Radiation Protection Dosimetry vol. 90 No. 3 2000, 295-301

Expert judgement for a probabilistic accident consequence uncertainty analysis

L.H.J. Goossens*, F.T. Harper**, B.C.P. Kraan* and H. Métivier***

* Delft University of Technology, POBox 5050, NL-2600 GB Delft, the Netherlands
** Sandia National Laboratories, POBox 5800, Albuquerque, New Mexico, USA
*** Institut de Protection et de Sécurité Nucleaire, F-92265 Fontenay-aux-Roses Cedex, France

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ABSTRACT

The development of two probabilistic accident consequence codes sponsored by the European Commission and the United States Nuclear Regulatory Commission, COSYMA and MACCS respectively, was completed in 1990. These codes estimate the risks and other endpoints associated with accidents from hypothesised nuclear installations. In 1991, both Commissions sponsored a joint project for an uncertainty analysis of these two codes. The main objective of this joint project was to systematically derive credible and traceable probability distributions for the respective code input variables. These input distributions will subsequently be used in two uncertainty analyses for each code separately. A formal expert judgement elicitation and evaluation process was used as the best available technique to accomplish that objective. This paper shows the overall process and reports on experiences of elicitors and experts of the eight expert judgement exercises performed under the joint study.

1 INTRODUCTION

The U.S. Nuclear Regulatory Commission (USNRC) and the Commission (EC) have both developed probabilistic accident consequence codes: MACCS[1] in the United States and COSYMA[2] in Europe. Uncertainty analyses have been performed with predecessors of both codes, whereby the probability distributions utilised were assigned primarily by the consequence code developers rather than by phenomenological experts in the many different scientific disciplines that provide input to a complete consequence code. For that reason, the decision was made to execute a full uncertainty analysis on each code separately.

It was also recognised that many input variables are still largely uncertain and that a rigorous procedure was required to arrive at uncertainty distributions which better represent the true values in the real world. As experimental evidence is sparsely available for most of the phenomena modelled in the codes additional assessments of the input variables were needed. One available source are experts in the many disciplines which constitute an accident consequence code. This entailed that subjective assessments provided by experts were required to fill in the “gaps”, in particular, to provide uncertainty distributions reflecting all relevant aspects of the specified phenomena.

Since variables on physical phenomena are determined by the natural and environmental conditions under which the phenomena take place, both Commissions decided to join their efforts as much as possible. They formulated a joint EC/USNRC project to achieve the experts’ subjective assessments on observable quantities, and they decided to perform the uncertainty analysis for each code separately. In this way, access was gained to a greater pool of experts and both organisations could combine experience and knowledge in the areas of uncertainty analysis, formal expert judgement elicitation and consequence analysis. Furthermore, the joint project would find greater technical and political acceptability. The available formal expert judgement techniques could be adjusted easily to the needs of the joint project. An overview of the joint expert judgement study (for an extensive overview, see Goossens & Harper[3]) are shown in Table 1.

The experts, who need do not necessarily have to be familiar with the codes, were neither forced to provide uncertainty distributions on code input parameters, nor to believe in the models used in the codes. Instead, they were asked to provide assessments on variables, which, in principle, are observable and measurable. This principle is further discussed in the next paper[4] in this special issue as well as the inversion of observable variables to code input variables in another paper[5] of this special issue.

This procedure also required the conversion of the experts' assessments into uncertainty distributions over code input variables. To do this, special techniques were developed to carry out the so-called probabilistic inversions. As dependencies between uncertainty distributions of various code input variables were anticipated, correlations were also derived, either directly by expert judgements, or indirectly as a result of the probabilistic inversion exercises. Both procedures are reported elsewhere in this special issue[5].

Table 1. Phenomenological areas with expert panels and number of questions in the EC/USNRC joint project (NOTE: the countermeasures panel was performed as an EC project)

Expert panel	Year of panel and reference	Number of experts	Number of elicitation questions
Atmospheric dispersion	1993[6,7]	8	77
Deposition	1993[6,7]	8	87
Behaviour of deposited material and its related doses	1995[8]	10	505
Food chain on animal transfer and behaviour	1995[9]	9	80
Food chain on plant/soil transfer and processes	1995[9]	6	244
Internal dosimetry	1996[10]	9	332
Early health effects	1996[11]	10	489
Late health effects	1996[12]	10	106
Countermeasures	1999[13]	10	111

2 FORMAL EXPERT JUDGEMENT APPROACH

Two important principles with respect to the application of expert judgement were established for this joint project:

(1) the elicitation questions (i.e., the questions on variables for which the experts provided uncertainty distribution data) would be based on the existing models already used in COSYMA and MACCS because both the EC and the USNRC were primarily interested in the uncertainties in the predictions of these codes, and

(2) the experts would only be asked to assess physical quantities which could be hypothetically measured in experiments.

Since many code inputs are mathematical constructs resulting from fitting a particular function (model) to the available experimental data, eliciting assessments on physical quantities rather than these mathematical constructs (code inputs) avoids ambiguity and disagreements in variable definitions. In addition, assessments that are formulated for physical quantities are deemed to have a much wider application beyond the joint study, and they are easier to imagine by other potential users.

Formal expert judgement elicitations were used to develop distributions for important consequence analysis input variables for which the experimental database did not provide all the necessary information, and the analytical models used for extrapolation were not indisputably correct. To ensure the quality of the elicited information, a formal expert judgement elicitation process, built on the process developed for and used in the NUREG-1150 study[14], was followed. Refinements were implemented based on experience and knowledge[15] gained from several formal expert judgement elicitation exercises performed in Europe[16] as well as in the U.S.[17]. This latter paper provides an overview of the method used in NUREG-1150. This expert judgement method emphasises the discussions with individual experts on the phenomena to be elicited.

The formal expert judgement elicitation process that was implemented in the joint project is illustrated in figures 1 and 2, and explained in greater detail elsewhere[3],.

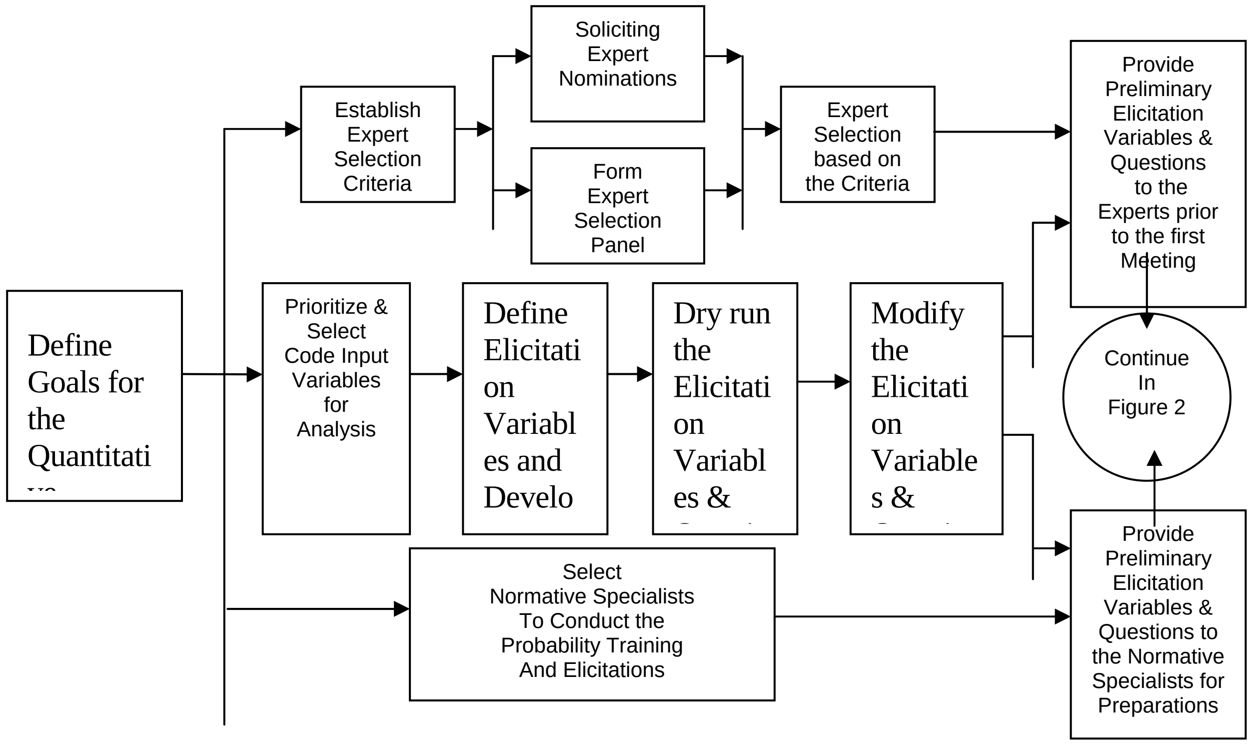

Figure 1: Sequence of methods implemented for the development of consequence code input distributions: Preparations for probability training and expert judgement elicitation

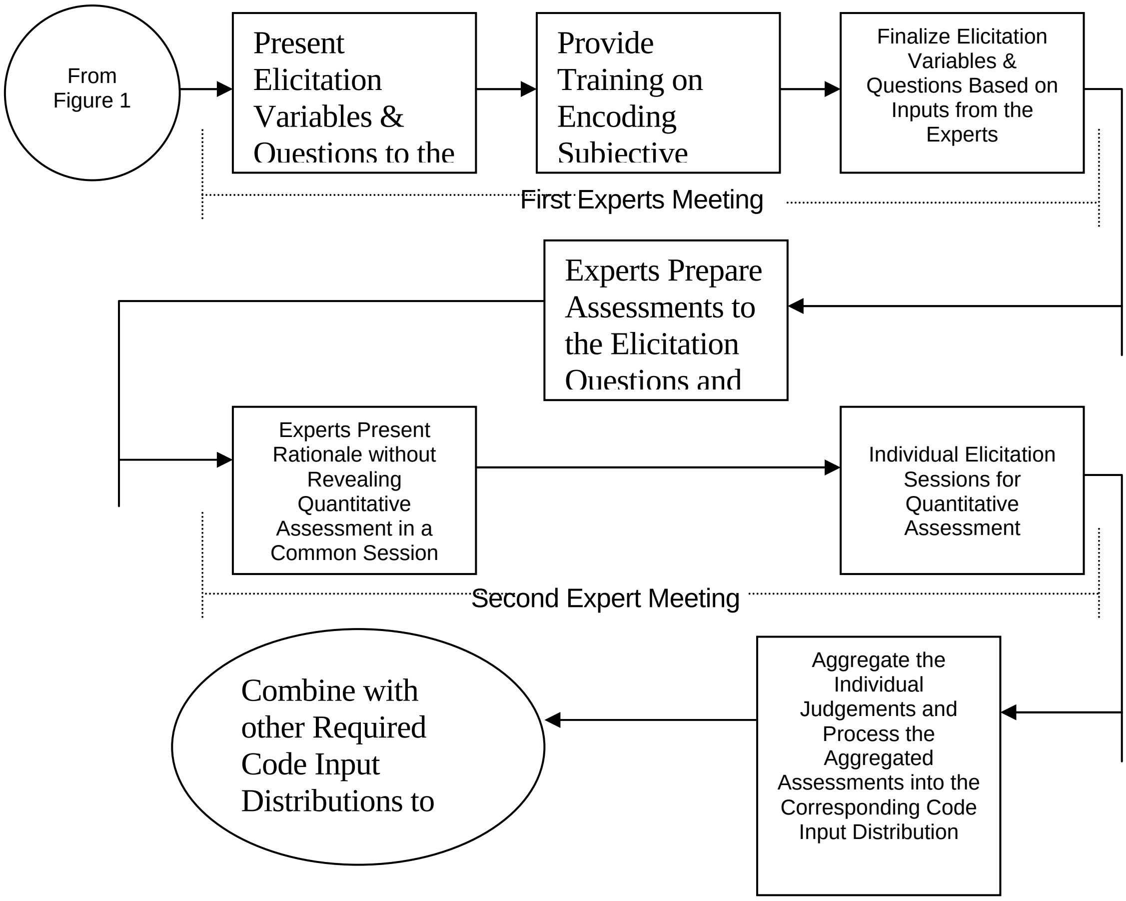

Figure 2: Sequence of methods implemented for the development of consequence code input distributions: Expert judgement elicitation and processing of judgements.

The objectives of the project were:

(1) to formulate a generic, state-of-the-art methodology for uncertainty estimation which is capable of finding broad acceptance;

(2) to apply the methodology to estimate uncertainties associated with the predictions of probabilistic accident consequence codes (COSYMA and MACCS) designed for assessing the consequences of commercial nuclear power plant accidents;

(3) to better quantify and obtain more valid estimates of the uncertainties associated with probabilistic accident consequence codes, thus enabling more informed judgements to be made in the areas of risk comparison and acceptability and therefore to help set priorities for future research.

Since the elicitation process is very resource intensive, the importance of clear understanding of the objectives, scope and constraints of each individual expert panel were fully recognised. Although the project focussed on the COSYMA and MACCS codes, application to other probabilistic accident consequence codes should be possible as well.

This paper emphasises the experiences of the elicitors and the experts and highlights the major outcome of the project, namely the consequences of deriving aggregated uncertainty distributions from multiple experts' assessments. Since expert judgements are subjective assessments and since there is no rationale to assign more weight to one expert than to another expert, excepting via performance based weighting (see another paper in this special issue), the aggregated uncertainty distributions might be less informativeness (i.e., much wider) than anticipated. This is typically the case once aggregation is based on equal weighting of the experts' assessments, which was programmatically chosen in this joint exercise.

3 EXPERIENCES FORM THE ELICITORS

The objective for each panel was to engage the best experts from various viewpoints in the phenomenological areas of interest. A large list of experts was compiled from the literature, and by requesting nominations from experts known by project staff and from several organisations. The experts were contacted and sent in curricula vitae (CVs). Impartial selection panels both in the U.S. and Europe have been formed. The CVs were evaluated by nomination committees and 68 experts were chosen on the same set of established criteria: reputation in the relevant fields, number and quality of publications, familiarity with the uncertainty concepts, diversity in background, balance of viewpoints, interest in the project, and availability to undertake the task in the prescribed time-scale. Experts were paid to cover for their time spent.

The main responsibility of a normative specialist is to conduct the expert elicitation sessions. Normative experts are experienced in subjective probability assessments and could be familiar with some of the areas of interest. Substantive experts are familiar with the area of interest. It is imperative that the normative specialist is able to assist the experts in encoding subjective assessments into coherent probability distributions during the elicitation sessions. The normative specialists were selected for the project based on their experience with other expert judgement exercises in the past. They were part of the project staff and they assisted in drafting the elicitation questions for the panels, which was the main task of the substantive experts of the project staff.

The experts were convened for a first meeting where they were briefed on the purposes of the study, introduced to the relevant material on the consequence codes, and provided training in probabilistic assessments. In addition, the complete set of elicitation variables and questions were reviewed by and discussed among the experts and project staff, and, if needed, further modifications were added. That was to ensure that the experts felt comfortable with and would respond to the same questions. The initial and boundary conditions were also discussed at the first meeting.

After the first meeting, the experts prepared their responses to the elicitation questions (during a period of 6 to 10 weeks). They were free to use any modelling techniques they believed were appropriate to assess the problems. For each elicitation variable, the experts provided three quantile points (5%, 50%, 95%) representing their uncertainty. No distribution shapes were required. In addition to the quantitative judgements, each expert also provided a written rationale to document the sources and explain the approaches used in arriving at the assessments. All data and rationales are (anonymously) reported in the references mentioned in table 1.

The experts were reconvened for a second session (except the food chain and external dose panels) where they shared approaches without giving their quantitative assessments during a common session. Individual elicitation sessions were held thereafter. During these individual sessions, each expert worked with two elicitors (a normative specialist and a project specialist, substantive expert, on the particular field of interest) on the same questionnaire, to arrive at the final quantitative assessments. The dependence among the various elicitation variables was elicited to facilitate the future uncertainty analyses for the codes, when all distributions will be linked and propagated through the codes.

4 APPROACHES USED BY THE EXPERTS

The dispersion experts generally relied on the Gaussian plume spread model, particularly to estimate the median assessments, and used different approaches to derive the 5% and 95% quantiles. The deposition experts used a wide variety of models for dry deposition and derived wide uncertainty bands. They also provided wide uncertainty bands for the wet deposition assessments indicating large modelling uncertainty. The deposited material and external dose experts based their assessments mostly on observations from the Chernobyl accident, which resulted in relatively narrow confidence bands.

The food chain experts used a variety of models and based their assessments largely on theoretical considerations and experiments. In some cases individual experts provided large uncertainty bands. For instance, the resuspension factors were assessed with an aggregated range factor of more than 10,000, with the 50% quantile relatively close to the 5% quantile. The internal dosimetry experts largely made use of knowledge and experiences gained in the ICRP (International Committee for Radiation Protection). For instance, the assessments for absorption of radionuclide elements to blood following ingestion were similar, reflecting current ICRP work. Other assessments, such as retention of strontium, caesium and plutonium in tissues after absorption to blood showed a wide diversity in the experts' answers.

For the early health effects assessments the experts used data on the survivors of the Japanese atomic bombs and on those exposed as a result of the Chernobyl accident. In general, where human data were available, they provided the basis for the median assessments. Where human data were deemed insufficient, extrapolations from animal data were used, supported by statistical and mechanistic models. For the late health effects assessments, there is a large measure of concordance in the data sets used by the experts. All experts made extensive use of the latest Japanese atomic bomb survivor mortality and cancer incidence data sets. The reliance on the latest Japanese atomic bomb survivor data for most cancers meant that there was a large degree of concordance in the median (50% quantile) cancer risk for most organs. For certain organs (e.g., bone and breast), the experts used various other data sets, generally referred to in the latest UNSCEAR[18] and BEIR V[19] reports. In contrast to the similarity of data and methods used to obtain the 50% quantiles, there is much more variation among experts in the methods used to obtain the 5% and 95% quantiles of cancer risk.

5 RESULTS

Uncertainty distributions were developed which represent state-of-the-art knowledge in the eight areas mentioned in Table 1. The quantile points of the uncertainty distributions (5%, 50% and 95%) assessed by the experts relate to physically measurable quantities, conditional on the case descriptions provided to them. The experts were not directed to use any particular modelling approach but were free to use whatever models, tools, and perspectives they considered appropriate for the problem. The elicited distributions obtained were developed by the experts from a variety of information sources. The aggregated distributions therefore include variations resulting from different modelling approaches and perspectives.

As already stated a rigorous expert judgement procedure was needed in order to get uncertainty distributions which reflect the true values as much as possible. The procedure thus required multiple experts. The resulting uncertainty distributions over the code input variables then depended on the process of aggregating multiple experts' assessments into a joint assessment for each variable which is termed the decision maker's assessment (DM-assessment). For programmatic reasons of assignment, the aggregation process was done using equal weights for each expert in a panel of experts. As the individual expert's assessments differed from each other, equal based aggregation resulted in relatively wide uncertainty distributions of the decision maker's distributions. To illustrate this effect, two typical examples of multiple expert judgements are shown in figures 3 and 4.

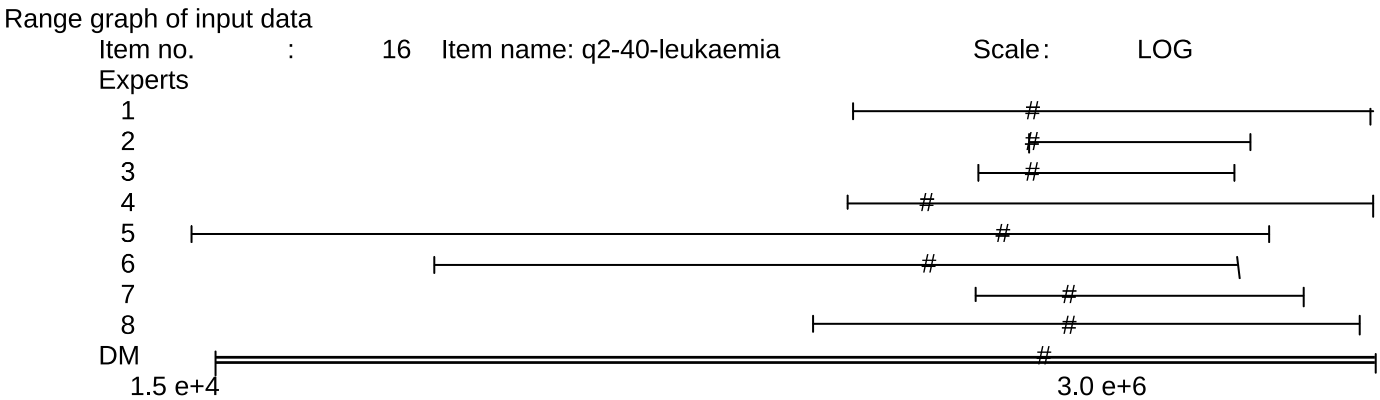

Figure 3. Range graph representing 8 experts' assessments and the aggregated DM-assessment of the number of leukaemia deaths 40 years after exposure to 1 Gy low LET-radiation during 1 minute; [---] is the 90% central confidence band, # the median value, the numbers are the lowest and highest value mentioned by the experts

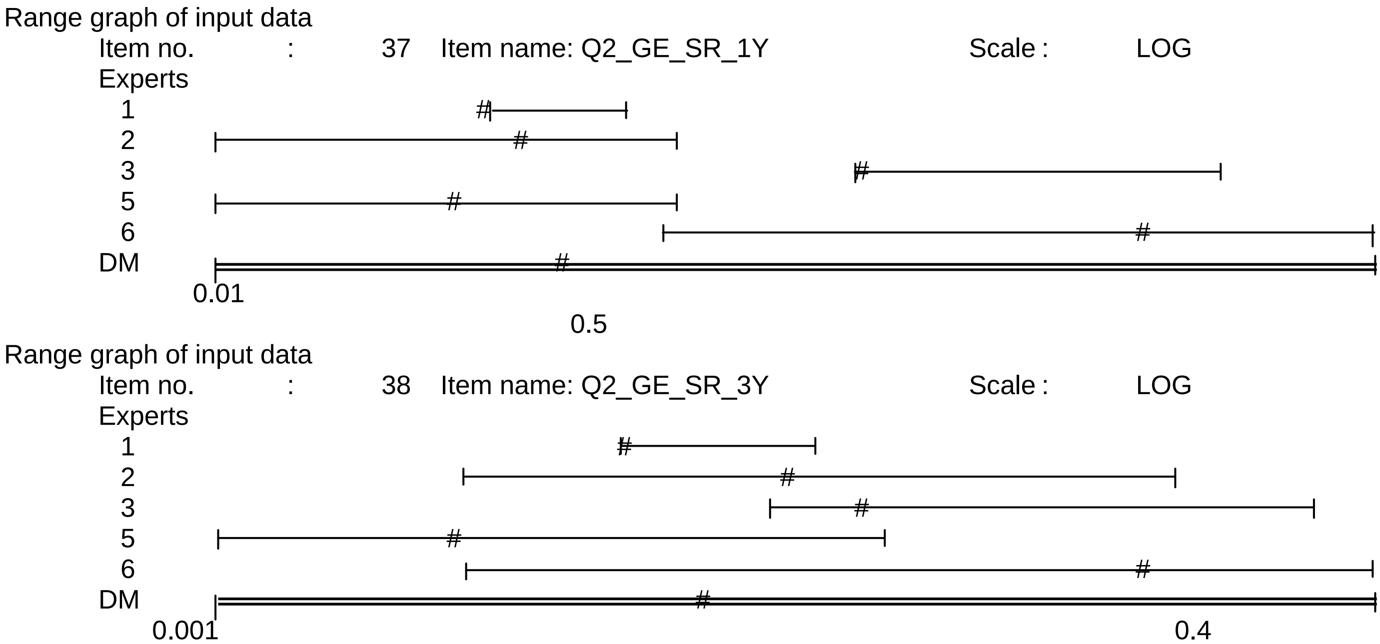

Figure 4. Range graph representing 5 experts' assessments and the aggregated DM-assessment of the fraction of strontium being unavailable for uptake by plants after 1 year and 3 years respectively; [---] is the 90% central confidence band, # the median value, the numbers are the lowest and highest value mentioned by the experts

Figure 3 shows one group of assessments for which the medians are close to each other, but differences appear in the lower end of the 90 % confidence bands. Two experts provided relatively large 50%/5%- uncertainty factors which determine the 5% quantile of the DM-assessment.In aggregating the individual assessments, each expert out of *N* experts gets weight (1/*N*). Figure 4 shows another typical group of assessments whereby large differences are found in the median assessments while the 90 % confidence bands are (somewhat) more similar. The resulting DM-assessments aggregate all assessments equally reflecting a much wider 90 % confidence band.

6 CONCLUSIONS

Valuable information has been obtained from this joint effort. The goal of creating a library of uncertainty distributions has been reached, and is applicable outside this project. In this project, teams from the USNRC and European Commission were able to work successfully together to develop a unified process for the development of uncertainty distributions on consequence code input variables. The joint effort of the team of elicitors and experts has proven to provide uncertainty assessments which could be used in the overall uncertainty analysis of the COSYMA code has proved workable and is reported elsewhere in this special issue (see also the paper by Ehrhardt et al. in this session). Aggregation of the individual experts' uncertainty assessments generally results in wider uncertainty bands for further use, as each expert's assessments counts equally in the aggregation process. Typical examples of multiple experts' assessments are shown in the paper.

ACKNOWLEDGMENTS

The projects were prepared under EC-contracts (DG XII, Radiation Protection Research, and DG XI, Radiation Protection) and under USNRC-contract (Office of Nuclear Regulatory Research, Division of Safety Issue Resolution). The authors express their thanks to many others who have contributed largely to what has been established in the joint project so far: EC and USNRC staff, the experts, and the persons who kindly provided us with additional information and data.

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