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Expert Opinion in SR 97 and the SKI/SSI Joint Review of SR 97

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SUMMARY: The role of sensitivity and uncertainty analyses for radioactive waste disposal assessments is reviewed. The report covers a description of the these concepts were applied in the authorities' review of the safety report SR 97.

SAMMANFATTNING: Rapporten beskriver känslighets- och osäkerhetsanalys inom säkerhetsanalysen för geologiska förvar i allmänhet och i myndigheternas granskning av säkerhtsrapporten SR 97.

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EXPERT OPINION IN SR 97 AND THE SKI/SSI JOINT REVIEW OF SR 97

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This review focuses both on SR-97 and on the joint SKI/SSI review of SR-97. The purpose of the review is to provide guidance to SSI in performing its regulatory role with regard to the use of expert judgement in the safety assessment of high level radioactive waste repositories.

The following questions about SR-97 and the SKI/SSI review are addressed in this report:

1. What should be role of sensitivity and uncertainty in radioactive waste disposal safety assessments and how are these concepts applied in SR-97?

2. Are the methods for selection of scenarios, data, and models adequate and do they follow the norms generally accepted for high level waste disposal post closure safety studies?

3. What are the main weaknesses in the described methods, and how might they evolve and improve with future generations of the safety study?

4. Are the methods for expert judgment sufficiently well described (traceability and transparency)?

5. Are there areas where formal expert elicitation procedures are warranted but not employed and are there areas where expert judgment has been misapplied? What criteria can be used to make these determinations?

6. Are important issues missing in the authorities' review document?

7. Is the SR 97 expert elicitation methodology including the selection and definition of issues, sources of data for quantification, and the integration, propagation, and interpretation of uncertainty and risk appropriate to the purposes of the study and does it conform to internationally accepted norms and protocols?

1 The Objectives of SR-97

SR-97 was written with four concrete purposes in mind (SR-97 Vol. 1 p 18.) These are roughly the following:

1. Demonstrating the feasibility of disposing spent nuclear fuel in Swedish bedrock.
2. Demonstrating a methodology for safety assessment. Included in this purpose is a systematic handling of the different types of uncertainty associated with background data.
3. Providing a basis for specifying site selection parameters.
4. Providing a basis for deriving preliminary functional requirements on the canister and other barriers.

The first of these purposes is the most direct. Feasibility is demonstrated by showing that a repository will meet the regulatory requirements of the authorities. The remaining three purposes are less direct and, to some extent, are byproducts of the effort to achieve the first purpose. These four purposes are repeated here as they will be cited later in this report.

The Role of Sensitivity and Uncertainty Analyses in Radioactive Waste Disposal Studies

Sensitivity and uncertainty analyses have distinct objectives and, although they can be conducted simultaneously [Helton et al., 1996], it is most straight-forward in this discussion to treat them as distinct activities. Sensitivity analysis has the objective of discovering those input values, intermediate values, models, scenarios, etc. that have the greatest influence on the performance of the repository. Sensitivity analysis can be conducted in a deterministic manner by fixing all input at their nominal values and perturbing individual values, usually one-at-a-time but possibly in pairs or groups, and then observing the change in output values. It is also possible to conduct a sensitivity analysis in a probabilistic mode via simulation where input values are selected from probability distributions and the model is evaluated a number of times with different randomly selected input values. Statistical measurements of the relation between the input values and the output values, such as rank correlations or correlation ratios, are made to gain knowledge of the influence of the input values on the output values.

Whether done deterministically or probabilistically, the objective of sensitivity analysis is to find those items in the safety assessment (parameters, models, scenarios, etc.) that have the greatest impact on the output values (safety measures.) A source of difficulty in making judgments about the impact of the various items is the range values or probability distribution assigned to various parameters. In both the deterministic and probabilistic modes of sensitivity analysis, this is often an issue. For example, one potential measure of sensitivity for a deterministic model is the derivative of the output with respect to an input variable. This would provide information on the impact of infinitesimal variations in the values of the various parameters. But the relative variation of these parameters may be quite different – a consideration that is not taken into account by the derivatives. To judge the impact of the various parameters, one must consider both the rate of change (the derivative) and the range over which the parameter may vary. For meaningful comparisons to be made among input parameters, meaningful ranges or probability distributions must be provided for these inputs. The meaningfulness of the distributions and ranges for parameters in SR 97 is in question as is discussed later.

The objective of uncertainty analysis, in contrast, is to provide both an overall view of the uncertainty about the safety of the repository and to provide insights into those factors that are driving the uncertainty. This second objective is similar to the objective of sensitivity analysis but the emphasis is on assigning to various inputs, some measure of the contribution of those inputs to total uncertainty. Such a measure can be a simple as a ranking or make take the form of a special measure such as an uncertainty importance measure (Hora and Iman, 1990). For the overall view of uncertainty about safety and for the attribution of uncertainty to causes (inputs), the input values must be represented by probability distributions that meaningfully represent the uncertainty about that input.

Of the four purposes proposed for SR 97, the third purpose, that of providing a basis for specifying site selection parameters, is best addressed through sensitivity and/or uncertainty analyses. Such analyses would point up those variables that most important in determining the safety of the repository. But in SR 97 Volume II, section 13.3 titled "Basis for site selection and site investigations" one is directed to other studies, evidently in progress at the time SR 97 was written, that address these issues. This raises several questions:

1. Why is it necessary to have separate analyses for overall safety and for site selection? Is the model used in SR 97 insufficient for site selection? If so, and a better model exists, why are not its features incorporated into SR 97?
2. Are there questions about the safety of a deep repository in Swedish bedrock that are beyond the scope of SR 97? An affirmative answer would raise the question of whether the first purpose of SR 97 (showing feasability) has been satisified.

The joint SKI/SSI review also addresses the question of repository design and siting. In this discussion, the question of achieving a design that not only meets regulatory requirements, but is also designed to achieve as low a level of risk as is reasonable, is raised. Roughly, this means determining those factors that are important in reducing risk doing one or more of the following:

1. Selecting a site for which the risk determinants collectively produce the lowest risk
2. Engineering systems to control or reduce the impact of important contributors to risk
3. Performing further studies of those factors who contribute most to uncertainty about risk.

It seems as though an opportunity has been lost, or at least postponed, in SR 97. The safety study could have been in such a manner that the calculations supporting the first purpose (showing feasibility) also support the third purpose (delineating design factors to differentiate among sites. It is recognized that the safety study is an on-going effort and that there is opportunity in the future for performing sensitivity studies. However, such studies are valuable in directing future scientific investigation and thus it is propicious to conduct such an investigation early in the design process.

Another issue surrounding SR 97 is the meaningfulness of the probabilistic calculations. The value of an uncertainty analysis depends on the quality of its probabilistic inputs. The methodology employed in SR 97 and the comments in the SKI/SSI review will be discussed more fully in a later section of this report. However, there is cause to believe that these distributions do not provide a reasonable representation of uncertainty. If this is true, the probabilistic measures of risk, such as shown in Figures 9-43 and 9-44 of SR 97 Volume II lose their usefulness. It is likely that they are conservative which in light of the first purpose of the study would not be a problem. However, conservatism can mask other important information. It may be, for instance, that conservatism affects the three studied sites differently. More importantly, undue conservatism can mask the importance of various determinants of risk to the extent that some factors that are important in repository design do not appear so. For example, it one assumes that canisters never fail, bentonite will appear to be useless. Likewise, if one assumes that all canisters fail immediately, then canister wall thickness will appear to have no effect on safety. Although these are extreme examples, the point that is being made is that unwarranted conservatism may mask important design considerations and therefore thwart both the third and fourth purpose of the SR-97.

The SKI/SSI review notes several times that SR-97 lacks a meaningful sensitivity and uncertainty analysis. KASAM point out the absence of an analysis of the significance of various uncertainties while and the international expert committee points out the lack of a systematic formal sensitivity analysis (SKI/SSI p 20.) These criticisms are repeated in the SKI/SSI analysis of the treatment of biospheric conditions (SKI/SSI p. 27). Moreover, Wilmot and Crawford note that the mixture of realistic, conservative, and simplified assumptions makes a probabilistic interpretation difficult to interpret (SKI/SSI p. 27). In the general conclusions of the SKI/SSI, a more comprehensive sensitivity and uncertainty assessment is suggested for geospheric and biospheric conditions and it noted that a main objective of the preliminary safety study is to provide feedback to the prioritization of future research efforts.

The SKI/SSI review does a good job in pointing SR 97's weaknesses in sensitivity and uncertainty. Perhaps it could go further it providing direction to SKB for the next generation of the safety study. For example, it might be suggested that the safety study should:

a. Employ a consistent and logical method of encoding and propagating uncertainties so that meaningful estimates of the uncertainties in releases and doses result.
b. Employ a methodology that will identify those factors that contribute to releases and dose and to the uncertainties in those quantities with the goal of providing information that will
    i. Help differentiate among alternative sites
    ii. Provide insights into the consequences of various design features
c. Provide information about the sources of uncertainty to direct future scientific research so that the magnitudes of important, resolvable uncertainties are reduced.
d. Assume a more balanced approach in reaching the four objectives laid out in SR 97.

2 Methods for selection of scenarios, data, and models

This review agrees with the position of SKI/SSI and their external experts on the lack of systematic process for the creation of scenarios. There has been fairly good international acceptance of the features, events, and processes approach (FEPs) [Nuclear Energy Agency, 1992]. Although this method is not a panacea, it does provide some assurance of thoroughness in the scenario creation process.

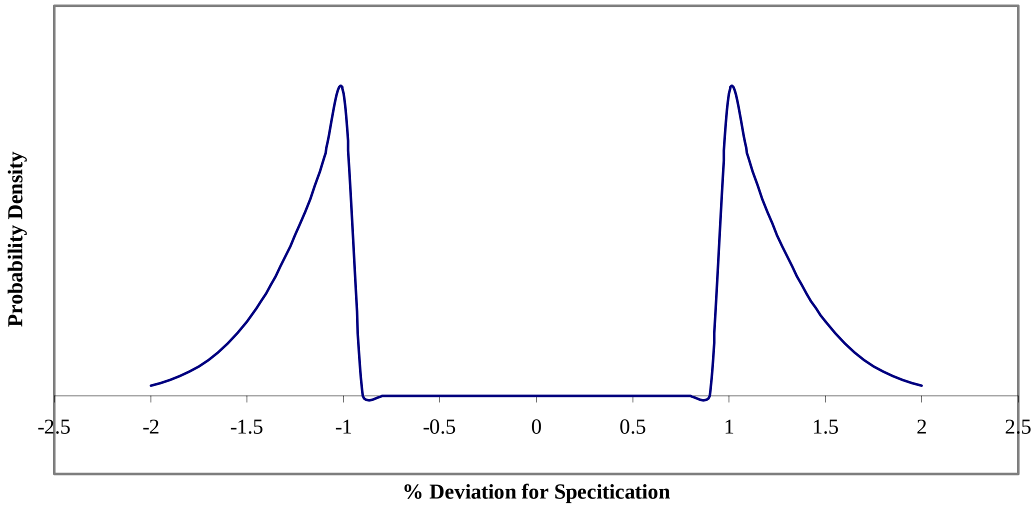
Three of scenarios proposed and analyzed by SKB deserve special comment. These are the canister failure scenario, the human intrusion scenario, and the base case. Canister failure is highly stylized and we have two major criticisms of this scenario. The first is with the failure rates employed and the second is the assumption of independent failures.

SKB's interpretation of canister defects assumes a two point distribution for the failure rate. Ninety per cent of the probability is at a failure probability of .00025 and the remaining ten per cent is at the pessimistic value of .001 [SR 97 Volume II pg 218.] The reasoning for the pessimistic value .001 is that this is a design criteria for the canisters and the manufacturer is required to meet this specification [SR 97 cites Werme, 1998 for this value.] It is noted, however, that the manufacturer is under no pressure to provide a lower defect rate as is assumed for the reasonable case [SR 97 Volume II pg 218.]

We digress for a moment to present a related situation that has arisen in quality control of electronic components in order to illustrate our concern. A company purchased a large number of identical electronic components from a supplier under a contract that specified the required output voltage of the component differ by no more than 2% from its design value. When the components arrived from the supplier, acceptance testing was performed on a sample of the components. The quality control inspector found that output voltages were not normally distributed as he had expected, but strongly bimodal as illustrated in Figure 1. The supplier had, evidently, screened out all components that operated within 1% of the design voltage in order to satisfy another order with more stringent specifications.

Of course the situation with the manufacturing of canisters is different in many respects. But the important point is that manufacturing specifications are minimums and it may be in the best economic interest of the supplier to meet those minimums but not to exceed them. Why, then, should it be most reasonable that the manufacturing specifications for canisters will be exceeded by a factor of four? A defect rate of .001 seems to be the best that can be justified, at least conservatively, and this value should be used as the most reasonable value.

Figure 1
Electronic Components



There is a second disturbing aspect of the canister scenario. This is the possibility of common cause failures. Common cause failures in nuclear power plant safety have been given a great deal of attention [U.S. Nuclear Regulatory Commission, 1988, 1989, 1990, 1998a, 1998b]. This is because common cause failures present greater risk than independent cause failures. The modeling of the canister failure scenario assumes that the canisters will fail independently with a failure probability of either .00025 or .001. But suppose it is possible, although unlikely, that there is an undetected, and perhaps undetectable, flaw in the manufacturing process, the materials, or the inspection process. This unknown flaw would, if it exists, affect many canisters. An example of an undetected common cause defect might be impurities introduced by the welding process that hasten corrosion of the welds internally. These defects might not be detectable with a noninvasive screening process.

With this in mind, consider two different models for canister defects. In both models, the overall expected defect rate is 1 in 1000. In the first model, it is assumed that the failures are independent. The number of defective canisters will then follow a binomial distribution and, assuming 4,000 canisters are implanted. The expected number of defective canisters is four. In the second model, it is assumed that a undetected common cause defect is possible. This defect would affect 10% of the canisters manufactured and the probability of this common cause being present is .01 leading to an expected number of failed canisters of (.01)(10%)(4000) = 4 consistent with the expected number of failures with the first model. While both models yield the same expected number of defective canisters, the differences in the distribution of defective canisters will have a substantial impact on the uncertainty in dose – the second model producing much greater uncertainty. The probability of twenty or more failures with the first model is virtually zero ($2\text{x}10^{-9}$) and nearly .01 with the second model. In fact, the second model gives the event of forty canisters failing an approximate probability of .005!

Of course, both models discussed here are highly stylized and neither could be construed as representing reality. The point is that at least some attention needs to be paid to the possibility of common cause failures as they have the potential to greatly impact risk and uncertainty.

On page 45 of SR 97 Volume I, the base case is laid out as ”…where no canisters have initial defects and where present-day ambient conditions are assumed to exist.” Thus, one might infer that the base case differs from the expected or reasonable evolution of the repository system in the following respects:

1. No canister will contain defects even though the manufacturing specifications permit a defect rate of .001.
2. The climate will remain constant even though processes of climate change are known to be currently underway and a long record of climate change exists.
3. No human activities will intrude even though the human intrusion scenario calculations show that the probability of such an occurrence is unity.

What then is the meaning and purpose of the base case? It should be clearly stated that this is not the expected or likely evolution of the repository. Instead, it seems to be put forward to highlight the fine work done on the chemical, radiological, geologic, and thermal properties of that portion of the disposal system that consists of the source term, the rock, and ground water flow and excludes other aspects of the system.
The danger is that a “base case” is likely to be conceived as a most natural evolution or a most likely case which it is not. It would be better to rename it.

The SKI/SSI review notes that both the climate change (p. 18, 20, 22) and human (p. 22, 27) activities are so probable that their exclusion from the “base case” is not reasonable. Their review does explicitly treat canister failures. We suggest that canister defects cannot be excluded from the base case for similar reasons.

3 Expert Judgment in SR 97

Whether the use of expert judgment is acknowledged or not, it permeates radioactive safety studies [Kotra et al. 1996, Bonano et al. 1989]. It is present in the selection of models, the definition of scenarios, the determination of those factors that are included in the study and those that are excluded, and in the formation uncertainty distributions for parameters. This last use of expert judgment is usually the most visible and best documented and, therefore, most subject to scrutiny. A common method for obtaining uncertainty distributions of parameters is probability elicitation. Protocols for probability elicitation are discussed in Morgan and Henrion [1990]. These protocols provide a formal structure for encoding the views of multiple experts into uncertainty distributions.

Although there is no single protocol that is always best, nor will a single protocol fit all situations, there are commonalities among those protocols that have been used in safety studies. These commonalities include procedures for the:

1. Selection, definition, and presentation of issues.

2. Qualification and selection of experts including the number of experts and the scope of responsibility.

3. Organization of experts, information, and elicitation.

4. Processing and use of expert judgments and the presentation of results.

SR 97 does not appear to employ a formal probability elicitation protocol. SR 97 and supporting documents show that SKB commissioned a series of studies (SKB R 97-13, TR 97-33, TR97-18, TR 98-03, R 97-15, TR 98-12, U 98-06) to acquire information on which to base uncertainty distributions. The researchers in these studies were asked to review existing studies in a subject area and from their review, provide reasonable and pessimistic values for a set of parameters. The parameters considered are related to:

1. The source term
2. Canister properties
3. Solubility, retardation, and flow parameters

Although on the surface, the presentation of issues to experts seems straightforward, it often is one of the more troublesome stages of an expert judgment process. In SR 97, the experts are asked to form judgments about two values – a reasonable and a pessimistic value. However, what do these terms mean in a quantitative sense? The introduction to TR-99-09 (p. iii) suggests that the pessimistic value is the most detrimental value within the uncertainty range and that the reasonable value is one that is neither optimistic nor pessimistic. We do not find these definitions reflected in the supporting studies (SKB R 97-13, TR 97-33, TR97-18, TR 98-03, R 97-15, TR 98-12, U 98-06) and it is entirely possible, even likely, that the researchers in these studies were not provided with these definitions.

These definitions are open to interpretation. The use of qualitative definitions in probability elicitation – definitions such likely, rare, expected, etc – have been studied extensively [Beyth-Marom 1982, Wallensten et al. 1986] and the unfortunate finding is that there is great variation in the interpretation of these values. For example, the notion of likely might produce quantitative interpretations varying from probabilities of .3 to .9 across a number of individuals. Who knows what pessimistic might mean?

It is not possible to comment on the procedures used to select either the parameters to be quantified by uncertainty distributions nor the procedures used to select the experts as there is no documentation of any process in SR 97. However, as discussed in an earlier section of this report, there is an absence of any sensitivity or uncertainty study in SR 97 to determine those parameters sufficiently important to be put to a formal expert judgment process. Thus, one might conclude that the parameters for which outside opinion was sought were chosen on the basis of the intuition of insider persons.

In the reports giving the reasonable and pessimistic values for various parameters, the number of authors varies from one to five, with two or three authors most common. Having only one expert interpret data is problematic as, often, the differences among interpretations by multiple experts is a great as the uncertainty within distributions provided by single experts. Three experts is a reasonable minimum number of experts to employ for parameters that are important in determining risk and uncertainty about risk. Again, there is no standard for the number of experts engaged or for a particular issue or any rationale method provided for the selection of these experts.

Another difficulty with the acquisition of expert judgment in SR 97 is the lack of any instruction or formal training for the experts. However, since the experts were not asked to provide probabilities it would seem that this step is irrelevant. It is mentioned here because if the study had involved a formal expert judgment process, as we suggest it should, training and working directly with the experts in the formation of uncertainty distributions should be part of the process.

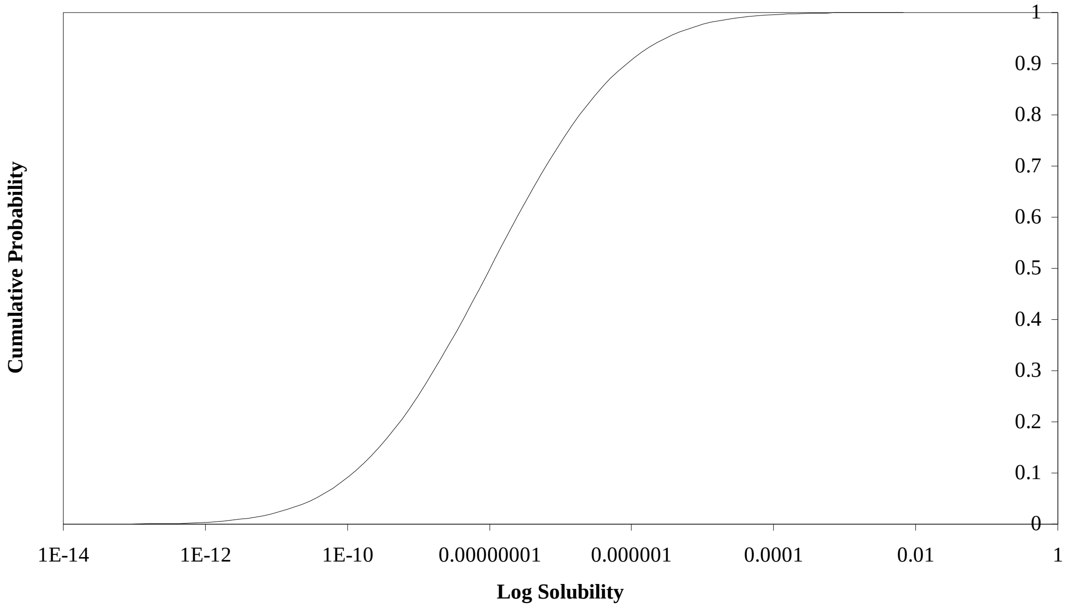
Lastly, the formation of probability distributions from the reasonable and pessimistic values is discussed. These values are used to form probability distributions with all probability concentrated at two values. A probability of .9 is given to the reasonable value and a probability of .1 to the pessimistic value. This seems to be a very arbitrary decision and has no foundation in the science of probability and statistics. It is just a convenient assumption that avoids having to construct meaningful probability distributions. Could there by any harm in this assumption? We think so!

Suppose that the experts had been instructed to provide two values, one representing the more benign interval of values where the interval has a total probability of .9, and the other representing an interval more unfavorable values and having a total probability of .1. This is consistent with the construction used in SR 97 although it is doubtful that the experts were provided with any such instruction.

Suppose that the expert, after interpreting all available knowledge, concluded that the two values -- reasonable and pessimistic – for the solubility of plutonium at Aberg are 6.56×10^{-9} and 3×10^{-6} (these values are taken from Table A.2.2.2 in the SR 97 data report, TR-99-09.) Further, suppose that the expert had in mind a lognormal distribution for the uncertainty of plutonium. Then the resulting distribution is that shown in

Figure 2. This distribution was constructed by making the interval medians equal to the two given values. Thus, this distribution has a cumulative probability of .45 at 6.56 x 10^{-9} and a cumulative probability of .95 at 3 x 10^{-6}. An important upshot is that the solubility at a cumulative probability of .99 is 13.2 x 10^{-5}. This is ten times greater than the pessimistic value that is used in the study so that if dose were linearly proportion to solubility, there is a .01 chance of underestimating dose by a factor of ten or more simply because a discrete two point distribution was used in place of the lognormal distribution. One can conclude that the method of constructing two point probability distributions may lead to severe truncation of the tails and, perhaps, understatement of uncertainty and risk, thus eliminating low probability, high consequence outcomes.

Figure 2
Lognormal Distribution for Pu Solubility



SR 97's data section refers to the pessimistic value as the most unfavorable value in the uncertainty range. Nevertheless, the experts seem to have taken the uncertainty range to be, in many cases, the range of experimental or observed values that have been included in their studies. (See for example Table A.2.2.2 in the data report.) There are two important difficulties with such an approach.

First, there is a logical inconsistency with making the uncertainty range equivalent to range of observed results. This inconsistency arises because the range of the data must mathematically be a (nonstrict) increasing function of the number of values used to create the range. That is, given n data points, the addition of an n+1st data point can only result in a range as wider or wider. Thus, the more information we have, the wider the uncertainty range and the less certain we appear to become. To have little uncertainty in dose, then, one needs to ignore all studies but one.

Second, consider a situation where three studies have been done, but the values from only two of the studies are available at a given point in time. Now suppose the third study's results become available. If the studies can be viewed as having only random error, the likelihood that the findings in the third study for a specific parameter lie outside the range of values provided by the first two studies is twice as great as the probability of the results lying within the range provided by the first two studies. This can be seen by envisioning the results of the three studies as being points on a line. Now, imagine successively that each of the three points represents the findings of the unavailable study. Two of the three points will produce results outside of the range of the other two.

In terms of probability elicitation, when faced with limited evidence, the experts must spread sufficiently the range of uncertainty to account for a wider range of possibilities than those suggested by the limited evidence. Acquainting experts with this phenomenon and with other aspects of psychological biases in judgment formation is usually accomplished during training sessions provided to the experts. There is no evidence, however, of such training in the SR 97 effort. There is reason, then, to suspect that the uncertainty ranges developed in the several studies are narrower than they should be.

The overview of the use of expert judgment in SR 97 must be rather critical. The procedures that were used ignore experience and past exercises. The problem is not with the scientific foundation for the judgments, but with the methodology that produces subjective probability distributions from scientific data. The following specific areas are in need of development for future generations of the safety study:

1. There should be documented procedures for the selection of experts including a process for nominations, qualifications for selection, and definition of the scope of responsibility. The experts should be neutral and free of both motivational bias and the appearance of motivational bias. There should be some reasoning for the number of experts selected the fields from which they are selected and the diversity of approaches included (and excluded) within the selected group of experts.
2. The experts should be informed of how their judgments will be used. If these judgments are used to produce probability distributions, then the experts should be involved in creating those distributions. Moreover, the experts should have the opportunity to review and comment on the distributions.

3. Consideration should be given to using formal probability elicitation. This means a structured environment staffed with persons having capability in probability encoding.

The SKI/SSI review of SR 97 identifies the weakness in the treatment of expert judgment numerous times: with respect to correlation factors for the source term, the systems analysis and creation/quantification of scenarios, the failure to treat conceptual model uncertainties, and the treatment of parametric uncertainty in the transport modeling in both the near and far field. Thus, the SKI/SSI review does a good job in recognizing this problem. There is little guidance, however other than to suggest that a formal expert judgment process would be appropriate. The very inadequate procedures used by SKB in handling expert judgements indicate that some more explicit guidance is warranted. Expert judgement procedures have been developed and successfully applied both in the United States [Bonano et al. 1989, Kotra et al. 1996, Rechard et al. 1993, Trauth, Hora and Rechard, 1993, Trauth, Hora, and Guzowski, 1994] and in Europe [Harper et al., 1994, Cooke 1991]. These successes would be a good starting point for SKB.

4 Suggestions for SSI

In this section, some guidance is given for SSI's preparation for executing its responsibilities with regard to expert judgement. The comments given earlier in this review indicate that SKB is not likely to have adequate capability, at this time, in the area of expert judgement. This makes SSI's job doubly difficult in that SSI must not only point out deficiencies but also provide guidance in how to correct the deficiencies. To do otherwise will lead to a series of unsuccessful successor studies. Thus, SSI needs to build its capabilities in expert judgement to play this dual role of critic and tutor.

First, resources need to be dedicated to this area. An individual or individuals should be tasked with the responsibility of oversight for all expert judgement in the safety study. This is preferable to distributing the responsibility to those individuals having oversight of specific scientific areas (source term, transport, etc.) as the selected individuals can prepare more deeply and there will be consistency of the oversight across the entire study. In addition, having a locus of responsibility will help ensure that the work does not fall through the cracks.

The individual or individuals tasked with expert judgement oversight need to gain both practical experience with expert elicitation and knowledge of the foundations underpinning its use. The recent "test" elicitation conducted on the issue of bioavailability is good example of gaining practical experience. Another avenue that should be explored is the possibility of attending formal probability elicitations conducted elsewhere such as at the Yucca Mountain project. Inviting SKB to provide an observer would be beneficial as it would help to create a mutual understanding of what needs to be done and would start a useful dialogue on expert judgement. Studying the underpinnings of expert judgement is largely a matter of becoming familiar with the relevant literature. Several books provide background [Cooke 1991, Winterfeldt and Edwards 1986, Morgan and Henrion 1990, Kahneman, Slovic and Tversky 1982] and there are numerous technical reports (many cited in the references given here) that provide insights into practical issues.

Another possibility for building expertise is to occasionally invite scholars and practicing consultants in the area of expert elicitation to SSI to give talks and perhaps some demonstrations. It is also possible for the SSI staff to attend sessions at meetings in which expert judgement issues are discussed. Unfortunately, there is no single organization dedicated to expert judgement so that a trip to a meeting might mean only two or three papers on the topic. The INFORMS section on decision analysis, however, usually has a session with papers in this area. There will be an INFORMS meeting in Turkey during the summer of 2003. SSI might also choose, in cooperation with SKB, SKI and perhaps the CEC, NEA, or US NRC, to sponsor a workshop or meeting dedicated to expert judgement. Participation would be funded by the organizations of the attendees.

SSI could decide to undertake expert elicitation exercises as part of the review and verification process for the Swedish spent fuel repository program. This would entail the hiring of outside experts who would participate in a formal elicitation process for one or more important issues. The results of such elicitations could then be used to benchmark the results provided by SKB. Such an activity would ensure a neutral environment of the quantification of important model inputs.

5 Conclusions

With a few exceptions, the SKI/SSI review singles out the same issues that this reviewer identified in SR 97 with the exception of assumptions about canister failure rates and the possibility of common cause failures. We both find that there is a notable absence of sensitivity and uncertainty analyses and that there is no systematic process for the selection of scenarios, data, and models.

With regard to the use of expert knowledge, the most significant weakness of SR 97 is absence of any standards, procedures, and even definitions for expert judgment. This situation needs to be dealt with by SKB in the near future as it denigrates the portions of the study that are well done.

In developing expert judgment processes, SSI should ensure that SKB creates procedures that guarantee traceabilty and transparency. This will become very important as the repository system matures and receives greater public scrutiny. Both the area of scenario creation and expert judgement, there are processes that have gained international acceptance. It would be in the best interest of SKB, and the public, to adhere these accepted approaches.

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SSI Rapport

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SSI är ansvarig myndighet för det av riksdagen beslutade miljömålet *Säker strålmiljö*.

SSI sätter gränser för stråldoser till allmänheten och för dem som arbetar med strålning, utfärdar föreskrifter och kontrollerar att de efterlevs. Myndigheten inspekterar, informerar, utbildar och ger råd för att öka kunskaperna om strålning. SSI bedriver också egen forskning och stöder forskning vid universitet och högskolor.

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Myndigheten har idag ca 110 anställda och är beläget i Stockholm.

THE SWEDISH RADIATION PROTECTION AUTHORITY (SSI) is the government regulatory authority for radiation protection. Its task is to secure good radiation protection for people and the environment both today and in the future.

The Swedish parliament has appointed SSI to be in charge of the implementation of its environmental quality objective *Säker strålmiljö* ("A Safe Radiation Environment").

SSI sets radiation dose limits for the public and for workers exposed to radiation and regulates many other matters dealing with radiation. Compliance with the regulations is ensured through inspections.

SSI also provides information, education, and advice, carries out its own research and administers external research projects.

SSI maintains an around-the-clock preparedness for radiation accidents. Early warning is provided by Swedish and foreign monitoring stations and by international alarm and information systems.

The Authority collaborates with many national and international radiation protection endeavours. It actively supports the on-going improvements of radiation protection in Estonia, Latvia, Lithuania, and Russia.

SSI has about 110 employees and is located in Stockholm.

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