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The conclusions and viewpoints presented in the report are those of the author/authors and do not necessarily coincide with those of any organisation participating in the RISCOM II project.

Foreword

This report is the final product of the contract no SKI 14.19-920900-99189 (NKS), a joint effort between the RISCOM II project and the Nordic NKS/SOS-1 project, starting 2001. It has been an interesting and very challenging work. The most demanding task of this project has been to organise responses and comments from the interviews in such a way that they both make justice to the interviewees' responses, and serve as examples of the building blocks that create the "safety case model" which summarises the findings. This work was not done in one sequence, and the "safety case model" was not an apriori theoretical construction. On the contrary, the structure of the paper and the resulting interpretations were laboriously created by bits and pieces eventually linked together by repeated listening to tape recordings, discussions at seminars, and writing and rewriting of the results. The purpose of this project was not to illustrate or explain the work of specific experts, such documentation is amply available elsewhere, but mainly to try to explain what (if any) implicit assumptions and values that guide or hinder the work related to the safe management of high level nuclear materials. Due to this focus of the work, the results presentation does not include all responses and comments from the interviews. A selection of themes was necessary to enable a comprehensive final product. I hope, however, that each of the interviewees will find evidence of something of their generous contributions in the presented material, and that I have correctly represented the expressed contents. If this would not be the case, the blame rests entirely with me, and I would look forward to a contact and discussion on the subject matter. In concluding this project I would like to thank all Finnish and Swedish participants of the interview study for their contributions and time invested in the project. I also want to thank the organisers of the RISCOM II European project, of which the current study was a small part, for their initiative to explore a highly interesting and complex subject area, for their constructive help during the project, and for their patience in waiting for the final report.

Vikhammer June 4, 2004

Britt-Marie Drottz Sjöberg

Abstract in English

The report focuses on values in risk assessment, and is based on interviews with safety assessment experts and persons working at the national authorities in Sweden and Finland working in the area of nuclear waste management. The interviews contained questions related to definitions of risk and safety, standards, constraints and degrees of freedom in the work, data collections, reliability and validity of systems and the safety assessments, as well as communication between experts, and experts and non-experts. The results pointed to an increased amount of data and relevant factors considered in the analyses over time, changing the work content and process from one of risk analysis to a multifaceted teamwork towards the assessment of "the safety case". The multifaceted systems approach highlighted the increased importance of investigating assumptions underlying e.g. integration of diverse systems, and simplification procedures. It also highlighted the increased reliance on consensus building processes within the extended expert group, the importance of adequate communication abilities within the extended expert group, as well as the importance of transparency and communication relative the larger society. The results are discussed with reference to e.g. Janis "groupthink" theory and Kuhns ideas of paradigmatic developments in science. It is concluded that it is well adviced, in addition to the ordinary challenges of the work, to investigate also the implicit assumptions involved in the work processes to further enhance the understanding of safety assessments.

Key words values, evaluations, risk, safety assessment, communication

Abstract in Swedish

Rapporten fokuserar på värderingar i riskanalysarbete och är baserad på intervjuer med risk- och säkerhetsanalytiker samt personer verksamma vid myndigheter i Sverige och Finland med arbetsuppgifter relaterade till området hantering av kärnavfall. Intervjuerna innehöll frågor om definitioner av risk och säkerhet, standarder, begränsningar respektive frihetsgrader i arbetet, datainsamlingar, reliabilitet och validitet av system och av säkerhetsanalyser, samt frågor om kommunikation mellan experter, samt mellan experter och icke-experter. Resultaten pekade på en ökad mängd data och relevanta faktorer som beaktades i analyserna över tid, vilket förändrade arbetsinnehållet och –processen från en fokusering kring riskanalys till ett mångfacetterat teamarbete i riktning mot värderingen av säkerhetsanalysen (”the safety case”). Den mångfacetterade systemtillnärmningen framhävde den ökade betydelsen av att undersöka underliggande värderingar i arbetet, exempelvis avseende integration av olika system och förenklingsprocedurer. Den visade också den ökade användningen av konsensusbyggande processer inom den heterogena expertgruppen, betydelsen av adekvata kommunikationsförmågor inom expertgruppen, liksom betydelsen av transparens och kommunikation relativt samhället i stort. Resultaten diskuteras med referens till exempelvis Janis "groupthink" teori samt Kuhns idéer om paradigmatiska utvecklingar i vetenskapen. Slutsatsen är att ett gott råd kan vara att, i tillägg till att konfrontera de normala utmaningarna i arbetet, även undersöka de implicita värderingarna i arbetsprocessen för att ytterligare utveckla förståelsen för säkerhetsanalytiskt arbete.

Centrala begrepp: värden, värderingar, risk, säkerhetsanalys, kommunikation

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Introduction

The foundation for work related to nuclear waste management is laid by laws and outlines e.g. the responsibilities of the reactor owners and the state, as represented by the authorities. The Swedish Nuclear Fuel and Waste Management Company (SKB), as well as Posiva Oy in Finland, were set up by the reactor owners in the respective countries in response to the responsibilities of planning, conducting research and to implement the physical structures leading to a safe management of nuclear wastes. The Swedish Nuclear Power Inspectorate (SKI) is the national authority supervising the nuclear waste program, and the Swedish Radiation Protection Authority (SSI) is responsible for radiation protection of personnel and of the biosphere (see e.g. SKI Rapport 99:15 and SKI Rapport 00:39/SSI-rapport 2000:17). In Finland those responsibilities are carried out by the Radiation and Safety Authority (STUK). (For a presentation of research see e.g. Salomaa and Mustonen, 2000.)

This report focuses on values that are stated or implicitly utilised in risk analytic work related to nuclear waste management. The results of an interview study, including representatives from the authorities and the entrepreneur or "implementor" firms in Sweden and Finland, will be presented below. First, however, a short introduction to the problem investigated in the study and some definitions of central concepts.

The problem is here defined as the task given in the contract, which was to:

- Outline "points-of-departure" and assumptions of a qualitative nature that experts in the area of risk analysis believe have relevance for the work of safety analysis.
- Investigate how risk analysts clarify (create awareness for themselves and others) such qualitative aspects.
- Investigate what importance risk analysts give values regarding qualitative decisions.
- Investigate how risk analysts make attempts to clarify values or "points-of-departure" in the resulting safety analysis.

Definitions of words and concepts are important, and central concepts in this report include "risk", "safety", "experts" and "values". The "risk" and "safety" concepts refer to the terminology used in risk- and safety analysis. (For reviews and discussions of the various uses and understandings of the risk concept see e.g. Lindell & Sjöberg, 1989; Sjöberg & Drottz-Sjöberg, 1994; Drottz-Sjöberg, 1991; Riskkollegiet, 1991.) "Experts" in this report refer to persons knowledgeable in risk- or safety analysis, among other specialities. The interviewed experts worked in the Swedish or Finnish authorities related to nuclear safety and radiation protection (SKI, SSI and STUK), and in the Technical Research Centre of Finland (VTT), Posiva Oy and SKB.

"Values" or "value judgements"[1] refer in this context to qualitative assumptions that are expressed as such explicitly, or that can be inferred from the context, as a basis upon which reasoning or conclusions are based. Values are to be understood as cognitive perspectives or "building blocks" in a process of e.g. thinking or planning. The concept of "evaluation", on the other hand, is understood as more related to a process of

[1] In Swedish "värderingar".

deliberations. “Evaluation” is often used in decision-making frameworks and includes considerations based on data, information and preferences or choices, resulting in decisions. Svenson (1990) described the decision process as follows: *“The process of making a decision starts with a decision problem appearing and the realization of the need for a decision. It continues with the identification and/or construction of decision alternatives followed by the remaining parts of the decision process*.” (p. 18). Svenson also highlighted that “*The consequences of a decision are important because they constitute input for later decisions*.”

In the illustration of a decision-analysis process given in Figure 1 below (from Muhlestein & Pierce, 2000) it is suggested that evaluations and values are integrated within the decision-making process.

In contrast to this decision-making framework, the “values” sought in the present study need not to be based on apparent deliberations or any realisation that there is a need for problem solving, or decision-making. The specific aim of the interview study was to try to outline assumptions or “values” that helped guide, or otherwise influenced, the safety analysis process without getting explicit attention. The discussion, following the presentation of results, will address the pros and cons of placing the step of “Identify key assumptions” task from the Muhlestein and Pierce model inside of a decision-making framework.

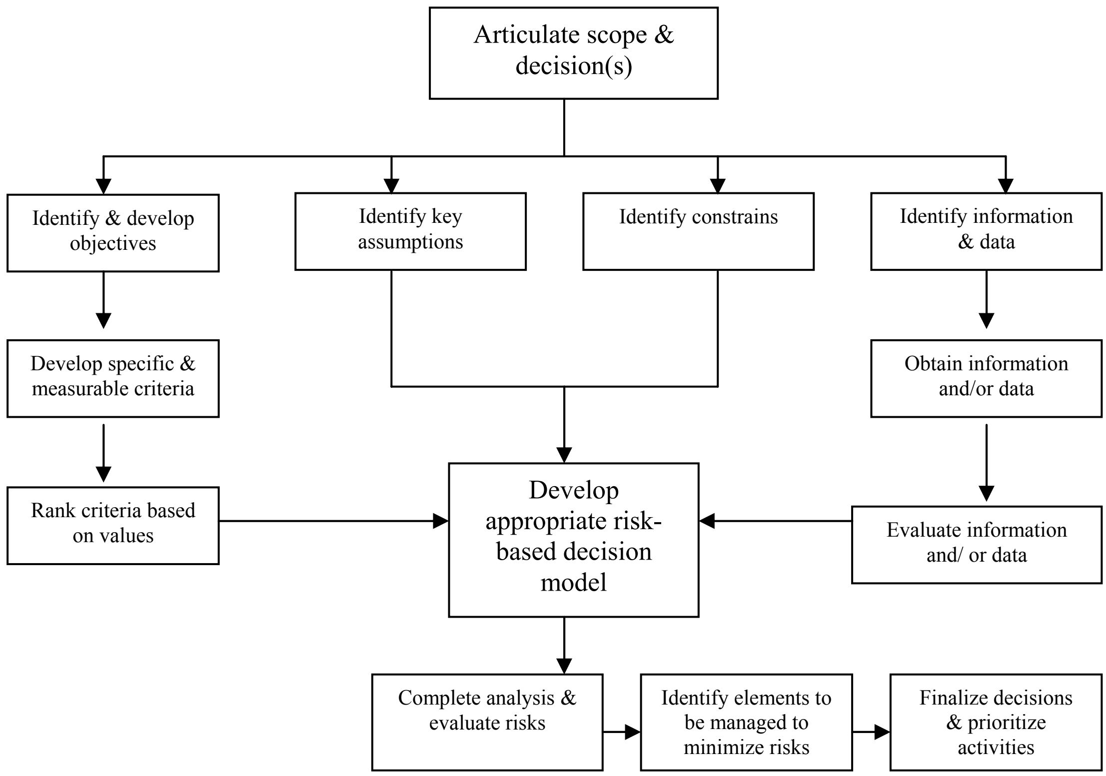

Figure 1. *A schematic model of a decision analysis process (from Muhlestein & Pierce, 2000).*

Method

Interviews

The interviews were semi-structured, i.e. the questioning followed a script of written questions but was not restricted to those questions or the structure planned for the interview. Thus, a semi-structured interview allows for follow-up questions and in depth inquiries of central themes. An interview was estimated to last approximately one hour per person, but the answers were often elaborate and there were plenty of additional comments why a trade-off between time and content was necessary. Almost no interview succeeded in including all of the prepared questions, but the experts could use time to elaborate on chosen themes and care was taken to include at least some questions from each main subject area of the interview script. The interviews were tape recorded, with the exception of one phone interview and technical problems disturbing two interviews. Information taken from these occasions is based on written notes.

All respondents were given a short introduction of the purpose of the study and the interview, and they were asked questions about their work, expertise and educational background. The main subject areas outlined in the interview script included questions about (1) work tasks, especially related to risk analysis, (2) definition of risk, (3) work with scenarios, models and data, (4) uncertainty and safety margins, (5) development of risk analysis over time, (6) considerations in relation to choices of scenarios, models or data, and (7) communication aspects.

The questions aimed at eliciting views of, e. g. purposes of risk analytic work, how (and if) risk assessment tasks can be standardised, what advantages and restrictions are involved due to computer capacity, availability of programs and analytic models. There were also questions about how results are validated and what characteristics that distinguish a good work product. It was of interest to get descriptions of how scenarios and models are chosen for the analyses, the bases for changes of criteria, parameters or data, and how one viewed the reliability of the analyses. Regarding uncertainty and safety margins questions were asked about acceptance criteria and standards, and e.g. change of standards and margins over time.

A few questions concerned the extent to which the risk analyst would make efforts to present results for experts from other fields and for novices or the general public. The last section asked if there were subject areas or types of knowledge that are especially difficult to explain to colleagues in other fields or to the general public, and how one could improve communication.

Most of the interviews in Finland, as well as the entire discussion session, were conducted in English. The language used in the interview project in Sweden was Swedish, and since this paper is written in English the author has made the translations of the interviewees' statements. In an attempt to clarify some concepts that have several connotations, the Swedish translation will sometimes be given in a footnote.

In addition to the individual interviews, conducted in April to August 2001, there were two group discussions. The first session was held in Helsinki (April 25, 2001) in connection with the interviews. The second gathering was held in Stockholm (November 22, 2001) at a combined RISCOM II seminar and group discussion session.

Participants

Experts from Finland and Sweden participated in interviews and most also participated in the later 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 consisted of totally 10 persons, six from the authorities (SKI and SSI), and four persons working at SKB. The experts had educational backgrounds in the natural sciences or in technology, e.g. degrees in physics, chemistry or mathematics, or degrees in various civil engineering specialities. They worked in the areas of safety assessments, system analysis, radiology, long term safety, localisation of the repository, canisters and corrosion issues, ecological modelling, and with spent nuclear fuel and the migration of radionuclides. There were several specialist areas represented, e.g. water chemistry, geology, biosphere and climate issues, criteria setting and control, computer systems and co-ordination of research. The participants were to different degrees directly involved in work connected to the nuclear waste programs in the respective countries.

Structuring and analysing of the collected materials

Interviews produce a vast amount of information. In contrast to the highly structured interview, the semi-structured variant allows for follow-up questions and elaboration of themes that are of specific interest and relevance relative the interviewee. The latter method was used in the present study because the investigated problem was related to a multifaceted work domain and various kinds of highly specialised experts. In such a context the semi-structured interview provides the most sensitive tool for detecting and exploring aspects within a complex problem area. The material resulting from the semi-structured interviews therefore included both responses to key questions and elaboration on unique themes. The task of the project was to extract implicit values and value judgements guiding the experts' work from those interviews.

The structuring process developed in several steps. Firstly, responses to specific questions were noted, and from these were various content themes extracted. Secondly, the task of organising the extracted themes into a coherent framework started. In the third and last step, the resulting models and conclusions were presented at a seminar in Stockholm where several of the interviewed experts were present. The seminar served as a forum for testing the face validity of the models and interpretations resulting from the collected materials.

The second step of the structuring process was the most demanding. Results were to be presented as stated on the one hand, and various idiosyncratic themes should be analysed with regard to explicit explanations, as well as implicit value assumptions, on the other. In addition, the results and interpretations should form a valid and coherent product that offered new insights or perspectives to experts already highly skilled in their work.

The results presented below include the skeleton building blocks from the interviews. Summaries as well as selected citations from the interviews are used to exemplify the developed models that illustrate assumptions and implicit values in the extended expert work area. The material is organised into five parts: a) assumptions in communication, b) risk definitions, risk and safety analyses, c) degrees of freedom, standardisation and constraints, and d) reliability, validity and transparency, which all contribute to “the safety case model”, explained in the summary.

Results

An overall model for clarifying assumptions in communication

A task for this report was to investigate the existence of qualitative assumptions that risk analysts saw as relevant to their work in the area of safety analysis. The experts usually described this work as framed by their specific competence and work assignments in relation to the interaction with the implementers or the authorities, respectively, and often extending the communication to the general public.

A structuring of the qualitative material, especially related to the communicative aspects, was necessary during the initial analysis of the results from the interviews. In the same interview, a respondent could describe his or her type of expertise and specific tasks, how it was related to other areas, the theoretical, legal and practical considerations underlying the current state-of-affairs, as well as comment on specific problems, the validity of assumptions or results, and communication aspects. There were also the results from the group discussions to consider and report - discussions that reflected a level of substantial sophistication. It therefor became necessary to structure an overall approach for the presentation of the results. The strategy chosen was a top-down process, where a general basis would precede the presentation of more specific areas and details. This choice of a presentation strategy led to a communication based first step, focusing on the parts of the interviews related to type of expertise, responsibilities and communication. Interview responses regarding these topics were used to present selected results and to create an overall model that could serve as a framework map of the discussed themes.

The emerging model, presented in Figure 2 below, organises the qualitative data material into a general, coherent structure on the basis of the responses from the interviews. The figure places the tasks and interactions related to the safe management of high level nuclear waste into a societal, communicative framework.

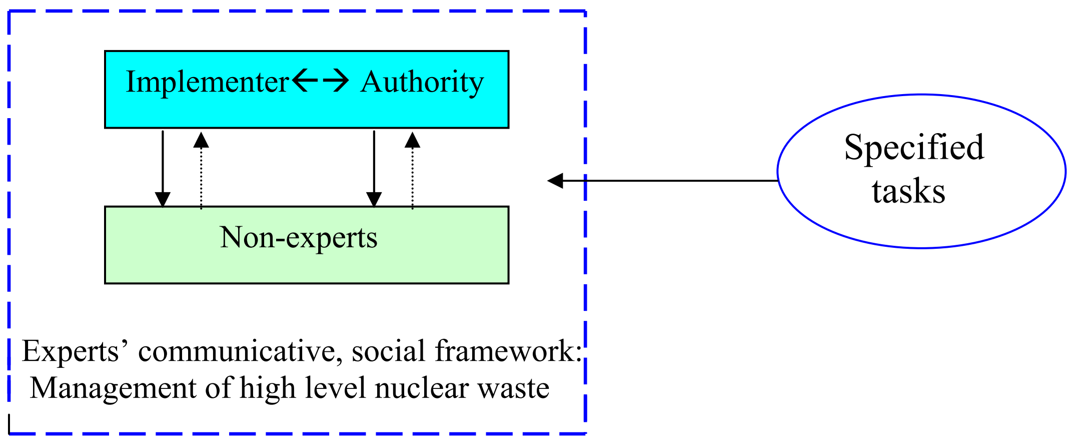

Figure 2. *Part of an emerging model for communicative parts and ways.*

The square of Figure 2 encloses a core relationship between the implementers and the authorities. These central actors then relate to the general public or the "non-experts". The former relationship is one between "the doer" and "the controller", and the reason to placing these actors within the same space is based on their close and continuos interactions. Their placement also aims at highlighting that the collective expert status carries more weight than individual, specific expert roles within the larger interaction context. The expert status relative various nuclear waste management issues becomes the main divider *vis-a-vis* non-experts. The figure also shows that the specified tasks assigned to experts of various kinds enter into a larger communicative social framework with already established groupings and networks of "non-experts". The communicative framework is, in this context, restricted to the issue of safe management of high level nuclear waste. The restriction is illustrated in the figure by the "specified tasks" arrow entering into the square. It was from this perspective of specified tasks that the experts explained their roles and relations to work partners, authorities, and the general public.

Asked about who is the customer of their work, the experts described several customers, i.e. the employer, the authorities, the implementers and the general public. The experts in SKB and Posiva Oy often mentioned their company or owner first when asked about who is the customer and then added that their work was certainly also for the authority and ultimately for the general public.

Examples from the diverse group of experts are "I work for Posiva management, the safety authorities and the public", "STUK, and the Commerce and Industry Ministry", "SKB is owned by the power companies, but the ultimate customer is the public", and "the Swedish people in a way through the authorities and the company, but also for my own interest". One of the experts from an authority said "the Swedish people, not the implementer". Another respondent mentioned that there are "several customers, within SSI as a first step, also SKB and the general public, and locally in the municipalities". "The customer of SKI is the general public and those who could be involved, for example also the representatives of the industry".

It seemed that the representatives of the authorities, as well as those of the implementers, were well aware of the immediate as well as the ultimate customers. Very few neglected to mention the larger society within which they worked. It was therefore concluded that the importance of communication relative to the general public had a high degree of saliency in the minds of the experts.

The acknowledgement of responsibilities relative to the public was also reflected in responses to a question about 'the good work product', although here it was made clear that the immediate purpose was to develop the specified work, and to satisfy the reviewers. A good work product was generally described as well structured, easy to follow, transparent, the result of good science, well written and communicative with respect to what had been done and the results, and it included descriptions of what was problematic. A few examples from the mentioned parts of the interviews follow below.

“SKB is formally owned by the nuclear companies in Sweden, so one can say that we work for them, but of course, the ultimate customer is on the one hand the authorities and on the other the general public…”

“You started by asking me who is the customer … and I thought you were considering expert groups and communication, and I suppose you could also ask who is the customer here … and I think that the work may have different customers at different times… and I think they should talk the language that the customer speaks at any time … What this leads to is a layered approach, it’s not possible that the experts completely get rid of the jargon – they need the jargon to be precise – but, of course, they should also be able to use other languages… to master several languages as ordinary people do when they are speaking different natural languages. But (…) when dealing with the public at large (…) why, in fact, should the public at large know so much about waste properties or migration things – I don’t think they do have to (….)”

Responses to follow-up questions on reasons for specific choices, or directions taken, within their areas of work sometimes steered the interviews away from the specified tasks of the experts. Such themes could best be described as meta-analytic considerations. For example, it could be mentioned that the tasks performed had their origin in choices or decisions from many years before, from the political arena, or due to scientific achievements and theoretical developments, that had come to influence practices, choices or major decisions. The work performed would partly be the result of such prior long-term decisions, strategies, or influential scientific achievements. Consequently, achievements and other developments in the wider area of “Science policy” that in some way influence the current work could be added to the previous Figure 2. The mentioning of political steering factors and the frequent references to the general public as the ultimate customer provided an overall frame of reference in the completion of the model. Figure 3 shows the inclusion of the former figure of specified expert tasks into a larger societal context (here called “Framework politics” and “Science policy” respectively). The arrows suggest exchange of influences across areas and groups. See Figure 3.

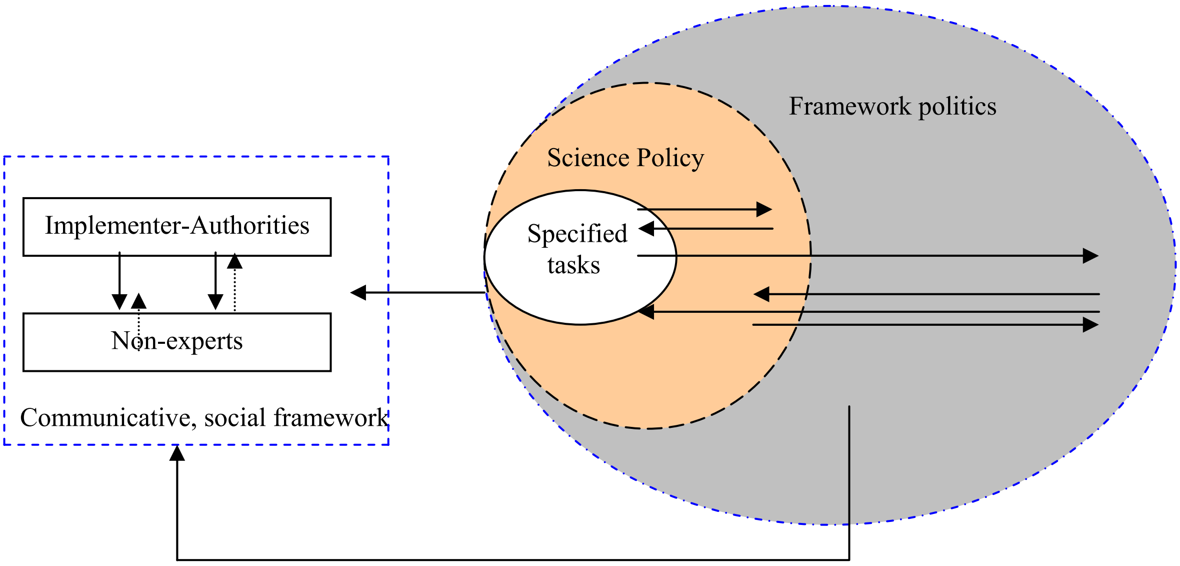

Figure 3. *A communication model of actors, arenas and interactions. The influences of the arenas "Science policy" and "Framework politics" are added to the previous Figure 2.*

The figure illustrates that the experts' "specified tasks" lie embedded within a "Science policy" domain that in turn functions within an overall social framework. Interpreted into the current context of nuclear issues and waste management the Swedish nuclear referendum in 1980 could be an example of influences from the "Framework politics" arena, whereas the development and refinement of the KBS-method over a long time period by the Swedish entrepreneur would be an example of "Science policy" influences.

The arrows in the figure indicate interactions and influences. The attention will here be focused on only one arrow, that is the one leading from the large area of "Framework politics" to the box on the left hand side of the communicative social framework of the experts. The arrow represents all the influences that non-experts bring into the restricted communication area of the experts from the wider societal or political domain. The arrow might also highlight an implicit assumption among some professionals within the area, i.e. that discussions of nuclear waste safety and management are to be confined to the knowledge and work domains of experts. This is not the place to discuss the validity of such a claim, or implicit assumption. Here is the place, however, to point out a possible underlying assumption that could steer experts' expectations into too narrow cognitive mindsets when interacting with the general public.

Risk definitions, risk and safety analyses

In the interviews risk was usually defined as the probability times consequences, but the risk definition did not always seem to be a matter of great concern. What seemed to matter, however, was the use of "risk" vs. "safety". Although some experts did not explicitly discuss the distinction, others did. The risk concept seemed to apply to a "lower level" type of analysis, more easily determined with respect to its components and structure, whereas the concept of "safety" was used for estimating composite models' or systems' reliability. Examples from the interviews are presented below.

"I use the standard definition of probability times consequences… but we don't use so much to present risk figures, because I don't think it is possible to give the quantitative estimates for the likelihood of different scenarios, …it is almost impossible to give a quantitative, meaningful likelihood for most of the cases…(…) we don't speak very much about risk… I think that nowadays in safety assessment and the safety case, the meaning of numbers is going down, and down, and down, and it's more about argumentation and how you present your system and how the system behaves, and then we <u>do</u> some calculations, but … they are not so important as they used to be, say 15 years ago".

Responses from the experts to a question about the *aim of risk analysis* were often straightforward. It was basically a matter of meeting the criteria and requirements set for their work by the Ministry or the authorities. The elaboration around this theme could vary somewhat due to the respondents' role or work tasks. For example, one person in the Finnish group explained that it is the Ministry that presents the official criteria and that it is important to show that the waste, especially the spent nuclear fuel, is managed safely. As another example, a representative of the Swedish entrepreneur SKB responded: "Partly to achieve understanding for the systems that one builds for the disposal of radioactive waste – how they work in the long run, to have the opportunity to quantify them, etc., and the next step then is to show that the systems that we suggest, or that we focus on, are sufficiently safe. And another purpose is to provide a basis for the authorities to evaluate our work". Alternatively, and from the perspective of the authorities, some respondents mentioned the task to control if the entrepreneur had met the requirements regarding dose limits, or the safety regulations related to a repository.

"We basically design it (the repository) to isolate the waste for a very long time – and basically there should be no releases from the repository… and the design should contain the waste for a long time and … nowadays this is considered the base case and we make those consequence analyses for defects etc… and in those analyses we use several conservative assumptions and models …"

A basic consideration among the experts was that achievements of the purposes in their work are rooted in the laws of nature. For example, to predict the behaviour of a repository it is necessary to know how nature works, in detail and in large systems. They mentioned the need to formulate criteria and standards for the work, to base the analysis on good and sufficient data, and to use appropriate models. A challenge was the risk estimations across very long time perspectives.

Furthermore, it was important to develop the right implementation techniques, to be able to do site specific investigations, include knowledge about e.g. climate, geology and ecosystems into models, and to accommodate the accumulated knowledge into a safety assessment of the overall system. At first, specific areas and problems were treated separately, and thereafter fitted together into more comprehensive models. Knowledge and data were acquired from (repository) site investigations, laboratory experiments, through natural analogies and from research presented in the international literature. The work products were continuously reviewed by authorities and by colleagues when ideas and results were presented or published. The care and thoroughness of the work was sometimes described as a continuous investment in credibility and trustworthiness.

The variety of, and challenges in, the work were many. How to get good data, how to cover the wide range of potential outcomes, how to select scenarios so that both the most likely and the most critical options were included? How to map the behaviours of decaying nuclides over very long times, or how to estimate climate changes and their effects on the surroundings of a repository? *How to synthesise, or integrate parts or models, into an overall coherent system?* Etc. Examples of comments follow below.

"First to create a theoretical system for how to handle the task and then to create the basis for the evaluation of how this system with barriers, which is built around the waste, functions in the long run … and to get data, by experiments or natural analogies, and then analyse or use them in the analysis for the production of quantitative evaluations of how the repository reacts. And finally to compare the quantitative values with the criteria given by the authorities…".

"SSI has norms of what is considered safe within radiation safety, and then one can say that it's necessary to consider a whole range of factors – and these factors can be rather soft – thus we do not have the same situation as in the United States in an early phase when it was said that (if you) produce a canister that is intact for 10.000 years and a matrix for the waste… and that (if the content disperses) 1/100.000 per year, then it's considered a safe disposal, i.e. one considers the detailed level – in Sweden, only the final level has been given, thus - if you can build a repository at this level of safety or for this maximal burden relative the environment in that case it's safe – and this (norm) is given by SSI...".

"The greatest danger with risk analysis, in my view, and that is the view that I have opposed several times, is the total reliance on the numerical model and the attempts to try to estimate the parameters that should enter the model – and especially in ecology and the like – seen the danger that – you could say the conceptual model, that you understand how it works – is much more important than the numerical model, or the parameters, to estimate them. But I think that if you look at the effort invested in the estimations, then more effort is put into the estimation of parameters and to get an idea (of them) instead of understanding the problem – this is the largest problem. I have seen this quite a lot within e.g. radioecology, but it is also partly an effect of the case that it's physicists that work in the area – they are not ecologists or something similar who know how the system works, so it's a large problem – and then you have an enormous reliance on these data …"

"The most important (aspect of the work) is to formulate the criteria[2] first … now that is done and the next step is to interpret it in the right way (…) We have first had a criterion which is similar to the one regarding (reactors), we have had knowledge of requirements which we put on the installations there are today, the nuclear power plants, it is the case for them that the general public shall, in accordance with ICRP's recommendations, not receive a dose larger than 1 mSv/year - that is a basic requirement that we support – and that means that one installation may not use more than one tenth of this (…). However, if this should apply to a repository which cannot be stopped (over time) but which shall be utilised in 10.000 years then we need additional margins (…) not only one tenth, but one hundredth of 1 mSv, 0.01 mSv for those living in a potential exposure of several sources. But there are a few philosophical problems here because it concerns people who live 10.000 years into the future and the question is how – or what one could say or think about them – and thus we have been rather a driving force internationally to achieve a deeper understanding here – it's not a matter of guessing about what will happen, but a matter of showing that the prerequisites are good for achieving the goal."

"You asked quite a lot about risk analysis and safety analysis, and we actually don't use those words very much. We don't use the word risk analysis – there is a fundamental difference between reactor safety analysis and safety assessment of a repository, and we are not able to give any clear-cut number, or quantitative estimate, of the repository system and – the role of the quantitative analysis has gone down and down and we are now speaking of the safety evaluation of the system…".

"It's from the risk analysis or safety analysis to the safety case – so that nowadays it's more about… how the system behaves and how it evolves over time … the calculations of radionuclides are really important, and doses and so on… it's scientific development – some 15-20 years ago it was a lot of calculations and making of risk analysis and now people understand that's real science and that you need to understand the processes and what happens and that is more important than those numbers…". And in ten years? "We will get more specific data and it will be more concrete when building the constructions…"

The question of risk definitions also highlighted another type of issue, however, the one of risk versus dose. Risk is the new evaluation basis of SSI for checking on acceptable, predicted performance of the future repository. The risk criterion has its basis in dose estimations and differs from the more commonly used probability times consequences estimate.

About the background of going from dose to risk: It is important "to actually make it clear that one cannot have a deterministic dose concept because the future is uncertain. We cannot work relative an absolute dose criterion because we do not know which scenarios that really will be realised – and even with a dose criterion there is a need to know, or be able to estimate, how probable it is that

[2] In Swedish "kravbild".

something will happen, preferably quantitatively, but often one has to accept a qualitative judgement – and that clarifies the aspect of it – and there is a driving force in the attempts to try to clarify this aspect (…) It is hard to communicate a risk concept, but at the same time I actually believe that it has been made clear that the future simply is uncertain, that one cannot work with something absolute. Plus that it illuminates certain problems for us, which we may not have reflected upon enough before (…) When one identifies a scenario it is so easy, when discussing, that one sees it as a prediction 'this is what the future will be like', but if one discuss more in terms of risk it becomes more obvious that one cannot work with a single scenario, but needs a lot of them to be able to cover a range of potential outcomes, but the risk concept is so much harder to communicate, and the bottom line is that in the end the problems remain in spite of using the dose or the risk concept…"

Regarding the change from dose to risk: "When we talked about dose before we meant that, if there were different possible doses, the weighted[3] expected value of dose should be used. When one starts to use the expected value[4] then it is really the same thing, it is proportional to the risk, and attached to a certain factor that ICRP states, with some reservations, so it is actually a rather simple change we have done. However, it has not been received so clearly by the public or by other researchers either, so there remain some explanatory work to be done. Internationally one has believed that there is a large difference, but there isn't (…). The reservations concern e.g. the development of risk – for example the results of the follow-up studies of those who survived the Hiroshima bomb – and it has been adjusted a bit, but we believe that it will not be adjusted very much, and there may be reasons to believe that the adjustments will be smaller regarding alpha-particles than the gamma…".

"Since SR 97 there is a discussion on 'risk', which we all believed to be well specified before that. But when we worked with SR 97 - I am not quite sure where it will be heading and where. SSI obviously has gotten some headache with respect to how they should interpret their own standards[5] (…). One has to make a clear interpretation – such an interpretation must be done and that is also what the international review has noted, luckily…"

Degrees of freedom, standardisation and constraints

The interviews included a question about how free or creative, alternatively how structured or standardised, the work was. Most of the respondents tended to place their judgements on the side of work being free and creative, although several of them remarked that the work was guided by criteria and continuous review processes. There was not a large difference in this respect between experts working for authorities and experts working for the implementers. Work was always guided in some way, usually expressed as by "recommendations from experts". However, it was also always necessary to check what each parameter meant in the specific analysis or type of model. The experts' recommendations

[3] In Swedish "sammanvägda".
[4] In Swedish "väntevärdet".
[5] In Swedish "föreskrifter".

were closely related to “agreed upon ways to work” or “traditions”. The responses indicated that criteria, guide lines and reviews shaped the work but did not interfere with the research spirit or creative achievements.

The international FEP (Feature-Event-Process) lists provide a systematic overview of available alternatives or input to the models. These lists facilitate the work and are constantly reviewed and updated, but they could become a restraint if they were perceived as given standards.

Ordinary scientific restraints or obstacles were also described, i.e. problems yet to be solved, problems yet to be handled within the scope of available knowledge and technological know-how. It was striking, however, the degree to which the work was sometimes seen as “open ended”. The responses included e.g. that the work varied a lot, that some parameters were easy to define (e.g. pH) whereas others were not (e.g. climate factors), and that work was rather creative. There had been a stronger emphasis on whether estimates were correct or not in the earlier days, whereas one today was urged to look closer at underlying values or evaluations. Considering that the authorities’ requirements were seen as more elaborate today than earlier, the actual work was nevertheless also considered more free than before. It was pointed out that it should be remembered that nuclear waste models deal with “open systems” in contrast to the reactor safety work, which operates within “closed systems” that are much more standardised and deterministic, i.e. the point being made that the systems are not comparable. A number of citations from the interviews follow below.

“The choices of parameters etc in models are based on ‘recommendations by experts’ and the authorities have specified (in Finland) that the assessments should be conservative. New scenarios can be taken into account if they are considered relevant”.

“Data on, e.g. climate development, can be based on the international research and this is an area that is under continuous development at this time”.

“Of course, the basic requirements are given by the authorities and there are special types given by STUK saying what the safety assessment should include, and what types of scenarios, and many things are given by them, but on the other hand, the safety assessment of nuclear waste is different from the safety assessment of say a nuclear reactor, because the reactor is in a way a closed system, a well-defined system, and you can analyse the behaviour of the reactor with standardised models, but with the nuclear waste repository – this is an open system, and its time frame is very long – so the work is somewhere between free and standardised “.

“There were some new findings, remains of mammoths, that have been found in places that previously were thought that there had been ice, so now it seems that (a scenario) has to be modified, and that permafrost may be more important than we thought… well, and of course, that has an impact on the program…”

“I work with safety analysis and investigate if the repository is safe in a long term perspective, and what could possibly happen to make it non-safe, i.e. what could introduce severe trouble, and among external influences, there is the glaciation which can influence a lot…"

"Generally, across everything, this is a very free process seen from the perspective that there are not many established methods… There are certain norms, of course, and physics and reality certainly provide bases to follow, but there are few established methods – and it's this development of methods that has been worked out in parallel with the analyses because – and such a development of methods is still going on internationally – thus it's a very creative work and it becomes more and more established the more acceptance is gained for the work… an exchange between the authorities and the company and maybe to some extent with the general public also…"

"Standardisation in the ordinary way will not happen, because standardisation in the reactor safety area took place because there were more units put to work – the more units one have the more pay off in standardising – and this is a difference, since there is no pay off in standardising one case in one environment and for one type of waste…" "… but there is comparable work in other countries where implementers work relative a regulator and from this perspective one can say that there exists a standardisation internationally – at least a development of consensus even though it's not a standardisation – but to some extent it's a standardisation of principles, and that work is done by IAEA continuously when they review the work and what seem to be promising methods…".

"What we have been thinking of a lot the last year(s) is how one should chose scenarios to be analysed in the risk analysis and how one shall do that in a systematic manner to feel somewhat certain about that one covers the most critical, or so that one gets the most complete analysis or description of the scenarios as possible. And it is not the easiest task to do this in a systematic manner, but that is very much an aspect that we have focused on lately. Then there is a strong connection here to the standards of SSI, and although this is primarily their area, it affects us – and it is this very set of problems that has emerged when one changes from having a dose criterion and go to a pure risk criterion so that the probability aspect becomes obvious in a totally different manner and results in new requirements on new models and assessment tools which are not available in a sufficient number as for today, but it might be a way to approach, maybe not the technical level, but there is more crafting behind it – the scenarios part is certainly more of central importance[6] and, maybe one can say, includes a larger part of subjective evaluations".

"Then you start from how the repository is described in the safety assessment, so that when you look at the external influences you fit it into that context … regarding external influences I have the opportunity to influence (the work), but when it comes to how the overall system is described in the safety assessment then there is a lot a work behind that, and it takes time to change parts of it. So it's obvious that I can have an influence, but then there are many who have an opinion about that, so I can influence from my area of responsibility but I also have to adjust to the total…"

[6] In Swedish "principiell".

"Generally, that's the current knowledge since that is what is available… also the ability to describe matters in a correct manner – that's also some kind of restraint, then model simplifications". Those are utilised both due to 'knowledge reasons' and 'computer power reasons' and "that certainly have importance for the results, but it is important to guard against optimism, and to be conservative…"

"Because the place is not yet chosen, all data are today chosen to be generically representative and as examples one uses different conditions found at different places – so from that perspective it's not only possible, but one has to show the variability of the indata which can be of interest in showing how different places … act in the long run – that is a part of the safety analysis. Then one can say that there is another factor which can be influenced and that is the case that one can chose materials for the technical barriers and conduct … have different quality requirements for achieving a certain level of isolation etc. And so one can influence from the perspective of making a long-lived or short-lived canister, and then there is a certain freedom in the interpretation of what is meant by safety recommendations…"

Reliability, validity, and transparency

Given few standardised ways to conduct the safety assessment in relation to the large number of potential and actually used parameters and their respective ranges, one can perhaps understand the joy, bewilderment or problems arising from the tasks. The aim of the risk analysis, and the system's safety assessment, is to judge performance or degree of safety, and then to compare the result with the standards or sets of available criteria. It ought to be challenging to achieve such goals given the number of actors and the creativity inherent in the work. Models as (testable) simplifications of the safety requirements were discussed, as well as the specific challenges of integrating various kinds of data models.

How reliable are the modelling achievements and resulting analyses? Measurement data cannot be altered, of course, but they may be flawed, insufficient or subjected to sampling errors. Much of the used data come from rigorous experimental tests as well as field or case studies, and more data will become available when the site specific investigations are well under way. The theoretical guidance of what information to look for and check is another matter. Theories are based on assumptions as well as interpretations of previous work, and the assumptions and interpretations may be more or less rigorously tested in the continuous work.

Test of reliability in data analysis: "Well, they are based on recommendations of experts and experiments and the natural analogues, and cross-checked with other safety assessments so there are lots of facts…" The expert agrees, however, to a suggestion arguing that the total system cannot be validated.

And how to produce a valid process or procedure to check results against the criteria? The interviews had suggested a tendency in the "risk analytic" arena that the work was advancing towards increasing complexity, and thus towards higher level systems' problems. It would not be possible to put a number to the final analysis of such systems, and therefor “risk analysis” had developed into a “safety evaluation” process. The final product was evaluated with respect to its parts and totality, and increasingly more so in a qualitative manner.

Such procedures, or products, were referred to as “judgements” based on the picture that emerged from a number of analyses, their corroboration, and based on knowledge accumulated in the scientific community, the logic of the models’ constructions and the performance of the analyses, etc. To summarise, the validity of the resulting work, as well as much of the control of it, was based on informed experts’ judgements.

”One has to do simplifications, and in the same manner as a map is a simplification of the geography in that it leaves the details out, it is still helpful to find the way. Then, how can one know that is sufficient? Well, that’s a philosophical problem indeed since the basis is the knowledge one has… One needs to engage in some kind of reasoning about this … of how we understand the reality and that this and that steers the development, but we assume in our model that we can do these simplifications, then it is handed over to the authorities to examine and to point out if we made some mistake … “

The need for basic research and development of “pure science” as a theoretical basis for the work to develop was often underlined. Therefore the used models will remain helpful as simplifications, but they will need further development and refinement. A “system” in this context is based on a large number of models. It does not only rely on the reliability of the input data, however, but also on the correct connections and systematisation of those building blocks from various models. The “integration” process emerges as a specifically tricky part in the work. It is a process with several facets.

The complexity of the “system” and the simultaneous development within different areas provide an “unstable” work situation, in so matter that a number of specialists are involved, there are requirements on design, content, function and communication. Changes in one area or aspect may demand adaptation of other areas or aspects of the system. Such an iterative process creates an interactive loop of continuous development that must be checked against some “overview” capability to determine the state of the system. It also demands a lot with respect to human capability to adapt to changes, to enable accommodation of the contributions, and still to meet dead lines.

Among the most important aspects of the work was “the interfaces of the work; there are several tens of scientists and engineers who work in the safety assessment area and who try to put things together and to make a synthesis…”. And the most difficult part in this context being “basically how to formulate the scenarios and the cases for consequence analysis…”.

About computers and integration: “We try to be as simple as possible… and the aim is to be as transparent, very simple and repeatable as possible, so that others can take them (the calculations or assessments) and repeat our calculus…” “Well, you see, after we have done the first judgements we intend to start a review… and, of course, we get feedback… and then, of course, in the field there are similar kinds of safety assessments, by SKI, SKB, etc, and there are kinds of international standards of the art of those who are included in safety…. It's an iterative process…"

What conditions are given or unchangeable in the analysis or the computer programs available? The answers can be summarised in that there is a structure, both in the hardware and in the software, which provides the basis from which to begin the work. However, there are more choices available today regarding software, and the computers are much more powerful than ever. This means e.g. that tests of chained models can be performed, and that the development has included a change from the 2-dimensional to the 3-dimensional perspective. Important work is also conducted internationally (IAEA, EU, etc) and by the authorities, e.g. in the areas of testing and developing models (e.g. BIOMOD, BIOMASS, etc). And, for example, "The biosphere has been given a very different role, as compared to what it has had before (…)."

"About missing something – which is there on the paper, about the worst case – you could perhaps say that even in the worst cases doses are within natural variation in Finland right now, if you have some dilution … "

"The uncertainty margins, they are very large… it has been said that they are overly conservative… and it has been argued against our assessment that they are overly conservative and overly simplistic model and that's not realistic – that kind of critique has come from the management of Posiva, the owners of Posiva, and the safety authorities… we need to take this into account and try to develop more realistic outcomes, but on the other hand… we have this situation, and here Finland may be different from Sweden, that we have a direct requirement that the safety assessment needs to be conservative, it is written in the regulations, and it is not written in such a way in the Swedish…"

About clarifications and communication: "Putting the values first; what is important really to do, what is important for setting the criteria and so on – that might be a way to start communicating with people; what is important to them and also the decision makers (…) and you couldn't start a big enlightening project for many reasons. One reason is clearly that everything cannot be explained, and second, that people have limited time (…) The key issues have been already raised here, and then it's a matter of doing it. I think also that - in a way we are stuck in a special framework – we are aware of this, what is important, but I think we just have to make small things, open new communication channels to discuss these issues about what is justified and to make it possible for people to evaluate your work – the role of the regulator is very important – the integrity of the regulator…".

"It should be well structured and easy to follow, at least to the examiners, … one should be able to follow the chains of thought… "

"The most difficult thing to gain understanding for is this uncertainty discussion, that is an important thing. It's much easier to say "it's like this" or "it's not like this".

“It is more that if they (people) want, they have a possibility to get it (…). We thought that it was important to us that to be – that people would see that we are – trustworthy (…) that they can believe that we are in earnest doing our job to keep this matter safe (…). We are worried about safety and we are looking into safety of this thing and we are not promoting anything, and we are not promoting nuclear energy. We are dealing with a problem. And I’m sure that people have different value systems and they are not going to change their opinion no matter what. But I think that being able to give [the] right kind of information, in the right places … being able to give interviews or talk to the media when they have questions, and talk to individual people if they have worries, I think that helps in believing that we, as authorities, are on their side … for their safety”.

The most difficult aspects to communicate from the work, apart from mathematical expressions or similar details, were perceived to be the concepts of risk and probability, uncertainty and conservatism. Communication issues were more related to the general public than to experts from other disciplines, but there were interesting comments with respect to the latter group especially in relation to accommodating materials into comprehensive safety assessments.

“… people are more interested in finding out if there are any conflicts, or if there is something wrong with the safety assessment, and what the critical reviewers or the critical scientists say about it … ( ) it’s a process of confidence building…“

“They (people) need information about the credentials, not about the technical details (…) and that may be something to try, to make the credibility of the experts higher than it is now…”

“…use the national and international experts in the field to find some alternative ways to communicate results”.

“I have been writing these reports for the general public and for the experts and I can say that it’s an endless road; it’s very, very difficult to communicate your problems, for instance, if you cannot use equations which you very rarely can use for lay people, you must work on the expression of these mathematical things, it’s quite difficult. On the other hand, very interesting these alternative safety indicators, seem to be of some promise in this area, so that you don’t have to be so “engineer-like” you can have more digestible arguments also. I think that’s going to gain some emphasis in the future”.

Interestingly enough there were but a few comments about communication, or the need for communication, between different expert groups. The issue was discussed at the group discussions in Helsinki and Stockholm, however, and considered to be worthy of further exploration.

“…the issue of communication between specialists is still valid, and we need quite a lot of communication, because everybody has to know his or hers special area which maybe is a very small part of the totality and still have a sort of picture of the total – the totality – and it’s not always easy to have both two things at the same time…”

“And somehow I think we have to make some approach between field chemistry and flow transport, and try to see how you could comfort better this field chemistry and flow simulations and that’s a hard question …. You have to work for such consistent model or consistent basis for it …”

“We have sometimes difficulties in understanding what the (other) experts say to us, and we have to ask and ask and say ‘please, explain so that we understand’, we cannot use what we cannot understand”.

“Perhaps I think that although we have used the combination of experts choosing the data for these safety analyses, I think it’s still [a] need for some improvement to have co-operation of experts that work in different fields, and selecting and feeding the data to be used in the performance assessment, and also I think that the fastest you can you should use the (results) we have from our sites…”

“Openness to criticism and … still have the tools, e.g. the safety indicators, to ensure that we are not that far from these standards…”

“I think we have tried to make a lot of efforts to be safe, transparent …”

Summary and conclusions

This report has tried to outline basic assumptions in the work of experts and specialists in the area of the management and safe disposal of radioactive wastes. On the basis of a series of interviews and discussions with experts in Sweden and Finland, their descriptions of work tasks, requirements and concerns were summarised and exemplified above. A few of the central themes will be illustrated in Figure 4 before the main conclusions are presented together with a list of central assumption presumably elicited from the work. See Figure 4.

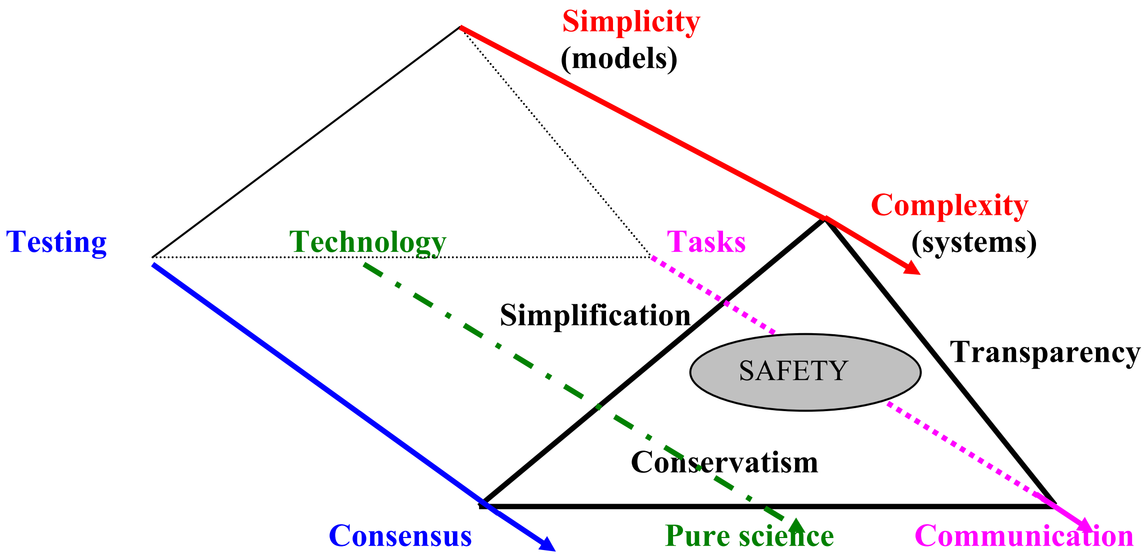

Figure 4. *The "safety case model" with the components of complexity, consensus and communication based on assumptions of conservatism, simplification and transparency.*

The figure aims at summarising the various perspectives and aspects mentioned in the study. Starting with the triangle in the back where the concepts of "testing", "tasks" and "model" illustrate the historic state-of-the-art when risk analysis was performed testing isolated, specified models. The front triangle instead shows the central concepts of "consensus", "communication" and "systems". The terms are meant to illustrate concepts in use in the safety analysis process.

The safety analysis involves multiple tests of various systems and the complexity emerges especially in the linking, or comparing, of different systems parts. The validation of the safety analysis results cannot be based on singular test results but must encompass several parts or the total safety case. The validation of the results therefore rests on successful communication between experts and their judgements or ability to reach consensus in combination with the use of conservative safety margins.

The figure thus illustrates several process contents of the "safety case" as well as of developments over time: (1) An increasing complexity (available data as well as numbers of sub-systems to accommodate the safety assessment). (2) An increasing interdependence across expert groups necessitating communication on top of task performances. (3) An increasingly more pronounced weight on consensus among experts, including consensus on safety standards and estimates across very different expert groups. In addition, and due to the development over time, (4) several of the central tasks or problems within the process of producing a safety analysis are purely scientific in nature, i.e. currently unknown or undetected phenomena need thorough investigations and valid explanations, in contrast to applications of known principles and technologically available practices.

The figure also includes the terms "simplification", "transparency" and "conservatism". "Simplicity" in this context means that in order to communicate and reach consensus, especially in cross-disciplinary expert groups, it is necessary to summarise, generalise and present a case, problem or situation on a less detailed level, thus to simplify, excluding e.g. details and anomalies. In a seemingly paradoxical way "simplicity" may here also represent an assumed correct way of handling increased complexity. That is, in the process of integrating an increasing number of data materials and of sub-systems into a safety analysis, the reduction of included factors and their interactions is necessary for the handling and overview of the system. However, the logic, choices and procedures included in the process guiding the simplification assumptions need not necessarily have been put to critical tests themselves.

The degree of uncertainty, or uncertainties, in one analysis or in an analysis of a complex system, can be estimated and subsequently counterbalanced by increasing the safety margins, i.e. applying conservative estimates. The uncertainties in the extremely complex systems are not easily reviewed or estimated, however, and the currently available level of expert knowledge provides, together with authoritative laws or recommendations, the standard against which consensus is established.

In sum, the study points at two major and simultaneous trends in current safety analysis work. First that the resulting safety estimate is based on a large number of data, facts and estimated interdependencies among which core problems require scientific or technological breakthroughs. Second, that the development seems to require an increasing taxing of human ability to, on the one hand, meet the challenges of reviewing massive data bases, reliably inferring and accounting for interrelated data and, on the other hand, to summarise, inform and communicate about the results without being unduly influenced by "groupthink" pressures (see Janis, 1972; 1982).

In a hypothetical kind of "worst case scenario" the experts consensus estimations are fundamentally invalid regarding one or several critical sub-systems within a comprehensive system analysis. What would it take to detect the problem? According to Janis descriptions of "groupthink" processes, the shared conclusions and views are extremely resistant to criticisms and re-evaluations. And "groupthink" types of decisions tend to be more extreme than views or decisions formulated by individuals. Such processes can evolve in either extreme direction, i.e. towards extreme risk taking or towards extreme conservatism. In the philosophy of sciences area, Kuhn (1962/1970) similarly described "groupthink" processes, although in the "Science policy" domain (as illustrated in Figure 3), and his terminology concerned theoretical “paradigms” that tend to live much longer than accumulated evidence of anomalies would ideally predict. In conclusion, and due to the imperfections of ordinary human functioning it may be advised to look closer at commonly used, as well as at more implicitly involved, assumptions, and especially so when independence and testability gradually become replaced with psychological processes.

Referring back to “the safety case model” in Figure 4, the mentioned problems may have a better chance of detection in a transparency motivated communication process (see e.g. Andersson et. al, 1998, 1999, 2003). Such a process may involve various experts, as well as experts and non-experts. As suggested in connection to “the communication model” in Figure 3, it may add value to the safety analysis not to consider the safe management of high level nuclear materials within a too narrow frame of reference. Similarly, it could be discussed if decision models, as e.g. the one borrowed from Muhlestein and Pierce in Figure 1, help solve problems that are not already known and well-structured. Several of the experts in this project remarked on the incompatibility of open and closed systems. And given that open systems may include currently unknown phenomena, the challenges of a complete scientific validation of “the safety case” will probably remain for some time.

The main conclusions and the “basic assumptions” can be summarised as follows:

- Safety assessments spring from attempts to evaluate complex systems which are built through a process of selections, modelling, tests, models’ integration, communication and consensus.

- The development seems to have emerged on the basis of less dynamic and more distinguishable, technological systems.

- The basic assumptions lie embedded within a work domain that acknowledges that central problems tend to be scientific rather than technological in nature and that the available tools and models for safety assessments are undergoing dynamic developments.

Without attempting to classify the following “basic assumptions” emerging from the project as true or false, simple or complex, or apparent or inferred they are listed below. The statements should be understood as those implicit “taken-for-granted” value types that were described shortly in the introduction.

- Communication regarding the safety of a nuclear waste repository concerns work and issues closely related to experts and their assigned specific tasks.
- Open systems can be modelled and analysed regarding safety level relative to recommended safety standards.
- Uncertainties in large systems can be assessed and accounted for in the modelling.
- Available computer programs and computer capacity are sufficient for the necessary tests checking for system reliability.

- Safety margins or conservative estimates compensate adequately for uncertainties inherent in simple models and in various compilations of advanced systems.
- Validation of comprehensive (safety) systems can be achieved by consensus in the expert peer group.
- Colleagues expert judgements are well informed across disciplines.
- Peers with different perspectives or critical comments will come foreward and positively contribute to improved solutions.
- Authorities or standard setters can make independent judgements of results without economic and personnel resources comparable to implementers and entrepreneurs.

References

Andersson, K., Espejo, R., & Wene, C.-O. (1998). **Buildning channels for transparent risk assessment. Final report RISCOM pilot project**. SKI Report 98:6/SSI-report 98-4. Stockholm: Swedish Nuclear Power Inspectorate, Swedish Radiation Protection Institute.

Andersson, K., Balfors, B., Schmidtbauer, J., & Sundqvist, G. (1999). **Transparens & medborgerligt inflytrande i komplexa beslutsprocesser – förstudie till ett beslutsinstitut i Oskarshamn**. Kalmar: Regionförbundet i Kalmar län.

Andersson, K., et.al. (2003). **Public values and stakeholder involvement – A new framework for performance assessment? A report from the RISCOM II** project. SKI Report 2004:24: Stockholm: Swedish Nuclear Power Inspectorate.

Drottz-Sjöberg, B.-M. (1991). **Perception of risk. Studies of risk attitudes, perceptions and definitions**. RHIZIKON: Studies of Risk and Hazard, 1. Stockholm: Center for Risk Research, Stockholm School of Economics.

Janis, I. L. (1972). **Victims of Groupthink**. Boston: Houghton Mifflin.

Janis; I. L. (1982**). Groupthink: Psychological Studies of Policy Decisions and Fiascoes** (2n ed.). Boston: Houghton Mifflin.

Kuhn, T. S. (1962/1970). **The Structure of Scientific Revolutions** (2^{nd} ed.). Chicago: University of Chicago Press.

Lindell, B., & Sjöberg, L. (1989). Vilket är viktigast vid riskbedömning: sannolikhet eller konsekvens? **Läkartidningen**, **86**, 4435-45.

Muhlestein, L. D., & Pierce, S. R. (2000). **Risk-based decision analysis in radioactive waste management processes: methodology with examples**. International Journal of Risk Assessment and Management, 1, 137-148.

Riskkollegiet (1991). (Riskdefinitioner). Stockholm: Riskkollegiet.

Salomaa, S., & Mustonen, R. (Eds.), (2000). **Research activities of STUK 1995-1999**. STUK-A180. Helsinki: Radiation and Nuclear Safety Authority, STUK.

Sjöberg, L., & Drottz-Sjöberg, B.-M. (1994). Risk perception. In **Radiation and society: Comprehending radiation risk** Vol 1. (pp. 29-59). Vienna: International Atomic Energy Agency.

SKI Rapport 99:15. **SKIs utvärdering av SKBs FUD-program 98. Sammanfattning och slutsatser**. April 1999. Stockholm: Swedish Nuclear Power Inspectorate, SKI.

SKI Rapport 00:39/ SSI-rapport 2000:17. **SKI:s och SSI:s gemensamma granskning av SKB:s Säkerhetsrapport 97. Granskningsrapport**. November

2000. Stockholm: Swedish Radiation Protection Institute, SSI and Swedish Nuclear Power Inspectorate, SKI.

Svenson, O. (1990). Some propositions for the classification of decision situations. In K. Borcherding, O. I. Larichev and D. M. Messick (eds.), **Contemporary Issues in Decision Making** (pp. 17-31). Amsterdam: North-Holland.