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Nuclear Safety in Perspective

Kjell Andersson et al
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Nordic Nuclear Safety Research (NKS)

organizes joint four-year research programs involving some 300 Nordic scientists and dozens of central authorities, nuclear facilities and other concerned organizations in five countries. The aim is to produce practical, easy-to-use reference material for decision makers and help achieve a better popular understanding of nuclear issues.

To that end the results of the sixth four-year NKS program (1998 - 2001) are herewith presented in a series of final reports comprising reactor safety, radioactive waste management, emergency preparedness, radioecology, and databases on nuclear threats in Nordic surroundings. Each report summarizes the main work, findings and conclusions of the six projects carried out during that period. The administrative support and coordination work is presented in a separate report. A special Summary Report, with a brief résumé of all projects, is also published. Additional copies of the reports on the individual projects as well as the administrative work and the Summary Report can be ordered free of charge from the NKS Secretariat.

The final reports - together with technical reports and other material from the 1998 - 2001 period - will be collected on a CD-ROM, also available free of charge from the NKS Secretariat.

During the last few years a growing interest has been noted among sister organizations in the three Baltic States, especially in the field of emergency preparedness, radiation protection and radioecology. This has widened the scope of our joint Nordic work and fed new influences and valuable competence into the NKS program. The Baltic participation is therefore gratefully acknowledged.

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Nuclear Safety in Perspective

Final Report of the Nordic Nuclear Safety Research Project SOS-1

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June 2002

This is NKS

NKS (Nordic Nuclear Safety Research) is a scientific cooperation program in nuclear safety, radiation protection and emergency preparedness. It is a virtual organization, serving as an umbrella for joint Nordic initiatives and interests. Its purpose is to carry out cost-effective Nordic projects producing seminars, exercises, reports, manuals, recommendations, and other types of reference material. This material, often in electronic form on the official homepage www.nks.org or CD-ROMs, is to serve decision-makers and other concerned staff members at authorities, research establishments and enterprises in the nuclear field.

A total of six projects were carried out during the sixth four-year NKS program 1998 - 2001, covering reactor safety, radioactive waste, emergency preparedness, and radioecology. This included an interdisciplinary study on nuclear threats in Nordic surroundings. Only projects of particular interest to end-users and financing organizations have been considered, and the results are intended to be practical, useful and directly applicable. The main financing organizations are:

- The Danish Emergency Management Agency
- The Finnish Ministry for Trade and Industry
- The Icelandic Radiation Protection Institute
- The Norwegian Radiation Protection Authority
- The Swedish Nuclear Power Inspectorate and the Swedish Radiation Protection Authority

Additional financial support has been received from the following organizations:
In Finland: Fortum (formerly Imatran Voima, IVO); Teollisuuden Voima Oy (TVO)
In Sweden: Sydkraft AB; Vattenfall AB; Swedish Nuclear Fuel and Waste Management Co. (SKB); Nuclear Training and Safety Center (KSU)

To this should be added contributions in kind by all the organizations listed above and a large number of other dedicated organizations.

NKS expresses its sincere thanks to all financing and participating organizations, the project leaders, and all participants, all in all some 300 persons in five Nordic countries and the Baltic States, without which the NKS program and this report would not have been possible.

Disclaimer

Abstract

The aim of the NKS/SOS-1 project has been to enhance common understanding about requirements for nuclear safety by finding improved means of communicating on the subject in society. The project, which has been built around a number of seminars, was supported by limited research in three sub-projects:

Risk assessment
Safety analysis
Strategies for safety management

The report describes an industry in change due to societal factors. The concepts of risk and safety, safety management and systems for regulatory oversight are described in the nuclear area and also, to widen the perspective, for other industrial areas. Transparency and public participation are described as key elements in good risk communication, and case studies are given. Environmental Impact Assessment and Strategic Environmental Assessment are described as important overall processes within which risk communication can take place.

Safety culture, safety indicators and quality systems are important concepts in the nuclear safety area, but they also offer important challenges for the future. They have been subject to special attention in the project.

Key words

Nuclear safety, risk assessment, risk communication, safety culture, safety indicators, quality systems, Environmental Impact Assessment, transparency

Summary

The SOS-1 project has highlighted current developments within the nuclear energy area on a broad basis. It has taken the view that safety essentially should be understood as awareness among those concerned in regard of the control of risk. This means that safety can not be said to be fully provided for until it has been communicated, implemented and well understood. There is thus a close connection between risk communication both within (and between) the experts groups, and between them and concerned citizens.

The project has made an attempt to describe nuclear safety with a broad spectrum of perspectives. This has been done with a variety of methods, such as questionnaires, interviews, seminars, special research projects and focus group discussions. Mostly people actively working with nuclear safety (in industry, regulatory bodies, universities and consultant companies) were involved. Parts of the project have also approached lay people, but with some connection to nuclear safety. In a broad sense, the project has been devoted firstly to how one can organize for safety and secondly how risk communication can be improved.

Three elements in the safety work

Experience from high reliability organisations has brought many insights in how to organise for safety, but has also demonstrated various mechanisms, which may introduce hidden deficiencies in the safety activities. The challenge is to detect and correct such deficiencies before the risk is realised. Three key concepts for this, which have been subject to special attention in the project, is safety culture, safety indicators and quality systems.

The concept of ***safety culture***, that emerged after the Chernobyl accident, has a considerable impact on the nuclear safety work, even if it may be hard, or probably impossible, to define it so that it can be measured. The interpretation of the concept as the ability of an organisation to create safety by knowledge and involvement seems constructive and inspiring. A special aspect of the concept concerns the regulatory authorities, since for them it has a two-fold purpose. They have to review the safety culture at the utilities at the same time, as they in their own work need commitment and responsibility to develop and maintain a safety culture appropriate for a regulator.

The safety culture must continuously be encouraged and stimulated by management, especially since it can be exposed to negative pressure from both inside and outside factors. Many see the deregulation as a potential threat for the safety culture and others have mentioned the difficulty of attracting young professionals to the nuclear area.

Even if the concept of safety culture can not be accurately defined, it is connected to the concept of ***safety indicators***, which is used to reflect the safety of a nuclear

facility. The indicators should also be able to provide warnings that future performance might be in danger. Furthermore, safety indicators should reflect a development over time to make a judgement if present development is for the better or for the worse. There are many benefits with the use of indicators, but they need to be reviewed and changed regularly to better reflect the goals of the organisation.

The concept of ***quality systems*** has also been subject to special interest in SOS-1. On a generic level it can be seen to contain documentation of an agreed quality together with a description of how that quality is reached. It seems clear that the quality systems have an important task of ensuring a systematic knowledge sharing and learning.

How to improve risk communication

It can well be said that the nuclear waste area is a forerunner in developing methods and frameworks for transparency and public participation, which have also been applied e.g. in the site selection process. The Environment Impact Assessment has been an "umbrella process" for this both in Sweden and Finland, within which many new and innovative initiatives have taken place. It is believed that some of the methods developed could set examples not just within the nuclear sector, but also for other complex areas such as biotechnology. The report suggests some elements in a strategy for risk communication:

- The overall attitude (among decision-makers, industry regulators etc) must become more communicative, with the point of departure that decisions on nuclear power, siting of repositories etc are grounded in public values

- The nuclear waste issues (as well as the investigations for a fifth reactor in Finland) have shown that communication can be based on an all-covering process ("umbrella process") such as EIA or Strategic Environmental Assessment (SEA)

- Within the umbrella process there is room for testing many kinds of means such as different forms of hearings, consensus conferences etc

- There is room for the regulatory bodies to play an active role in this communication

- One should not underestimate "the public", which also possesses various areas of expertise. The experiences in Oskarshamn show that laypeople (non-professionals in nuclear safety such as politicians, civil servants, students etc) can develop capacity for "stretching" and challenging the industry implementer.

- The concept of "stretching" has become very useful for understanding how transparency can be achieved. Enhancing the stretching capacity of lay

people also in the nuclear reactor area would be good also for the utilities. In Sweden, this may be possible with the local safety councils.

The safety analysis is at the core of risk assessment for decision-making both in reactor safety and for waste disposal. One key element in the improvement of risk communication is thus the development of more communicative ways for safety analysis and performance assessment.

Sammanfattning

NKS/SOS-1 har sökt ta ett brett perspektiv på säkerhetsarbetet inom det kärntekniska området. Säkerhet uppfattas som medvetenhet hos alla berörda om de risker som kan finnas och det skydd som finns att lita på. Det betyder att säkerheten är uppfylld först när den har kommunicerats, implementerats och blivit förstådd. Det finns alltså en stark koppling mellan säkerhet och riskkommunikation, dels mellan olika expertgrupper men också mellan dessa å ena sidan och en bredare allmänhet å andra sidan.

Projektet har använt ett brett spektrum av metoder som intervjuer och frågeformulär, seminarier, särskilda forskningsinsatser och fokusgruppdiskussioner för att nå sina målsättningar. Deltagare har i första hand varit sådana som arbetar inom kärnteknikssektorn inom industri, myndigheter, forskningsinstitutioner och konsultfirmor. Delar av projektet har även involverat lekmän med någon anknytning till den det kärntekniska området.

Tre aspekter på säkerhetsarbetet

Organisationen har den mest centrala betydelsen för säkerheten. Det finns goda erfarenheter från kärnteknisk och annan industri, men det finns också exempel på hur svagheter i säkerhetsarbetet kan uppstå. Det gäller att uppmärksamma och åtgärda sådana defekter innan de ställer till skada. Tre nyckelbegrepp i detta sammanhang, som undersökts inom SOS-1, är säkerhetskultur, säkerhetsindikatorer och kvalitetssystem.

Begreppet ***säkerhetskultur***, som fick en framskjuten plats efter olyckan i Tjernobyl, har haft betydande inverkan på säkerhetsarbetet även om det kan vara svårt, för att inte säga omöjligt, att definiera begreppet så att det kan mätas. Begreppet kan närmast uppfattas som en organisations förmåga att skapa säkerhet genom kunskap och engagemang. För myndigheter tjänar begreppet ett dubbelt syfte: dels ska de granska industrins säkerhetskultur, dels måste deras eget arbete präglas av engagemang och ansvar.

Säkerhetskulturen måste ständigt uppmuntras och stimuleras av ledningen eftersom den kan utsättas för negativ påverkan av både interna och externa faktorer. Många ser avregleringen som ett möjligt hot mot säkerhetskulturen och andra framhåller svårigheterna med att rekrytera kompetens till kärnkraftområdet inom den unga generationen.

Säkerhetskulturen har en stark koppling till kvantitativa ***säkerhetsindikatorer*** som är instrument för att få mått på säkerheten. Indikatorerna bör kunna ge varningssignaler om en anläggnings säkerhetsmässiga status kan komma att minska. Säkerhetsindikatorer bör även kunna ge indikationer på utvecklingstrender så att man kan bedöma om utvecklingen har positiv eller negativ karaktär.

Att använda säkerhetsindikatorer har många fördelar med det finns också problem i sammanhanget. En risk är att indikatorerna ges för stor betydelse som målsättningar. Säkerhetsindikatorerna bör behållas som just indikatorer, vilket bland annat innebär att de bör kunnas bytas ut relativt ofta som anpassning till organisationens förändrade förutsättningar och målsättningar.

Begreppet ***kvalitetssystem*** har också uppmärksammats särskilt i SOS-1. Det syftar till dokumentation på en bestämd kvalitetsnivå och en beskrivning av hur kvalitet ska uppnås och upprätthållas. Kvalitetssystem har också en viktig funktion för kunskapsspridning och lärande i en organisation.

Riskkommunikation

Om säkerhet ska uppfattas som medvetenhet om risker och hur de ska hållas under kontroll får riskkommunikation central betydelse. I de nordiska länderna har kärnavfallsområdet varit föregångare i att utveckla metoder för riskkommunikation genom transparens och medborgarinflytande, inte minst i platsvalet för slutförvar. MKB-processen (MiljöKonsekvensBeskrivning) har varit den övergripande processen för detta både i Finland och Sverige inom vilken många initiativ till nya arbetsformer har tagits. De nya arbetsmetoder som kommit fram bör kunna vara till nytta även inom andra samhällsområden, som t.ex. biotekniken. SOS-1 rapporten anger några inslag i en strategi för god riskkommunikation:

- Attityden hos beslutsfattare, industri och myndigheter måste vara kommunikativ, och ta sin utgångspunkt i att beslut om kärnkraft och kärnavfall måste ha sin grund i samhälleliga värderingar.

- Platsvalsprocesserna för slutförvar har, liksom frågan om en femte finsk reaktor, visat att dialogen med fördel kan grundas i en ”paraplyprocess” som t.ex. MKB.

- Inom en sådan övergripande process finns det goda möjligheter att pröva olika metoder som t.ex. olika former för utfrågningar och konsensuskonferenser.

- Myndigheterna bör spela en aktiv roll i dialogen.

- Man får inte underskatta ”allmänheten” som också har expertkunskaper inom olika områden. Erfarenheter från framför allt Oskarshamn visar att lekmän (personer som inte har expertkunskaper om kärnsäkerhet som t.ex. politiker, tjänstemän, studerande etc.) kan utveckla betydande kapacitet för att ”stretcha” industrin och utmana med frågor från nya perspektiv.

- Begreppet ”stretching” har visat sig mycket användbart för att öka transparensen i komplexa frågor. En utvecklad förmåga till detta hos lekmän även för reaktorsäkerhet skulle vara en tillgång även för

kraftbolagen. I Sverige skulle detta kunna åstadkommas hos de lokala säkerhetsnämnderna.

Säkerhetsanalysen har en central roll som beslutsunderlag inom både reaktor- och avfallsområdena. Riskkommunikationen måste alltså även omfatta säkerhetsanalysen, vilket kommer att ställa nya krav på dess experter.

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1. Introduction

The aim of the NKS/SOS-1 project was to enhance, through enhanced communications and transparency, common understanding of nuclear risk and safety to enable wider appreciation of what is required for nuclear safety to be established and trusted. The project, which was built around a number of seminars, supported by limited research efforts had three sub-projects:

1. Risk assessment
2. Safety analysis
3. Strategies for safety management

Risk assessment is a necessary ingredient in identifying various risks and assessing their importance as compared with other risks. Research has however shown that risk assessment is built not only on objective considerations, but also on more value-laden and subjective approaches. That means that due considerations also has to be given to issues such as risk comparisons between different areas, values, risk perception, risk communication and transparency. The point of departure is that risk assessment is not something just for the ”experts”, but ought to involve contributions from all concerned, including laymen.

Thus, “to enhance the understanding about requirements for nuclear safety” does not simply mean that the industry experts must be better to inform the public. They must also increase their own understanding about what are the factors that govern layman’s risk assessment. Often the industry (and the authorities) has not listened carefully enough to different arguments and there might have been an underlying perception that those who express different opinions do not understand the facts.

The work within SOS-1 has included a series of interviews, focus group discussions and questionnaires within the reactor safety and waste disposal areas. Furthermore, a study on values in the performance assessment of nuclear waste repositories have been accomplished in cooperation with the European Union RISCOM –II project.

Safety analysis is concerned with the question what can be considered safe enough. It is clear that any safety analysis has to rely on a risk assessment in which various threats are identified. To these threats there are various measures introduced to either remove the risk, make it far less probable or make the consequenses less severe. The SOS-1 work in the area of safety analysis has dealt with common issues within the entire nuclear field as concerns safety assessment, such as:

- Description of “risk patterns” and regulations in reactor safety and nuclear waste disposal
- Requirements for safety assessment for the entire nuclear field

- The role of safety analysis
- Uncertainties: Their structure and how to treat them, expert judgement
- Transparency, required to make the safety analysis accessible also for stakeholders and interested citizens.

The work has essentially been done through conducting a seminar and a project about risk management in Europe outside the nuclear sector.

Strategies for safety management is the basis for the activities by which the required safety is reached in practice on a continuing basis. The strategies for safety management include, but are not restricted to, quality systems, feedback of operational experience and indicators for the reached level of safety. Sometimes safety culture of the organisations involved is considered to be the basis for safety management. In SOS-1 key components in a strategy for safety management have been addressed in seminars supported by limited research activities. Seminars have been held on the following topics:

- Safety indicators. March 17-18, 1999. VTT in Espoo, Finland.
- Safety culture. October 26-27, 1999. TVO, Olkiluoto, Finland
- Quality assurance. January 16-17, 2001, Ringhals, Sweden

A special subproject has been conducted to follow up the EU project "Organizational Factors; their definition and influence on nuclear safety, ORFA". In this subproject interviews were held with persons at utility management level. Even if the task was to prepare a new EU project, experiences and results were fed into this SOS-1 report.

In this report we start by a short description of "an industry in change" in chapter 2. We then introduce the concepts of risk and safety in chapter 3. Chapter 4 deals with risk and safety management first in the nuclear sector, then in other industrial areas. Chapter 5 deals with risk communication and trust, as well as the related concept of transparency. In chapter 6 we describe processes for how risk assessment is used in decision making. Chapters 7, 8 and 9 summarize the meaning and use of safety culture, safety indicators and quality systems in the nuclear safety work. Chapter 10 discusses some challenges that the nuclear industry meets and, thereafter chapter 11 summarizes conclusions from the project.

2. An industry in change

The nuclear industry has been faced with a lack of societal support. At the same time media and the public have been increasingly attentive to problems at the nuclear power plants. This has created a situation where small incidents, as judged by the expertise, sometimes have been perceived as serious events by the public. It thus needs to be communicated that there is from the outset common knowledge that equipment fail at times and that humans make errors and that this is accounted for in existing, well-established safety strategies. These strategies build on known safety principles, which are guiding the design, construction and operation of nuclear power plants. The NKS/SOS-1 project has addressed some of the strategies and principles for ensuring a continuing safety of the nuclear power plants. In this section we give a background description of recent and current developments in the nuclear sector.

Decreased societal support

The nuclear industry has gone through several changes since the nuclear power plants in Finland and Sweden were built and taken into operation. There have been changes in the society, in the ownership of the electric utilities, in the economic conditions for electricity generation, in regulatory requirements, in technical solutions, etc. Among the changes in the society there is not only the massive opposition against nuclear power that developed during the 70-ies and 80-ies but also changing values and expectations among young people starting their professional careers. The changes have initiated various processes of adaptation to a new situation by the nuclear utilities, which in turn has led to various changes in organisation and work processes.

A great deal of opposition towards nuclear power has been one of the characteristics of the environment in which the industry is operating today. It is easy to understand that the accidents at Three Mile Island and Chernobyl aroused a large public concern. The recent accident in Tokai-mura[1] and the scandal connected to the falsification of data at BNFL[2] are other examples of accidents and incidents diminishing public trust and confidence in the industry as a whole. With these events in mind, it is easy to understand that an accident in any nuclear power plant in the world is influencing the whole industry.

In Sweden phasing out of the nuclear industry was started in 1999 with the shutting down of the Barsebäck 1 unit. The second unit is presently scheduled for shut down in 2003. This development is contrasted by the application for a decision in principle to build a fifth nuclear unit in Finland as filed in 2000 by TVO, the company operating the two nuclear reactors in Olkiluoto.

The low societal support can also be seen in a decreasing number of nuclear engineering programmes at the universities. This development has apparently several

causes, but it has raised concerns for how the specific nuclear competence can be maintained.

Deregulation in the electricity market

A deregulation of the electricity market has been initiated in many countries over the world. The deregulation of the electricity market in the Nordic countries started in Norway in 1991. Finland and Sweden followed in 1995 and 1996 and now also Denmark has joined the deregulated market. In this process competition has been introduced in electricity production instead of former regional monopolies. Decreasing electricity prices have been the most visible effect of the deregulation. The deregulation influences the nuclear industry in several ways as discussed in a recent report by the OECD/NEA[3].

The deregulation has led to changes in the ownership of the electric utilities in a process of acquisitions and mergers. This has also resulted in a change of the societal responsibility of the utilities towards a responsibility restricted to that of a commercial company. In this development some actors on the market have mothballed excess production capacity in a hope to be more profitable. The problem in the Nordic grid is that there is a very large difference in available capacity depending on how much it rains during a year. Some experts even argue that present capacity is not enough for meeting the demands during a cold winter which follows a dry year.

Decreasing commercial profitability has forced the nuclear power plants in Finland and Sweden to search for ways to reduce their costs while at the same time pursuing demanding investment programs as required to ensure competitively in the future and meeting increasing regulatory requirements.

A decreasing vendor base

The de-facto moratorium of the nuclear power programmes has led to a decreasing vendor base. That has forced the nuclear utilities to put a larger emphasis on ensuring that crucial services are available. Some recent projects at the nuclear power plants have had components of ensuring that crucial components of knowledge are maintained for the future. In Sweden there have been large projects aimed at reconstituting the design base for the present power plants. In Finland the modernisation's of the Olkiluoto and the Loviisa plants to some extent also contained these components.

The development in electronics and computers brought digital instrumentation and control systems to the conventional industry already many years ago, but the nuclear industry has been lagging behind in this development. The main reason has been that very few nuclear power plants have been built world-wide since the mid eighties. Another reason has been the difficulty in licensing these systems. Simi-

larly computer based control rooms have, in spite of their obvious benefits, not been used very extensively.

Progress in nuclear waste management

In comparison to other countries both Finland and Sweden have made remarkable progress in the management of nuclear waste. Both countries have operating facilities for final disposal of low- and intermediate level waste and for interim storage of spent nuclear fuel. Furthermore, Finland now has one site selected for permanent disposal of spent nuclear fuel, with support from the municipality and its citizens. In Sweden, the SKB company has proposed three municipalities for site investigations with extensive drilling programs. The municipality decisions whether to accept these investigations or not are pending but the acceptance in the three municipalities seem high, although there exists outspoken opposition in at least one of the municipalities.

In comparison to the situation in the 1980s this is a significant change not just for the waste disposal as such but also for the industry at large. There may be several reasons for the present situation. One is clearly that all these communities, except one in Sweden, are communities hosting nuclear reactors. Other reasons, though, are most certainly the societal processes stipulated by legislation (the Environmental Impact Assessment concluded in Finland[4]), the active involvement by the regulatory authorities in these processes, and initiatives taken by the municipalities in order to get good participative involvement (e.g. the “Oskarshamn model in Sweden[5]).

3. Concepts of risk and safety

Risk assessment and risk management is an increasingly important matter in modern society. For example, a study[6] has shown that about 30 % of all motions submitted in the Swedish Parliament concern risk management in a broad sense. It is thus relevant to analyse what could be the meaning of the concepts of risk and safety from political, individual and technical perspectives.

Various perspectives on risk

Clearly the concept of risk involves probability and consequence as basic elements. Provided they can be determined by experience, experiment or theoretical risk assessment, this part of the risk assessment can be done in a technical/scientific manner, and different alternatives can be compared by using a simple risk measure. However, from political decision making point of view, risk management is not just a matter of calculating consequence and probability. In fact the resources society uses to reduce risk (per life saved) vary remarkably between different areas[7], which demonstrates that other factors have a strong influence.

Also, from the individual perspective, the seemingly objective risk concept has many underlying dimensions. Vlek[8] has grouped them into eleven categories:

1) potential degree of harm/fatality, 2) physical extent of damage (area affected),

3) social extent of damage (number of people involved), 4) time distribution of damage (immediate and/or delayed effects), 5) probability of undesired consequence, 6) controllability (by self or trusted expert) of consequences, 7) experience with, familiarity, imaginability of consequences, 8) voluntariness of exposure (freedom of choice), 9) clarity, importance of expected benefits, 10) social distribution of risks and benefits, and 11) harmful intentionality.

Clearly how to weigh theses dimensions in risk management decisions is often a matter of cultural norms and values. The public must be granted the right to see what the factual elements are and what are the value-laden elements in a given decision situation.
There are results from a number of questionnaire surveys of the opinions and perceptions of various risks by groups of "experts" and groups representing the public. The risks in question are not just concerned with nuclear power and nuclear waste disposal but there are also surveys concerning a broader spectrum of risks, illustrating the factors that influence a person’s perception of a certain risk. Apart from registering the differences in risk perception between experts and laymen one survey[9] has also examined each group’s perception of the other group's perception of risk. The general picture here was that the experts had a fairly correct perception of how laymen judge various risks, whereas the laymen are less successful in judging how the experts judge the same risks. Laymen tended to believe that experts saw larger risks than they actually did. This is considered an important result to note,

since it must be assumed that risk communication (and probably any other communication, as well) is enhanced if the different actors have a correct picture of how the other actors judge the risks in question.

Preconditions for safety

Safety is concerned with the absence of risk, but it can be argued that it also is connected to a certainty that all reasonable actions have been taken to remove undue risks. This implies that safety requirements are not placed only on object, but also on the work processes required to produce these objects. Safety is also associated to a general precautionary principle according to which actions should always be taken with safety margins.

The low probability high consequence events pose one difficulty in risk management. Because the events occur very seldom they cannot be managed purely using experience feedback, but they have to be assessed and reacted on using predictive models. Preconditions for safety will then be established based on assumed scenarios which can be prevented or mitigated by technical or administrative systems.

Safety is commonly viewed purely as a matter of technical and administrative safety provisions, complying as a minimum with current regulatory requirements. We have felt it to make remarkable sense to understand safety essentially as comforting *awareness* among those concerned with respect to the control of risk. Taking this view, safety could not be said to be fully provided for until such a claim has at least been *communicated* and well understood.

Awareness

It can be argued that safety always builds on an awareness of, on the one hand, possible threats and, on the other hand, of actions by which these threats can be removed. This has been further elaborated in a paper produced within SOS-1[10] which discusses the usefulness of this perspective on safety – e.g. nuclear safety - in regard of achieving a working communication on the matter between the experts and the laymen, including political decision makers, media and the public, as well as among the experts, representing different types of expertise. Safety is thus proposed to be seen in having provided for *"awareness of required conditions for remaining in control of risk*". There are two types of awareness:

1. *Awareness of the risks and what is required to ensure safety (functional assurance);*
2. *Awareness of what is required to assure that the imposed safety requirements will be permanently met in actual practice (quality assurance).*

Gaining awareness in these respects is certainly fundamental and the two sentences clearly represent *basic safety objectives.* They also represent a sound view to be emphasised in the safety work and referred to in communicating information on the

strategies used for the management of safety. One can see that awareness can be implemented as a governing principle in the context of safety culture, safety indicators and how it could help in transparency and risk communication.

4. Safety management and regulatory oversight

Safety management on the hand of the utilities and regulatory oversight are the key pillars on which safety is built in the nuclear industry and also in other industries. The division of roles and responsibility is that the utilities have the undivided responsibility for safety, which also means that regulatory oversight should never take control of any of the utility activities nor take any responsibility for the safety of the installations. The regulatory body is instead assumed as the agent of the society to set the limits of acceptability for the installations and to inspect that all requirements have been met. In this chapter we give an overview of safety management and regulatory oversight within the nuclear sector including reactor safety and nuclear waste disposal. In order to widen perspectives, we also give an overview of European risk management in other sectors, including the Seveso Directive and certain national approaches.

4.1 Safety management in the nuclear industry

Aspects of safety management

Today there is an increasing recognition that safe and reliable operation within the nuclear industry depends not only on technical excellence, but also on individuals and the organisation.[11] In general these issues are encompassed with the concept of safety management.[12] There have also been examples arising attention internationally where a completely logical development in the small has led to organisational deficiencies in the large.[13] [14] In hindsight one may argue that the root cause in these cases was a weakened understanding of the business risk resulting from a poor safety management. Also recent incidents give demonstrations of poor safety management at least in that respect that an understanding of fundamental safety issues have not reached the shop floor.

Basic safety principles

Nuclear power plant site selection, design, manufacturing, construction and decommissioning is governed by a number of basic safety principles.[15] The perhaps most important basic safety principle is the application of a graded approach in all activities which is based on the importance a function, an activity or a system has for safety. This implies a very deep understanding of how the plant behaves in various conditions and how various work activities contribute to nuclear safety.

One of the most important means to reach safety ends is the application of sound safety principles in the design and construction of nuclear power plants. The most important principle in this connection is that of providing *defence in depth*[16] of the safety. The principle relies on multiple, self-contained means for protecting each one of the multiple barriers constituting the containment of the radioactive materials. The defence-in-depth principle includes providing for means to mitigate as far as possible the consequences also of severe accidents.

Another important principle is the *single failure criterion*, which means that an assembly of equipment can meet its required purpose despite the occurrence of any single random failure in that assembly. Failures that are a direct consequence of the initiating failure are considered to be a part of the sequence of events covered by the single failure criterion. This criterion is also applied for human errors to require that a single human error should not trigger a sequence of events, which may be a threat for plant safety.

Safety assessments

Safety assessments are important parts of safety management activities. The safety assessment methodologies can be divided into two broad classes: deterministic and probabilistic methods. The deterministic methods basically make a series of assumptions of certain accident conditions and then calculate how the plant systems will interact to ensure that no margins of acceptability will be exceeded. The probabilistic methods are based on a causal model, typically derived from deterministic calculations, of how various errors and failures propagate through the plant with the aim of arriving at a probability estimate of certain defined undesired conditions to ensure that they are unlikely enough.

The probabilistic safety assessments (PSA) have had an important function at all plants in Finland and Sweden in that respect that they have helped in identifying and correcting weaknesses in the original design of the plant. The PSA is a good tool for assessing the relative importance of various sequences of events at the same plant, thereby helping to optimise the design. However, PSA should be used with great caution for comparing different plants.[17] In combination, deterministic and probabilistic methods provide an excellent ground for making judgements regarding if the safety of an installation is acceptable.

At present stages of repository development in Finland and Sweden long-term safety assessments are used to provide the safety-related basis for the sequence of decisions leading up to the realisation and licensing of the necessary waste disposal capacity.

As for the operational safety, both probabilistic and deterministic methods are used to evaluate the post-closure safety for nuclear waste repositories. The appropriate balance between the methods can be different in the various stages of repository development, and is highly dependent on the quality of the database available for the most sensitive parameters.

Probabilistic methods are utilised for two main reasons:

- The necessity to take account for unavoidable natural variability in input parameters e.g. spatial variability of hydraulic conductivity in rock

- The necessity to demonstrate how sensitive the repository safety is to uncertainties, e.g. in the understanding of important processes, in the mathematical models, and in the input data available.

The Swedish criteria for acceptable post-closure safety contain a criterion of maximum risk. Although bounding risk evaluations can be made deterministically, probabilistic approaches are necessary for a full understanding of the risk-spectrum.

Feedback of operational experience

The feedback of operational experience is a necessary means for continuous improvement of the operational safety of any nuclear installation. The most important part of the feedback of operational experience has been connected to the analysis of incidents and accidents. Whenever an incident occurs at any plant in the world, it should be rapidly analysed to reveal its root causes and, in addition, there are systems for the distribution of this information to other plants worldwide.

The nuclear power plants have internal activities for analysing their own experience together with the reported experiences from other plants in the world. When an important report is obtained it is analysed with respect to plant construction and operational practices to find possible needs for improvements.

There has also been a systematic exchange of operational experience in many programmes of the international organisations such as IAEA, OECD/NEA and WANO. At the nuclear power plants in Finland and Sweden it has been an outspoken management policy at the utilities, and at the regulatory bodies, to support a participation in these programmes. Vendors and research organisations have also played an important role in a rapid transfer of good operational experience between nuclear power plants in the world.

For repository post-closure safety the international exchange is often in the form of reviews asked for by the national organisations and done by internationally recognized experts appointed by eg IAEA or OECD/NEA.

Inspections and reviews

At nuclear facilities there are well-established practices for inspections and reviews. In principle one could say that all equipment and work activities will go through consecutive inspections and reviews to ensure that they fulfil their required quality. For example plant modifications are going through a long process from a suggestion, project plans, design, construction, installation and testing before it finally is taken into operation. All these intermediate steps are thoroughly inspected and reviewed in order to discover if there are possible safety issues that have not been properly accounted for.

The consecutive inspections and reviews should as one part include persons who are independent from the people who have been involved in the work. This requirement has often been taken care of by organising a group of experts specialising in these reviews. This group will then review not only the plant modifications, but actually most of the activities which are safety relevant such as writing procedures, issuing reports, preparing safety assessments, etc.

One type of review is connected to the quality systems, which require regular audits of all work activities. These audits are typically carried out by a small team, which through observations and interviews create for themselves an image of how specific activities are carried out. This is then compared with the instructions for the activities. Observations and deviations are then brought to the attention of the management to be corrected for instance by training, issuing new instructions or changing the organisational structure.

For repository post-closure safety the reviews are either focused on systems descriptions and safety assessments for planned repositories and coupled to the various stages in repository development and licensing, or to the recurring reporting of results and programmes for the supporting R&D.

Self-assessments and peer reviews

A continuous assessment of operational performance is also part of the safety management activities. This assessment is ongoing as a part of all activities, but to be efficient it has to be systematised. One part of the continuous self-assessment is taken care of in the line-organisation in the process of setting goals and following up their fulfilment. Other parts are taken care of in specialised meetings or group activities. One example of such meetings is the review meeting of the annual refuelling shut-down experience most nuclear power plant use.

The performance appraisals used in annual discussion between superiors and subordinates are another form of continuous self-assessments within the organisation. These discussions are important for the managers in assessing the general organisational climate together with indicators of emerging problems. In addition many nuclear power plants use various surveys to collect a more general impression of the contentedness of the personnel.

Organisations cannot rely completely on internal self-assessments, but should now and then collect also outside views on activities and performance. Peer reviews have become an established way for that purpose. Peer reviews are offered by the international organisations such as IAEA, OECD/NEA and WANO typically in a team of 10-15 experts during a two-week mission. Peer reviews can also be carried out on the initiative of the nuclear utility itself as reported by Vattenfall[18] and Sydkraft.[19] An important side-effect of the peer reviews is also that they have a function of sharing good operational practices between the nuclear power plants, because some of the participating experts often come from other nuclear power plants.

Examples of two recent Peer Reviews of post closure assessments are the reviews of the Swedish SR 97 and the Finnish Tila 99.

4.2 Regulatory oversight

Basic requirements

The regulatory requirements are always anchored in the national legislation, because they imply the exercise of authority in the case a utility fails to live up to the requirements. Another anchoring point is international agreements such as the IAEA International Safety Convention, which regulate a number of issues, which have a direct influence on various safety activities.

Regulatory oversight is the final part of fundamental safety management activities. Regulatory oversight can be divided into two parts of which one is concerned with the definition of safety requirements and the other with activities ensuring that they are followed. Regulatory requirements are anchored in national legislation to define the conditions by which nuclear installations can be constructed and operated and the process by which operational permits are granted.

Regulatory oversight was earlier very much connected to inspection and review of the technical solutions presented for various purposes. Today it is instead an outspoken strategy by many regulators to move more towards inspection and reviewing of the work processes by which nuclear power plants themselves ensure that their safety management activities are covering and efficient. Similarly the concept of risk informed regulation has also been associated to an allocation of resources for regulatory activities, which is governed by their importance for safety.

National approaches

The NKS/RAK-1 report described some of the main features of the regulatory systems in Finland and Sweden[20]. In the report it is concluded that the similarities between the two countries are predominant. The main principle is the same: the utilities have the full responsibility for safety whereas the authorities have the mission to seek assurance that the utilities take this responsibility. However, there are also differences.

According to the ”Swedish model”, SKI promotes its safety goals on the basis of the willingness, competence and ability for achieving them as naturally to be expected on part of the utilities, being ultimately responsible for the safety. The aims are similar in Finland, but the approaches differ in the degree to which full and detailed verification against prescribed rules is required.

In Finland, the operating licenses are typically granted for 10 years. The required renewal of the licenses in Finland provides for thorough re-assessment of the overall safety of the nuclear plants, largely on the basis of a compilation of the inspec-

tion and assessment work done during the previous license period. The license renewals thus serve as an important complement to the ongoing inspection and assessment activities.

In Sweden the operating licences are usually not limited in time. The purpose served by the licence renewals in Finland is instead served by periodic safety reviews, the ASAR programme. ASAR has been concerned, in particular, with management and quality issues, performance records, past and current safety issues and plans for future safety improvements. The efforts were in the early eighties for a large part devoted to developing the PSA methodology and undertaking the first plant specific PSA analyses.

Although there are differences in the arrangement of regulatory oversight in Finland and Sweden, there are also indications of a narrowing down of these differences. These first steps towards a harmonisation of regulatory oversight can most likely be attributed also to the dialogue created in the regulatory reviews.[21] [22] Based on experience from Finland and Sweden it is beneficial to maintain an efficient working dialogue on a high managerial level between the regulatory body and the nuclear installation.

A changing regulatory frame

The knowledge base obtained from an increasing number of operational years of the world fleet of nuclear power plants has been reflected in the regulation. The probabilistic safety assessments (PSA) and the preparation for severe accidents are just a few of the new requirements, which have been brought into the regulatory requirements.

Due to experiences in operation, the regulatory bodies also have had a leading role in bringing in the MTO (man – technology – organisation) area into the safety work. These questions have mostly been connected to the control room design, operator training and procedures. They have also been connected to the understanding and modelling of human actions in the control room. Lately safety culture has been brought in as a concept encompassing many of the so-called "soft" issues connected to safety, such as organizational aspects.

Finally the deregulation has brought a new regulatory concern, which is connected with problems in maintaining competence during major organisational changes. Such changes occur during mergers where rationalisation benefits are sought, but they also occur in a process of outsourcing and downsizing. Some regulators actually today require rather comprehensive safety cases when major organisational changes are planned. In a discussion with members of the senior management group at the nuclear power plants in Finland and Sweden, there were fears expressed that differences in the safety requirements may introduce undue restrictions in the competition.[23]

Regulatory bodies are often using independent reviewers to support their own decision making. Today these reviews are often carried out by international teams to ensure a broadest possible expertise. This practice may in due time bring in a better understanding of differences in national legislation and regulation.

Nuclear waste disposal

The area of nuclear waste disposal provides some extra challenges with regard to regulations and criteria, for example the long time scales involved in the safety assessment and the fact that there will be limited feedback from operational experience. However, for low- and intermediate level waste there are good experiences from the licensing of final repositories in Forsmark, Olkiluoto and Loviisa. Standards and criteria for final disposal of spent nuclear fuel and high level waste have been subject for intensive international and Nordic cooperation during at least twenty years. Both Finland and Sweden now have regulations in place, although work still remains for guidance on how they should be applied.

There has been a trend from dose criteria to more general risk related criteria. Examples of issues where the practical application of regulatory criteria needs further consideration are their use with respect to very long time scales, setting probabilities to specific scenarios, and the issue of how human intrusion should be dealt with. Another trend is that regulations now tend to include more of other aspects than the protection of humans, i.e. the protection of nature in a broader sense. For years to come, the regulatory bodies will meet programs that advance from a generic level to site selection and licensing of real installations. In Finland, a site for final disposal has already been selected and approved, and in Sweden there are three candidate areas for siting.

4.3 Other industrial areas

This section intends to give an impression of the handling of safety of other types of industrial installations than those in the nuclear industry, especially the chemical industry. Focus will be on the situation in the European Union with respect to chemical industry. The description given here is based on an overview report[24] written for the SOS-1 project.

Historical development

From the 1960's the increasing scale of operations and the introduction of new technology called for a more analytical approach than previously used for the assessment of risks from chemical facilities. Methods such as HAZOP (HAZard and OPerability analysis), which can be applied before a facility is put into operation, were developed by industry. This technique is now an "industry standard". Leading companies use HAZOP as part of a series of safety reviews during the design process. Safety reviews are also carried out periodically on existing facilities handling hazardous materials. From the middle to late 1970's the same detailed attention has been paid to protection of the environment.

In parallel with the identification of hazards came the requirement to predict their consequences. Early models used simple correlations; for example, an early correlation for predicting the effects of explosions related all explosions to an equivalent quantity of TNT. Considerable work has been devoted to this aspect of risk assessment through theoretical work, large-scale experiments and the development of computer codes. Models are now available for the most important physical effects.

A number of major accidents in chemical factories, such as the Flixborough accident in 1974[25]and the Seveso accident in 1976[26] gave rise to new legislation in many countries and were part of the background for the European Community's formulation of the directive known as the Seveso directive. A revised version of this directive, the "Seveso II directive", was adopted in 1996.

Safety- and risk-related matters within the EU are subject to consideration at three levels: (1) EC directives, (2) European/international standardisation, and (3) national legislation.

EC directives define the “essential requirements”, e.g. protection of health and safety, that must be fulfilled when goods are placed on the market or some industry is put into operation. The directives are implemented in the individual member states by national laws and directives.

Standardisation, as well as the regulation of technical risks, is increasingly being undertaken at the European or the international level. The European standards bodies (CEN, CENELEC and ETSI) have the task of drawing up the corresponding technical specifications meeting the essential requirements of the directives. Such specifications are referred to as “harmonised standards”. Compliance with harmonised standards remains voluntary, and manufacturers are free to choose any other technical solution that provides compliance with the essential requirements. This view is referred to as the “New Approach” to technical harmonisation and standardisation.

The Seveso Directive

The aim of the Seveso II Directive is two-fold. Firstly, the Directive aims at the prevention of major-accident hazards involving dangerous substances. Secondly, as accidents do continue to occur, the Directive aims at the limitation of the consequences of such accidents to man and the environment, in order to ensure high levels of protection throughout the EU in a consistent and effective way. Industrial operators that use large amounts of dangerous substances must demonstrate that they have assessed the risks and are managing them. However, no corresponding procedures are contained in the Directive; these are to be specified on a national level. As a result of differences of cultures and traditions in the member states, a variety of such procedures are currently in use.

The scope of the Seveso II Directive is solely related to the *presence of dangerous substances in establishments*. It covers both, industrial *activities* as well as the *storage* of dangerous chemicals. The Directive can be viewed as inherently providing for three levels of proportionate controls in practice, where larger quantities mean more controls. A company holding a quantity of dangerous substance less than the lower threshold levels given in the Directive is not covered by this legislation, but will be proportionately controlled by general provisions on health, safety and the environment provided by other legislation, which is not specific to major-accident hazards. Companies, who hold a larger quantity of dangerous substance, above the lower threshold specified in the Directive, will be covered by the *lower tier* requirements. Companies with even larger quantities of dangerous substance (*upper tier establishments*), above the upper threshold given in the Directive, will be covered by all the requirements contained within the Directive. Threshold quantities are specified for a number of individual substances as well as for classes of substances, e.g. carcinogens.

Important areas excluded from the scope of the Seveso II Directive include the nuclear industry, the transport of dangerous substances and intermediate, temporary storage outside establishments, the transport of dangerous substances by pipelines and the mining- and oil production industries.

Operators of "upper tier establishments" are required to produce a Safety Report within a fixed time frame, demonstrating that:

- A major accident prevention policy and a safety management system for implementing it are in effect.
- Major accident hazards have been identified and necessary measures have been taken to prevent such accidents and limit their consequences for man and the environment.
- Adequate safety and reliability have been incorporated into design, construction, operation and maintenance linked to major accident hazards.
- Internal emergency plans have been drawn up and information has been supplied enabling an external emergency plan to be drawn up (the external emergency plan is the responsibility of the authorities).

Less extensive requirements are placed on operators of "lower tier establishments". For instance, they do not need to produce a safety report, but they are required to draw up a document describing their major accident prevention policy and to ensure that it is properly implemented.

Contrary to the first Seveso directive, Seveso II explicitly sets out requirements for making the safety report and other information available to the public (possibly excluding commercially or personally confidential parts). Furthermore, the directive prescribes that member states shall ensure that the public is able to give its opinion in cases of planning for new establishments, modifications to existing establishments, and developments around existing establishments subject to the di-

rective's articles 9 or 10. These requirements for information to and involvement of the public in the licensing process to a large extent cover the requirements set out in the 1998 UN-ECE Convention on Access To Information, Public Participation in Decision-Making, and Access to Justice in Environmental Matters (the Aarhus convention).[27]

In addition to the information of the public, mentioned above, the directive requires member states to supply to the Commission information about major accidents, which have occurred, and other experience acquired with respect to prevention of accidents and limitation of their consequences. The Commission on its side undertakes to maintain a database containing this information.

National approaches

For substances identified as potentially damaging, a range of regulatory controls exists at both national and international levels. The approaches adopted in setting such controls vary across countries and regulatory agencies. In some countries, regulation is based on a precautionary stance, which requires that risks be minimised where the causes and mechanisms are unknown, or human health or the environment health is under threat. In the extreme, such an approach implies that many hazardous chemicals and activities are considered unacceptable because of the uncertain nature of associated risks. This type of approach to the management of chemical risks may neglect the benefits that the chemicals could confer on society. Less extreme interpretations of the precautionary principle stress the cost of taking precautionary measures, while others come closer to a “safe minimum standards” approach.

Other approaches to risk reduction are technology-led: for example, where they are based on the concepts of making emissions ”as low as reasonably practicable” or the use of ”best available techniques not entailing excessive costs”. Both these concepts recognise, at least implicitly, that a balance should be struck between the costs involved in reducing risks and the benefits gained from risk reductions.

The extent to which the Quantified Risk Assessment (QRA) of different industries has gained acceptance in addressing major accident hazards varies from country to country. Within Europe some regulators were very enthusiastic requiring QRA studies by law, e.g. the UK and the Netherlands. Other countries, e.g. France, preferred to adopt more of a consequence based approach, while others, e.g. Germany, focused on adherence to codes, standards and good practice[28].

At a national level, in the Netherlands, probabilistic risk analysis is a requirement of the safety report. The Netherlands has a clearly defined policy on the maximum levels of risk that are acceptable when considering land-use decisions. In the UK, the probabilistic approach to risk analysis is favoured, but up until now, quantitative risk criteria have been published only as far as the control of land-use in the vicinity of industrial facilities is concerned, whereas criteria for siting of new ac-

tivities are being developed. In Germany, deterministic approaches are extensively used in the chemical process industry to demonstrate the quality of measures taken to avoid risk inside and outside the installation. The hazard potential is primarily determined by the impact range of material and energy emissions on the basis of exceptional incidents and nomogram techniques.

A summary of some current individual risk criteria is presented in the table below. It is important to stress that these criteria are, in effect, actual or implied government guidelines, which are applied with varying degrees of rigour. Furthermore, the criteria are applied to ”members of the public” rather than to ”workers”. This distinction is sometimes made with reference to ”involuntary” and ”voluntary” risks. Broadly speaking, the limits for workers, who ”voluntarily” expose themselves to risks, are a factor of ten - or more - higher.

Country	**Nature of risk**	**Limit of unacceptability**	**Limit of acceptability**	**Criteria applied in between**
Netherlands	Fatality risk to residents close to hazardous facilities	1 in 1 million	None, but until recently: 1 in 100 million	ALARA*
Netherlands	Cancer risks	Not given	1 in 100 million	N/A
UK	Fatality risk to residents close to hazardous facilities	1 in 100,000	0.3 in a million	ALARP**
*As low as reasonably achievable **As low as reasonably practical				

Table 1: Examples of Actual and Implied Risk Criteria (per year of becoming a fatality or contracting a fatal risk)

It can be seen that the criteria levels of acceptable/unacceptable risk vary by type of risk and by country. There is broad agreement that risks above 1 chance in 100,000 per year (1 in 10,000 for workers) are ”unacceptable”. Risk levels of less than 1 chance in 100 million per year are ”acceptable”, although a risk of 1 chance in 1 million per year is ”acceptable” in many places. Generally, the level of ”unacceptable” risk corresponds to about 10% of the risk level associated with normal ”voluntary” risks (driving, working, etc.) and is similar to the higher ”involuntary” risks (being murdered, hit by a car, etc.).

In summary, for existing technologies and ”known” risks, legislation or current best practice usually ensure that measures are considered for mitigating those risks

that are likely to be regarded as ”unacceptable”. Similarly, the presence of trivial risks is accepted as a matter of course. The concern is, therefore, over what approaches are to be used in mitigating the non-trivial risks, which fall into the 'grey' area where a balance needs to be reached between risks, costs and benefits, and other wider decision criteria.

The reason that countries have different approaches to risk analysis methods and acceptance criteria probably should be sought in national traditions for how to handle safety matters and national accident experience. An important element is the fact that chemical industry has developed over many years from small enterprises with only limited potential for harming people in the surroundings to very large factories and industrial areas with a substantial hazard potential. Thus the basis for the regulation has been laid by the rules for e.g. pressurised components at a time where no international collaboration on the area existed. It, therefore, is easy to understand that regulation has grown in different ways in different countries, and that the present very large regulatory systems are not easy to harmonise.

Contrary to the chemical industry, the regulation of the "young" nuclear industry has developed in a much more uniform way - at the least in the "western world". From the very beginning the potential risk from nuclear power plants was recognised and risk analyses were undertaken. Furthermore, there has always been extensive international exchange of ideas within the field, and international organisations such as the IAEA have supported common approaches to safety.

5. Risk communication and trust

The communication of hazards and risks to stakeholders and the general public has got an increased societal emphasis. The need for a proper communication can be seen from two different perspectives, firstly people have a right to know what kind of threats they might be exposed to and secondly proper actions in the case of an accident requires a certain participation of those who live near to the risky facility. Proper communication is also required when new potentially hazardous facilities are sited. Several studies have shown that efficient communication can be enhanced in an atmosphere of trust and confidence.

5.1 Basics for risk communication

The establishment of large industrial facilities did not meet much opposition during the first half of the 20th century. Industry was equal to a prosperous future with opportunities for the population. When environmental concerns became acute in the sixties and seventies decision-makers (industry, government and local authorities) continued to do ”business as usual”. Decisions where made centrally, then announced and when ”surprising” opposition arose the decision was defended - this is often referred to as the DAD phenomena (Decide, Announce and Defend). This lack of understanding of the new environment resulted in distrust towards industry and numerous project collapses in the western world.

In parallel with this development the analytic expert community grew in size and skill. The science community produced better understanding of health effects and exposure pathways. The engineering community designed safer systems. However, the decision-makers and their advisors lagged behind regarding going beyond traditional analysis in making risk-based decisions.

Social science research described this problem early but it took quite some time before it was taken seriously by legislators and industry. Initially information was seen as the solution. By massive information everybody should be convinced. Also this strategy failed because it was still ”we and them” and no sharing of values or participation by the concerned people in the decision making process. The decision-makers have now understood the flaws in this approach as was expresses by the Swedish Minister of the Environment in 1999[29]:

> “Still an obstacle in this process is the differences in values between the experts and the public. Values, consciously or unconsciously, are always involved how we relate and judge the world around us. This will of course influence the decision-making process, even when we think we stick to facts. We are always choosing, consciously or unconsciously, which facts we want to present, the way we present them, what weight we give them or how we relate them to each other.”

All communication basically includes the following general concepts: the *intent* of sending of a message, the *coding* procedure used by the transmitter of the message, the *information channels*, the *decoding* procedure the receiver is using and the *interpretation* of the message by the receiver. For a message to be transferred correctly this implies among other things that the coding and decoding procedures do not corrupt the message, that the information channel can convey the coded information and that the intent of the transmitter of the message is not conceived as improper by the receiver. These concepts are relevant for risk communication on the basis of the following arguments:

- the initiator of the communication should not be perceived as manipulative with own hidden motives,
- the parties communicating should be able to code the message in a common frame of reference using the same language,
- the receiver of the message should be able to respond with own messages of concern,
- the communication should result in mutual understanding of frames of reference, issues of concern, actions to be taken, etc.

Risk communication is now developing into a science of its own. In 1997, *Understanding Risk*[30] gave very little space to traditional analysis, but concentrated on working with what the book calls interested and affected parties to decide what should be examined, how it should be examined, and how any decision should be made. This report stressed the need to bring in value issues from the beginning of any process and to iterate throughout the decision-making process, what the report calls an analytic-deliberative process.

5.2 Case studies in reactor safety and nuclear waste

The NKS/SOS-1 project has made attempts to get indications on the status of risk communication in the Nordic nuclear community, both in the reactor safety area and in nuclear waste disposal, which are described in this section.

Reactor safety – the case of Oskarshamn

This project[31] was initiated in consideration of a specific event in 1998 where results from a probabilistic safety analysis (PSA) related to a Swedish nuclear power plant (O2) was unfavorably compared to PSA results at the Ignalina nuclear power plant and published in the media. The headlines and articles caused concern at the national level, and especially in the local community of Oskarshamn where the nuclear power plant in question is situated. Politicians of the local government, and specifically the members of the local safety council, were suddenly and rather forcefully faced with complex technical questions involving PSA results and risk comparisons, as well as questions about their work regarding the reliability and safety of the local nuclear power plant.

Focus groups and questionnaires were used to explicitly pinpoint the problems encountered when informing about or discussing risk and technologically advanced information (e.g. PSA-results) relative to the public and across professional groups with different types of expertise. Personnel at the Oskarshamn nuclear power plant and politicians in the local safety board provided their views of essential communication problems related to their work tasks in focus group discussions. Central topics that emerged from these discussions were later used in a questionnaire study, distributed to similar groups of power plant personnel, and politicians and administrators, in the local community.

The overall conclusion of the study[32] is that it seems feasible to continue the search for reliable constructs for a better understanding of various interacting parts of the communication process.

The project paid attention to communication problems within the nuclear company and within the local safety board, between these two bodies, and between them and the "public". As these communication problems are not normally dealt with in the "day to day" work, the focus group discussions were instrumental in the elicitation of experiences.

Among the suggested initiatives that could improve communication about nuclear safety issues, the need for descriptions of nuclear technology activities provided in easily understandable language was rated highly in the focus groups, together with the need to develop measures which would increase the trustworthiness of risk information, and the education of various kinds of technical experts to become good information providers. The group of politicians emphasized more than others the need to clarify the responsibilities of various actors regarding providing media and the general public with information.

As a result of this activity the local safety board decided to change certain modes of work and also to take more initiatives of their own in setting issues on the agenda. This later decision is especially interesting since if it is carried through in real terms, it will give the board a more active role in stretching (see section 5.3.) the power company.

Hidden values in nuclear waste disposal

There are hidden values in the assessment of various solutions for nuclear waste management, and also in the radiation protection standards. For example, the application of individual dose and collective dose concerns dilution, which is a value-laden issue. There are also other examples, such as:

- Can dose optimisation be used for evaluating different nuclear waste management systems, such as reprocessing (possibly as part of a transmutation system), versus direct disposal?

- How should human intrusion be dealt with?

- How should very long time scales be dealt with?

The choice of an overall approach to the long-term management of high level nuclear waste must rely on a number of value based considerations. The very question whether to act in our lifetime for a final solution, typically including a deep repository, or to wait for a possible technical and economical breakthrough for new technologies, such us transmutation, that eventually could decrease the amount of radioactivity is maybe the most obvious value laden issue. Closely linked to this are considerations about how closed and "final" a repository should be. If the principle of retreivability leads to a "final" repository that may be left open for an undefined period of time, one values flexibility more than final solutions to the extent that the consequences for future generations can not be foreseen.

Some environmental groups prefer the "wait and see" strategy before looking for disposal sites. Others, however, would like to see even more "final " solutions (such as disposal in very deep boreholes) than the traditional methods (such as the Swedish KSB-3 method). In the technical community, on the other hand, value-laden arguments are mostly avoided, and the arguments and discussions go on in purely technical terms. This is one of the most important reasons why transparency should be enhanced.

In Sweden and Finland work on risk analysis has been done by interviews with safety analysis experts in the spring of 2001, as a joint effort between SOS-1 and the RISCOM-II project[33]. Briefly the aim of this work was to investigate assumptions of a value-laden nature that safety analysis experts have and use in their analyses, how the importance of this is recognized by the experts themselves and if information about this is provided in a transparent way.

Experts from Finland and Sweden participated in interviews and in group discussions. There were in all five persons from the Radiation and Safety Authority in Finland (STUK), the implementer Posiva Oy, and the Technical Research Centre of Finland (VTT). The Swedish interviewees were in total ten persons; six from the authorities (SKI and SSI) and four persons from SKB.

The results from this study uses a model of the entire context within which the communication about safety analysis takes place. The model includes the specified "expert tasks" within "science policy" which in a larger societal context is included in "framework politics". A general conclusion is that there is a need, and maybe a current tendency, to go from the tasks area to the science policy area to be able to clarify points of departure and assumptions for the safety analysis and related actions in waste management. With respect to information and communication vis-à-vis the public, however, it is not the "experts tasks" that are in focus but the larger context of framework politics.

The results emphasize that the underlying assumption of system understanding makes possible using ”conservatism” and “all relevant interactions can be foreseen” as arguments for safety and reliability. Furthermore the use of safety analysis as a tool in societal decision making relies on the basic assumption that the relevant questions are asked and put forward in the work.

5.3 Transparency and public participation

The RISCOM Pilot Study[34], funded by SKI and SSI has given a framework for ***transparency*** that builds on three blocks: ***facts, values and authenticity***. Facts can be clarified with scientific methods and relate to questions like “Is it true?” or “Are we doing things right?” Value-laden issues relate to questions like “Are we doing the right things?” and reflect what is considered fair and acceptable in society – what is legitimate. Authenticity is what builds trust – it has to do with the consistency between the actions of a person (or organisation) and who the person (or organisation) is, and the role in the decision making context.

To achieve transparency there must be appropriate procedures in which decision makers and the public can validate claims of truth, legitimacy and authenticity. Another element in the transparency model is the concept of ***“stretching”,*** which means that the environment of the implementer (of e.g. a nuclear waste management programme) is sufficiently demanding and that critical questions are raised from different perspectives.

Transparency is strongly linked with public participation. In fact, if you accept the RISCOM model this has to follow. It is needed for clarification of facts and values, as well as for testing stakeholders authenticity and stretching of arguments. Laymen posses important knowledge that is often neglected in decision making whereas citizens values should be reflected in the decisions. And authenticity is for the public to evaluate. Finally stretching can not take place without normal citizens because they often give new angles in testing arguments.

Transparency needs public involvement – and meaningful public involvement can not take place without transparency in procedures. Thus if we want decisions with the best possible political and societal awareness, it follows that we also want citizens participation. This is at the core of good risk communication.

6. Risk assessment for decision making

In the society there has been an increasing recognition that issues connected to risks have to be considered in a process of deciding on new possibly hazardous facilities. Due to the difficulties described earlier in this report there may be a large variety of different views on how the risk analysis should be carried out and interpreted in the decision making process. This interest in the consequences of certain large scale decisions is also in line with problems observed with unintended consequences of technology based solutions.

6.1 Current developments

Ideally, as most of us see how democracy should work, the politicians take their decisions based on the societal values they are elected to represent. Politicians consult scientists in accordance with practical needs, and the experts provide the factual material to the decision-makers. However, the expert role is not always so clean as one would expect. Experts may allow their own values to filter into their assessments, or rather, the underlying assumptions in the assessments. Experts may also have their own interest in the assessment results. Therefore, in a transparent decision- making system, the public must have a possibility to evaluate the arguments of the experts, and if the experts are credible.

The need for more influence by citizens and for better understanding about public attitudes in controversial issues, has caused a number of participative processes to emerge. Their aim is usually to capture values through the creation of small public spaces where issues are discussed. Consensus Conferences, Science Shops, Lay Peoples Panel, Team Syntegrity and the Oskarshamn model are only a few of a large number of participative and deliberative processes. On a larger scale there are broad frameworks for public participation. Two the most important ones are related to Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA).

6.2 Environmental Impact Assessment (EIA)

According to most environmental legislation, every large construction project must be assessed in relation to its environmental impact, the societal need of the project, and the alternatives (including a ”zero-alternative”, i.e. doing nothing). This Environmental Impact Assessment (EIA) is often judged as an important tool for the general public and different organisations to enter the decision-making process and influence the decisions. EIA is not only a document, where different environmental impacts are listed, but also a public decision-making process, where technical knowledge as well as social and political factors are negotiated and given legitimacy in the wider society.[35] The EIA should give a comprehensive overview of the impacts on the environment and human health and on the conservation of natural resources of a planned facility, activity or measure. It is usually the applicant who is responsible for the EIA.

Legislation requires that an EIA process has to evaluate the environmental consequences of a planned project at an early stage, and definitely before it is realised. Furthermore, it is required that alternatives, including the zero-alternative, are investigated in order to make as relevant comparisons as possible. However, the way in which an EIA process is carried out depends to a high degree on the applicant, for example if citizens are allowed to influence the process or not. Therefore, important questions of who constitutes the public and what is participation and influence have to be solved in practice.

In 1985 a Directive on the assessment of the effects of certain public and private projects on the environment [36] was adopted by the Council of Ministers in the European Union. The EU Directive includes provisions on EIA for two classes of projects, one mandatory (Annex I to the Directive) and one discretionary (Annex II to the Directive).

In 1993, a review of the Directive 85/337 was carried out and a report was published [37]. The review report emphasises the need for a better coverage of certain projects. Furthermore, consultation and public participation as well as information about alternatives were regarded as insufficient. Monitoring needed to be strengthened and there was a lack of consistency in Member States' implementation. The review process resulted in an amended Directive 97/11/EC[38]. This Directive was adopted by the Council of Ministers in 1997. In the new Directive there will be more projects subject to mandatory EIA (Annex I) and discretionary EIA (Annex II). Alternatives will be mandatory and there is a stronger emphasis on consultation and participation.

Environmental degradation as a result of development activities is a problem with a multitude of dimensions. During the last decades the focus has shifted from using reactive "end of pipe" solutions to applying proactive preventive approaches to development activities. These approaches put demands on an adequate prediction of potential impacts before action takes place. This is particularly true for complex projects where a systematic assessment is necessary.

6.3 Strategic Environmental Assessment (SEA)

During nearly 30 years Environmental Impact Assessment (EIA) has been applied to identify the environmental impacts of projects prior to decision making and implementation. Since the introduction of EIA in the National Environmental Policy Act (NEPA) in the United States in 1970, EIA has been introduced in several countries and international organisations. However, experiences of EIA in projects have shown the advantages of assessing impacts early in the process. As a result, EIA has been adopted into earlier and more strategic stages of the planning process such as policies, plans and programmes (PPP). In this context, the concept Strategic Environmental Assessment (SEA) is generally applied.

Basic SEA principles

SEA has been established worldwide, although there is a discussion on the role and the aim of SEA. There exists however a certain consensus on the core of SEA. According to Sadler[39] it should be the primary tool for integrating environment in decision making at a strategic level, and thereby preventing environmentally negative decisions. Others argue that SEA is one of many tools to reach environmental consideration in political decision-making.[40] Partidario states briefly that SEA is a step on the road towards sustainable development.[41] Sadler and Verheem[42] have given the following definition of SEA:

> *SEA is a systematic process for evaluating the environmental consequences of proposed policy, plan or programme initiatives in order to ensure they are fully included and appropriately addressed at the earliest appropriate stage of decision making on par with economic and social considerations*

The concept of SEA differs from EIA of projects in content and in process, due to the strategic level of decision making. The acronym ”SEA” can also be problematic by concealing the differences between policies, plans and programmes, which may lead to the assumption that SEA is a homogenous and standardised activity. [43]

Policy is in general defined as an inspiration and guidance for action, and a plan as a set of co-ordinated and timed objectives for the implementation of the policy, and a programme as a set of projects in a particular area.[44] Theoretically policies, plans and programmes are linked to each other in a hierarchy (tiering), however in practice these links can be diffuse and overlapping.

There is no general SEA-procedure or methodology applicable to assessments at policy, plan and programme level. As these levels of decision making differ in the processes used and in the detail and scope of the outcome of the decision (the policy, plan or programme), the SEA-approach used has to be adapted to the specific planning context. However, through practical experience and theory building of SEA a number of SEA principles have crystallised. According to Hildén et al.[45] these principles and tasks include:

i) awareness of which policy, plans and programmes that may have significant environmental impacts (screening),
ii) identification, formulation and consideration of different alternatives,
iii) scoping to identify which impacts to assess,
iv) transparent, open and documented decision making,
v) mechanism for consultation and public participation

Current SEA practices

The application of SEA is still often undertaken on a voluntary basis as to test SEA methodology in a real planning context. Many countries are however incorporating

SEA provisions in their legislative frameworks (Finland, the Netherlands etc.), that in the prolongation will lead to an extended application of SEA, mainly on plans and programmes. Some countries have already included SEA provisions for the policy level. One example is Denmark where governmental bills are made subject to environmental assessment.

In 1997, a proposal for an EU Directive on the environmental assessment of the effects of certain plans and programmes on the environment (SEA Directive) was published.[46] This can be seen as a complement to the EU Directive on EIA [47], which was implemented in 1985 and amended in 1997.[48] In 1999, an amended proposal for a Council Directive on the assessment of the effects of certain plans and programmes on the environment was published. The proposed SEA Directive sets out procedural requirements, which are similar to those of the EIA Directive. In particular, an environmental statement describing the significant environmental effects of implementing the plan or programme, alternatives and mitigation measures must be prepared.

While the strengthening of environmental considerations at strategic planning levels has been the main objective of SEA, public participation is often stressed as a crucial part of a SEA process. In the view of SEA as a tool in a framework of communicative planning, one of its main aims is to provide a knowledge basis for decision making, which involves the participation of all interested parties.

However, the communicative aspect of the SEA procedure is not always stressed. In the Swedish application of SEA within the transport and infrastructure planning at the national and regional level public participation was not an explicit part. [49] SEA is in this case seen as a tool to identify the interests of different sectors and to show the direction of the development in relation to environmental goals if the policy or plan is implemented.

6.4 Nuclear applications

In the nuclear area, risk assessment ("safety analysis" in reactor safety and "performance assessment" in the waste area) was for long time used for decision-making almost entirely in the expert community. For higher level decision making the results of risk assessment were transformed by the experts. Only in the latest decade has demands on a more commutative risk assessment emerged, especially then in the nuclear waste area. Here EIA has played a significant role – in Finland formally for the EIA for site selection, and in Sweden as a source of inspiration for opening a transparent process in the site selection program.

Lately also EIA has been formally used in Finland for a possible new nuclear power unit at either of the Olkiluoto or the Loviisa sites. The EIA reports were submitted to the Finnish Ministry of Trade and Industry, which was as the coordination authority.

The EIA reports are comprehensive descriptions of all possible environmental effects – the traditional risk assessment only being one part. In fact, the main environmental impact of the new Finnish unit would (according to the utilities) occur during construction and involve discharge of cooling water into the sea after it becomes operational.

In the field of decommissioning of nuclear facilities EIA will also play an important role. In Denmark an EIA process has just been initiated concerning the decommissioning of the research reactors and other nuclear facilities at Risø National Laboratory.

Generally accepted methods and tools for performance assessment have been developed within the expert community. The greater integration of dialogue and performance assessment will inevitably require these methods to be revisited. For the future it can be expected that risk assessment for decision-making, using EIA and SEA processes, will be much more interactive and communicative than has earlier been the case.

This would include conducting risk assessment by starting from the issues of concern among stakeholders and communicating with them during the risk assessment work. Almost certainly this would mean a broad evaluation framework considering possible alternative regulations and indicators of risk. The dialogue should build confidence among stakeholders so that they can express their concerns, feel that their concerns/values are legitimate and see that their values are being incorporated.

7. Safety culture

Safety culture was introduced as a concept after the Chernobyl accident when an international review group identified lacking concern and poor attitudes in regard of safety as the root cause for the accident.[50] The concept attracted immediate interest and several activities were initiated to concretise it and make it operational[51]. Already in 1991 the Council of State in Finland decided to amend a requirement for "advanced safety culture" in the safety regulations for the nuclear power plants[52]. In Sweden a joint working group between the nuclear safety authority and the utilities wrote a pamphlet explaining and promoting the concept of safety culture[53].

In the SOS-1 project, safety culture has been addressed in a seminar and in a field study based on interviews at the Finnish and Swedish nuclear power plants.

The Olkiluoto seminar on safety culture

The seminar, held at the Olkiluoto NPP in Finland in October 1999, gave a broad view of the developments and current approaches to foster safety culture, both at the nuclear utilities and at the safety authorities[54]. Presentations were given from a regulatory and a utility perspective. Preliminary results from the field study were presented and discussed. Two presentations from the outside of the nuclear area were also given, one discussing organisational culture in a larger context and risk management in the society in general from other regulatory perspectives. One presentation from IAEA described ongoing activities connected to safety culture. In addition group discussions on different aspects of safety culture were held and reported in plenum.

One of the generic themes discussed at the seminar was to what extent it is possible or even appropriate to try to measure the safety culture. According to one view it is important to measure to be able to control and therefore good indicators of safety culture should be applied. The other view is that culture is something, which cannot be controlled, because it is anchored deeply in common values and underlying assumptions of people. Even if the seminar did not give any definite answer to this very fundamental question, the report concludes that the interpretation of the concept as the ability of an organisation to create safety by knowledge and involvement may be constructive in giving ideas of prerequisites for safety. We should have the ambition to continuously test new ways and learn from experience in order to further develop the understanding of what is good and bad safety culture.

Views on safety culture at the nuclear utilities

A series of interviews were carried out at all nuclear power plants in Finland and Sweden.[55] In the study a total of 39 persons were interviewed on their views on safety culture, its assessment and possible threats to the safety culture. In general there were no large differences in views, but the way people answered the ques-

tions may have reflected the way in which the concept had been introduced to them and their organisation.

In the discussion of the concept itself many referred to openness in communication to make it possible also to address difficult issues. Many also made reference to attitudes and commitment and pointed out that a good safety culture builds on competence. The question on indicators of safety culture brought many observations on what can be considered as a good respective bad safety culture. On a question on how to foster a good safety culture many pointed to the example shown by the management and the need for discussing and explaining. Many saw the deregulation as a potential threat for the safety culture and others mentioned the difficulty of attracting young professionals.

The study gave a good overview of present activities at the nuclear power plants, which have an application to safety culture. The report also gave a reason for an in-depth discussion of aspects of the concept safety culture.

Organisational culture within a regulatory body

A case study was carried out to investigate the organisational culture at the nuclear regulation department of the Radiation and Nuclear Safety Authority (STUK) in Finland.[56] The goal for the study was to survey views on the present and an ideal organisational culture within STUK. The study was built on a series of development seminars in which the participants were engaged in several group exercises.

The study shows, as also was expected, that the organisational culture of STUK is strongly oriented towards norms. This was not viewed completely ideal because people also felt the need for goal orientation, support and innovation. The regulatory activities can be seen as having an indirect effect on the safety of the nuclear power plants, which means that it is difficult to get feedback on how they are carried out. A typical characteristic is also an emphasis on individual expertise, which is connected to the large span of competence required to approach all safety related issues at a nuclear power plant.

The study shows a very large commitment to safety and actions at the nuclear power plants for improving safety. A commitment to own work and a sense of responsibility are the main reasons for people to stay within the organisation. People have a shared view that the work they do as agents for the society, has an important function in ensuring safety of the nuclear power plants. The study provided many important insights and ideas for a further development of regulatory activities.

Some observations

Discussing the concept of safety culture with people one could note a slight difference in the views, which appears to depend on the educational background of the person. Engineers and others with a background in natural sciences tend to view

the concept in more straightforward ways and they often advocate the view that safety culture should be measured in one way or another. People with a background in behavioural sciences instead tend to view the concept in a more complex way, which makes it very difficult to measure and control. Relying on literature in behavioural sciences this more complex interpretation of the concept of culture seems to be more correct at least if it is understood to account for all underlying mechanism's which are influencing the behaviour of people.

Safety culture in this broader context is not something, which can be controlled by the management, but it can certainly be influenced. The way safety culture can be influenced is not through speeches and instructions, but it is through the whole atmosphere as created jointly by the management and the personnel. People are very sensitive to dishonesty, which managers have to understand in making their messages and acting believable. The creation of a good safety culture also builds on a willingness to take responsibility and to act, which means that whatever the management is not satisfied with should be enacted on strongly.

8. Safety indicators

Indicators are often used as instruments in managing organisations when it is difficult to get objective performance measurements. Performance indicators are specific performance measures (positive or negative, like the production capacity on a yearly basis and collective radiation dose, respectively), which may be assumed to reflect the general performance characteristics of a plant. Safety indicators (e.g. numbers of scrams) are similarly assumed to reflect the safety of the plant in general. Nuclear power plants have searched for suitable indicators for assessing safety and the present part of the report is intended to give an account of some issues connected to the use of safety indicators. The following text is a reflection of material presented and discussed at a NKS/SOS-1 seminar which was held at the Technical Research Centre of Finland (VTT) in Espoo, Finland at 17–18 March 1999.[57]

The definition and use of safety indicators

Supervision of operational safety is generally concerned with the *safety provisions* as well as the resulting safety, reflected in observed accident rates as compared to applied safety criteria. However, in the case of nuclear power plants, accidents may be conceived that have to be altogether excluded. The supervision will in this case be confined, in practice, to ensuring that the *safety provisions*, administrative as well as technical, are all in place, under control and adequate as to be confirmed by safety analyses.

There are clearly many aspects to be accounted for in supervising safety. Safety indicators basically represent aspects paid particular attention. All that can be observed, relating to the efficiency of the safety provisions, e.g., through auditing, regular inspection, testing, drills and follow-up of operating experience, may in fact be considered safety indicators. The observations may concern preparedness, conditions and performance of the safety provisions, partly as inferred from observed failures and incidents. Examples of primary safety indicators thus include, e.g., rate of unscheduled scrams, collective radiation exposure, numbers of defective fuel assemblies etc.

Primary safety indicators may be compounded to provide, in combination, measures of integrated features, e.g. safety system availability (in regard of the utilization of allowed repair times), coolant chemistry performance etc. Compounded indicators, usually referred to as “soft” or “safety culture indicators”, are also used in attempting to reflect the ability and the dedication of the organization and its individuals in maintaining and developing the safety provisions. Examples include rate of incidents relating to human behaviour, rate of repetitive failures, relative numbers of corrective measures required on the basis of auditing, which are completed according to plans etc. Safety culture indicators are, in addition, identified and observed through surveys and interviews.

Safety indicators are usually chosen to be countable (e.g. numbers of scrams, number of repeated errors) or measurable (e.g. tightness, chemistry index) so that simple criteria may be applied in judging them and trends may be observed. However, safety indicators should be seen in qualitative observations as well, e.g. as obtained in audits and interviews. Observations that, e.g., safety deficiencies are increasingly being revealed by chance rather than in regular quality control, or gaps are being revealed in the basic understanding of important safety aspects, thus provide important indications of needs to improve the management of safety.

Safety indicators are closely connected to safety management activities in general. The definition and use of safety indicators should, therefore, be connected to the definition and follow up of organisational goals. In principle it is possible to weigh together safety indicators from lower levels of the organisation to form more general indicators on a higher level. This is actually carried out in application of the balanced score card approach[58] that has been taken into use by some of the nuclear power plants.

International activities on safety indicators

IAEA has for a number of years worked with the task of finding a feasible set of safety indicators. A recent report describes an effort of four plants to define and gain experience from pilot implementations of safety indicators.[59] OECD/NEA has also issued a report on safety indicators.[60]

Most nuclear power plants have adopted the so-called WANO indicators (cf.Table 2), which are followed on a regular basis. The WANO-indicators give a good basis for participating plants to establish a basis for their own performance as compared with a world average. They are however not that useful in the day to day safety management activities.

USNRC has used an indicator system called SALP (Systematic Assessment of Licensee Performance) for their periodic reviews. That system was discontinued in 1998 and has now been replaced with semi-annual performance reviews. This system evaluates a number of performance indicators grouped under seven safety cornerstones: initiating events, mitigating systems, integrity of barriers to release of radioactivity, emergency preparedness, occupational radiation safety, public radiation safety and physical protection.[61]

1	Unit capability factor
2	Unplanned capability loss factor
3	Unplanned automatic scrams per 7000 hours critical
4	Safety system performance (HPSI, AFW, AC)
5	Thermal performance
6	Fuel reliability

Table 2: The WANO indicators

Some observations

NKS has sponsored earlier contributions to work on safety indicators. During the period 1991-94 the project SIK-1 contained one activity on safety indicators.[62] There was also a more detailed study[63] pondering how safety indicators can be used and which candidates would be relevant. The point of departure for that work was technical although some indicators were proposed to be connected also to the personnel and the organisational systems.

At the seminar the use of indicators at other industrial areas were also discussed. These presentations gave focus especially on indicators connected to attitudes and beliefs as contributors to safety. The indicator systems were built on the use of questionnaires, which have been analysed with a factor analysis to identify important dimensions of influence.

There are many benefits with the use of indicators, but there are also some dangers. One specific danger is that the indicators are lifted up and treated as organisational goals. When indicators are used they should remain as indicators, which also implies that they should be changed regularly to better reflect the goals of the organisation.

9. Quality systems

Quality systems are used at the nuclear power plants to ensure that all activities are carried out with an acceptable quality.[64] The quality systems can on a generic level be seen to contain a documentation of an agreed quality together with a description of how that quality is reached. The quality systems used at the nuclear power plants today are rather comprehensive covering most activities, which have a relationship to safety. In the SOS-1 project an activity to survey views on quality and experiences with the quality systems used at the nuclear power plants in Finland and Sweden and at the research reactor in Halden, Norway, was carried out. An important part of the activity was a seminar, which was arranged in Ringhals 16-17.1.2001.[65]

Views on quality and quality systems

In the study a total of 74 people at the NPPs in Barsebäck, Forsmark, Loviisa, Olkiluoto, Oskarshamn and Ringhals, and at the research reactor in Halden were interviewed concerning their views on quality and quality systems. The aim with the study was to get information on the suitability and efficiency of the quality systems, which presently are in use. Ten areas (cf. Table 3) closely connected to quality and quality systems were covered in the interviews. The interviews were taped and transcribed for further analysis. The first impressions of the study were reported at the seminar and more extensively in a separate report.[66]

As it was to be expected there was a complete agreement that quality is essential in ensuring safety at the nuclear installations. Quality was generally well understood in line with currently established definitions. Good quality systems are associated with structure and understandability. All regarded the quality audits as important, in promoting the concept of quality as well as in identifying the needs for improvements in various activities. The system of procedures, instructions and handbooks, was seen as one of the most important means to reach defined quality ends. Many of the interviewed were concerned that their systems of procedures, instructions and handbooks had been allowed to grow too large. Some of the NPPs have on voluntary basis selected to comply with ISO14000 to minimise environmental impacts and to have this activity certified.

Process orientation in the work activities has been introduced in many organisations as a means to put a larger emphasis on a smooth progress of work. In fostering quality thinking, many emphasised the need for applying a motivating approach instead of only considering the formal aspects of the quality system. Many agreed on that in a longer term there will be considerable difficulties in maintaining competence in specialised nuclear fields. The largest future challenge is to maintain public trust and confidence in the safety of the plants at the same time, as they are economically competitive. Many of the interviewed in Sweden referred to the uncertainty for the future in regard of the political decision to close down the nuclear

plants in a foreseeable future, in many instances well before the end of their economic life expectancy.

1. The quality concept
2. Quality systems
3. Topical quality related issues
4. Means to reach quality ends
5. Rules and procedures
6. Competency and training

Table 3: Areas discussed in the interviews.

Organising for quality

Quality systems can in a broader context be seen as providing a management tool for ensuring that all NPP activities are carried out safely and economically. There are regulatory requirements on quality systems that they should be documented, reviewed and updated. The quality systems are typically described as starting from top with a quality policy, which is broken down in managerial directives and requirements applying at different organisational levels. The directives and requirements link further to detailed instructions and working procedures. Today the quality systems are actually expanded and merged with other systems to become integrated management systems providing a documented account of all activities with a start from a broad mission statement and ending in the detailed instructions for tasks to be carried out.

The challenge in developing quality systems seems to be in finding a suitable structure, which makes it easy to navigate between principles, requirements and solutions. Another challenge is to break down general goals and requirements to give guidance for the practical safety activities. There is a natural strive to build good quality systems, but already the notion that a quality system is good contains a hidden danger of complacency. It seems clear that the quality systems have an important task of ensuring a systematic knowledge sharing and learning.

It is evident that modern information technology offers several opportunities to build systems, which contribute to better quality. The accessibility of the quality

system can be improved using computerised information systems with hyperlinks between different parts of the system. The transfer of procedures and documentation to a suitable computerised platform, has a large efficiency potential as compared with traditional paper based systems.

10. Challenges for the future

The SOS-1 project has highlighted current developments within the nuclear energy area on a broad basis. It has taken the view that safety essentially should be understood as awareness among all concerned in regard of the control of risk. This means that safety can not be said to be fully provided for until it has been documented, communicated and understood. There is thus a close connection between risk communication both within (and between) the experts groups, and between them and concerned citizens. In this chapter we discuss some challenges for the future, first with regard to risk communication and then to organizing for safety.

10.1 Organizing for risk communication

Expert domination

The nuclear industry evolved from newly discovered principles in physics that had been used in the nuclear weapons development. The new industry was thus characterized by advanced science, large scale projects and a great deal of secrecy. It is obvious that this was not the best environment for communication with the public. Indeed, communication was not really seen to be needed in the expert dominated society where the decisions were taken by the so called DAD (Decide, Announce and Defend) principle.

With time, however, nuclear power met increasing public opposition, which, together with weakening economy, very complex licensing procedures in the US and the accidents in TMI and Chernobyl, led to almost a total stop for new reactors world-wide. Now one can perhaps see a turning point, with the proposed new reactor in Finland motivated by e.g. future electricity demands and as a means to fulfil the Kyoto convention. It seems, however, evident that the industry must take a more communicative mode of action than was done in the early phase, so that the DAD principle is abandoned and decisions are made transparent to gain public participation on the basis of awareness.

Progress in nuclear waste

Also in the nuclear waste area, experts have dominated the decision process. In Sweden this has occasionally been criticized. In a supporting document to the R&D Programme of 1995[67], it was said by SKB that "scenario selection, or the selection of premises for different scenarios, is done by experts." KASAM[68] criticized this; “The selection of scenarios is not a science but a question of deciding which hypothetical future events need to be included in the safety assessment. This is a decision which cannot be considered to be reserved exclusively for ‘experts’.”

The choice of overall approach to the long-term management of high level nuclear waste must rely on a number of value based considerations. The very question whether to act in our lifetime for a final solution, typically including a deep reposi-

tory, or to wait for a possible technical and economical breakthrough for new technologies, such us transmutation, is maybe the most obvious value-laden issue. Another example is retrievability which leads to a repository that may be left open for an undefined period of time – then one values flexibility over final solutions to the extent that the consequences for future generations can not be foreseen. Also, the selection of a site for a repository involves more value-laden aspects than is normally acknowledged.

Still, it might be fair to say the nuclear waste area is a forerunner in developing methods and frameworks for transparency and public participation, which have also been applied e.g. in the site selection process. The Environment Impact Assessment has been an "umbrella process" for this both in Sweden and Finland, within which many new and innovative initiatives have taken place. It is believed that some of the methods developed could set example not just within the nuclear sector, but also for other complex areas such as biotechnology[69].

Some elements for improved risk communication

From this it is possible to suggest some elements in a strategy for risk communication:

- The overall attitude (among decision-makers, industry regulators etc) must become more communicative, with the point of departure that decisions on nuclear power, siting of repositories etc are grounded in public values

- The nuclear waste issues (as well as the investigations for a fifth reactor in Finland) have shown that communication can be grounded in an all-covering process ("umbrella process") such as EIA or Strategic Environmental Assessment (SEA)

- Within the umbrella process there is room for testing many tools such as different forms of hearings, consensus conferences etc

- There is room for the regulatory bodies to play an active role in this communication

- One should not underestimate "the public", which also possesses various areas of expertise. The experiences in Oskarshamn show that laypeople (non-professionals in nuclear safety such as politicians, civil servants, students etc) can develop capacity for "stretching" and challenging the industry implementer.

- The concept of "stretching" has become very useful for understanding how transparency can be achieved. Enhancing the stretching capacity of lay people also in the nuclear reactor area would be good also for the utilities. In Sweden, this may be possible with the local safety councils.

The safety analysis

The safety analysis is at the core of risk assessment for decision-making both in reactor safety and for waste disposal. A strategy for risk communication should thus include the safety analysis as one element. Generally accepted methods and tools for the safety analysis have been developed within the expert community of both areas. Greater integration of dialogue and safety analysis will inevitably require these methods to be revisited. At many levels, it is difficult to see how to reconcile the two - for example public concerns about worst case situations vs a probabilistic approach to modelling the future, and concerns about spectacular or tangible future events vs structured analysis of features, events and processes to derive base and variant scenarios to be analysed. How to do this is certainly a challenge for the future, which for the nuclear waste part is addressed within the EU RISCOM-II project.

A word of caution

Finally a word of caution may be appropriate. There is a danger that some with "communication" and "improving the decision making process" could mean that their values ("the right values") necessarily would come forward as more decisive than others. Using sophisticated methods for risk communication in such strategic purposes would be close to manipulation. Transparency should mean that both the factual issues and the value laden aspects should be as clear as possible for the decision-makers and the public. All in all, this would increase the awareness in societal decision-making. This will not necessarily lead to decision-making in consensus – there will often be remaining opposing attitudes. But after all, this is why we have a democratic system with politicians who should represent our values.

10.2 Organizing for safety

Experience from high reliability organisations has brought many insights in how to organise for safety, but has also demonstrated mechanisms, which may introduce hidden deficiencies in the safety activities. The challenge is to detect and correct such deficiencies before an incident makes them obvious. The issues discussed below are some of the insights, which have been facilitated by the discussion within the SOS-1 project.

The principle of continuous improvements

In the interviews carried out within the SOS-1 project many people made a reference to the principle of continuous improvements, i.e. to ensure at all times continuing efforts aimed at achieving further improvement of safety. This principle is not new as it was introduced many years ago as a part of the Japanese quality approach, called Kaizen. This principle has also been written into IAEA documents as one of the guiding principles in reaching safety[70]. To an outsider it may seem strange that this kind of continuous improvement is necessary or even possible. The view that something is good enough however carries the implicit understand-

ing that nothing more has to be done, which often is a first step to complacency and further neglections on a slippery road towards an accident.

The principle of continuous improvement also contains the recognition that work activities need a continuous reassessment of the people involved to define for themselves where the margins to safety are. This has also the benefit of making the safety culture overt and accessible for new persons entering the group.

A balanced approach to safety

There are many challenges to which managers at the nuclear power plants have to respond. Safety and economy are sometimes seen as conflicting, but on a long term compromised safety is always bad economy. On the other hand a proactive approach to safety requires a good economy. The allocation of resources on various activities have an important influence on safety and the management therefore has to select for instance between technical improvements in the plant as compared with investments in personnel skills.

Balanced approach to safety implies that no reallocation of resources for the purpose of safety would lead to increased safety. Increasing the resources will thus have about the same marginal influence on truly balanced safety whatever alternative means are considered. In practice, this insight is important for ensuring that available resources are made the most of in providing for safety.

There are also a number of other balances to be considered for an optimal result. Safety of nuclear power builds on traditions, but it is still necessary to be open for renewal. In all phases of plant design, construction and operation it is necessary to combine a consideration of the entirety with the details. At all levels supervision has to be combined with confidence in people and their willingness to do their best. The safety has to build on systems, but the systems cannot function without devoted and competent individuals.

Issues connected to management and organisation

The SOS-1 project investigated safety indicators, safety culture and quality systems. They are all connected to the management systems, which are concerned with formulation of goals and follow up of how they are achieved. These issues were also touched on in an earlier NKS report.[71]

Managing nuclear power plants is on one hand a matter of managing people in a dynamic business environment and on the other hand of strictly meeting the requirements for safety. This requires a great deal of assurance that the managers well understand their roles and tasks. What are the important things, where can you make compromises and where is it necessary to proceed unyieldingly?

Managing is also concerned with communicating with people. Managers have to be able to motivate, but also to sense signals of people and the whole organisation of

emerging difficulties. There will always be differences in views on various matters and then the managers should be able to see the real issue of the dispute and make a choice. Many of the managers at the plants in Finland and Sweden have a solid background in technical sciences, which certainly is a good thing, but it may also imply that they should be given training also in more general managerial skills.

Maintaining competence

A challenge for the whole nuclear community is to maintain an adequate competence over the remaining lifetime of the nuclear power plants.[72] Present prospects call for a total life-time of reactors of even 60 years, which means that even those hired today most likely will retire before the plants finally are shut down. Many of the persons interviewed in the SOS-1 project voiced concerns in this respect.

There have been discussions within the nuclear community for how to address this issue. A recent OECD/NEA report describes the issue of education and training in more detail.[73] In Finland the Ministry of Trade and Industry set up a working group to analyse the contents and scope of know-how required for a continuing the safe operation of the existing plants.[74] Research has been and will still continue to be an important component in building up the present level of competence at the nuclear power plants.[75] In Sweden both the industry and the government have taken initiatives to clarify future needs for nuclear safety competence.

International co-operation is an important component in maintaining competence within the nuclear community. The international organisations such as IAEA and OECD/NEA have had an important role in helping people to build contact nets all over the world. The research programmes of the European Union have also been very important in providing possibilities to do something more. Also the next programme of NKS has an important function to fill as a contact forum between researchers in the Nordic countries.

11. Conclusions

The project has attempted to describe and analyse approaches for achieving nuclear safety across a broad range of perspectives. This has been done with a variety of methods, such as questionnaires, interviews, seminars, special research projects and focus group discussions. Mostly people actively working with nuclear safety (in industry, regulatory bodies, universities and consultant companies) were involved. Parts of the project have also approached lay people with some connection to nuclear safety. In one report we describe approaches to risk management in other sectors.

Experience from high reliability organisations has brought many insights into how to ***organise for safety***, also with respect to mechanisms, which may introduce hidden deficiencies in the safety activities. The challenge is to detect and correct such deficiencies before an incident makes them obvious.

The concept of ***safety culture***, that emerged after the Chernobyl accident, has a considerable impact on the nuclear safety work, even though it may be hard, or probably impossible, to define it so that it can be measured. The interpretation of the concept as the ability of an organisation to create safety by knowledge and involvement seems constructive and inspiring. A special aspect of the concept applies to the regulatory authorities, concerned with regulating and overseeing the safety management on part of the utilities, and indeed reviewing their safety culture. The term organisational culture may accordingly be preferred in this case. However, competence and commitment are clearly key prerequisites also for the authorities.

The safety culture must continuously be encouraged and stimulated by management, especially since it can be exposed to negative pressure from both inside and outside factors. Many see the deregulation as a potential threat to the safety culture and others have specifically mentioned the difficulty of attracting young professionals to the nuclear area.

Even if safety culture can not be estimated with precision, it is connected to the concept of ***safety indicators.*** Due to the high level of safety required in operating nuclear plants, excluding reference to prior accidents for assessment, the safety indicators play an important role in safety management by providing measures of the current condition of safety. The indicators should be able to provide warnings that future performance might be in danger. Furthermore, safety indicators should reflect a development over time to make a judgement whether the present development is for the better or for the worse.

There are many benefits with the use of indicators, but there are also some dangers. One specific danger is that the indicators are lifted up and treated as organisational goals. When indicators are used they should remain as indicators, which also im-

plies that they should be reassessed continuously to better reflect the goals of the organisation.

The concept of ***quality systems*** has also been subject to special interest in SOS-1. Quality systems are presently to a great deal on the agenda of the Nordic nuclear power plants and have throughout been subject to intense review and development from time to time. On a generic level it can be seen to contain documentation of an agreed quality together with a description of how that quality is reached. It seems clear that the quality systems have an important task of ensuring a systematic knowledge sharing and learning.

The main challenge in developing the quality systems concerns finding structures presenting lucidly and consistently the break-down of the goals and principal requirements all the way to the detailed, procedural requirements. Modern information technology is seen to be important in facilitating overview and access to the information contained in the quality systems but is in general not fully exploited so far. Process orientation, having important bearing on quality, is in the process of being introduced and evaluated in many of the NPPs. The concept is about paying particular attention to the performance of those processes in the organisation that flow across the line organisation in order to ensure proper coordination.

In chapter 4 we made an overview of safety management in both rector safety and nuclear waste disposal. Even if the two areas in some respects are very different, the basic safety approaches to safety management and regulatory oversight are similar. We also summarized the results from a special report on ***risk management in other industrial areas*** in Europe. Also here we see similarities with the nuclear sector. For example, there seems to be a broad consensus about levels of acceptable and unacceptable risk and some of the procedural requirements are similar. Deterministic and probabilistic methods are used in the risk assessment, although they are given different importance in different countries. However, in the nuclear area, the advanced safety work is perhaps more mature with e.g. more established procedures for internal reviews and a strong regulatory framework on the national scale.

Communicating risk and safety was for long a neglected area in the nuclear sector. Although the basic principles for good risk communication are now well known, it is still a long way to go before they are fully acknowledged and used by the nuclear society at large. Here the nuclear waste area has been a forerunner with both formalised and informal methods. The Environmental Impact Assessment principles have proven to be a suitable overall framework. Well informed groups of laypeople can play a key role in providing for transparency by stretching the experts. This has taken place in the nuclear waste area but to a very limited extent in the field of reactor safety. One part of the SOS-1 work has indicated that groups like the local safety councils that exist in Sweden could play an active role in this respect.

Another part of SOS-1, conduced in cooperation with the European RISCOM-II project, has been devoted to the safety analysis of final repositories for nuclear waste. More specifically the aim was to investigate assumptions of value-laden nature that experts make in their analyses; the importance this is given by the experts themselves; and if such value-laden assumptions are made in a transparent way. The results provide a basis for more in-depth understanding about how risk communication can be enhanced in the nuclear waste area. In many cases, it is difficult to see how to reconcile expert methods and public concerns, indeed, it may be necessary to consider alternative tools within the safety analysis framework to achieve effective dialogue. This would include conducting the safety analysis by starting from the issues of concern among stakeholders and communicating with them during the assessment. This may mean a broader evaluation framework considering possible alternative regulations and indicators of risk. The dialogue should build confidence among stakeholders so that they can express their concerns, feel that their concerns/values are legitimate and see that their values are being incorporated.

A challenge for the whole nuclear community is to maintain an adequate ***competence*** over the remaining lifetime of the nuclear power plants, and beyond. Many of the persons interviewed in the SOS-1 project voiced concerns in this respect. In Sweden and Finland both the industry and the government have taken initiatives to clarify future needs for nuclear safety competence.

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Appendix 1: Acronyms

BNFL	British Nuclear Fuels Ltd.
EIA	Environmental Impact Assessment
DAD	Decide, Announce and Defend
HAZOP	HAZard and OPerability analysis
MTO	Man – Technology – Organisation
NPP	Nuclear Power Plant
PA	Performance Assessment
PSA	Probabilistic Safety Assessments
QRA	Quantified Risk Assessment
SALP	Systematic Assessment of Licensee Performance
SEA	Strategic Environmental Assessment
TMI	Three Mile Island
WANO	World Association of Nuclear Operators

Appendix 2: Reports produced within the project

Säkerhetsindikatorer inom kärnkraftindustrin; definitioner, användning och erfarenheter. Rapport från ett seminarium på VTT den 17-18 mars 1999; Björn Wahlström (red.), Rapport NKS-3, 1999.

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NKS/SOS-1 Seminarium om säkerhetskultur, Rapport från ett seminarium i Olkiluoto den 26-27 oktober 1999; Björn Wahlström, Lennart Hammar, Rapport NKS-10, 2000

Syn på säkerhetskultur vid svenska och finska kärnkraftverk; Lennart Hammar, Björn Wahlström, Jari Kettunen, Rapport NKS-14, 2000

Safety and risk analysis activities in other areas than the nuclear industry; Igor Kozine, Nijs Duijm, Kurt Lauridsen. Rapport NSK-21, 2000

L. Hammar & K. Andersson, Communicating on risk and safety in terms of awareness VALDOR Symposium Stockholm, June 1999

L. Hammar & K. Andersson, Awareness – A key to safety management and risk communication, ESREL-2000; SRA Annual Conference, Edinburgh den 14-17 May 2000

NKS/SOS-1 Seminar on safety analysis -Report from a seminar held on 22-23 March 2000, Risø National Laboratory, Roskilde; Kurt Lauridsen, Kjell Andersson, Urho Pulkkinen. NKS-34, 2001

NKS/SOS-1 Seminarium om riskkommunikation i Oskarshamn; Kjell Andersson, Rapport NKS-33, 2001

NKS/SOS-1 Seminarium om kvalitetessäkring, Rapport från ett seminarium i Ringhals den 16-17 januari 2001; Lennart Hammar, Björn Wahlström, Rapport NKS-30, 2000

Syn på kvalitetssäkring vid svenska och finska kärnkraftverk; Lennart Hammar, Bengt Lidh, Björn Wahlström, Teemu Reiman. Rapport NKS-38, 2001

Gränsöverskridande kommunikation, Problem och lärdomar i kommunikationen över expertområden; Britt-Marie Drottz Sjöberg, Rapport NKS-37, 2001

From Risk Analysis to the Safety Case. Values in Risk Assessments. Britt-Marie Drottz Sjöberg, Draft, January 2002

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Appendix 3: Financing

Financing of the studies within SOS-1 including the preproject.

Country	**Participation organi-sations**	**NKS-financing**	**National financing**	
		kDKK	**Financier**	**kDKK**
Denmark	Risø		Risø	400
Finland	VTT, Posiva, TVO, Fortum, STUK, HIM		VTT, Posiva, TVO, Fortum, STUK, HIM	820
Iceland	-			0
Norway	IFE, NTNU		IFE	140
Sweden	Karinta, ES-Konsult BMD Reserach, SKI, SSI, SKB, Kraftbola-gen		SSI, SKI, SKB, Kraftbolagen	2750
Total		3657		4110

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Bibliographic Data Sheet **NKS-60**

Title	Nuclear Safety in Perspective. Final Report of the Nordic Nuclear Safety Research Project SOS-1
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Abstract	The aim of the NKS/SOS-1 project has been to enhance common understanding about requirements for nuclear safety by finding improved means of communicating on the subject in society. The project, which has been built around a number of seminars, was supported by limited research in three sub-projects: 1) Risk assessment, 2) Safety analysis, and 3) Strategies for safety management. The report describes an industry in change due to societal factors. The concepts of risk and safety, safety management and systems for regulatory oversight are described in the nuclear area and also, to widen the perspective, for other industrial areas. Transparency and public participation are described as key elements in good risk communication, and case studies are given. Environmental Impact Assessment and Strategic Environmental Assessment are described as important overall processes within which risk communication can take place. Safety culture, safety indicators and quality systems are important concepts in the nuclear safety area are very useful, but also offer important challenges for the future. They have been subject to special attention in the project.
Key words	Nuclear safety, risk assessment, risk communication, safety culture, safety indicators, quality systems, Environmental Impact Assessment, transparency

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