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# JOINT USNRC/EC CONSEQUENCE UNCERTAINTY STUDY: THE INGESTION PATHWAY, DOSIMETRY AND HEALTH EFFECTS EXPERT JUDGMENT ELICITATIONS AND RESULTS


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## ABSTRACT

The U.S. Nuclear Regulatory Commission (USNRC) and the European Commission (EC) have conducted a formal expert judgment elicitation jointly to systematically collect the quantitative information needed to perform consequence uncertainty analyses on a broad set of commercial nuclear power plants. Information from three sets of joint U.S./European expert panels was collected and processed. Information from the three sets of panels was collected in the following areas: in the phenomenological areas of atmospheric dispersion and deposition, in the areas of ingestion pathways and external dosimetry, and in the areas of health effects and internal dosimetry.

This exercise has demonstrated that the uncertainty for particular issues as measured by the ratio of the 95th percentile to the 5th percentile can be extremely large (orders of magnitude), or rather small (factor of two). This information has already been used by many of the experts that were involved in this process in areas other than the consequence uncertainty field. The benefit to the field of radiological consequences is just beginning as the results of this study are published and made available to the consequence community.


## I. INTRODUCTION

The US Nuclear Regulatory Commission (USNRC) and the European Commission (EC) began a joint uncertainty analysis of their respective consequence codes, MACCS and COSYMA, in 1991[1]. A formal expert judgment elicitation process was formulated and implemented jointly to systematically collect the quantitative information needed to perform the consequence uncertainty analysis. Three sets of joint U.S./European expert panels were formed. Their exercises were carried out in a staggered fashion so that project staff could evaluate the results, consider the lessons learned from the earlier expert panels, and then further refine the process. The elicitation of the first set of joint panels on


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atmospheric dispersion and deposition were completed in 1993 and a joint report was published in 1995[2]. The second set of joint panels on ingestion pathways and external dosimetry was completed in 1995 and a report is being prepared. The responses from the panels on health effects and internal dosimetry will be completed in 1996. This paper provides some examples and insights from the preliminary results of work by ingestion pathway, dosimetry, and health effects panels. The methodology used is summarized elsewhere in the proceedings for this conference.

Owing to the massive amount of information generated in this project, examples are used to illustrate points in this paper in order to give the reader an awareness of the nature and the size of the technical problems confronted by the joint US/EU team. Considerable effort was expended designing the elicitation questions which had to meet the following requirements:

a. The code input variable that is related to the elicitation variable must be important to a consequence measure.

b. The elicitation variable must be potentially observable (potentially observable implies that an experiment could be performed to observe the variable, although the resources required might be prohibitively high).

c. It must be possible to construct distributions for the code input variables from the elicitation variable distributions through mathematical processing (in a few cases, the code input variable and the elicitation variable were identical, but in most cases, the elicitation results had to be processed to generate distributions for the code input variable from the distributions provided for the elicitation variables).

An example of a processing methodology is presented to illustrate the mathematical complexity of processing elicitation variable distributions into code input variable distributions.

Some preliminary results used to illustrate the uncertainty distributions developed in the food chain, deposited material and related doses, and health effects and internal dosimetry.

## II. EXAMPLES OF ELICITATION QUESTIONS FOR UNCERTAINTY DISTRIBUTIONS

A. Ingestion Pathway Elicitation Questions

Following a single deposit, what are the concentrations (Bq $kg^{-1}$) at maturity of Sr and Cs in grain, green vegetables, pasture grass, root crops and potatoes which are grown on soil that contains 1 Bq $kg^{-1}$ of Sr and Cs?

Consider an animal that is continuously fed Sr or Cs at a constant daily rate under field conditions. What is the observed equilibrium transfer of activity to the meat of the animal for each element?

B. External Dosimetry Elicitation Questions

What is the effective dose-rate and effective dose to an adult outdoors in"typical" urban and rural (open field) environments, following initial deposition of 1 Bq/$m^2$ of Zr-95/Nb-95, Ru-106/Rh-106, I-131 and Cs-137/Ba-137m to the lawned areas of the ground?

What is the ratio of time-integrated air concentration indoors to that outdoors, given an outdoor value of 1 Bq $m^{-3}$ for Pu-240?

What is the fraction of an average population in the expert's own country that would be classed as (i) agricultural and other outdoor workers, (ii) indoor workers, (iii) non-active adult population and (iv) schoolchildren?

C. Internal Dosimetry Elicitation Questions

What is the initial deposition in the extra thoracic (ET) region, % of total deposition in the respiratory tract?

What is the retention of Pu on endosteal bone surfaces (considering a 10 μm depth of bone mineral) as a percentage of total skeletal retention, as a function of time after entry into blood?

D. Late (Stochastic) Health Effects Elicitation Questions

Estimate the number of radiation induced cancer deaths up to 20 years following exposure in a population of a hundred million persons ($5 \times 10^7$ male, $5 \times 10^7$ female), each receiving a whole body dose of 1 Gy low LET (= gamma) radiation at a uniform rate over 1 minute.

E. Joint Dosimetry/Late Health Effects Questions:

Estimate the number of radiation-induced cancer deaths up to 40 years following exposure in a population of a hundred million persons ($5 \times 10^7$ male, $5 \times 10^7$ female), each of whom inhales 10 kBq of the radionuclides specified (Pu-239 and Sr-90 were specified).

F. Early (Deterministic) Health Effects Elicitation Questions

For inhalation of aerosols that contain transuranic radionuclides, provide:

- The threshold lung dose rate below which no deterministic fatalities are observed within 3 years.
- The lung dose rate that will result in deterministic dose in 10% of exposed individuals within 3 years. (There are additional questions for 50 and 90% of exposed individuals.)

## III. PROCESSING METHODOLOGY

One of the many mathematical procedures that was used to translate the elicitation variable distributions into distributions that could be used by the consequence codes is discussed in this section. The example is from the ingestion pathway work and illustrates how the distributions for the concentration of radioactive material in grain at harvest are converted into the distributions required by MACCS for an uncertainty study. This is one of the more complicated ingestion pathway processing issues for the U.S. models. The EU and the U.S. panel members were able to use the same base elicitation variable distributions, even though the code input variables required by the European ingestion pathway model (FARMLAND) that supports the COSYMA consequence code differed from the code input variables required by the U.S. ingestion model (COMIDA) that supports the MACCS code. Different processing methodologies were required by the U.S. and the EU.

The question asked of the experts was as follows:

*What is the concentration (Bq $kg^{-1}$ [wet weight]) of Sr and Cs in the edible portion of grain at harvest, for a single deposition of 1 Bq $m^{-2}$ to the ground occurring 15, 30, 60 and 90 days before the grain is harvested? This quantity is designated as* $QC_{grain}$.

The deposition is the total amount of the two radionuclides deposited on the soil and the plants. The uncertainty should include that coming from the relative amounts of material intercepted by the different parts of the grain, and the subsequent translocation to the edible portion of the grain, taking into account increases in biomass. The estimates of the activity concentrated in grain should make no allowance for material originally deposited on soil and subsequently taken up by the plant roots. The experts were instructed to include contributions from the uncertainty due to the lack of specificity in the following parameters in their distributions: the type of deposition (wet or dry), the rainfall rate , the stage of crop development, and the yield of edible grain.

In this case, the elicited quantity is not what is required in order to use MACCS in an uncertainty study. What is needed is the foliar absorption rate ($K_{ab}$). A complication arises because, even in a simple foliar absorption model, the elicited quantity $QC_{grain}$ depends not only on the time of deposition but also on the percolation rate constant ($K_p$), resuspension rate constant ($K_r$), weathering rate constant ($K_w$ ), rainsplash rate constant ($K_{rs}$), the maximum edible crop biomass, Kg-dry/$m^2$ ($B_{MAX}$), interception factor (FV), and ratio of dry to wet weight (FD). If all of these quantiles are held at their median values, a corresponding median for $K_{ab}$ can be estimated.

First, a value of FV needs to be determined as a function of time to harvest. This can be done using an expression relating initial edible crop biomass ($B_I$), growth rate constant for crops ($K_g$), $B_{MAX}$ (maximum edible crop biomass, Kg-dry/$m^{-2}$), $\alpha$ (the foliar interception constant ($m^2$/kg) measured as the ratio of vegetation concentration (Bq/kg) to the total deposition (Bq/$m^2$)). Best estimate values used for $B_I$ and $K_g$ come from the COMIDA manual. The values for the other variables come from the processed elicitation questions for soil and plants.

A deposition time is selected from the stated choices of 15, 30, 60, and 90 days before harvest. $K_p$, $K_r$, and $K_w$ are set at their median values as determined from the post processing of other soil and plant questions. $K_{rs}$, $B_{MAX}$, and $FV$ are held at their point estimate values. $QC_{grain}$ is set equal to the elicited median and then the expression is solved for $K_{ab}$. (the expression is not reproduced here because of its length). This is repeated for the other four deposition time choices. The results for $(K_{ab})_{50}$ should be reasonably consistent. A conservatively wide estimate of the uncertainty in $K_{ab}$ can be obtained from

$$(K_{ab})_{50} = (K_{ab})_{50} \frac{(QC_{15\ day})_{05}}{(QC_{15\ day})_{50}}$$

$$(K_{ab})_{95} = (K_{ab})_{50} \frac{(QC_{15\ day})_{95}}{(QC_{15\ day})_{50}}$$

The median values for $K_{ab}$ were obtained by performing a fixed-point iteration. The 5th and 95th quantile values were obtained using the two preceding equations. In this manner, the COMIDA model should replicate the results given by the experts for $QC_{grain}$, when the uncertainty distribution for $K_{ab}$ is used, when the same initial conditions that were defined for the elicitation are assumed, and when processing values for the other parameters are replicated. The post processing here involves no less than 12 COMIDA variables. This makes this evaluation inherently difficult since none of these variables are known with certainty.

## IV. SOME RESULTS

A. Some insights from Ingestion Pathway Assessments

Figure 1 (at the end of the paper) shows information based on the ratio of the 95th percentile to the 5th percentile for several Sr soil migration questions that were answered by the soil and plant subgroup of the ingestion pathway panel. This ratio is used in this paper as a measure of uncertainty (higher ratios indicate more uncertainty). Sometimes this ratio is called the range factor or the error factor squared. In the figure, the individual experts are designated by a number (1 through 5), the aggregated result is designated by the term Equal Wt. (which refers to the fact that responses of the experts were weighted equally when aggregated), and the item refers to which depth (1 cm, 5 cm, 15 cm, and 30 cm) is being considered. All cases presented in the figure are for Sr migration in sandy soil.

As Figure 1 shows, the aggregated distributions are more uncertain (demonstrated by a higher ratio) than any of the individual elicited distributions. This is not unexpected: our experience in past studies indicates that the uncertainty in aggregated results is often higher than the uncertainty in any of the individual expert distributions.

Some additional insights from the ingestion pathway panel follow:

For soil migration, the aggregated uncertainty bands (range factors) are generally smaller for Cs than for Sr. For generic soils, the range factors can be ten times larger for Sr than Cs, a factor of 5 larger for sandy soils and similar for highly organic soils. For fixation in soil, there is no significant difference in the magnitude of the range factors between Cs and Sr. Range factors range from 2 to 50, being larger for the highly organic soil.

For all root uptake concentration factors, wide uncertainty range factors are found for the aggregated distributions: (ranging from about 20 to about 5,000). The overall trend is that the range factors for Sr are smaller than those for Cs for all crops. Range factors for root uptake from sandy soils are smaller than those observed for the generic soils; those for highly organic soils are typically larger than both generic and sandy soils, particularly for Cs.

The aggregation of data for interception factors results in uncertainty range factors of about a factor of 10 to 20 for all crops. The aggregated resuspension factors give rise to large 95th/5th percentile ratios which are about 10,000, with the 50th percentile relatively close to the 5th percentile. For the retention times, range factors on the order of 20 are found for all crops.

The aggregated data for the concentrations in grain at harvest show similar results for both Sr and Cs with uncertainty range factors ranging from 70 to 600. The smaller uncertainty ranges are seen for deposition at 30 days and 60 days before harvest for Cs and at 15 days and 30 days before harvest for Sr. For concentrations in root crops at harvest, the range factors are much higher than those seen for grain, with the range factors for Sr significantly smaller than those observed for Cs. For root vegetables, the range factors are smallest for deposition occurring 60 days and 90 days before harvest for both elements.

The husbandry practices in Europe and the United States are, in general, significantly different. Therefore, the European and American experts were given different questions. As with the plant/soil results, the ratios of the 5th and 95th percentile values indicate that the width of the aggregated uncertainty range factor is typically greater than for the elicited distributions of individuals. Aggregation of the European and U.S. data is, therefore, limited.

The results from the aggregated European distributions on the availability of radionuclides in ingested feed for transfer across the gut are shown to be least uncertain for I (95th/5th percentile ratios on the order of 2 to 3), and more uncertain for Sr and Cs (95th/5th percentile ratios ranging from 2 to 4,000). In all the assessments on transfer to meat, milk and eggs, the experts are least uncertain for Cs, with 95th/5th percentile ratios ranging from 10 to 80. The ratios for Sr are higher by between about a factor of 2 to a factor of 50. The largest ratios were observed for transfer to lamb, eggs, pork, and chicken. The transfer of I to eggs and sheep milk is also very uncertain, with 95th/5th percentile ratios of about 1400 and 600, respectively.

For the biological half-lives in animals, the data for the U.S. and European experts have been combined. In the aggregated data, the 95th/5th percentile ratios are smallest for Cs (ranging from 10 to 30), intermediate for I (ranging from 200 to 500), and highest for Sr (ranging from 500 to 1300).

B. Deposited Material and Related Doses

Figure 2 ( at the end of the paper) depicts the aggregated EU and U.S. results of the time-integrated air concentration. In this figure, the ratio presented is the ratio of the air concentration inside a building to the air concentration outside a building.

As Figure 2 shows, the ratio of time-integrated air concentration is consistently higher for Cs than for Pu. The ratio of the 95th percentile to the 5th percentile ranges from 4 to 80 and is higher for the Pu cases than for the Cs cases. The ratio of concentration inside over that outside exceeds 1 for both Pu and Cs in the 95th percentile for the open window case.

C. Joint Late Health Effects and Dosimetry

The following request was provided to teams of experts (typically, one late expert was combined with one early expert).

Please provide the number of radiation-induced cancer deaths up to 40 years following exposure in a population of a hundred million persons ($5 \times 10^7$ male, $5 \times 10^7$ female) each of whom inhales 10 K Bq of Pu-239 particles (1 micron of activity median aerodynamic diameter (AMAD)) in the oxide form).

Although the individual expert results have not been aggregated at this point, the ratio of the 95th percentile to the 5th percentile for each expert was typically on the order of 25. Some sources of uncertainty were as follows:

- The factor for the uncertainty in dose conversion.
- The relative biological effectiveness (RBE) which was assumed to range from 5 to 40.
- The uncertainty in risk for a given exposure due to a variety of uncertainties in the A-bomb data.

## V. CONCLUSION

As can be seen, the uncertainty for particular issues as measured by the ratio of the 95th percentile to the 5th percentile can be extremely large (orders of magnitude), or rather small (factor of 2). This exercise has shown the project staff and the many experts who participated in this study where the more uncertain aspects in each of the phenomenological areas are, and has provided a quantitative measure for each uncertainty. This exercise is a very good way to measure the state of the art in the various phenomenological areas. The information obtained has already been used by many of the experts in areas other than modeling consequence uncertainty. Many have found this exercise invaluable in adding additional perspective to an understanding of their own field. The benefit to the field of radiological consequences are just beginning to be seen as the results of this study are published and made available.

## REFERENCES

[1] C. H. Lui, F. T. Harper, L. H. J. Goossens, and G. N. Kelly, "Joint USNRC/EC Consequence Uncertainty Study: An Overview", presented at PSA '96.

[2] F. T. Harper et al., *Probabilistic Accident Consequence Uncertainty Analysis: Dispersion and Deposition Uncertainty Assessment*, NUREG/CR-6244, EUR 15855 EN, SAND94-1453, Sandia National Laboratories, Albuquerque, NM, USA, January 1995.

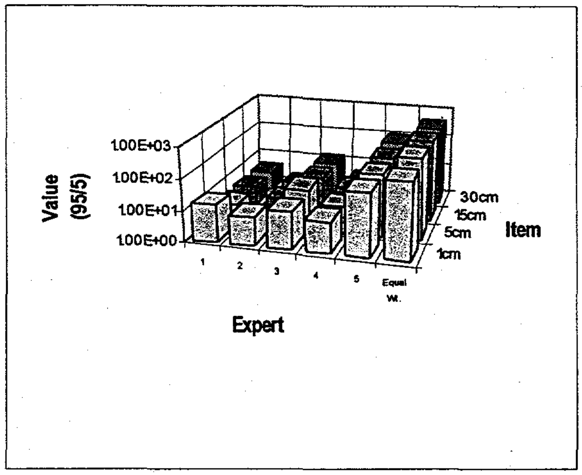


**Figure 1 Ratio of the 95th to the 5th percentile expert response for one of the soil and plant subgroup questions of the ingestion pathway panel.**

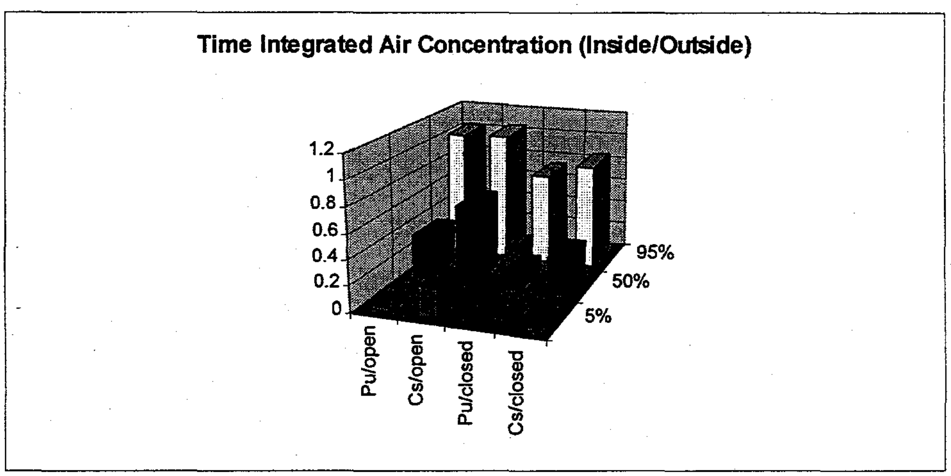


**Figure 2 Aggregated EU and U.S. results of the ratio of the time-integrated air concentration inside a building to the time integrated air concentration outside a building**