- Safety Requires Knowledge, 2006 (available in Dutch only)

The *Nota Ruimte* (Spatial Policy) provided the motivation for the first advisory report. By this policy, more authority with regard to land use planning and licensing was delegated to provinces and local government. In its advice, the AGS identified the implications of this policy in terms of the need for knowledge on the part of provinces and local governments and the requirements that the decision-making process and the tactical and operational knowledge levels should be expected to meet. On the basis of this a case was made for the creation of a hazardous substances expertise centre for municipalities and provinces.

In preparation of the second advisory report, the AGS on 31 October 2006 organised a meeting with stakeholders at management level from business, research, education and government on the issue of the knowledge infrastructure for safety and hazardous substances. The need for improved interaction within and among all knowledge levels was discussed with them. In its report 'Safety Requires Knowledge', the AGS noted that it is difficult and sometimes impossible to mobilise the required

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7 Hydrogen. Fuel for Transitions. Advice issued by the Platform Nieuw Gas *(New Gas Platform)* Hydrogen Workgroup, October 2006.

knowledge at the strategic level from universities and technological knowledge institutes in the Netherlands. The knowledge is highly fragmented and furthermore seriously depleted. At the same time, experts are identifying various trends that are resulting in complex knowledge requirements. There was a broadly felt urgency for strengthening the knowledge level in the area of safety and hazardous substances particularly at the strategic level – in terms of research as well as the related education programmes. This was also expressed in the Cabinet's position in response to the report.
Strategic research is defined as research that contributes to the development of a vision and that can also set far-reaching goals, i.e., primarily work at the university level. This concerns research that generally results in applications over the long and medium term.

This report
In its report 'Safety Requires Knowledge', the AGS announced a follow on report to address the question as to which knowledge areas are lacking and/or require strengthening in the Netherlands in order to safeguard the safe handling of hazardous substances. At the same time the question was raised as to how to accomplish and organise the strengthening process. The time horizon in this respect is ten to fifteen years. After completing a preliminary study, the AGS in November 2007 once again approached stakeholders from the ranks of policymakers in the chemical industry, fuels sector, academia and government.

In this present report, the AGS first describes the current state of affairs. An overview of the relevant knowledge areas in the safety and hazardous substances knowledge domain was prepared. To identify the nature and scope of the strategic knowledge position in the Netherlands as objectively as possible, an analysis of the literature was carried out. The performance of the Netherlands in the area of new knowledge development was identified and compared to other countries on the basis of publications issued over the past ten years. The comparison also included the Dutch performance in a number of related disciplines. Furthermore, the relationship between sales in the chemical industry in the Netherlands and population density was explored. In addition, a survey of current (in 2007) strategic research was completed on the basis of interviews and a desk study.
Discussions were held with experts in government, business and knowledge institutes concerning trends and future knowledge requirements in order to develop an overview of future knowledge needs in the Netherlands.
The future need for knowledge is not only related to knowledge development, but to education as well. Various basic education programmes are relevant to this knowledge domain. In the context of this advisory report, the focus is on education for process technologists, due to their central role in the design and management of installations. Therefore interviews were held with representatives of academic education for process technologists about the focus on safety in the curriculum of current education programmes.
Finally, the AGS prepared an estimate of the minimum required mass of the academic knowledge base in this domain.

The AGS draws a number of conclusions based on this analysis that subsequently lead to a series of recommendations.

Knowledge levels and knowledge flows

In its report 'Safety Requires Knowledge', the AGS made a distinction between three levels within the knowledge infrastructure (strategic, tactical and operational) and outlined the importance of the interaction among these three levels. Horizontally, knowledge exchange within a level is important, for example between communities and disciplines. The vertical exchange of knowledge between different levels is of importance in order to place relevant subjects on the knowledge agenda and also to translate new insights into actual practice.

On the basis of the AGS' recommendations, the Ministry of Housing, Spatial Development and the Environment undertook some initiatives over the past year designed to improve the exchange of knowledge at the operational as well as tactical level. Furthermore there were some developments in the educational sector in the area of safety at the university of applied science bachelor level (HBO) and upper secondary education levels (MBO). The AGS is of the opinion that the present recommendations, focused on the strategic knowledge level within the knowledge infrastructure, can also be applied to encourage interaction within and among the other levels, i.e., to promote both horizontal and vertical knowledge flows.

Questions

The Advisory Council considered the following questions:

- What is the critical mass of research and researchers required to develop the required knowledge within the safety and hazardous substances knowledge domain, and to create and preserve focus, and to safeguard the availability of education programmes in this field in the Netherlands?
- What are relevant research topics for the Netherlands to be able to understand and exploit research carried out abroad?
- What spearheads should be adopted for research in the Netherlands, both for future knowledge requirements and to facilitate the exchange of knowledge with foreign researchers?
- How can interaction between knowledge areas be promoted that makes it possible to consider safety across the entire chain?
- How can an organisational structure be created that stimulates consistency between the strategic level that deals with long-term issues and the tactical level that studies short-term issues?

The knowledge position in the Netherlands and trends

The scope of the safety and hazardous substances knowledge domain is defined below. The results of an extensive bibliometric analysis of the production of strategic knowledge in the Netherlands over the past ten years are subsequently presented and a comparison is made with other countries. In addition, the current (2007) research is surveyed.

Following this, the coordination of research and education in the United States and Europe is addressed. After this, the key trends in relation to the chemical industry and the relationship with society are described. The knowledge requirements and the need for education arising from this are then further detailed. Finally, an estimate of the required academic mass for this domain is produced.

DESCRIPTION OF SAFETY AND HAZARDOUS SUBSTANCES KNOWLEDGE DOMAIN

In brief, the AGS advises government and Parliament with regard to policy and regulations designed to prevent disasters involving hazardous substances and to limit the consequences of potential disasters. The Advisory Council's area of activity emphasises the consequences of an incidental, one-time release of hazardous substances, i.e. the so called major accident hazards. This survey is therefore focused on knowledge areas with the potential of contributing to the prevention of such disasters or limiting the consequences of potential incidents.

Multidisciplinary and integral

Establishing which content fits within the boundaries of the safety and hazardous substances knowledge domain is not a simple task. The domain is characterised by aspects derived from many different knowledge domains with a much broader orientation, such as chemistry and physics, process technology, risk analysis, (acute) toxicology, safety research, industrial and general design, storage and transportation safety, and areas of research in which more people-oriented aspects play a role, such as human-machine systems, organisation science, safety and general organisation cultures, risk perception, risk communication, emergency assistance during disasters and psychology. Furthermore, safety is a sub-component within all of these areas of research that is sometimes looked after by specialised centres within the larger whole; for example, a specialised centre for safety cultures within the faculty of psychology. Partly as a result of this, the involvement of universities with the 'safety and hazardous substances' knowledge domain has many facets and little coherence.

Improving performance in the area of safety not only requires development in separate knowledge areas, but it also requires interaction and the creation of coherence. This requires a network of people that are active in the relevant knowledge areas.

Safety is often bracketed together with health and sustainability. While there are similarities among these areas, there are also differences. The most striking difference is that safety more often tends to be viewed as a cost item than as an investment, while the costs associated with health and sustainability play a much smaller role in the decision-making process. Their importance is apparently given more weight.
Furthermore, it is hard to identify the impacts of decisions concerning safety. The difficulty in measuring safety is primarily due to the small probability that an incident will occur – determined by of a diversity of technical, organisational and human factors – and due to the difficulty of predicting the consequences, and the often huge scale of these consequences. Often what is at issue are phenomena involving extensive dynamics that occur within a very short period of time and with potentially disastrous consequences. This confronts the beta disciplines as well as the gamma disciplines within this knowledge domain with specific questions. Questions in which organisational and technical issues must be studied together.

Three sub-domains
This knowledge domain consists of three sub-domains. These sub-domains comprise different disciplines, knowledge areas or areas of research. At the same time there is a certain degree of overlap among the sub-domains. These sub-domains and knowledge areas are defined in further detail below.

Hazardous properties of substances
Knowledge about the specific hazardous properties of substances constitutes the starting point for the safe handling of these substances. On the one hand this involves knowledge about the physical and chemical properties of substances and the behaviour of substances under extreme conditions (pressure, temperature and reactivity). On the other hand it involves knowledge about the impacts on people. This knowledge can be subdivided into knowledge related to toxicological, mechanical or thermal radiation exposure (burns) injury and psychological injury.

Hazardous properties of substances
- Physical and chemical properties – in normal and extreme conditions – (of mixtures or preparations) of substances
- Human injuries/effects:
  - (acute) toxic effects
  - mechanical injuries, injuries from thermal radiation exposure or burns
  - psychological effects

System safety
A second sub-domain – system safety – concerns the safety analysis and conceptual approach of a system, including the operation of its components and the controllability of the entire system. This regards technical knowledge used in multiple

disciplines – for example, nuclear technology and airplane construction – that is related to the long-term safe and reliable operation of installations. It also involves the knowledge required to quantify the reliability of a system and to model or simulate the probabilities of failure and uncertainties.

System safety
- Methods for safety analysis (failure mode and effect analysis, fault tree analysis)
- Operability
- Controllability
- Technical resilience engineering of systems
- Reliability and maintenance of systems
- Uncertainty analysis

Process safety

The third sub-domain is process safety. This regards knowledge about the safe design and safe operation of chemical and physical processes in – fixed and transportable – installations and about the required operating organisation. Furthermore, this regards knowledge about the influence of human behaviour and organisation with respect to safety and the maintenance of installations. In addition, this includes knowledge about investigating and learning from incidents and knowledge about limiting the consequences of a disaster.

Process safety
- Safe design and inherent safety
- Process technology and process stability (process dosage, mass and heat transfer processes, process control, integrity of containment, layers of protection, safety integrity systems, risk mitigation)
- Human and organisational behaviour, safety management (safety culture, safety at work, human factor)
- Incident analysis (hazard identification, consequences, probabilities)
- Emergency response
- Organisational resilience

Process safety-related research in the sixties focused on technical aspects. New research areas involving human error and human behaviour emerged later. Organisational factors received greater attention during the eighties and from the nineties onward new insights emerged concerning safety management systems. During recent years significant attention was focused on safety cultures in companies and how to improve on these where necessary. Figure 1, originally developed by Visser[8], outlines the development of the process safety knowledge area over the past forty years. The AGS added the focus on safety culture to this diagram and estimates that this focus gained a foothold in the mid-nineties.
Recently the concept of organisational resilience has been gaining ground. This term denotes the capacity of an organisation to anticipate on changes and failures while preserving safe operations. Organisational resilience is expected to counteract the now recognised process of creeping safety deterioration (‘drift’) under pressure of efficiency and cost saving measures in an organisation. Organisational resilience in process safety is the human-oriented equivalent of the technically-oriented resilience within system safety.

8 Visser JP. ’Managing Safety in the Oil Industry -The Way Ahead’, 8th International Symposium Loss Prevention and Safety Promotion in the Process Industry. Antwerp, 1995, 3rd Vol., 169-220.

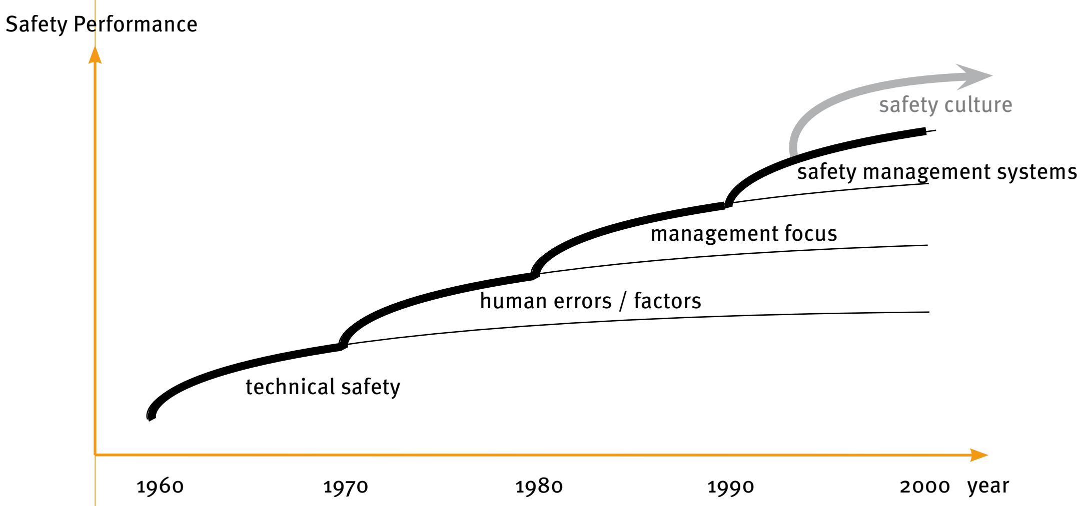


Figure 1: Outline of the development of process safety over forty years, as presented by Visser, with the element 'culture' added by the AGS.

The three sub-domains outlined above were more or less developed independently over the years. For the future, improved interaction is important to facilitate the further development of safety performance in companies in spite of the potentially increased pressure of competition and cost saving measures. Furthermore, a further shift in focus is required in the direction of safety in chains and safety in company clusters.

Risk analysis and risk management

A sub-set of these three sub-domains is formed by knowledge about risk analysis and risk management. In striving for safety, a balance is met between the costs and benefits of the measures to be implemented. This is why there is a need for an instrumentarium for determining and balancing risks and measures. To assess the risks inherent in handling hazardous substances, so-called quantitative risk analysis methods are used. These methods make use of knowledge about process safety, system safety and the hazardous properties of substances. In addition, risk analysis is based on specific research in various areas: identification of hazards, consequences and probabilities of failure, scenario analysis, presentation of risks, risk assessment, risk perception, communication, liability and dealing with of risks, from a societal and from a business-economic perspective.

Knowledge about process safety in particular, as well as knowledge about system safety and about the hazardous properties of substances contributes to knowledge in the area of risk analysis. Risk analysis could be positioned in the overlapping area of these three domains. Due to the special importance assigned to the risk analysis of processes involving hazardous substances and the transportation of such substances in the Netherlands in relation to land use planning and the licensing process, this subject is dealt with separately here.

Risk analysis and risk management

- Hazardous properties of substances, system safety, process safety
- Hazards identification, consequences and probability of failures, scenario analysis
- Risk management (presentation and assessment of risks, risk mitigation, risk perception, communication, liability), risk governance

A number of events and the policy developed, played an important role in the development of the risk analysis research area. For example, the risk strategy used for the design of the Delta Works in the fifties and following this, the risk strategy used by the nuclear industry in the seventies were used as a basis for developing the risk analysis methodology for the process industry. The accident in Seveso (Italy) stimulated further research in this area. Experience in the offshore industry, development of offshore legislation in Norway and the accident at the Piper Alpha platform resulted in renewed research in the eighties. This research formed the basis for an important portion of the development of the second Seveso Guideline[9].

RESEARCH IN THE NETHERLANDS AND OTHER COUNTRIES 1997 – 2006

The CWTS Institute for science and technology studies in Leiden, under contract to the Advisory Council, identified the knowledge areas within the safety and hazardous substances knowledge domain. A bibliometric analysis was carried out on the basis of articles published in peer-reviewed journals[10]. The articles were selected on the basis of keywords and journals. The articles were linguistically searched on the basis of combinations of nouns used and grouped by frequently occurring word combinations. The groups were displayed on a map in the form of circles placed close to each other or further apart depending on the degree of association (see Figure 2). Each of these circles represents a terminology set that defines an aspect of the safe handling of hazardous substances. The selection criteria and the subsequent analysis were reviewed by members of the AGS Exploration of Safety Knowledge for Hazardous Substances Committee (see Appendix 1 for membership). This produced a database with approximately 8,300 articles published during the ten-year period 1997-2006. Appendix 2 includes a description of the analysis methodology and the criteria used for selecting the articles. Appendix 3 includes additional details about the concepts used in these articles.

Because the origin of every article is known, it is possible to identify the relative contribution of, for example, the Netherlands, to the worldwide academic production in a certain discipline. Of course the analysis only identifies knowledge areas that are addressed in the scientific literature. This means that areas that are subject to primarily practical application-oriented research are relatively understated.

The quantitative interpretation of the circles shown on the maps in Figure 2 is as follows:

- Size of the circles: indication of the number of articles in which the specified combination of nouns appears;
- Position/distance between the circles: indication of the relationship – based on the use of nouns – between the articles;
- Profile by country: figure within the circle is the contribution of the country as a percentage of the worldwide total. The colour intensity reflects this value.

The word combinations used in the articles can be subdivided into the three sub-domains identified earlier: hazardous properties of substances, system safety and process safety. This classification corresponds to the description of the knowledge domain described earlier on pages 17-21. Figure 2 identifies these sub-domains in relation to the different knowledge areas. Where these three sub-domains touch

9 Guideline 96/82/EC of the Council dated 9 December 1996 on the control of major-accident hazards involving hazardous substances.
10 The articles were selected from Thomson Scientific's Web of Science data file, a subsidiary of Thomas Reuters.

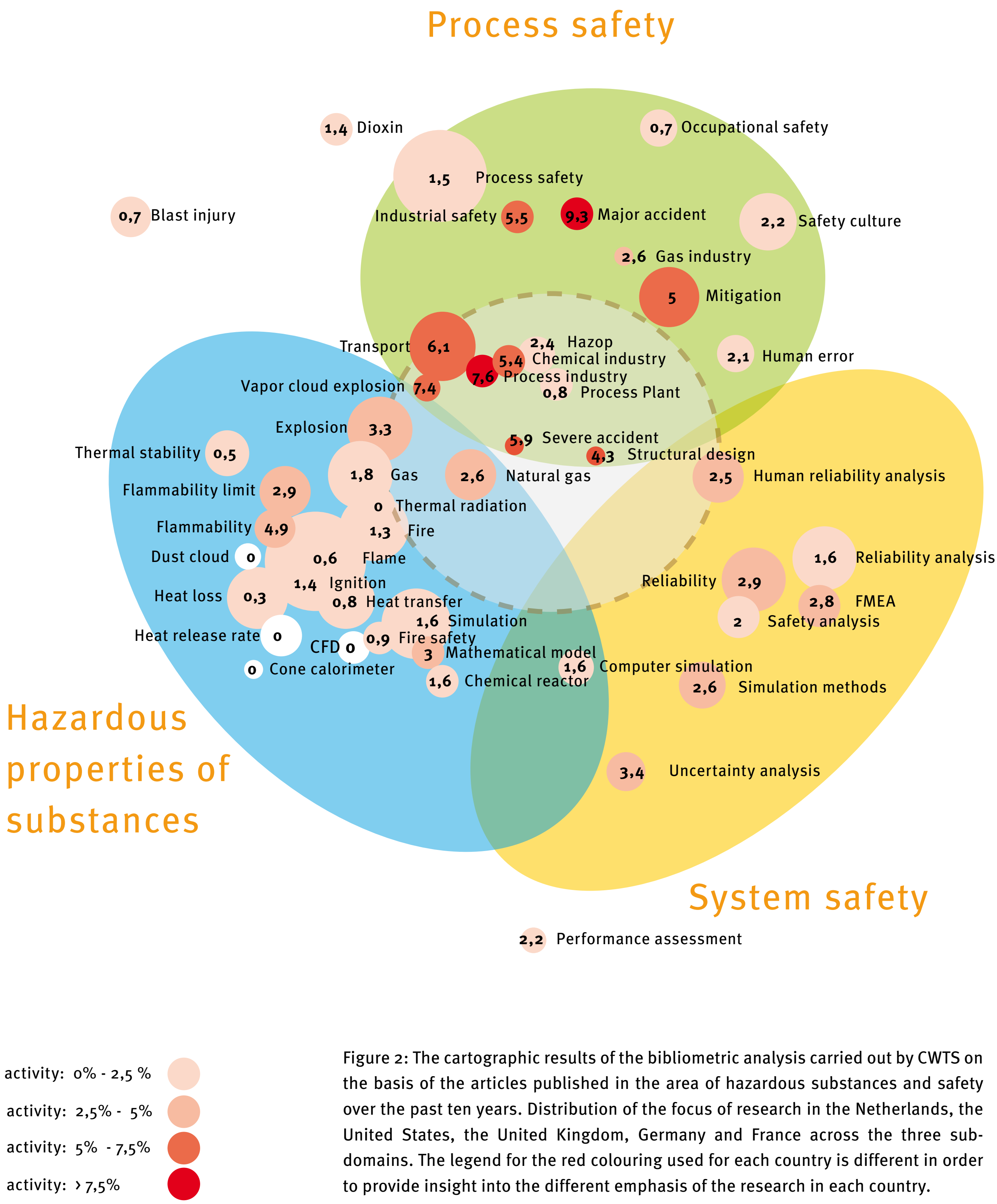
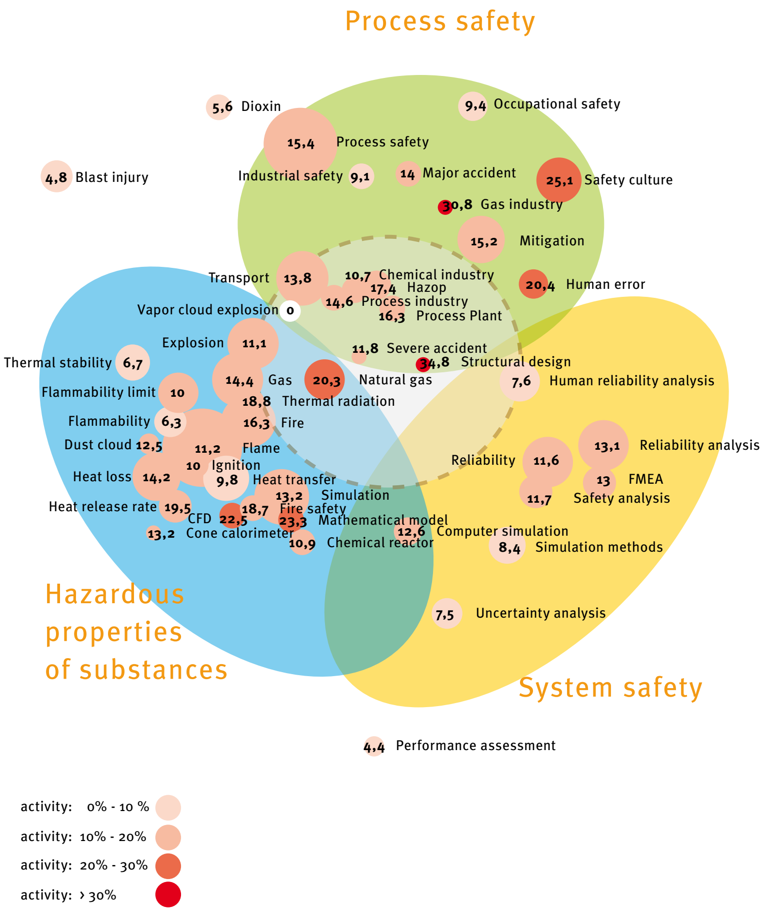
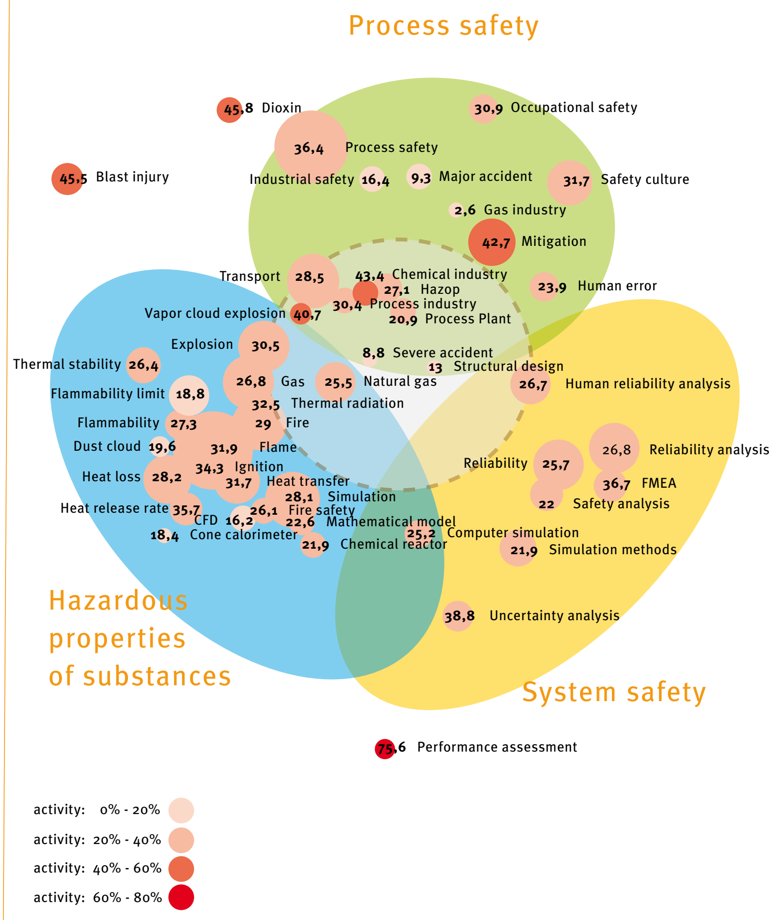


Figure 2: The cartographic results of the bibliometric analysis carried out by CWTS on the basis of the articles published in the area of hazardous substances and safety over the past ten years. Distribution of the focus of research in the Netherlands, the United States, the United Kingdom, Germany and France across the three sub-domains. The legend for the red colouring used for each country is different in order to provide insight into the different emphasis of the research in each country.

Research profiles in the three sub-domains: **UK**

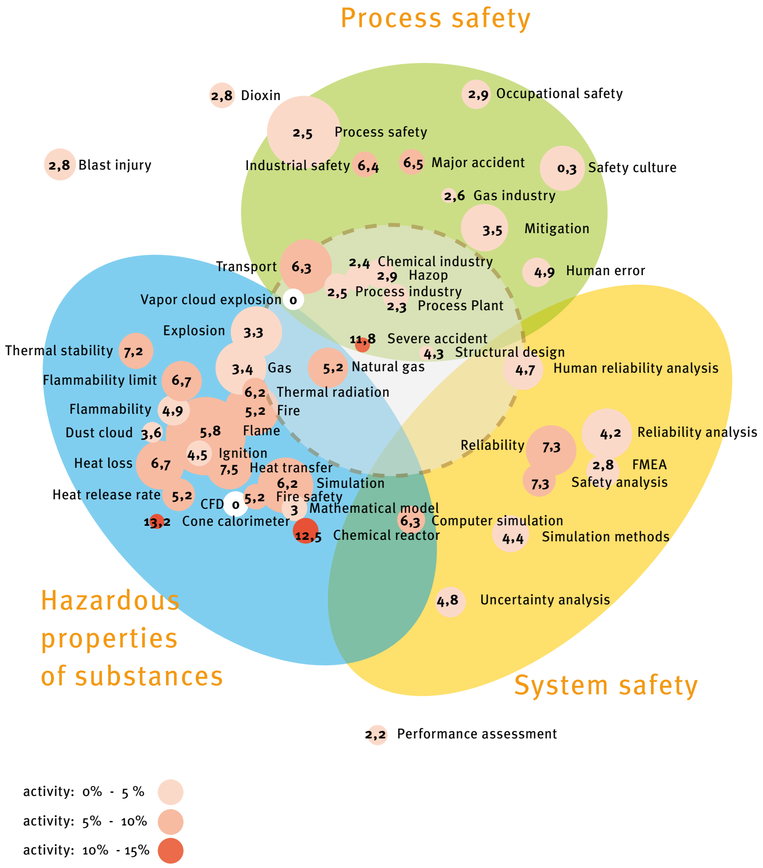


Research profiles in the three sub-domains: **USA**



Research profiles in the three sub-domains: **Germany**

Research profiles in the three sub-domains: **France**



each other is where the knowledge areas that are important in terms of the risk analysis are located. For the sake of completeness it should be noted that a small number of circles is located outside the three sub-domains: blast injury, dioxin and performance assessment. These 'anomalies' can be explained. The first one is related to knowledge about the impact of explosions on people and concerns a field of research that is isolated from the other three knowledge areas. The term 'dioxin' comprises articles focused on a specific group of substances and here too involves a somewhat isolated sphere of research. 'Performance assessment' is a term that is primarily used in American literature, as well as in German literature. These two countries produce respectively 75% and 11% of the international literature in this domain. Performance assessment involves research focused on measurable performance in the area of safety (under the slogan 'to measure is to know'). The somewhat distinct position can be explained by the fact that the subject is also related to adjacent disciplines.

Hazardous properties of substances

This sub-domain contains publications concerning the hazardous properties of gas mixtures, aerosols, liquids and solid substances, such as combustibility, explosive properties, including dust explosions, thermal stability and detonation behaviour. This concerns research that provides insight into the behaviour of substances under normal as well as extreme conditions. It comprises research conducted using test equipment configurations on a laboratory scale, as well as in test facilities and in open spaces.

The research into hazardous properties goes hand-in-hand with the further development of research methods. To a significant extent, it also includes research into modelling the behaviour of reactive substances (mixtures), for example in installations, reactor vessels, during the accidental and planned releases and dispersion of substances in and near buildings. Using new modelling techniques, such as Computational Fluid Dynamics (CFD) attempts are being made to improve existing models. Research into the toxic properties of substances that are relevant to one-time high-level exposures barely appears in the database of approximately 8,300 articles. Over the past few years, research into the acute effect on people appears to have been limited to the effects of dioxins and to blast injury, the mechanical effects of an explosion.

Current research is insufficiently oriented on as yet not well understood issues concerning the behaviour of substances under extreme conditions. For example, how thermal decomposition can lead to a violent explosion and/or detonation. This complicates the predictability of the behaviour of substances and consequently the identification of criteria for things such as the design of installations.

The following important and desirable developments in the area of research were identified by the experts that were consulted:

- Renewal of flow models, particularly gas dispersion, for the purpose of creating greater accuracy and sharper reliability boundaries;
- Influence of environmental factors on gas cloud explosibility;
- Risk of dust explosion;
- Improvement of the probit functions for acute toxicity and development of methods for modelling non-lethal injuries;
- Improvement of methods for identifying the hazardous properties of substances.

System safety

As installations become increasingly more complex, issues are emerging concerning the safety of regulating and control systems, error diagnostics, probabilities of failure and reliability. The publications in the database are primarily related to research conducted on the basis of fault trees (fault tree analysis), Petri nets, Markov models, fuzzy logic, genetic algorithms, but primarily also on the basis of Bayesian statistics, expert opinions, uncertainty boundaries and decision theory. During recent years, the research has been extended to include the safety of complex networks, such as the safety of the power supply network or safety within transport chains.

The following important and desirable developments in the area of research were identified by the experts that were consulted:

- Improvements in the accuracy and uncertainty limits of the probability of failure values of equipment, vessels, pipelines, etc. and the impact of management effectiveness in this respect, and the load due to corrosion, vibrations and fatigue;
- Higher predictive power in terms of determining the reliability of components and systems such as pressure vessels and software;
- Further development of methods for Risk-based Inspection and Reliability-centred Maintenance;
- Further development of methods for the Safety Integrity Level certification of components and systems;
- Further development of knowledge concerning operator-system ergonomics and the prevention of errors.

Process safety

Research in this sub-domain is focused on the safety of process installations, storage and transportation systems. A portion of the research is related to the technical safety of installations and unit operations, the development of design requirements and the analysis of incidents. The research is focused on the safety of process operations, particularly the physical and chemical factors: heat and dust transmission, catalysis and the influence of contaminants. Sub-areas also include process operability, process control, control room design and alarm management. Aside from this, an important portion of the research is focused on organisational safety aspects, such as safety management, human error and safety culture.

The following important and desirable developments in the area of research were identified by the experts that were consulted:

- Inherently safer systems;
- Improvement of safety through process intensification;
- Quantitative approach to the resiliency of installations;
- Improved use of lessons/experience from the past and information stored in the database;
- Better metrics – performance measurement – concerning a safety level that has been attained, including the safety culture;
- Better computer supported hazard identification methods (HAZOP, PLANOP);
- Expansion of Layers of Protection Analysis (LOPA) to include self-rescue and emergency response layers, inclusion of data concerning the effectiveness of communication between emergency response teams and crisis management;
- Methods for improving the safety management and culture in organisations.

Risk analysis and risk management

The three abovementioned research sub-domains produce the source of information and data for the risk analysis domain. The quantitative risk analysis methods make use of the output of these three sub-domains. For example, the explosion limits of substances or mixtures, the probabilities of system failure or the identification of accident scenarios. The research into risk assessment and analysis is highly diverse and is fed by different disciplines. The relevant risk areas in this regard include: quantitative risk analysis, risk communication, risk perception, risk assessment methods from a societal and business-economic perspective. Articles related to risk analysis are located near the centre of the map.

The risk governance domain has been the focus of research in the public administration domain during recent years. This research was not a prominent part of the results produced by this bibliometric analysis, probably because research in the public administration sector is not specifically focused on safety and hazardous substances, but rather on risks in a much broader context.

The following important and desirable developments in the area of research were identified by the experts that were consulted:

- More precise identification of risks;
- Less dependence on model and analyst;
- Better input data with improved reproducibility;
- Better demarcation of reliability;
- Nuanced expression of risks;
- Development of scenario analysis for emergency assistance with time as the parameter (such as the inclusion of time-dependency in models that deal with fire propagation and with the prediction of sub-lethal injuries, and the inclusion of data concerning self-rescue possibilities).

Focus on different sub-domains by country

The contributions made by the Netherlands (see Figure 2), pertain to all three sub-domains. However, the focus in the Netherlands is concentrated on the process safety sub-domain and to a lesser degree on system safety. Relatively little attention is devoted to the hazardous properties of substances sub-domain in the Netherlands.

The United Kingdom by far makes the largest contribution to the number of publications within the EU (33%) and worldwide approximately 14%. The research activity appears to be equally distributed across the three sub-domains. The large number of articles in the area of safety culture is striking (the relative contribution in this area is 25%). A similar picture emerges from research activities in the United States in this knowledge domain. Both countries are pursuing a proactive policy to be active across this entire domain. Key forces driving the research in this knowledge domain in recent years were the AlChE (American Institute of Chemical Engineers) in the United States and the IChemE (Institution of Chemical Engineers) in the United Kingdom (also see pages 31 and 32). Of special note is the relatively large contribution of the United States to the somewhat isolated areas mentioned earlier, such as blast injury, dioxin, and in particular performance assessment.

The map illustrating publications originating from Germany shows that there is a relatively large focus on research into the hazardous properties of substances (in particular flammability limits). The number of publications in Germany focused on process safety is notable. This is probably due to the relatively large size of companies that manufacture equipment for the chemical industry. In Germany, just as in the United States, there is a relatively strong focus on performance assessment. Research in France appears to be focused even more on the hazardous properties of substances than it is in Germany and in addition on system safety.

Focus on risk analysis by country

A more detailed analysis of the articles related to risk analysis (total of 775 or 9.2% for the period analysed) produced the following diagram (Figure 3). The diagram includes the six key EU countries and the United States. The right hand column depicts the performance of each country across the entire knowledge domain (percentage of the number of publications in comparison to world production over a period of ten years). The left hand column depicts the performance of each country in the area of risk analysis (percentage of publications in comparison to the world production of articles related to risk analysis in the database). Three countries appear to place a somewhat relatively higher focus on risk analysis, in particular Italy and to a lesser degree the United Kingdom and the Netherlands as well.

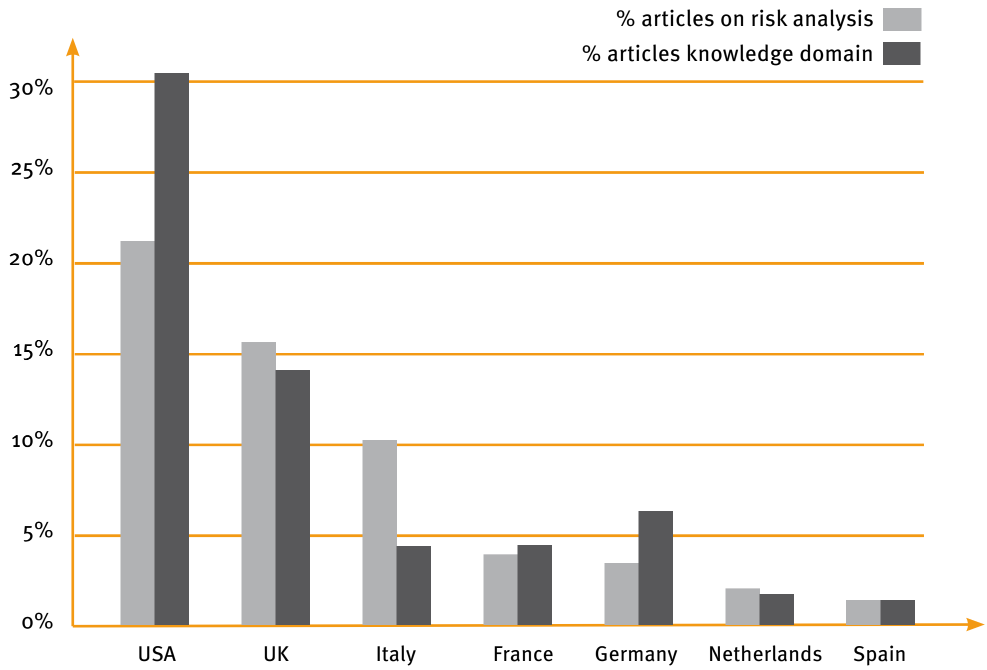


Figure 3: The relative contribution of the top six EU countries and the United States in the area of risk analysis compared to the relative contribution of these countries to the entire safety and hazardous substances knowledge domain.

Contribution of organisations within the Netherlands

Within the Netherlands, a total of 80 organisations contributed to 179 publications in the area of safety and hazardous substances. The largest contribution (63%)

originates from five organisations: TU Delft, TU Eindhoven, RIVM *(National Institute of Public Health and Environmental Protection)*, Utrecht University and TNO *(Netherlands Applied Scientific Research Institute)* (Rijswijk). Approximately 50% of the total contribution in the period covered by the analysis originates directly from universities. The other half of the publications concern applied scientific research published by four types of organisations (GTIs/other research institutes/governments, consulting bureaus, business and other organisations).

Comparison of impact scores with the chemical sciences discipline

The performance of chemical research in the Netherlands is periodically assessed by the Netherlands Organisation for Scientific Research (NWO). This assessment is not based on the relative percentage contribution to the overall world production, but rather on the basis of an impact score. This is expressed in the form of the ratio CPP/FCSm, or the average number of citations per publication (excluding self-citations) for a certain research unit in relation to the average number of citations per publication in the relevant discipline throughout the world (Field-based Citation Score mean value).

For the chemical sciences the impact score was 1.55 during the period 1991-2000, or 55% above the world average[11]. For the chemical engineering discipline, the score was 2.26 and for process technology it was 1.61. The impact score for the safety and hazardous substances knowledge domain was 1.2 for all of the Netherlands during the period 1996-2006. Aside from the quality of the research, this somewhat lower value could also be related to the multidisciplinary character of the research in this knowledge domain. Multidisciplinary research in general has a lower impact score.

Contribution of the Netherlands in comparison to other countries

The number of articles published in the Netherlands during the past ten years was 179 or approx 2.1% of the worldwide production (see Table 1). This is lower than the 2.5% scored by overall research in the Netherlands[12]. Within Europe, the United Kingdom heads the list with 1,169 publications for the period analysed. Based on the number of publications, the Netherlands ranks sixth in Europe.

Table 1: Top six countries in Europe based on the number of publications in the safety and hazardous substances domain.

	Number of publications	% EU-25	% world
UK	1169	33,2%	14%
Germany	547	15,6%	6,5%
France	376	10,7%	4,5%
Italy	366	10,4%	4,4%
Spain	193	5,5%	2,3%
Netherlands	179	5,1%	2,1%

Comparison with a related discipline and with sales in the chemical sector

Figure 4 compares the contribution illustrated in Table 1 with the publications in a

11 The third bibliometric study on chemistry research associated with the council for chemical science of the Netherlands Organization for Scientific Research (NWO-CW) 1991-2000. Van Leeuwen TN, et al. CWTS. The Hague, September 2002.

12 Scientific and Technology Indicators 2005. Netherlands Observatory for Science and Technology (NOWT). Leiden 2007.

comparable research domain (chemical engineering)[13] and with sales in the chemical industry[14]. The sales figures regard the chemical and pharmaceutical industry and comprise the basic chemical industry (petrochemicals, rubber and plastics, synthetic fibres, inorganic substances, industrial gases, artificial fertilisers, 42.7%), pharmaceuticals (27.9%), specialty chemicals (paints and crop protection, 19.2%) and consumer items (cosmetics and detergents, 10.2%).

The major contribution made by the United Kingdom as shown in the diagram below is striking; not only in relation to other countries, but in relation to both criteria identified.
Among other things, experts attribute the strong British focus on this knowledge domain to the anchoring of the focus on safety within the Institution of Chemical Engineers (IChemE, also see page 32).

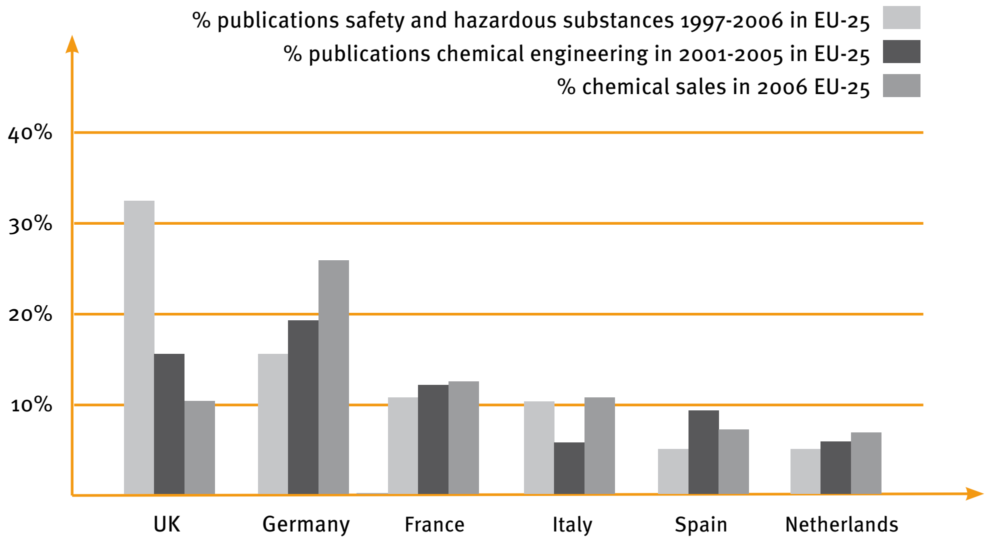


Figure 4: Contribution of the Netherlands and five other countries to the number of publications in the area of safety and hazardous substances in 25 EU countries compared to the relative contribution to the chemical engineering discipline and to the sales of chemical companies in 2006. See footnotes 13 and 14 for the sources of this information.

Population density

In the past, population density in the Netherlands combined with the size of the chemical sector influenced the knowledge questions and determined the research's spearheads. It was a reason for specialising Dutch research in the area of quantitative risk analysis.
The population density in the Netherlands is now almost twice what it is in Germany and in the United Kingdom. See Figure 5. Comparison with Figure 3 demonstrates

13 At the request of the AGS, the CWTS surveyed the number of publications in the area of chemical engineering for the period 2001-2006. A previous study conducted by the NWO-CW was used to define the scope of the chemical engineering knowledge area. The third bibliometric study on chemistry research associated with the council for chemical science of the Netherlands Organization for Scientific Research (NWO-CW) 1991-2000. Van Leeuwen TN, et al. CWTS. The Hague, September 2002.

14 Facts and Figures: The European chemical industry in a worldwide perspective. Geographic breakdown of EU chemical industry sales. Cefic. Brussels, September 2007. The chemical sales figures in Figure 4 exclude the pharmaceutical industry.

that at present it is not possible to identify a relationship between the (still increasing) population density and the Dutch production of scientific articles on risk analysis.

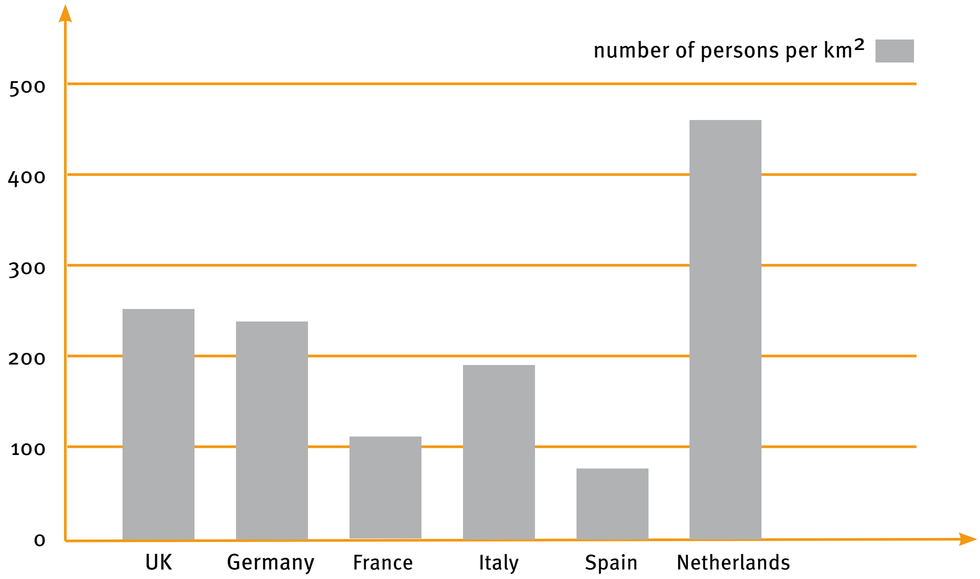


Figure 5: Population density (number of persons per km^2) in various European countries.

CURRENT STRATEGIC RESEARCH IN THE NETHERLANDS

The survey described above only identifies the knowledge areas that are the subject of publication in the scientific literature. Furthermore, the survey covers research activity over the past ten years. For this reason, this bibliometric analysis was supplemented with research concerning the nature and scope of presently conducted strategic research and the related future prospects in this regard. Technopolis BV (in Amsterdam) under contract to the AGS approached the knowledge/research institutes, universities and companies that were identified by the bibliometric analysis described above[15]. The nature of current research programmes (in 2007) and the associated budgets were identified on the basis of interviews and a desk study. Additional information was obtained from the NWO and by consulting the database with projects carried out as part of the EU's Sixth Framework Programme (FP6) for Research and Technological Development. The interrelationships among the various actors were identified on the basis of a social network analysis.

From the response provided by various interviewees it is apparent that current research is limited to sub-areas[16]. An integral approach to the problem is missing. Dutch research is still living off the innovations produced during the seventies and eighties. New opportunities, for example in the area of risk analysis are not exploited. One of the possible implications is that the Netherlands could miss the connection with international developments.

A disturbing picture emerges from this survey of current research (in 2007) in this knowledge domain[17]. Research groups that in the past performed research in this

15 Appendix 1 includes the names of the parties interviewed.
16 Hazardous substances knowledge domain: background study. Technopolis BV, November 2007.
17 Ditto.

domain have disappeared or are about to disappear. It is estimated that companies, knowledge institutes and universities in the Netherlands currently employ between 90 to 140 FTEs dedicated to the development of strategic knowledge in the area of safety and hazardous substances. Of this figure not more than approximately 20 FTEs are employed by – three different – universities.
Furthermore, the capacity and focus is not equally distributed across all knowledge areas identified by the AGS for this knowledge domain. The focal points currently are damage and effect modelling, safety management and safety policy. Less pronounced or almost not represented at all are system safety, safe process technology and design, hazardous properties of substances (physical, chemical or toxicological), external safety in land use planning issues and emergency response in relation to dangerous substances.
From the social network analysis it is apparent that the TNO, RIVM and TU Delft play a central role in strategic knowledge. The TU Delft and the TU Eindhoven make the largest contribution to fundamental research in this domain. It appears that there are very few contacts across the walls built up around the various knowledge areas. Fragmentation is evident. Given the current research capacity this represents a danger in terms of continuity. People with an overview of the entire domain are scarce.

The budgets of the Ministry of Housing, Spatial Planning and the Environment, the Ministry of Transport, Public Works and Water Management, Ministry of the Interior and Kingdom Relations include funding of a few research programmes in the area of safety and hazardous substances. However, the amount of long-term and strategic research is negligible. Furthermore, the plans show that financing will be reduced over the coming years and there is no overarching government policy concerning the development of knowledge in this knowledge domain[18].

A shift in the policy for financing research is evident over the past few years. Not only in the Netherlands, but in other EU countries as well, project-based financing of research is gaining in importance. This will worsen the noted fragmentation if there is no master plan that serves as a basis for providing the financing and proposals are only submitted on a bottom-up basis.

A strategic plan for the knowledge infrastructure for the safety and hazardous substances knowledge domain would be of major importance for the Netherlands, but none is available. This requires coordination and the promotion of cohesion in addition to financing and attracting talent. Two conditions are linked to this. An exploration of the future must be prepared as the basis for a roadmap for the science required. Furthermore, top-down guidance is required. This requires the necessary overview to be available and the capacity to deliver the necessary effort.

FOCUS ON SAFETY IN THE USA AND EUROPE

USA

Process safety and the safe handling of hazardous substances received particular attention in the United States after the disaster in Bhopal (1984). Congress and the Senate assigned responsibility for this to the American Institute of Chemical Engineers. This resulted in the periodic organisation of Loss Prevention symposia and the creation of the Center for Chemical Process Safety in 1985. This Center works

18 See the advisory report 'Safety Requires Knowledge' prepared by the Advisory Council on Hazardous Substances, the Cabinet's position on this advice (TK 30373, no. 13) and the budgets of various departments (not translated in English).

with representatives from companies and government on the protection of employees, the population and the environment. Its activities result in Guidelines. Furthermore, the Center organises thematic symposia and training programmes. The Safety and Chemical Engineering Education Group[19] looks after the curricula of university teaching.
Finally, there is the Chemical Safety and Hazard Investigation Board that investigates accidents involving hazardous substances. The accident in March 2005 in a BP refinery in Texas resulted in a report that showed the erosive tendencies in business organisations that led to this and other accidents. This report provides a new stimulus for knowledge development in this domain (also see footnote 2).

European Countries
There are differences between the approaches used by different countries in Europe. Just as in the USA, professional associations are active in the United Kingdom, Germany and France, and one is emerging in Italy[20]. A focus on safety and hazardous substances already has existed for a relatively long period of time in the United Kingdom. The disaster in Toulouse has heightened attention in France. In other countries, attention is a derivative of developments at the European level.

The United Kingdom is a leading country in Europe in the area of safety and hazardous substances. The Institution of Chemical Engineers (IChemE) has played an important role for many years in defining the requirements that chemical engineers are expected to meet and provides advice about the direction of research. Since the late sixties, the IChemE has been certifying education (curricula) and organising symposia. Furthermore, there was good feedback from incident investigations to the design of new processes in the process industry. This created new knowledge questions. Furthermore, for years safety has had a position on the UK national research agenda due to the central focus on safety provided by the HSE (Health and Safety Executive), as a result of which the relevant knowledge areas were already coherent as far back as the seventies.
The directions for research are outlined in the Roadmap for 21st Century Chemical Engineering[21]. Safety occupies a prominent position on this roadmap. The IChemE devotes particular attention to the education of chemical engineers in sustainability as well as safety programmes. Both topics require a form of realisation for coming up with new technologies and concepts. According to the IChemE, sustainablity and safety must be an inherent component of the basic education of chemical engineers.

Following the disaster in Toulouse, the Industrial Safety Culture Institute was created in France in 2003 *(Institut pour une Culture de Sécurité Industrielle)*. Activities comprise interdisciplinary research focused on industrial safety, education and training at the master level (in close collaboration with industry) and the organisation of meetings concerning risk management and risk acceptance. The financiers consist of major industrial companies, trade unions, academic research institutions, government bodies and NGOs.

Europe
The European Federation of Chemical Engineering (EFCE) has been organising Loss

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19 See http://www.sache.org/newsletters/SacheNewsFall2007.pdf
20 In the United Kingdom, the Institution of Chemical Engineers (IChemE), in Germany the *Verein Deutscher Ingeniöre* (VDI), in France the *Association Chimie Industrielle et Génie des Procédés (l'A.C.I.G.P.) and in Italy the Associazione Italiana di Ingegneria Chimica* (AIDIC).
21 A Roadmap for 21st Century chemical engineering. IChemE. Rugby, May 2007.

Prevention symposia every three years since the seventies (i.e., well before the American Institute for Chemical Engineers), and in the nineties, the European Process Safety Centre (EPSC)[22] was established.
During the eighties and nineties, research and method development was centrally stimulated by the EU, linked to the development of regulations in the context of the Seveso Directive. However, the thrust behind these initiatives gradually disappeared for a variety of reasons.

A few years ago the EPSC and France (following the disaster in Toulouse) took the initiative of creating the *European Technology Platform for Industrial Safety* (ETPIS)[23]. Various research institutes and companies from various EU countries are joining forces within the ETPIS. This technology platform is one of the platforms established as a result of the EU's objective to become one of the most competitive and dynamic knowledge economies in the world, whereby sustainable economic growth leads to more and better jobs and greater social cohesion (European Council, Lisbon, March 2000). The European Council added the environmental dimension to the objectives in Gothenburg (June 2001).

At the beginning of January 2006, ETPIS published a first draft of a strategic research agenda[24]. It is the intent of the research parties and other stakeholders to motivate the EU to make money available for research as part of the Seventh Framework Programme.
Aside from the abovementioned Lisbon objectives, the ETPIS is using the importance of safe industrial production for employees and civilians as an argument for a unified approach to safety and a common implementation of a research agenda. The European industrial and transportation networks are furthermore increasingly cross-border and dependent on each other. Efficient and undisturbed production is consequently of common importance for the reliable supply of materials and products. The targeted objectives are more efficiently attained through European collaboration. Joint development and support of European standards promote legislative harmonisation and a level playing field. This also results – particularly for companies operating in multiple EU countries – in greater clarity, which ultimately results in cost savings.

The intent is for national groups to feed the platform. In the meantime, fourteen national platforms are associated with the ETPIS, including platforms in the United Kingdom, France, Germany, Italy and Spain. These national platforms are focused on the coordination of public and private research financing, promoting synergy among sectors and stimulating knowledge development and innovation in the area of industrial safety. The Netherlands is currently lacking a sufficient base to establish a national platform.

ETPIS' research agenda (2006) focuses on the following themes:
- Development of new risk assessment and risk management methods addressing the complexity of industrial systems;
- Improving methods and technologies to reduce risks at work and to prevent major accidents;

22 Most major European chemical companies are members of the EPSC.
23 This platform is broader than just process safety and also focuses on building and construction. This way multiple sectors are pulling together to invest in knowledge development in the area of safety.
24 Safety for Sustainable European Industry Growth: Strategy Research Agenda, Detailed Version, First Edition. ETPIS. Brussels, January 2006.

- Development of knowledge, methods and technologies for the safe design and maintenance of installations (structural safety);
- Understanding the impact of human and organisation factors in risk control
- Development of knowledge, methods and technologies concerning the identification and assessment of emerging risks, exploration of the implications related to legislation, norms and standards, economic risk management aspects, integration of risk management into the lifecycle of installations;
- Improvement of knowledge transfer to industry and in particular SME's, education and training activities;
- Improvement of the (knowledge on) safety of nano-technologies and the use of nano-materials.

TRENDS, KNOWLEDGE QUESTIONS AND EDUCATION

During discussions with thirty-some experts from business, universities and government, trends were explored: trends in the chemical industry and in transportation, trends among citizenry, trends in government and trends in knowledge and knowledge infrastructure in the field of safety and hazardous substances[25]. Furthermore, knowledge questions for the long term were discussed. In addition, the ambitions in the business plan of the Regiegroep Chemie[26] were included in this analysis.

Trends

A key trend consists of the growth in the transportation of hazardous substances, which in fact even exceeds economic growth. The role of the Netherlands as a transit nation for this transportation flow is expected to become even more important. In addition, the production and use of hazardous substances is expected to increase. The Dutch investment climate for the chemical industry and the competitive position of the Netherlands in relation to China and other countries in the Far East constitute an uncertain factor.
The Regiegroep Chemie forecasts growth for the chemical sector and furthermore is formulating stringent objectives in the area of sustainability, including a drastic reduction in the use of fossil fuels.

Furthermore, the Regiegroep Chemie is emphasising the importance of knowledge development in the Netherlands for the chemical sector, aware of the fact that – as outlined above – there is increased coordination and joint knowledge development within Europe. Dutch knowledge in the area of catalysis was very advanced for many years. From a more general perspective as well, the Dutch chemical sciences have a good position on the international stage and are still scoring high citation indices[27]. Today, the influx of students, the scope of the research and the alignment with issues from industry give cause for concern, something that is also noted by the Regiegroep Chemie. The Regiegroep Chemie therefore wants to stimulate enrolment in chemical education programmes. Furthermore, the Regiegroep Chemie has plans for extensive research programmes and for restructuring the present knowledge infrastructure for

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25 Appendix 1 includes a summary of the experts consulted. Appendix 4 contains a summary of the results.
26 Innovation in, by and of the Dutch chemical sector. Elaboration and implementation of the Regiegroep Chemie's Business Plan "Key Area 'Chemistry' Generates Growth". Regiegroep Chemie. The Hague, August 2007.
27 The third bibliometric study on chemistry research associated with the Council for Chemical Science of the Netherlands Organisation for Scientific Research (NWO-CW) 1991-2000. Van Leeuwen TN, et al. CWTS. The Hague, September 2002.

chemical sciences and engineering. Government and business are jointly financing these plans. The proposed research programmes are not specifically related to safety issues. The NWO Chemical Sciences' current research programmes also do not finance any research in the area of safety and hazardous substances except as part of the Sustainable Hydrogen Programme.

Knowledge questions

In addition to the trends described above, the long term knowledge questions were also classified in with the same group of experts. These knowledge questions can partly be classified into one of the three sub-domains (process safety, system safety and hazardous properties of substances) (see Table 2). In many cases, however, these knowledge questions require research using a multidisciplinary approach across the sub-domains. This means interaction and cohesion of the research across the various disciplines will be critical factors of success.

Table 2: Examples of knowledge questions by sub-domain

Hazardous properties

- Improvement of the probit functions for toxicity and for the development of non-lethal injuries caused by fire or an explosion;
- Improvement of methods for identifying the hazardous properties of substances; At the same time development of methods that are suitable for a greater range of conditions (new conditions (e.g., higher pressure or temperature));
- Improvement of gas dispersion models to create greater accuracy and clearer confidence limits;
- Development of models on the explosiveness/ of a gas/vapour cloud that take conditions (e.g. atmosphere) and environmental factors (buildings, structures, trees) into consideration;
- Improvement of the understanding of dust explosion mechanism.

System safety

- Development of knowledge about the analysis and design of systems (chains or complex industrial systems) with a certain resilience against failure (technical resilience);
- Research into the impact on safety of the interdependency of industrial plants in light of the shift of standalone companies to networks of smaller companies. In this respect it is, among other things, the push for energy cost savings that contributes to the interdependency of plants.

Process safety

- Improvement in hazard identification methods in support of incorporating preventive measures into design;
- Development of inherently safer processes;
- Research into the possible impacts of process intensification on process safety;
- Improvement of performance indicators ('lagging and leading') concerning operational safety;
- Research into organisational resilience;
- Evaluation and further development of methods designed to enhance the safety awareness and safety behaviour of individuals in an organisation, including over the longer term.

- Research into more effective risk communication;
- Knowledge about emergency assistance aimed at specific target groups;
- Effectiveness of training methods for decision makers;
- Research into the effectiveness (risk reduction) of preparative near-field measures;
- Expansion of Layers of Protection Analysis (LOPA) with a layer for communications for self-rescue and a layer for communications between emergency assistance teams and crisis management;
- Research into methods for incident analysis and into effective learning from incidents by companies and government;
- Application of safety knowledge to the design of new more inherently safe processes and installations, to the operation of existing installations and to the inspection and enforcement by government;

Knowledge questions about risk analysis and risk management are included in Table 3. Research in this area requires knowledge from the three earlier identified sub-domains, including knowledge about the data that is to be processed by risk models.

Table 3: Examples of knowledge questions about risk analysis and risk management

- Development of models for calculating risks that are more consistent with reality (taking spatial densification, transportation, tunnels and coverings into consideration);
- Development of scenario analysis methods in which time dependency and consequently the progression of hazards and the initiation of counter measures is incorporated into quantitative risk analysis models;
- Development of methods for modelling sub-lethal effects;
- Development of methods for predicting sub-lethal injuries and self-rescue possibilities;
- Improvement of the prediction reliability of dispersion and effect models in the near-field (e.g. for use of emergency response and design of protection devices);
- Development of risk evaluation decision support methods from a societal, as well as a business-economic perspective, in which, aside from quantitative estimates, qualitative estimates are also used.
- Further development of knowledge about the consequences of responsibility allocation for inspection and enforcement.

Education: areas for attention in the curriculum

The education programmes for process technologists and chemists are important basic education programmes for professionals who, from as early as the process design stage, are involved in preventing incidents and disasters involving hazardous substances or in limiting and fighting the consequences. They are also the individuals who must transfer their knowledge of safety and hazardous substances to their colleagues and staff. Especially in their education, the focus on safety is therefore of key importance.

Consultation with the directors of the four Dutch universities that offer education programmes for chemical technology demonstrates that there is some attention for safety within the curriculum, at the bachelor as well as the master level[28]. However, there are major differences among education programmes in terms of scope and content. The TU Delft education programme meets the criteria specified by the British Institution of Chemical Engineers in the area of safety and is accredited by this institution. However not all education programmes cover the key knowledge areas related to the 'safety and hazardous substances' domain. The focus on the key knowledge areas in the curricula requires improvement, as well as more interaction and cohesion with research conducted in these areas.

The combination of research and education is essential to academic education. When the relationship with research is lacking there is little certainty that the newest insights are incorporated into the study material or that the uncertainties concerning present knowledge are dealt with. For two education programmes, the safety discipline is for the most part covered by guest lecturers from actual practice. Only in one case is the course on safety covered by a professor who at the same time is involved in safety research.

Anchoring safety into the basic education programme of process technologists and chemists is also a topic abroad. This is evident from Reniers' arguments concerning the benefits of modifying the curriculum[29]. Already back in 2003, the OECD recommended that safety be included in the basic education programmes of individuals to be employed in the process industry and individuals to be charged with responsibility for this subject in government institutions[30]. In the United Kingdom, safety has been part of the curriculum for chemical engineers for years. In other countries within the EU this is less clearly the case. A good overview is lacking here, however.

In a survey of 180 universities with education programmes for chemical engineers, the American Institute for Chemical Engineers noted that only 25% of the education programmes in the curricula included a focus on process safety. In view of the challenges faced by the process industry to improve its safety record, the AIChE is advocating that process safety be incorporated into the curriculum as a fixed component[31] (also see page 32).
In the Netherlands there are programmes for further education in the area of safety that include safety and hazardous substances as a component. These programmes have been created to counteract the lack of skilled workers experienced in actual practice. These education programmes consequently meet a business and government need. Examples of such education programmes include the advanced education programmes for safety experts and technologists (offered by the Stichting Post Hoger Onderwijs Veiligheidskunde (Institute for Advanced Safety Studies)) and post-graduate programmes *(Management of Safety, Health and Environment* by TU Delft's TopTech. TopTech also offers the Master of Public Safety programme).

In a certain sense, the further education programmes mentioned above can be considered to supplement the basic education programmes of process technologists and chemists that in terms of safety fall short of the mark in actual practice. These

28 Appendix 1 includes a summary of the educational programme directors consulted.
29 Reniers GLL, Pauwels N, Soudan K. Teaching Safety Management to Commercial Engineers: Investing in the Future. CHISA (Czech abbreviation for Chemical Engineering, Chemical Equipment Design and Automation), Prague, 2006.
30 Report of the OECD workshop on sharing experience in the training of engineers in risk management. Montreal, Canada, 21-24 October 2003. OECD series on chemical accidents, Number 13, March 2004.
31 Mannan MS and Startz D. Process Safety Curriculum in U.S. Universities. Centerline, Vol. 10, no. 1, Spring 2006.

further education programmes, however, offer insufficient safeguards for safety in actual practice if there is no additional requirement for embedding safety courses into the relevant basic education programmes.

ESTIMATE OF REQUIRED ACADEMIC MASS

The AGS prepared an estimate of the number of FTEs employed by universities and the distribution of these FTEs across the various sub-domains. In addition, an estimate was made of the order of magnitude of the critical mass required by sub-domain for research and education. Critical mass here is defined as the size and cohesion of a research group required to be able to sustain internal motivation and the ability of the group to maintain itself internationally.

This is illustrated in the table below. In addition, the most important knowledge areas for the Netherlands within each of the three sub-domains are identified. Research into risk analysis and risk management forms part of these sub-domains and is included in the estimate of the number of required FTEs.

To be able to sustain a knowledge area (critical mass) requires at least 5 FTEs (leader, theoretician/analyst, experimenter and 2 assistants). The table below identifies the ten knowledge areas that the AGS considers necessary for balanced knowledge development in the area of safety and hazardous substances. Due to the complexity of the subject matter and due to the required scientific progress and education, several knowledge areas require a somewhat higher complement than the minimum of five persons. This means that a critical mass of university research amounting to a total of 60 FTEs is required in the Netherlands.

Table 4: Estimate academic mass for research into safety and hazardous substances

Cluster	Knowledge area	Number of FTE	
		current	required
Hazardous properties of substances	Vapour cloud explosion and dust explosion Chemical reactivity/runaway Acute toxicology Effect/damage modelling Computational Fluid Dynamics	7	25
Systeem safety	Probability of failure/reliability Maintenance strategy Safety concepts/resiliency	0	15
Proces safety and riskanalysis	Process technology /design Safety management/culture Risk communication/risk perception/ risk governance/ quantitative risk analysis	13	20

Conclusions

The current financing and programming of research into safety and hazardous substances in the Netherlands are inadequate to safeguard the critical mass required to maintain existing knowledge and to evaluate and further develop it. Furthermore, there are insufficient safeguards to ensure the quality of the university education programmes in this domain and for translating knowledge into national policy.

Dutch research activities in this knowledge domain, based on the number of publications, were less than would be expected during the past decade given the degree of spatial densification in the Netherlands and the scale of the chemical industry and transportation of hazardous substances.
Over the coming years, the number of researchers and teachers within this knowledge domain is expected to further decline due to factors such as retirement, decrease in the number of beta students and a lack of focus and financing.

Little research was conducted in the Netherlands in 2007 in two of the three sub-domains: hazardous properties of substances and system safety. The process safety sub-domain is weak in terms of the technical process safety aspects and the consequences of hazardous substances in fighting disasters. Strengthening of external safety in land use planning issues is also required. While the knowledge institutes (TNO, RIVM) are still maintaining a reasonable mass in the area of risk analysis at tactical level, the strategic, university component – concentrated in TU Delft and TU Eindhoven – is significantly declining. Research in the area of safety cultures is limited to Leiden University and TU Delft.

Other European experts also sense the need and urgency for strengthening the focus on knowledge development in this knowledge domain due to the important role of the chemical industry in Europe and the need for safe undisturbed production and transportation[32]. The resulting European collaboration in this area is also grounded in the fact that the direct consequences of an incident in certain cases are border-transcending. Furthermore, there is an awareness that it is important to learn from incidents in other countries. This awareness – in addition to the economic driving forces mentioned in the previous section – strengthens the emergence of agreements at the European level and the formulation of EU regulations.

It appears that the Netherlands will miss the opportunity to link up with European developments leading to a joint research programme in this knowledge domain. The

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32 Safety for Sustainable European Industry Growth: Strategy Research Agenda, Detailed Version, First Edition. ETPIS. Brussels, January 2006. A Roadmap for 21st Century Chemical Engineering. IChemE. Rugby, May 2007.

previously mentioned critical mass of Dutch strategic research is also sorely needed for this.

In view of Dutch growth ambitions in the chemical industry and transportation sector, further spatial intensification and the switchover to other energy carriers, further development of knowledge concerning the involved risks and how to manage these is indispensable for government as well as the business community. Furthermore, striving for greater safety and transparency and the changed perceptions concerning the allocation of responsibility, supervision and enforcement will require the further development of knowledge in government as well as in business communities.

Recommendations

On the basis of the conclusions contained in this advisory report, the AGS recommends that government and Parliament strengthen the strategic top layer of the knowledge infrastructure for safety and hazardous substances, safeguard the critical mass and independence of knowledge development as well as the focus on the safety 'discipline' within university education programmes. The creation and maintenance of the knowledge base is a task that belongs to government and requires public funding. The universities are responsible for applying these funds to the relevant knowledge areas.
This allows the scientific basis of knowledge concerning safety and hazardous substances to be maintained and used as a building block for further research into the safe use of new substances, new applications or other developments in business and society. For more applied research on safety aspects there are separated public interests and private interests, as well as joint interests. This finds expression in the financing, e.g. joint public/private funding.

The AGS addresses this aspect in further detail in the following two recommendations and in a third recommendation argues for the creation of a public/private coordinating body.

1. A continued university focus on safety

Safeguarding a critical mass of research potential

The AGS recommends that government and Parliament together with universities take responsibility to ensure that a critical mass for research into safety and hazardous substances in the Netherlands is safeguarded. The AGS has discussed the social relevance with the 3TU Federation. The federation has indicated that additional financing should be allocated to this knowledge domain. Critical mass is defined as the size and cohesion of a research group required to be able to sustain internal motivation and the ability of the group to maintain itself internationally.

In each of the three sub-domains (hazardous properties of substances, system safety and process safety), a research group is needed for fundamental research and innovations. This requires public financing. In this regard it is of primary importance that leading top researchers with an overview of national and international developments within at least one of the sub-domains be involved. They must be capable of improving the interaction among the sub-domains (horizontal flow) in order to be able to effectively study the various issues mentioned earlier in this report in the area of hazard identification, risk analysis and risk management.

Examples of fundamental research into safety and hazardous substances:
- Better methods for identifying and anticipating hazards. These methods support elements such as the inherently safe design of processes and installations;
- Quantification of technical resilience and optimisation of process installations;
- Greater insight into the opportunities for organisational resilience (in support of robust management control) and the avoidance of 'drift' towards unsafe conditions;
- Improving reliability and defining the limits for uncertainty in determining risks, by applying advanced risk identification and statistical methods.

The volume of the presently conducted strategic research conducted by universities is estimated to be 20 FTEs, whereby research into the hazardous properties of substances and in the area of system safety are currently receiving the least attention. On the basis of the analysis in this report, the AGS estimates that a threefold increase in university research, to 60 FTEs, is required. These research groups can then also provide the university education in the area of safety and hazardous substances.

Embedding knowledge into basic university education programmes
In various nearby countries – such as the United Kingdom, Belgium and France – the need to safeguard the focus for safety within university curricula has already been recognised[33]. This applies in particular to the education of process technologists who often work on designing or testing process installations or on operating these.

The AGS recommends that government and Parliament encourage universities to ensure that the curricula of bachelor and master studies – starting with the education programmes for process technologists – include a focus on safety. For example, agreements could be formulated concerning the desired depth and breadth of a safety course and the incorporation of current insights. Government and business could approach universities on this subject in collaboration with the Royal Institute of Engineers in the Netherlands (KIVI) and the Royal Netherlands Chemical Society (KNVC) professional associations and the Netherlands Process Technologists (NPT) partnership. If the research groups are strengthened as described above, they can also provide the required education programmes. Furthermore, the AGS recommends that a similar adjustment to the curriculum be considered for other relevant basic education programmes – for example for civil engineers or urban designers. This would serve a broader interest.

In addition, the AGS recommends that an investigation be conducted to determine if in the Netherlands there is a case for special masters studies on safety for students to graduate on safety in the chemical process industry, external safety and fighting disasters. This would also produce future teachers not only at academic level, but also for technical professionals.

Aside from this there will continue to be a need for post-graduate education[34], such as the existing Management of Safety, Health and Environment or Master of Public Safety offered by TopTech in Delft for students who wish to assume management positions in internal operating safety and external, public safety (land use planning, licensing).

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33 CHISA 2006, Praag presentations: session on Teaching Safety to Chemical Engineers. Perrin L, Laurent A. An Overview of Safety and Loss Prevention Teaching in French Chemical Engineering Education. Reniers GLL, Pauwels N, Soudan K. Teaching Safety Management to Commercial Engineers: Investing in The Future.

34 The same applies at the professional education level for existing further education programmes offered by the Stichting Post Hoger Onderwijs Veiligheidskunde *(Institute for Advanced Safety Studies)*.

2. INCLUSION OF SAFETY IN CURRENT PUBLIC/PRIVATE RESEARCH PROGRAMMES

In support of this advisory report of the AGS, in collaboration with business, universities, knowledge institutes and governments identified trends and on the basis of these trends formulated issues or themes for which knowledge development over the coming years is particularly relevant. A shared sense of urgency was already apparent among these stakeholders when the 'Safety Requires Knowledge' report (December 2006) was prepared. Furthermore, there is a need for coordination and cohesion among the improvement initiatives. Due to the joint interests of government and business in safety, the public/private financing of such a research programme is mandatory.

The AGS recommends that the government and Parliament mandate the Ministry of Housing, Spatial Planning and the Environment, the Ministry of Transport, Public Works and Water Management, the Ministry of the Interior and Kingdom Relations, the Ministry of Social Affairs and Employment and potentially the Ministry of Health, Welfare and Sport to jointly, on behalf of government, coordinate the safety aspect in the research issues and funding of strategic research and to align it with industry. The proposition made by the VNCI to earmark a percentage of the budgets for current research programmes for research into safety and hazardous substances, is part of this advisory report. Examples of such publicly/privately financed research programmes include: *Nanotechnology Network in the Netherlands* (NANONED), *Dutch Separation Technology Institute* (DSTI), *Dutch Polymer Institute* (DPI) *and Advanced Chemical Technologies for Sustainability* (ACTS)[35], also see Figure 6.

The Regiegroep Chemie identified in its Business Plan for the Key Area Chemistry[36] objectives for innovation on the basis of research programmes and improvement of the knowledge infrastructure with public and private financing. This involves current chemical research programmes as well as supplementary programmes in areas such as polymer innovation, biotechnology, catalysis, hydrogen and process intensification. Through public/private coordination it is possible to promote cross fertilisation in the area of safety here as well.

Thematic knowledge development: national choices within an international context

It turns out that business and government have knowledge questions about things such as the further improvement of the safety performance of companies and about greater transparency in relation to risk assessments in the Netherlands, a country that is subject to continued spatial intensification. These questions require a multidisciplinary approach involving multiple knowledge areas.

The AGS recommends that strategic choices be made for specific knowledge questions and for strengthening specific knowledge areas (as specified in Tables 2 and 3), because focus makes it possible to excel in the relevant areas in the Netherlands, attract top researchers and will result in improving the exchange of knowledge with other countries. For the exchange of such knowledge, the AGS recommends that relations be established with existing international forums, such as ETPIS *(European Technology Platform on Industrial Safety)*, EPSC *(European Process Safety Centre)*, EU-JRC *(Joint Research Centre)*, WHO *(World Health*

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35 ACTS comprises various programmes such as: Advanced Sustainable Processes by Engaging Catalytic Technologies (ASPECTS), Bio-based Sustainable Industrial Chemistry (B-Basic), Integration of Biosynthesis and Organic Systems (IBOS), Process on a Chip (POAC) and Sustainable Hydrogen.

36 The Dutch government formulated an innovation policy in order to strengthen the competitiveness of the Dutch industry. Part of this policy is the framework of six Key Areas of importance to the Netherlands and the chemical sector is one of these Key Areas.

Organisation), OECD *(Organisation for Economic Co-operation and Development)* and WADEM *(World Association for Disaster Medicine)*.

Furthermore, AGS recommends that steps be taken to avoid research in the area of safety and hazardous substances from becoming isolated, and instead to link it to current research programmes as indicated above. This way knowledge questions about safety are directly linked to current knowledge developments in a specific domain. This avoids safety from becoming isolated from the mainstream. Figure 6 identifies the budgets associated with various current research programmes supported by public/private financing. The AGS recommends allocating a percentage of the budget of these programmes – for example, from 1 to 5% – for research in the area of safety and hazardous substances. This proposal assumes that the core for strategic knowledge development (critical mass) described earlier exists within the Netherlands and that it is financed with public funds – no research proposals could otherwise even be formulated.

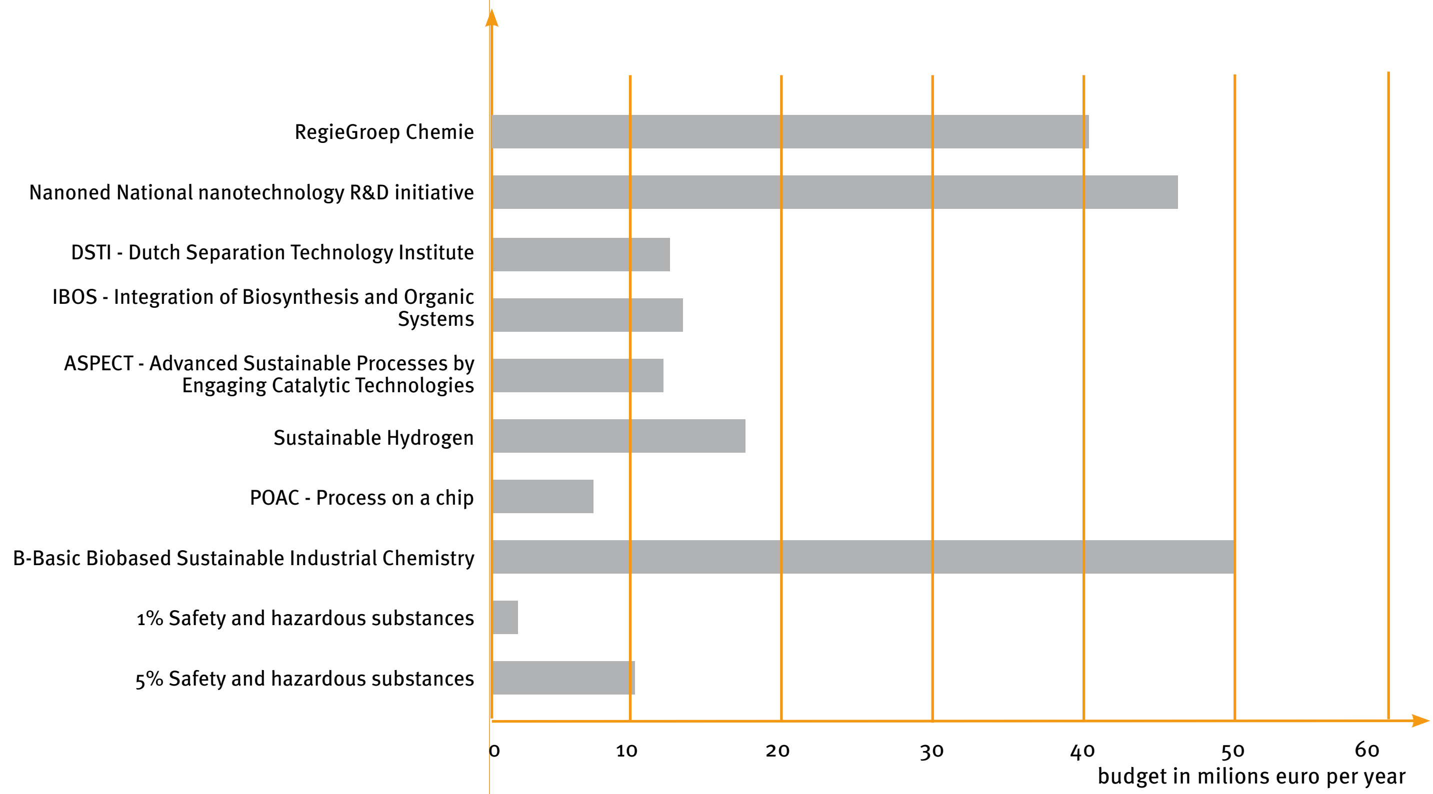

Figure 6: Ongoing research programmes (budgets in millions of euros per year, with a duration varying from 4 to 8 years) where there is a ground to allocate a percentage of the budget for the safety and hazardous substances dimension[37].

37 Regiegroep Chemie: budget estimated on the basis of the Polymer Innovation Programme, August 2007 and 'Innovation in, by and of the Dutch Chemical Sector', August 2007. The estimated resources of the Regiegroep Chemie comprise new projects that supplement already ongoing projects. The budgets for the remaining research programmes are estimated on the basis of information supplied by NWO. June 2009: this figure is adjusted with information on the granting of research programmes in 2009.

Promoting cross fertilisation among business, universities, knowledge institutes and government

Collaboration and interaction among business, government, universities and knowledge institutes is a condition for ensuring the issues are put on the knowledge agenda that are relevant for actual practice and that the developed knowledge can be translated into actual practice (Fit for Purpose).

Furthermore, cross fertilisation during the articulation of knowledge questions, the development of knowledge and the translation of research results into actual practice can stimulate separate communities to in the future develop more common terminology and methodologies – leading to unity in terms of understanding and approach. Coordination can also create added value by establishing relationships between areas of research and ensuring that researchers remain informed of each other's work.

Universities should take the lead in tackling fundamental issues because they are important for innovations in design and engineering. This is illustrated in Figure 7. Science and knowledge are expressed in concrete processes and products through engineering. From the start safety should be an intrinsic component of the design process, but particularly in engineering safety aspects should be the focus of ongoing attention. Due to the close link with the area of application, the AGS considers collaboration among universities, knowledge institutes (GTIs), companies and government in this knowledge domain to be essential.

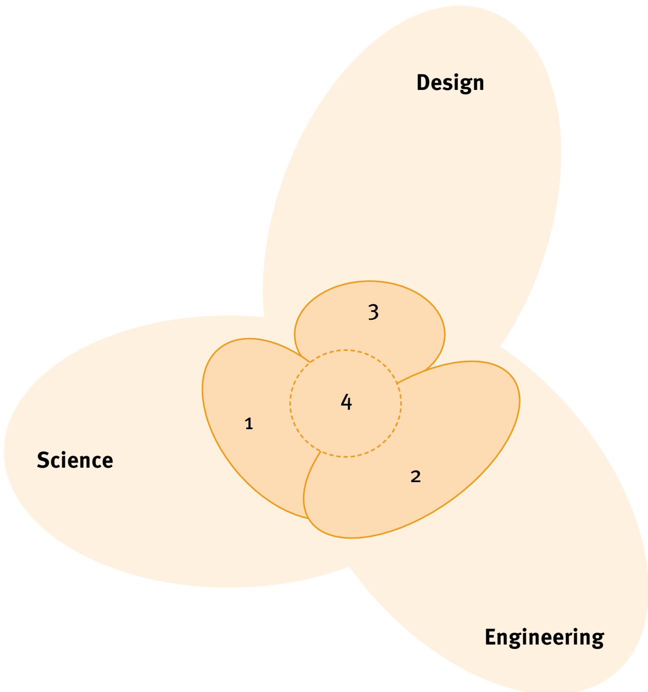

Figure 7: The three safety and hazardous substances sub-domains: hazardous properties (1), system safety (2) and process safety (3). These form part of the broader fields of science, design and engineering. Furthermore, the positioning of risk analysis and risk management (4) is indicated.

3. ORGANISATIONAL STRUCTURE FOR A PUBLIC/PRIVATE COORDINATING BODY

The AGS recommends that a public/private coordinating body be established for the safe handling of hazardous substances, in which government, business, knowledge institutes and universities participate and which accommodates the funds earmarked for safety. This coordinating body can promote focus and strategic choices in research programming within an international context, as well as promote cross fertilisation among science, design and engineering, among research and actual practice, and among different knowledge areas. The public/private coordinating body can take on the tasks outlined above under the aegis of the Netherlands Organisation for Scientific Research (NWO). The NWO has the facilities for this and is prepared to accept this responsibility.

To strike a proper balance, it is desirable that a representative from business is the leader of such a coordinating body, supported by a representative from a knowledge institute and from government. Business must be leading because that is where the direct responsibility lies in actual practice and consequently the key driving force for safety and gathering knowledge within this domain. Business perceives the long term trends within the industry and the direction in which applications are expected to evolve. Universities have insight into the development of fundamentals. Government is involved to safeguard the required societal safety framework in the chemical industry and in transportation.

The AGS perceives several opportunities for linking the coordinating function for this knowledge domain to existing bodies from an organisational perspective. A separate ambassador function for this domain is of key importance, precisely because attention for this subject apparently cannot take off without encouragement. The organisational structure could be comparable to that of the Advanced Chemical Technologies for Sustainability Programme accommodated by the NWO. The involvement of stakeholders, as well as their contribution to the financing could differ by programme.

Appendices

APPENDIX 1 Samenstelling raadswerkgroep en commissie; geïnterviewde personen

Leden van de raadswerkgroep kennisinfrastructuur
Prof. dr ir H.J. Pasman, voorzitter
P. van der Torn, arts-MMK, D. Env.
Prof. dr A.J. van der Wal

Secretaris:
Mevr. ir Y.M. Oostendorp

Leden van de commissie Verkenning veiligheidskennis gevaarlijke stoffen
Prof dr ir H.E.A. van den Akker (TU Delft)
Prof dr B.J.M Ale (TU Delft)
Prof dr P.T.W Hudson (Universiteit Leiden)
Prof dr J. Meulenbelt (Universiteit Utrecht)
Prof dr ir W.P.M. van Swaaij (TU Twente)
Mevr. dr T. Kulkens (NWO Chemische Wetenschappen)

Over trends en kennisvragen geïnterviewde personen

Individuele gesprekken
Prof. dr B.J.M. Ale (TU Delft), 12 oktober 2005
Dr B.J. Blaauboer (Institute for Risk Assessment Sciences), 27 september 2007
Prof. dr ir K. van Breugel (TU Delft), 28 september 2007
Prof. dr ir A.C. Brombacher (TU Eindhoven), 12 september 2007
Dhr. R. Dirven (AON risicomanagement, employee benefits en verzekeringen), 27 augustus 2007
Ir M. Furth (Jacobs Engineering), 7 september 2007
Prof. dr B.P.R. Gersons (Impact en Centrum '45), 7 september 2007
Dr J. Gutteling (Universiteit Twente), 6 september 2007
Prof. dr A.R. Hale (emeritus hoogleraar TU Delft), 6 oktober 2005
Prof. dr I. Helsloot (Vrije Universiteit Amsterdam), 19 oktober 2007
Dr W. Hesselink (Shell Global Solutions), 26 september 2007
Ir R.E.W. Husmann (voorheen Binnenlandse Zaken, Directie Brandweer), 21 september 2007
Ir L.W. Jansse (AKZO Nobel Technology and Engineering), 1 oktober 2007
Dr ir F. Koornneef (TU Delft), 18 oktober 2005
Dr S. M. Lemkowitz (TU Delft), 3 oktober 2007
Drs F.H. von Meijenfeldt (Ministerie van Economische Zaken), 25 juli 2007
Ir J. van der Schaaf (Save Oranjewoud), 26 september 2007
Dr T.W. van de Schaaf (LUMC Leiden en TU Eindhoven), 6 oktober 2005
Prof. dr ir J.A.A.M. Stoop (TU Delft), 19 september 2007
Prof. dr R.J. in 't Veld (Raad voor Ruimtelijk, Milieu- en Natuuronderzoek), 6 november 2007
Dhr N.T. Verbree (Koninklijke Vopak NV), 25 september 2007
Prof. dr C.A.J. Vlek (emeritus hoogleraar Rijksuniversiteit Groningen), 14 september 2007
Prof. ir A.C.W.M. Vrouwenvelder (TU Delft/TNO Bouw en ondergrond), 18 september 2007

Groepsinterviews
RIVM (ir K. van Luyk, dr M.T.M. van Raaij, ir J. Kliest, dr G. de Hollander), 28 september 2007
TNO (ir W. Buijtenhek, ir N. Verschoor, ir A. Hollander), 19 september 2007
DCMR (ir J. van Steen, ir. W. Kooijman, dhr. S. Post, dr ir L. Vijgen), 4 oktober 2007

Deelnemers bijeenkomst prioritering trends, 9 oktober 2007
Prof. dr ir K. van Breugel (TU Delft)
Ir M. Furth (Jacobs Engineering)
Dr S. M. Lemkowitz (TU Delft)
Drs F.H. von Meijenfeldt (Ministerie van Economische Zaken)
Prof. dr ir J.A.A.M. Stoop (TU Delft)
Ir J. Wessels (TNO Bouw en ondergrond, vervanger Prof ir A.C.W.M. Vrouwenvelder, TU Delft/TNO Bouw en ondergrond)
Ir J. Meulenbrugge (TNO, vervanger ir W. Buijtenhek)
Drs B. de Wit (RMNO, toehoorder)
Prof. dr ir H.J. Pasman (voorzitter raadswerkgroep Kennisinfrastructuur)

Deelnemers stakeholdersbijeenkomst, 30 november 2007
Drs A. Deelen (DCMR, lid directieteam en hoofd expertisecentrum)
ir C.L. van Deelen (TNO, tevens directeur stichting Kennis voor Klimaat)
Dr ir C. van Gulijk (vervanger Prof. dr B. Ale, onderzoeker bij TU Delft Safety sciences)
Dhr P. Hoogewoning, RE, RA (vervanger Prof. dr R. in 't Veld, RMNO)
Ir W.P. Kooijman (DCMR, hoofd bureau veiligheid)
Prof. dr ir H. Pasman (voorzitter raadswerkgroep Kennisinfrastructuur)
Mevrouw ir A. van der Rest (Shell Nederland, hoofd Veiligheid en Milieu)
Drs J. van Staalduine (VROM/SVS)
Dr L.B.J. Vertegaal (NWO, directeur Chemische Wetenschappen, directeur Exacte Wetenschappen, directeur ACTS)
Dr ir K. Visser (lid Onderzoeksraad voor Veiligheid)
Ir R. Willems (voorzitter Regiegroep Chemie)
N.H.W. van Xanten, apotheker, toxicoloog, MPA (algemeen secretaris AGS)
Ing. E. Zuidema (adviseur logistieke veiligheid van de directie en Raad van Bestuur DSM)

Lijst benaderde onderzoeksinstituten, universiteiten en bedrijven voor lopend strategisch onderzoek
Prof. dr ir H.E.A. van den Akker (TU Delft)
Prof. dr B.J.M. Ale (TU Delft)
Prof. dr M. van den Berg (Universtiteit Utrecht/Institute for Risk Assessment Sciences)
Dhr H.J. Bril (SABIC Europe)
Prof. dr ir A.C. Brombacher (TU Eindhoven)
Ir H.S. Buijtenhek (TNO)
Ir. H.J. Edelijn (AKZO Deventer)
Dr W. Hesselink (Shell Global Solutions)
Drs R.T.A. Holdert (Railion Nederland NV)
Dr ir A. Hollander (TNO)
Ing. A.R. Jonkers (DCMR)
Ir F.J.C.M. Kempenaers (DOW Chemical)

Prof. dr R.J. Kleber (Universiteit Utrecht/Instituut voor Psychotrauma)
Dr G.R. Kuik (Gasunie)
Mevrouw dr T. Kulkens (NWO Chemische Wetenschappen)
Dr J. Lembrechts (RIVM)
Ir M.J.M.P. de Lepper (DSM)
Prof. mr dr E.R. Muller (COT)
Prof. dr ir H.J. Pasman (TU Delft)
Dhr G.H.B. Schreurs, BC, MSHE (NIFV/NIBRA)
Prof. Dipl. Ing. J.N.J.A. Vambersky (TU Delft)
Dr P.G. van der Velden (Instituut voor Psychotrauma)
Dr T.W. van der Schaaf (TU Eindhoven, Universiteit Leiden)
Ir H.A Versloot (TNO)
Prof. ir A.C.W.M. Vrouwenvelder (TU Delft/TNO Bouw en ondergrond)

Interviews met opleidingsdirecteuren

Dr P.J. Hamersma
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APPENDIX 2

Description of CWTS' analysis method; mass and profile of research in the Netherlands and in other countries during the period 1997 - 2006

The CWTS Institute for Science and Technology Studies in Leiden carried out a bibliometric study for the safety and hazardous substances knowledge domain. The objective of this study was to characterise this knowledge domain by means of a bibliometric analysis of publications and furthermore to compare the contribution made by the Netherlands with that of other countries. The method used for this purpose is described by the CWTS[38]. The result is an interactive map through which the database with articles can be accessed[39].

Delineation of the knowledge domain and selection of articles

The bibliometric study includes all knowledge areas with the potential of contributing to the prevention of disasters involving hazardous substances or to limiting the consequences of such incidents. This knowledge domain comprises different fields of research and disciplines of which the profile does not exclusively fit this knowledge domain. This is why the scope of the relevant literature cannot simply be defined on the basis of a list of journals or a list of authors. The database with relevant articles was generated from the Web of Science of Thomson Scientific partially selected in the basis of a list of journals and partially on the basis of a series of keywords (used for searching titles and abstracts). Experts in the field were closely involved in defining the selection criteria and verifying the completeness of the database. This produced a database with approximately 8,300 articles published during the period 1997-2006.

Data analysis and map configuration

The approximately 8,300 articles can be characterised by a collection of selected nouns that describe their contents. An analysis of these selected nouns produces circles on a map that relate to separate knowledge areas and that can be used to characterise the knowledge domain. The result of the analysis is depicted on a map. The results of the selection and the clustering of the reserved words affect the degree of detail and coverage of the map.

Selection of selected nouns

The selected nouns – from the titles and the abstracts – were in the first instance selected on the basis of statistical considerations and linguistic properties. These selected nouns constitute the groups of nouns that occur the most frequently in the database of 8,300 articles and that also best characterise the research in the knowledge domain. Experts assessed whether the analysis resulted in a proper reflection of the structure of the underlying data (the articles). Furthermore they assessed whether the depiction of the articles on the map is consistent with the image they have of their discipline. A number of analyses was therefore successively submitted for review to a group of experts. This process ultimately resulted in the selection of a set of selected nouns, as well as a structure of clustered terms or knowledge areas that are displayed on a map as circles in relation to one another.

Selection of the number of circles (clustered selected nouns)

The number of circles that is used to display the knowledge domain on the map is determined on the basis of a number of statistical principles: stability of the structure when the level of detail is changed (choice of the number of circles and the clustering

38 Noyons E. Bibliometric Mapping as a Science Policy and Research Management Tool. Leiden. DWXO Press, 1999.

39 The database can be accessed via a website. Access to the database can be arranged in consultation with the Advisory Council on Hazardous Substances.

of selected nouns). This is a local optimum because the analysis produced several local optima. The objective and the desired characteristics of the map determine the area in which the optimum will be found. In most studies in which a map is to be prepared, the purpose of the map is to provide a comprehensible overview of the structure of the knowledge domain. Too much detail blurs the overview. In most cases the number of circles (knowledge areas) will therefore not exceed 60. During the consultation with experts in the current study, it became apparent that the diversity of the knowledge areas to be displayed on the map required at least thirty-some circles. The local optimum consequently was set at 47. The spread of the circles (knowledge areas) was determined on the basis of the interrelationships (associations between the selected nouns used in the articles). In the resulting map it turned out that the circles (knowledge areas) did not fall into more than three knowledge area clusters (knowledge sub-domains).

Of course the choice of selected nouns and the number of circles to a high degree determines the appearance of the map. However, ultimately many of these choices had little influence on its basic structure. This means that the structure is robust.

Choice of labels

The map displays 47 larger and smaller circles. Each of these circles is given a label that in the first instance reflects the most prominent selected nouns. However, in view of the fact that the circles ultimately represent publications that represent comparable research and consequently a knowledge area, it is better in some cases to replace them with a label that is considered more informative by the experts[40]. The underlying word combinations are contained in Appendix 3.

Field delineation: criteria for the selection of articles

All publications (1997-2006) in the following (peer-reviewed) journals:

- Journal of Loss Prevention in the Process Industries
- Process Safety Progress
- Process Safety and Environmental Protection
- Reliability Engineering & System Safety
- Journal of Fire Sciences
- Fire Safety Journal

Furthermore all publications in the Web of Science selected on the basis of one of the following search commands (applied to titles, abstracts and keywords of the publications). The following special symbols are interpreted as part of the search commands as described below:

* Right-hand truncation. Any series of characters is accepted in place of this symbol.
[ab] One of the letters in these brackets must occur in this position.
? This position contains one or no letter.

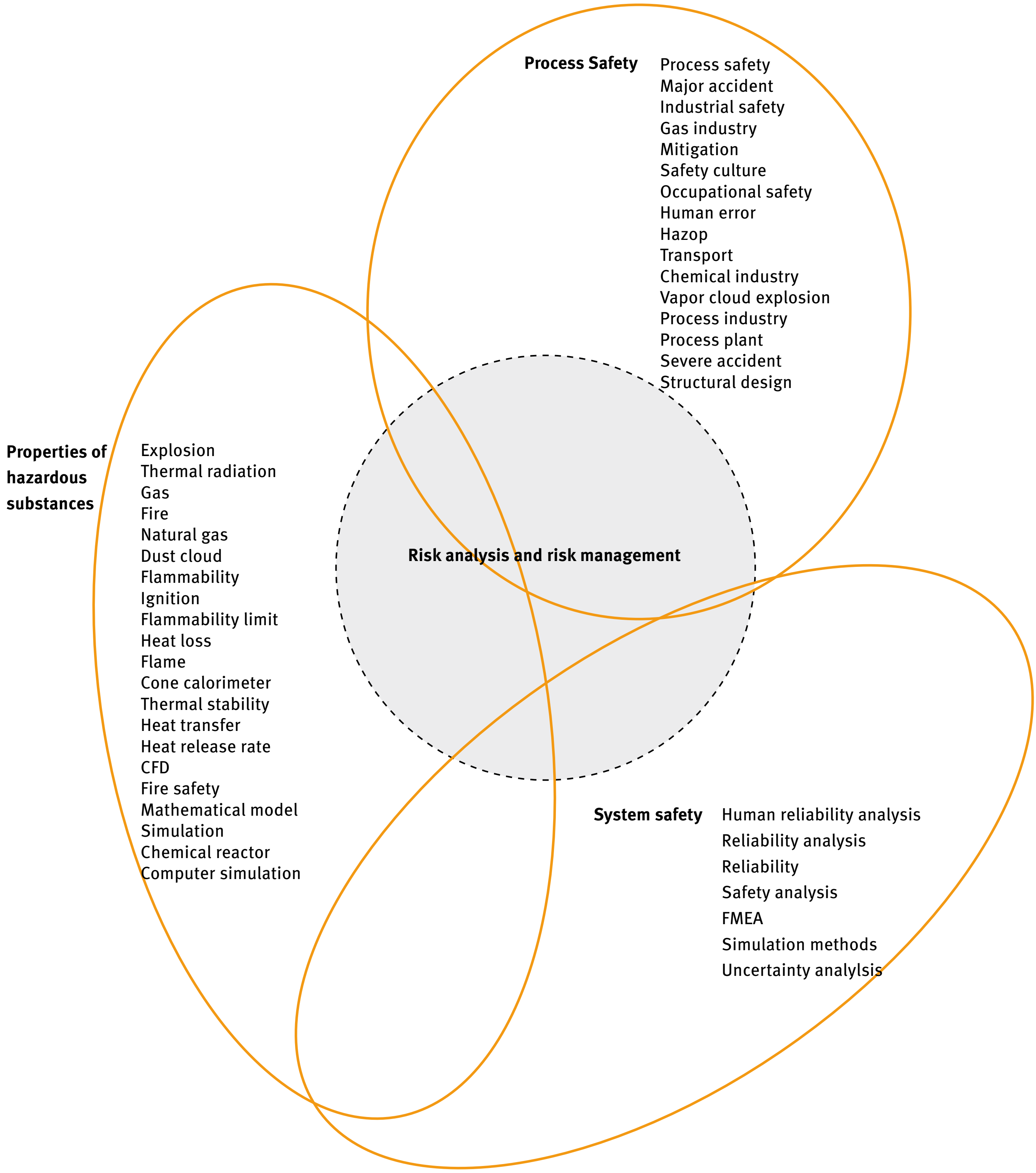
Search commands:

1 industrial safety
2 process safety
3 (safety or incident? or accident? or security) and ("hazardous material*" or hazardous good*" or "hazardous substance*" or dangerous material* or "dangerous good*" or "dangerous substance*")
4 (incident? or accident?) and ("chemical safety" or "external safety")

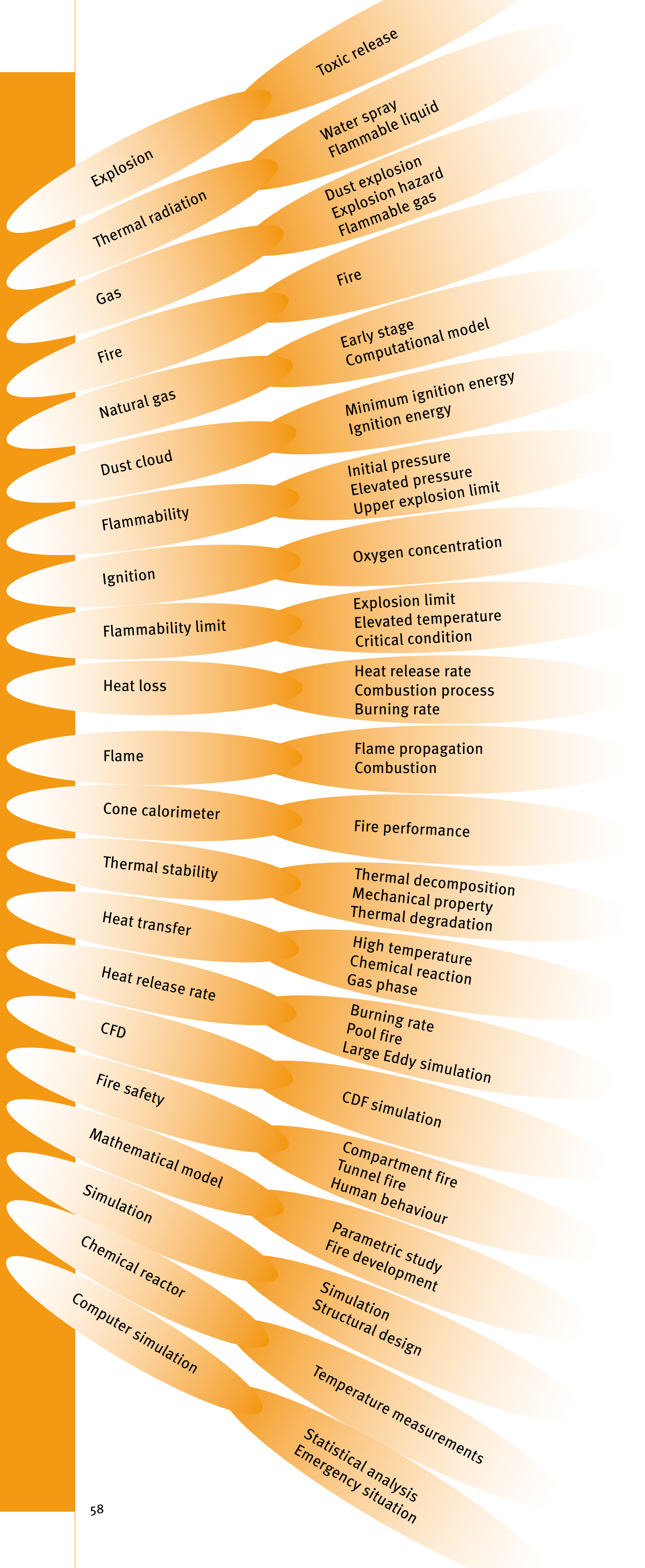
40 Following the meeting with stakeholders on 30 November 2007, the word combination-based analysis was further specified and refined and a few labels were modified.

6 (“hazardous installation*” or “major industrial hazard?” or “hazardous site*” or “hazardous plant?” or “hazardous industry”) and (“land use planning” or “probabilistic design” or “probabilistic safety analys[ie]s” or “operations research” or “system analys[ie]s” or “risk optimi[sz]ation” or “inherent safety” or “precautionary principle” or “public safety” or “risk assessment”)
10 Toxic and industrial and (accident? or incident?)
12 chemical agent? and (acute or emergency or fire?)
13 blast injur*
14 burn injur* and “chemical burn*”
15 damage model* and (toxic or fire or blast)
16 (Liability or “public safety” or law or legislation or regulation) and industr* and (accident? or incident?)
21 (nbc or nbrc) and terrorism
22 ammonia and hazard* NOT (pig or animal or manure or urine or feed* or fertili*)
23 organic peroxide*
24 ((hazard* or safety) and (“ammonium nitrate” or “natural gas” or phosgene or lpg))
25 (“ploughing back” or “organisational learning” or “organizational learning” or “lessons learnt” or “root cause*” or “knowledge transfer*” or “underl* cause*”) and chemical and (“major hazard*” or industrial or dangerous or “proces* safety”)
26 (“major hazard*” or industrial or dangerous or “proces* safety”) and (“risk analysis” or “risk analyses” or “scenario analysis” or “scenario analyses” or qra)
27 (Industrial and (accident* or incident* or safety)) and (“human error*” or “safety culture*” or “behavior based safety” or “behaviour based safety” or “human factor*” or ergonomic* or “safety management system*”)
28 lopa and layer* and protection
29 ((“gas cloud*” or “toxic cloud*” or “vapour cloud*” or “vapor cloud*”) and (dispersion or toxi*)) NOT (star* or stell* or gala*)
30 mitigation and safety
31 emergency venting or “explosion index” or “minimum ignition” or “explosion limit*”
32 (autoignition or “auto ignition”) and (safety or explosion or hazard*)
33 tunnel safety
34 water spray curtain*
35 (fire and (simulation or cfd)) NOT (wild* or wood* or eco* or tree* or forest*)
36 safety culture* or “safety climate*”
37 ((hazard* or safety) and chlorine) NOT(microbio* or water or salmonel* or food or “e coli”)
38 (“Disaster? medicine” or “Disaster? respons?” or “Disaster? management” or “Disaster preparedness” or “Emergency respons?” or “Disaster relief”) and “Industr*”
39 human reliability and (industr* or plant*
40 Flixborough or seveso or “piper alpha”
41 (enschede and (accident* or incident* or disaster*))
42 (toulouse and (accident or accidents or disaster* or industry or industries)
43 bhopal and isocyanate*
44 deflagration not (star* or astro* or stell* or gala* or supernov*)
45 Flame propagation not (star* or astro* or stell* or gala* or supernov*)
46 BLEVE or “Boiling liquid expanding vapour explosion*”
47 Fault Tree
48 fmea

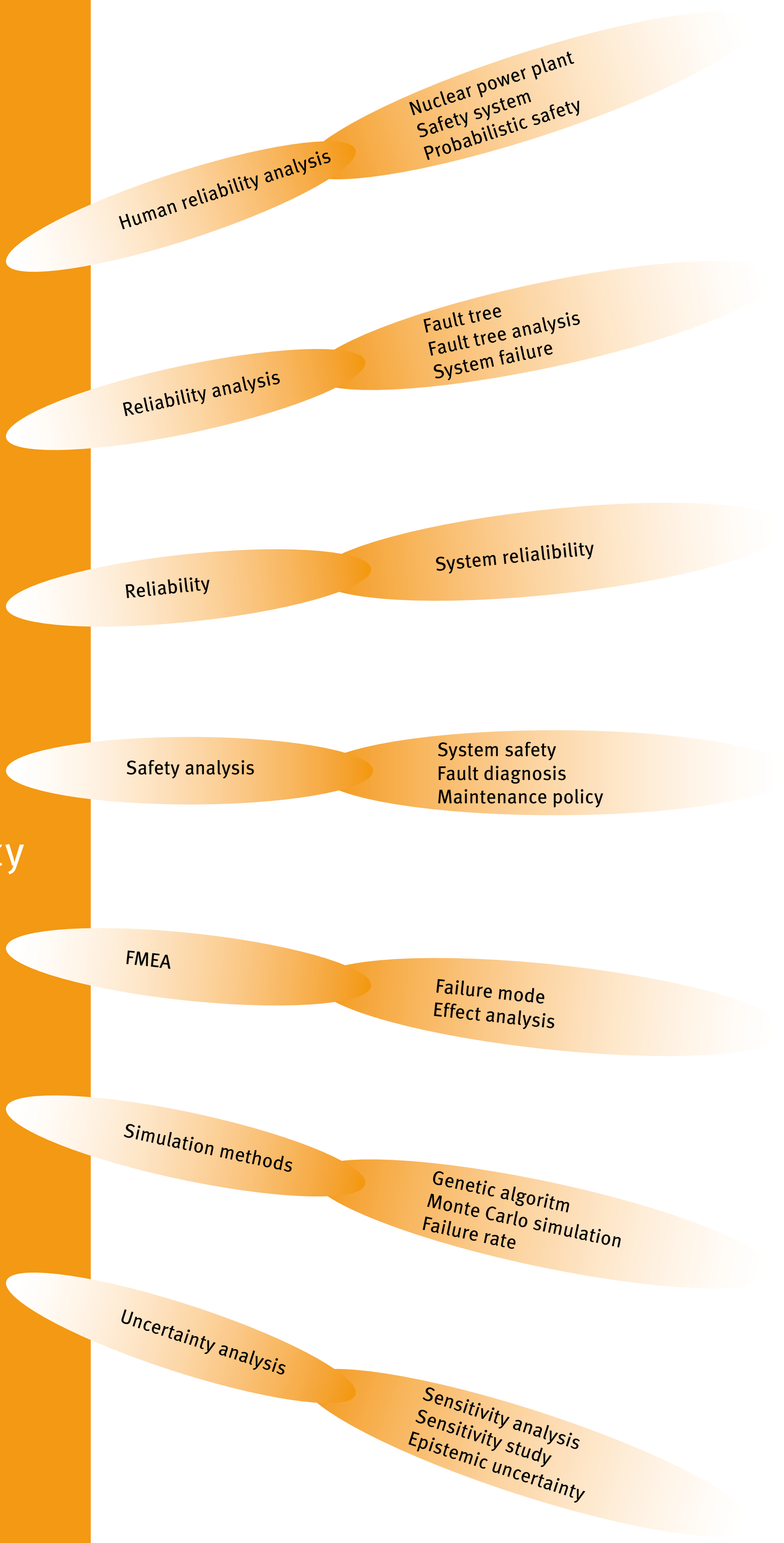
49 hazop
50 runaway or (storage and “thermal explosion”) or (storage and “thermal stability”)
51 “safe design” and (“fire endurance” or “risk reduction” or spring)
52 “tank rupture” not transformer
53 “pipe failure” not water
54 “loss of containment” not (leg* or hip)
55 “nuclear safety” and (model? or instrument or “management system” or “risk informed regulation” or “uncertainty analys[ie]s” or scenario)
56 “chemical accident*”
57 “disaster medicine” not (terroris* or earthquake)
58 “emergency services” and (disaster or chemical) not earthquake
59 “hazardous release”
60 “chemical release”
61 (“post traumatic” or posttraumatic) and chemical and (disaster* or industrial or hazard* or incident*)
62 “intercrystalline corrosion”
63 “sulfur dioxide” and (hazard*) not (chronic or climate)
64 transport* and (rail* or road*) and chemical and (safety or incident* or accident* or spill* or loss) not water
65 (Risk perception or risk communication or ((risk* or hazard*) and (communicati* or warn*))) and ((chem* and industr*) or disaster or hazard or calam*) AND NOT (“patient safety” or inundation or tsunami* or landslide* or interstell* or stell* or volcan* or forest* or flood* or drought* or erupt* or seism* or earthquake* or animal* or avelanch*)


Process Safety
Process safety
Major accident
Industrial safety
Gas industry
Mitigation
Safety culture
Occupational safety
Human error
Hazop
Transport
Chemical industry
Vapor cloud explosion
Process industry
Process plant
Severe accident
Structural design
Properties of hazardous substances
Explosion
Thermal radiation
Gas
Fire
Natural gas
Dust cloud
Flammability
Ignition
Flammability limit
Heat loss
Flame
Cone calorimeter
Thermal stability
Heat transfer
Heat release rate
CFD
Fire safety
Mathematical model
Simulation
Chemical reactor
Computer simulation
Risk analysis and risk management
System safety
Human reliability analysis
Reliability analysis
Reliability
Safety analysis
FMEA
Simulation methods
Uncertainty analylsis

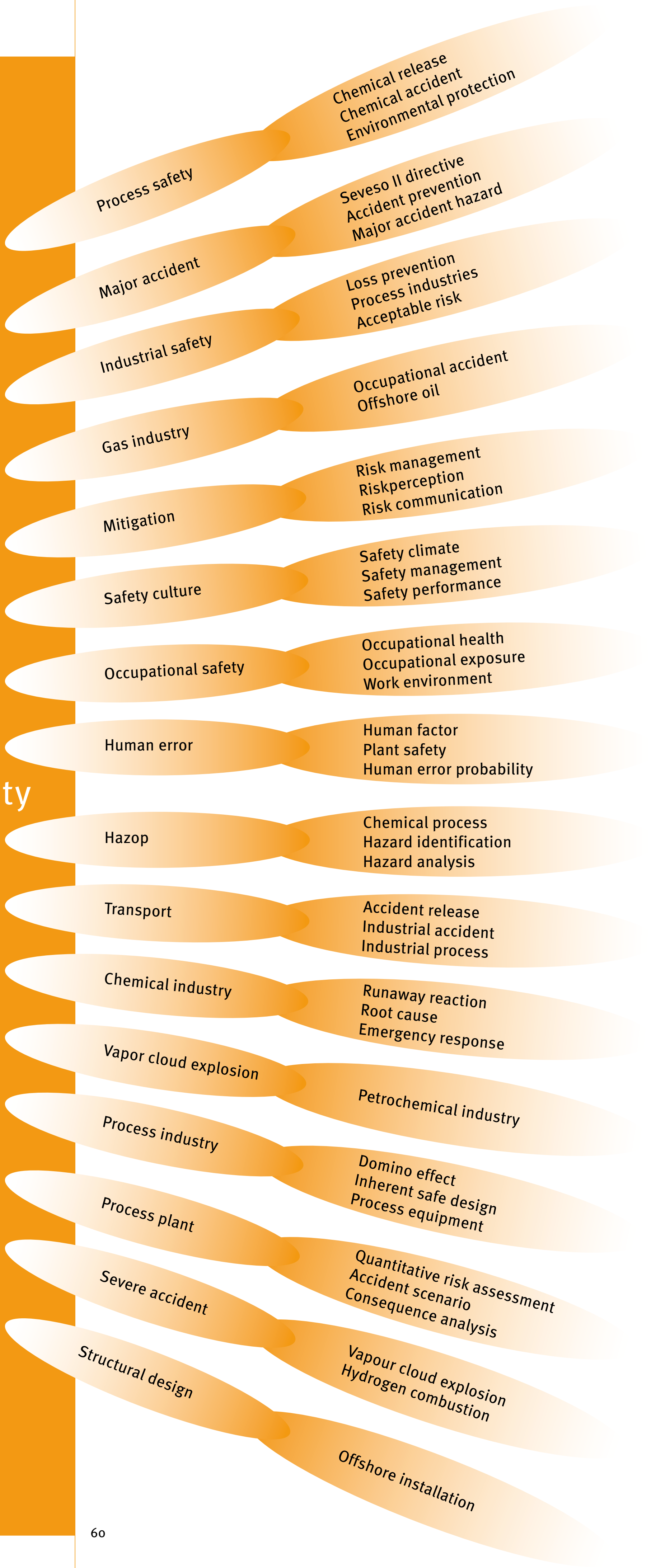
Properties of hazardous substances



System safety



Process safety



APPENDIX 4

Overzicht trends, kansen en bedreigingen met relevantie voor het kennisdomein veiligheid en gevaarlijke stoffen

In gesprekken met een dertigtal deskundigen vanuit bedrijfsleven, overheid en universiteiten zijn trends in chemie en transport, trends bij de burger, trends bij de overheid en trends bij de kennis(infrastructuur) op gebied van veiligheid en gevaarlijke stoffen verkend[41]. Aansluitend zijn de lange termijn kennisvragen besproken, die in tabel 2 en 3 op resp. pagina 35 en 36 worden genoemd. De belangrijkste trends zijn hieronder kort samengevat.

Trends in chemie en transport

- Bulkchemie groeit gestaag (met de economie). Deze groei wordt voor een belangrijk deel gerealiseerd door intensivering en schaalvergroting in bestaande installaties
- Transport van gevaarlijke stoffen groeit sterker dan de economie onder andere door toename van de import/doorvoer van bulk en halffabrikaten
- Globalisering heeft invloed op ontwikkelingen in chemie en transport waardoor rentabiliteit daalt, concurrentie en kostendruk toenemen en kennis meer internationaal verspreid wordt
- Complexere ketens – het opsplitsen van bedrijven in kleinere onderdelen en diversificatie – geven aanleiding tot suboptimalisatie van de veiligheid in de (afzonderlijke onderdelen van de) keten
- Toenemend gebruik van nieuwe stoffen als energiedrager (biobrandstoffen, LNG, waterstof) leidt ook tot nieuwe spelers met minder kennis over veiligheid en gevaarlijke stoffen en tot nieuwe risico’s
- Ruimtelijke verdichting en oprukkende bebouwing beïnvloeden uitbreidingsmogelijkheden van industrie en transport of zetten bestaande met geaccepteerd risico onder druk
- Er is de komende 5 tot 10 jaar een *brain drain* te verwachten bij de bedrijven door uittreding en pensionering op het gebied van kennis over veiligheid en gevaarlijke stoffen. Instroom van in Nederland, of zelfs in Europa opgeleide personen, is een groot probleem
- Aandacht voor veiligheid neemt toe vanuit het inzicht dat een ongeval veel geld kost en vooral imagoverlies oplevert; ook groeit de aandacht voor veiligheid omdat een storingsvrije productie dikwijls niet alleen veiliger maar ook goedkoper is
- Naarmate een langere tijd sinds een ramp verstreken is, is onderhoud van de kennis over veiligheid lastiger

De Regiegroep Chemie, waarin vertegenwoordigers van industrie, VNCI en NWO samenwerken, stelt in het businessplan voor de chemische sector in Nederland een aantal ambities: verdubbeling van de bijdrage van chemie in het BBP in 10 jaar, halvering van het gebruik van fossiele brandstoffen in 25 jaar, uitbouwen van de aanwezige technologische competenties op het gebied van industriële biotechnologie, katalyse, materialen en procestechnologie[42]. Het voorstel van de regiegroep – met 1 miljard euro aan projecten onder andere voor kennisontwikkeling – omvat ook plannen om de aanwas van gemotiveerd (en opgeleid) personeel te vergroten, het imago van de sector te verbeteren en de regelgeving te stroomlijnen.
Kennisontwikkeling over veiligheid krijgt nog geen expliciete aandacht in de plannen.

41 Zie Bijlage 1.
42 Innovatie in, door en van de Nederlandse chemische sector. Uitwerking en uitvoering van het businessplan van de Regiegroep Chemie, “Sleutelgebied chemie zorgt voor groei”. Regiegroep Chemie. Den Haag, augustus 2007.

Risicobeheersing zou echter een speerpunt moeten zijn, onder andere omdat de veiligheid van deze sector mede bepalend is voor het imago. Door toepassen van meer inherent veilige procesvoering en procesintensificatie zal de kernprocesveiligheid wellicht toenemen. Deze ontwikkeling gaat echter gepaard met een grotere doorzet van stoffen, waardoor de opslag en transportsystemen – met hun risicopotentie – groeien. Vanwege de groei van de woonkernen in de omgeving van bedrijven blijft bovendien de druk op risicobeheersing bij de bedrijven toenemen.

Ook de WRR duidt in de achtergrondstudie over gevaarlijke stoffen en fysieke veiligheid een aantal kennisvragen op het gebied van gevaarlijke stoffen[43]. Zo onderschrijft de WRR de inbreng van de AGS voor de WRR studie dat zou moeten worden bezien of het huidige onderscheid tussen interne en externe (publieke)veiligheid op termijn nog steeds functioneel blijft. Tevens gaat de WRR – zoals eerder door de AGS geagendeerd[44] – in op de mogelijkheden om het huidige criterium voor het groepsrisico (GR) te verbreden, zodat in een maatschappelijke afweging van het risico zowel de kosten als de baten kunnen worden betrokken.

Trends bij de burger

- Individualisering verandert de risicoperceptie van burgers (gevoeliger; risico-intolerantie); ook wordt de burger kritischer over bijvoorbeeld wat de overheid doet om incidenten te bestrijden
- Door verminderde interesse voor bètakennis, teruglopende instroom in technische (bèta) opleidingen en vergrijzing, neemt bij de burger de onwetendheid over gevaren en risico's toe
- Juridische aansprakelijkheid gaat een grotere rol spelen in externe veiligheid
- Radicalisering, afnemend burgerschap, dreiging van terrorisme kan de kans op het intentioneel verkeerd gebruik van gevaarlijke stoffen vergroten
- Gebrek aan informatie en kennis maakt dat van sommige risico's veel meer dreiging uitgaat dan eigenlijk nodig is. Gebrek aan kennis kan leiden tot onnodig uitbannen van overigens waardevolle activiteiten en dus tot verlamming, of althans tot ondoelmatige investeringen. Kennis geeft vertrouwen
- Kennis is vergankelijk en moet als investering over een beperkte periode (3-5 jaren) worden afgeschreven door veroudering en verloop van kenniswerkers

Trends bij de overheid

Europa/Internationaal

- Globalisering stimuleert ontwikkeling en gebruik van internationale standaarden over veiligheid en gevaarlijke stoffen
- Invloed vanuit Europa wordt sterker en leidt tot meer harmonisatie van wetgeving op dit gebied
- Uitbreiding van de EU geeft grotere verschillen in kennis over veiligheid en gevaarlijke stoffen
- Uitbreiding van de EU geeft een grotere markt voor NL als transportland en ook ontwikkelingen als import/doorvoerland van gevaarlijke stoffen

Nationaal

- Verdere ontwikkeling binnen beleidsorganen van het op centraal niveau sturen op proces en het op afstand plaatsen van kennis (in kennisinstituten) met gelijktijdig

43 Gevaarlijke stoffen. Case studie ten behoeve van het project veiligheid. Webpublicatie 36. WRR. Den Haag, oktober 2007.

44 Beleidsplan 2004. Adviesraad Gevaarlijke Stoffen. Den Haag, 2004.

een brain drain (zie ook Trends bij de kennis)

- De algemene trend bij de overheid om meer nadruk te leggen op de verantwoordelijkheid van burger en bedrijven (met gelijktijdige verschuiving van middel naar doel) zal ook consequenties hebben voor beleidsterreinen op het gebied van veiligheid en gevaarlijke stoffen
- De overheid wil niet worden afgerekend op rampen. Verrassingen mogen niet voorkomen, onvoorziene risico's betekenen zwakte van de voorbereiding

Lokaal (gemeenten en provincies)

- Decentraliseren stelt niet alleen eisen aan instrumenten maar ook aan professionalisering
- Toenemende interesse voor *risk governance*
- Toenemende rol van de rampenbestrijding – met name brandweer en geneeskundige hulp bij ongevallen – bij preventie (planvorming en proactie) leidt tot kennisvragen

Trends bij de kennis

- Door verminderde interesse voor bètakennis, teruglopende instroom in technische (bèta-) opleidingen en vergrijzing (en uittreding) is er bij de universiteiten en overheden een braindrain gaande
- Bij universiteiten verdwijnen onderzoeksgroepen die relevant zijn voor het kennisdomein veiligheid en gevaarlijke stoffen
- Prestatiemetingen voor wetenschappelijk onderzoek, zoals citatie index score, beperken de interesse voor toegepast onderzoek en vergroten de kloof tussen universiteiten en praktijk. Bedrijven kunnen met kennisvragen steeds minder terecht bij universiteiten
- Toename van complexiteit van vraagstukken over veiligheid en gevaarlijke stoffen (installaties, ketens etc.) vereist ook een verandering van type kennis enerzijds bij de beleidsformulerende en anderzijds bij de handhavende overheid. De huidige opsplitsing van proces en inhoud is onvoldoende antwoord hierop. Bij de beleidsformulerende overheid is overzicht nodig over deze complexe vraagstukken op een hoger niveau
- Het is de vraag of het de overheid voldoende zal lukken om capabele mensen aan zich te binden op gebied van veiligheidstoezicht en inspectie. De trend bij de overheid is om functies op gebied van inspectie en toezicht te bundelen. Daarbij is het van belang de benodigde specifieke kennis van de fundamentele gevaarsmechanismen te behouden. Bovendien is bij veiligheid de *'devil'* vaak in het belangrijke 'detail'

  Kennis over veiligheid en gevaarlijke stoffen is zowel bij bedrijven als bij overheid een factor van belang om te blijven zorgen voor veilige installaties en veilig vervoer, veilige bedrijfsvoering, effectieve rampenbestrijding. Tevens is kennis op dit gebied van belang om de besluitvorming over de ruimtelijke context rond installaties en vervoersassen beter te kunnen onderbouwen.

AGS

The Hazardous Substances Council of the Netherlands (AGS) has been instituted, by law, in 2004. The AGS advises the government and parliament with regard to policy and regulations concerning the prevention and mitigation of major accidents with hazardous substances.

COLOFON

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