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Expert Judgement Elicitation

Statens strålskyddsinstitut
Swedish Radiation Protection Authority

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TITLE/ TITEL: Expert Judgement Elicitation

SUMMARY: The report describes a trial expert panel elicitation with 4 experts in the field of radioecology.

SAMMANFATTNING: Rapporten beskriver en teknik med formell expertbedömning genomfört med en panel av 4 experter inom området radioekologi.

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Expert judgement elicitation

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1 Background

In the safety assessment of the final disposal of radioactive waste, expert judgement will undoubtedly play a significant role. Moreover, appropriate review by the authorities of the methods employed for obtaining expert judgements, and the uses of the judgements in the safety assessment, will also have an important role as they have elsewhere [1,2]. The study reported here was conducted with the aim of gaining some practical experience in probability elicitation for those that will be reviewing expert judgment. The study consisted of a fully implemented, but small-scale, probability elicitation exercise conducted using both external experts and SSI staff.

In the early phase of a repository concept development, the implementer/operator focuses on the development of conceptual models and the building of an experimental database for the calibration of those models. Developing uncertainty distributions for parameter inputs may not be more most important activity of the research program at this time. In addition, the implementer/operator will need to evaluate alternative designs, which may lead to a particular line of research being completely abandoned, along with the corresponding models and data.

In the review of the last major safety report SR 97, the Swedish Radiation Protection Authority, SSI, underlined the need for a systematic approach to quantifying and documenting parameters. In its report about parameter values [3] used in the safety report SR 97, the Swedish Nuclear Fuel and Waste Management Company, SKB, has taken a step in this direction.

Towards the final stage of developing a repository system, when a licence application is submitted for review, the documentation and arguments for model and parameters can be expected to be much more detailed. This was indeed the case for the licensing process of the US Waste Isolation Pilot Plant, WIPP [4].

The most obvious regulatory requirement in connection with expert judgement is that the expert's arguments are documented and open to review. There are several ways to fulfil this requirement. One way, using formal expert panel elicitation, is described below. This approach was developed by the US NRC during the safety studies of nuclear reactors [1] and provides the basis for expert judgement methods used in the license application for the WIPP. This approach has also been adopted for the US high level waste repository at Yucca Mountain [2]. Professor Stephen Hora of the University of Hawaii has been directly involved in the development of these methods over the past twenty years [5,6,7,8]. He served as the normative expert in this study and had responsibility for conducting the probability elicitations. Dr. Rodolfo Avila acted as scientific secretary for the meeting, and the project was lead by the Dr. Mikael Jensen of SSI.

2 What is expert judgement elicitation?

2.1 WHEN ARE EXPERT JUDGEMENT ELICITATION USED?

The technique has been studied within many disciplines. Examples of fields that have contributed to probability elicitation are decision analysis, psychology, risk analysis, Bayesian statistics, mathematics and philosophy.

Quantification of subjective probabilities is employed in a number of circumstances. These include [1,2]:

- when evidence is incomplete because it cannot be reasonably obtained
- data exist only from analogue situations (one might know the solubility of one mineral and might use this information to infer the solubility of another mineral)
- when there are conflicting models or data sources
- when scaling up from experiments to target physical processes is not direct (scaling of mean values can is often much simpler than rescaling uncertainties)
- when the uncertainties are significant relative to the demonstration of compliance
- there is likely to be public scrutiny of the uncertainties

2.2 THE TECHNIQUE OF EXPERT JUDGEMENT ELICITATION

The form of expert judgements described here are experts' knowledge encoded into a probability distribution, usually a density function of a cumulative probability function (distribution function). Descriptions of processes designed to encode knowledge into probability or uncertainty distributions are found in a number sources [9,10,11]. One particular set of steps, termed a protocol, was developed by the US SANDIA National Laboratories and the US Nuclear Regulatory Commission, NRC, and is sometime referred to as the SANDIA-NRC protocol.

Even within a given protocol, there may be some variations and innovation in the elicitation. For example, the elicitation may involve experts in one or several different fields, i.e. it may be one- or multi-dimensional. It could involve teams of experts rather than individual experts as in [12, 13]. In the following, the scope is limited to the case of experts in one field so that the experts are redundant of one another. This redundancy is a normal aspect of a formal probability elicitation.

2.2.1 Expert meetings

The SANDIA-NRC protocol is designed to work with a group of experts that called a panel. The panel would normally meet on two occasions:

- The first meeting is called to discuss the issue, and various approaches to finding the elicited quantity. During this meeting, experts are free to debate the issue among them and to revise their views as a result of the discussions. In addition to an open general discussion of the issue, training in probability elicitation is provided. This training gives the experts practice in the tasks they must perform and gives information and feedback on potential biases in the probability formulation process.

- The second meeting usually begins with presentations by the experts on the data sources and models they used to address the issue, but stops short of the discussion of probability distributions. Experts are then asked, now individually, a series of questions that allow the expert and the normative expert, together, to form an uncertainty distribution for the parameter in the issue.

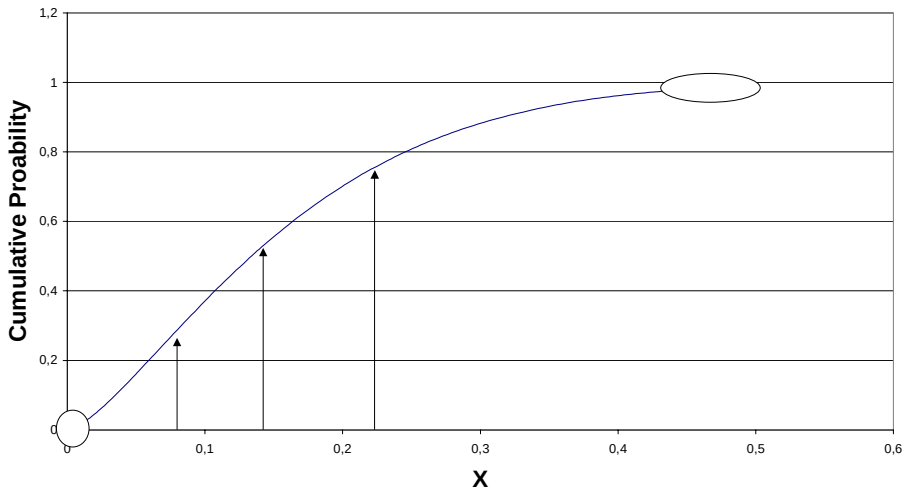
For example, Figure 1 gives the cumulative probability for a quantity X and the values for the median and 25th and 75th quartile. The density function is the derivative of this curve. The definition of lowest and highest possible values also must be obtained and, often, additional points such as the 5th and 95th percentiles are obtained.

2.2.2 Calibration

At the first meeting, prior to the elicitation, the experts are given questions about quantities to outside their field of expertise. The elicitation project leader knows the quantities, which may be taken from encyclopaedias and examples are the suicide rate in Japan or the Earth-Sun distance etc. Questions about such quantities are often called almanac questions as they refer. The experts are asked to form probability distribution for these unknown quantities.

An expert cannot be expected to give the correct answers, or rather to place all the correct an-

Fig. 1 Continuous Distribution Function



swers near the median, but a well-calibrated expert would be free of bias, i.e. the expert would estimate the median so that half the correct answers would be above and half below. Similarly, the answers below would divide evenly in the first and second quartile, and the answers above between the 3rd and 4th quartile. Giving uncertainty as probabilities is not a natural act, and in many cases, the real value of the test lies outside the entire uncertainty range provided by the expert. Natural scientists often overestimate their ability to frame a quantity and use too narrow distributions. The experts are given the opportunity to reflect about the quiz, and usually score better a second time.

2.2.3 Information

Beside the issue of calibration, there is the issue of the information content in the expert's estimation. If the expert were to give very narrow uncertainty interval around the correct value, the expert's opinion would have high information content. This is of course desirable but high information content is sometimes obtained only the cost of poor calibration. The goal is therefore double: to have well calibrated experts with high information content.

2.2.4 The concept of subjective probability

Experts sometimes think that there is a probability distribution that they should know and that this distribution should be their answer. However, this is not the case. The probability distribution that is sought reflects the experts own uncertainty about a quantity, which, at conceptually, could be a known value. The purpose of obtaining the experts own personal probability distribution is to measure the uncertainty that exists about this quantity –thus measuring both what

we know and what we do not know. These probability distributions will differ from expert to expert and may change over time as new knowledge is obtained.

The fact that there is no objective distribution to be estimated implies that a particular subjective probability distribution cannot be true or untrue, except in some extreme cases. An expert may limit the elicited quantity by upper and lower estimates so extreme that the probability for the quantity to be found outside the chosen range is zero. If the quantity is outside the chosen interval, the expert is wrong.

2.3 PHILOSOPHICAL CONSIDERATION REGARDING MEASURABILITY

Expert judgement elicitation involves many issues of a philosophical nature, and different schools of thoughts will often be present in the discussion among experts in an elicitation process. Examples of issues that may always create a discussion are

1. "Objectivism" vs. "modelism". A physical quantity that can be looked at and measured directly may seem better that something that must be measured invoking a model. However, to quote Jan Nolin from the Gothenburg University Theory of Science Institute [14] "There is always a distance between the signifier and the signified and a translation from the object into a system of signs or code, even when the most elementary observations are involved". The description of the elicited quantity itself is interwoven with this assessment process, and will require a number of conditions to be specified. Measuring a water level may be depending on averaging over waves, a phenomenon that may require a quantitative description in the process. Even in a glass of water, the level may be depending on the capillary effects, so that the glass' form and the reference point's distance from the glass surface may have to be specified. Such delineations may not be justified without models. During the elicitation, a number of issues were up for debate related to these questions.

2. What can be measured now and what in the future. Measurements cannot be made after thousands of years but it may be possible to define a question about conditions in the future, that experts agree could be measured in principle, i.e. in a thought experiment now, and in a real experiment in the distant future, with certain reservations.

3. The treatment of uncertainties as probabilities and the further aggregation of multiple uncertainty probabilities in the form of an average. These issues could lead to discussion and possibly experts rejecting the value of the exercise. For this reason, it is valuable that the elicitation "customers" know in advance and that the experts accept the process. In principle, an expert's opinion may be of value to the "customers", even if an expert rejects the method, but the issue should be addressed as early as possible in the process.

2.4 ALTERNATIVE METHODS OF EXPERT JUDGEMENT ELICITATION

There are several ways to vary the above scheme. One is to ask the experts individually for the answer, and to add to this answer a number of arguments why the answer was chosen. Such an elicitation was made by NRC's technical support organisation, Center for Nuclear Waste Regulatory Analyses, CNWRA, regarding climate change for Yucca Mountain [15]. Another would be to carry out the elicitation approximately as described in section 2, but to exclude interaction among the experts.

It is possible to grade the experts by their information content based on their score on questions outside their field, but it may lead to strong rejections by some experts who scored badly, and perhaps generate a discussion of the fairness or adequacy of the questions in the test quiz. In our case, the experts were not graded. Another possibility discussed in [9] is to grade the experts

based on a similar procedure, but based on questions in the experts' field, the answer of which is known to the elicitor.

The two first examples above might result in wider distributions, but they are not necessarily better or worse. A third is the example of expert negotiation. A negotiation would have similarities with our approach:

1. The experts would allow "new" information to emerge in the exchange of views between experts.

2. Every expert has his own position before negotiation. The last step is

3. The final decision, the outcome of the negotiation

It appears to the authors that the main difference between a negotiated result and a probability distribution from the SANDIA-NRC protocol is the third step of making the decision. In our view (or in our situation), the decision may be better made by the "customer" who needs to make the ultimate decision in any case, once all the arguments have been presented.

Different alternatives may well have more merits than is acknowledged here. The SANDIA-NRC protocol has gained wide acceptance although other protocols have been used as discussed in [11].

3 The elicitation

In the following, elicitation issues refer to the actual elicitation carried out 4-6 of June 2002. Four experts were invited to the elicitation. Each received a letter describing the elicitation quantity in advance. This was done to compensate for the fact that the elicitation was done in one rather than two meetings. The elicitation lasted 2 days. Most of the first day was used to describe the elicitation technique, the elicitation quantity, to discuss various possible estimation techniques, and to provide training and feedback. The elicitation lasted until late the next day. The scientific part of the elicitation will be reported elsewhere. This report will concentrate on the methods and lessons learned.

4 Expert judgement elicitation as a project

The cost of two meetings with four experts, each lasting three days, with international travel etc. is substantial. The order of magnitude cost could be, in a Swedish environment may be, in USD, 4 experts * 2 meetings * 1 000 ≈ 10 000 for travel, 4 experts * 6 days ≈ 20 000, in total around USD 30 000. With cost for elicitation experts, time and costs allotted for the "customer organisation's" personnel and their preparation for the project, the full cost of the elicitation is in the order of USD 100 000.

The cost itself implies that considerable caution must be exercised in choosing the basis for the elicitation. This is part of the rationale for the low-budget elicitation presented here. The elicitation gave valuable experiences in establishing contact with experts, and building the elicitation team. The exercise gave valuable experiences in several fields from a project management point of view:

- For risk assessments, or review of risk assessments, time must be given to identifying the issues relevant for expert judgement elicitation, if any, in the assessment. Perhaps other approaches may be more relevant.
- The quantity must be well defined to avoid confusion as to its meaning, implicit assumptions, or confusion with neighbouring issues.

- The need for a careful examination of the definition of the area for which experts are chosen. Experts in the general area may not consider themselves experts on the particular quantity for elicitation.

5 The elicited quantity

The quantity determined to be subject of elicitation may generate a heated discussion among experts. In a sense, this is logical: if there were nothing unclear about a quantity, it would probably not be selected for elicitation. The mere fact that it was chosen in the first place implies that it is critical in some sense, and perhaps the difficulties extend to its definition.

The experts were asked to estimate bio-availability for a number of combinations of different soils and nuclides, Cs and Sr a number of years (eleven) after deposition from the air. The answers were later compared to the Chernobyl fallout in Gävle area in Sweden.

Bio-availability is the portion of nuclides in soil that is available for plant uptake during the growth season. In simple terms, a nuclide may be in three states in soil, i) in solution, ii) on mineral surfaces and iii) fixed inside minerals. Only the two first categories are available for plant uptake. There was a substantial discussion about the quantity, whether it was indeed a physical quantity. Is the qualifier "during the growth season" a semantic addition or does it imply that bio-availability is a plant-specific quantity since growth season is different from different plants?

A recent publication [16] discusses techniques available for transfer of uncertainty measured in expert judgment elicitation of a measurable quantity to a model quantity which may not have physical meaning.

6 Training - calibrating input to the experts

As pointed out above, giving uncertainty as probabilities is not a natural act. The calibration quiz demonstrated a large amount, in some case more than half of the experts' uncertainty intervals, did not catch the correct almanac value.

The lesson learnt regarding calibration is that much more weight must be placed on preparatory work, and it is doubtful whether this can be done with the experts working in isolation. Since the elicitation technique incorporates - and places a high value on - the dialogue between experts, this should also be true for the preparation. It is therefore likely that the obtained distributions might be different if a more strict protocol had been used, with two expert sessions. Extra training, with potential further reduction of overconfidence, and also a more stringent procedure for choosing experts is necessary. In the elicitations, one expert did not give values for strontium and another for cesium. One expert had expertise primarily in an adjacent field and consulted colleagues in the elicitation procedure.

7 The issue of bias

In the exercise, the organisers used an expert who had done considerable work for SKB. In an elicitation in connection with review of SKB's work, this would not have been possible because of the potential for a motivational biases [2, 10].

The possible existence of reward systems and political/policy bias is one of the most important issues in public confidence. Public criticism is most likely to stem from the ways the experts are chosen. This calls for a separate procedure with strict protocols for identifying experts.

8 The results

The results of the elicitation in scientific terms will be discussed elsewhere. Here are some more general observations. Figure 2 shows the uncertainty distributions of bio-availability of strontium for sandy soil for three experts presented as cumulative probability functions and the aggregated distribution which is a simple average of the three individual distributions. Not all experts could participate in all cases, as mentioned earlier, leaving three experts for strontium and three for caesium in soil.

The single spike in figure 3, stemming from one expert using a very narrow interval, is evident also in the cumulative probabilities in Figure 2.

What is also clear from Figure 2 is that even if a risk analysis were made based on the combined results, one single extremely narrow distribution would not make a large difference. In both cases there is a considerable probability mass below and above the extreme. It would take a real performance assessment to evaluate the impact of such an extreme case.

Figure 2.
Cumulative probability (bioavailability of Sr) for experts 1,2 and 4.

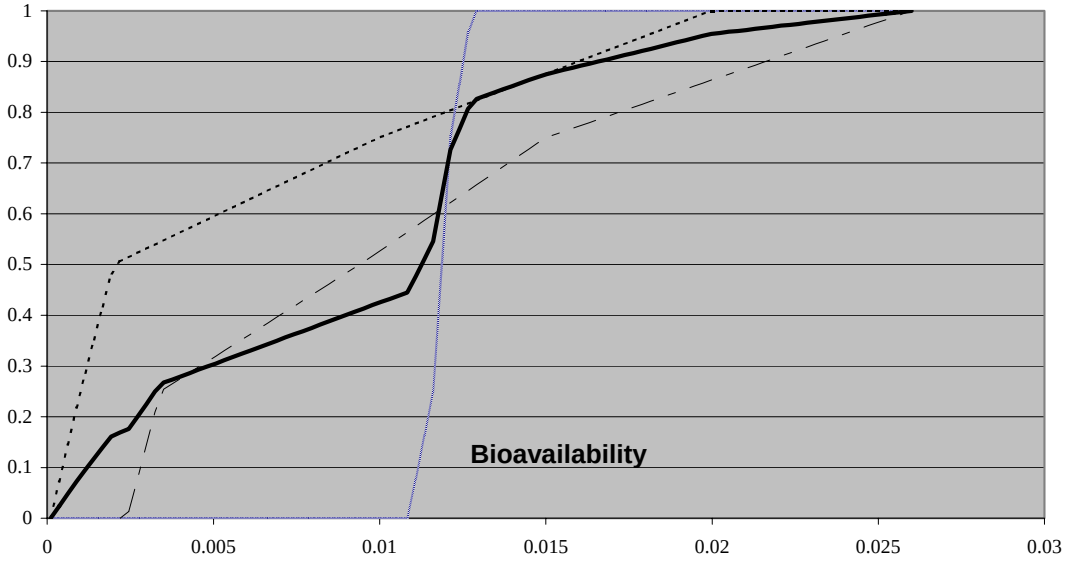
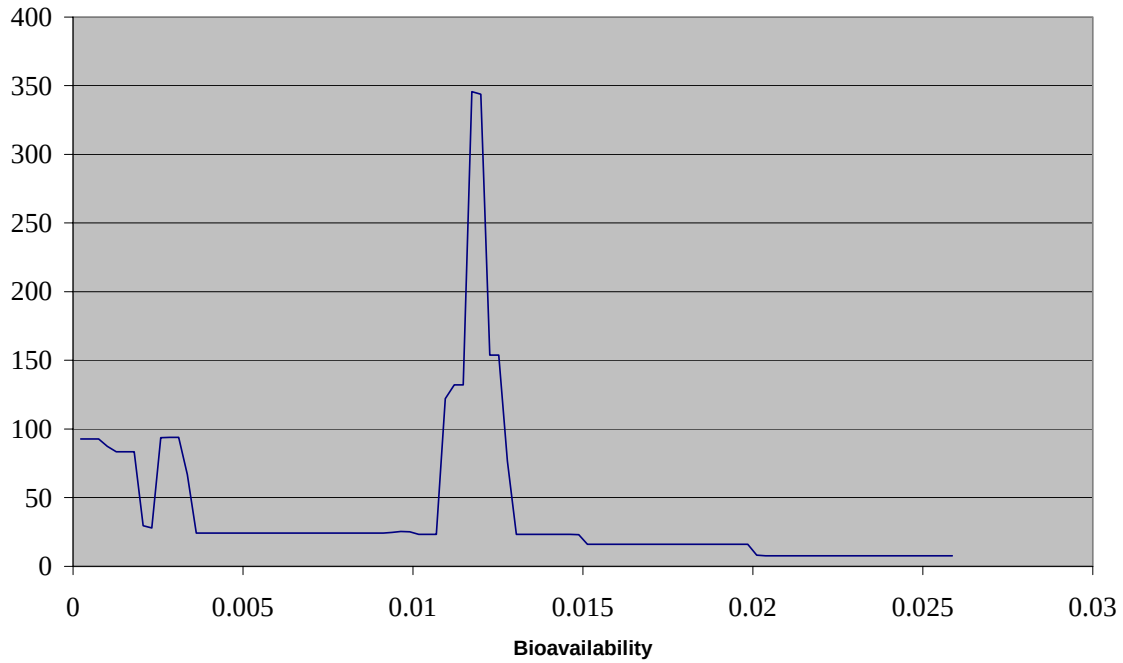


Figure 3. Probability density (Sr)



This underlines the issue of the number of experts needed in an elicitation. It should be equal to or more that three, and seldom more that six. Adding experts in excess of 6 seldom gives new information according to the advice of Professor Steve Hora. The fact that the experts were given the opportunity of abstaining from giving estimates for particular issues, underlines the significance of setting out with more than the minimum number of experts.

9 Elicitation in the context of a regulator-operator dialogue

In Sweden, the operator has the ultimate responsibility for the steps leading up to application to construct a safe repository. Therefore, formal expert judgement elicitation may be of potential interest to SKB. Experiences from the licensing process of the WIPP, it is also possible to imagine that the operator is forced to perform an elicitation based on parts of the safety analysis determined by the authority.

It may be, in some cases, a better solution for SSI to perform expert judgement elicitations of its own to highlight important issues. The justification for such cases could be:

- **to increase review competence** by studying in detail a certain segment of the safety assessment.
- **to illuminate SSI's regulatory activities** to ensure those conditions stipulated as requirements in the regulations or guidance documents are reasonable and amount to a safe situation.

Since there may be several reasons to conduct elicitation projects, it is valuable to get some experience early in the process, well before the licence application is foreseen.

10 Preparation for a full scale elicitation

Based on the experiences from the elicitation some conclusions can be made as guidance for a "full-scale" elicitation. The whole experience of preparations and the elicitations itself may be seen as a project, of which the in-house part may turn out be the most time consuming.

10.1 EARLY PREPARATIONS

10.1.1 The goal of the elicitation

One of the first issues to consider is the goal of the elicitation. In reviewing an area where SKB takes a predominantly experimental approach, there is a need for the authorities to see the overall picture, and correspondingly less need for a large-scale investigation to determine one parameter out of many, when all may be poorly known. A possible motivation for elicitation would be make cost estimations for cost-optimisation rather than determining risk. In Sweden, cost estimates are mainly a concern for SKB and, regarding the nuclear waste fund, for SKI.

As pointed out above, the technique may also be used in decision analysis. This would mainly be relevant for SKB. However, the approach would be considerably different for an experimentally oriented setting than for a licence application. Such work must require that steps be taken to focus on parameters known early in the process, since many parameters may not be available until later.

The case of a preliminary safety assessment falls somewhere in between an experimental situation and the licence application, and the circumstances and rationale for elicitation in that phase would require a thorough analysis in the beginning of the project.

10.1.2 The elicited quantity

In the described hypothetical project, the question must be asked what quantity is a critical issue and can it be found by other means than expert judgement elicitation? The conclusion is that one can visualise a fairly large amount of activity prior to the elicitation exercise itself. The list above pointing to i) limited data, ii) data existing only in an analogue form and iii) scaling experiments up or down may all be relevant issues. Scaling some of SKB's experiment up in time is a possible question, although a better formulation may be to discuss the relevance of an experiment under a limited period for the results to be used in models, not necessarily to scale up in a mechanical way to millennia from a few years.

SSI will investigate closer the potential for expert judgement based on a case study involving SR 97 and the authorities' review of that report.

10.2 PREPARATORY WORKSHOPS

10.2.1 In-house Workshop

In order to get a feeling for the problems involved in the elicitation, an in-house dry run is often recommended as a first step. This dry run may not necessarily foresee all the problems however, since all in-house experts may be tuned to the same thinking. Still it would bring forward enough issue to make it worthwhile.

10.2.2 The philosophical or ideological issues

Between elicitation experts, the philosophical issues involved in combining subjective probabilities are discussed extensively, and any elicitation result may be subject to such discussion, but these issues were not important in the elicitation procedure itself. In some cases, and in particular if the elicitation is related to a license application, there might be a component of policy/politics. It must be foreseen, therefore, that there might be a pressure felt by the experts from various sources, and even from journalists to leak their distribution, if the event was

known to take place and the outcome was felt to be important. It may therefore be necessary to expand the strict protocol inherent in the expert elicitation to the social environment outside the elicitation room itself.

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SSI Rapport

STATENS STRÅLSKYDDSINSTITUT, SSI, är central tillsynsmyndighet på strålskyddsområdet. Myndighetens verksamhetsidé är att verka för ett gott strålskydd för människor och miljö nu och i framtiden.

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.

SSI håller beredskap dygnet runt mot olyckor med strålning. En tidig varning om olyckor fås genom svenska och utländska mätstationer och genom internationella varnings- och informationssystem.

SSI medverkar i det internationella strålskyddssamarbetet och bidrar därigenom till förbättringar av strålskyddet i främst Baltikum och Ryssland.

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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