HOW TO USE EXPERT JUDGEMENT TO ASSESS UNCERTAINTIES

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1. BACKGROUND

Uncertainties in the understanding of physical phenomena have been, and should be, a major element in assessing the performance of commercial nuclear reactors under accident conditions. In fact, these uncertainties should be, and are, part of the assessment for reactors under normal power conditions. The difference being that there are orders of magnitude greater experience with the phenomena controlling normal operation and the design basis conditions than there is with severe accident behavior. Hence, the uncertainties treated in the first two cases are typically much smaller than those used in severe accident analyses.

As a result of the limited experience in some physical phenomena, some studies have adopted a form of expert judgement as a surrogate for experimental data to (1) develop a perspective on the type, (2) estimate the magnitude of uncertainties that should be considered and (3) determine how these influence the conclusions of integral analyses. Perhaps the most extensive example was the expert elicitation done as part of NUREG-1150 [1] in which a well documented expert judgement process was used. In this paper, an additional step is added to the expert selection process to maximize the insights realized through the study.

2. THE GOALS OF EXPERT JUDGEMENT

Expert judgement is only required in the absence of sufficient relevant analytical and experimental data. Hence, the ultimate goal is to find a credible substitute for a detailed understanding of the phenomena and the magnitude of uncertainties that could be anticipated as a function of the reactor design, the accident behavior and corrective actions that could be taken by the operating staff. In NUREG-1150 "expert judgement was needed to supplement and interpret the available data" on severe accident phenomena. Experts were selected and elicitation of these experts was carried out according to a formal set of procedures. The experts were divided into seven panels and were selected on the basis of their expertise in various areas as indicated by publications in referred journals. Individuals were selected from a range of backgrounds including the nuclear industry, the Nuclear Regulatory Commission, contractors for the NRC, and universities. A similar process was used to assess the uncertainties associated with severe accident consequences modeling [2]. This formalized process has been effective, however, there is one important element missing in this process and that is closure on the question; has everything been considered that needs to be considered?

It is reasonable to expect expert judgement would result in wider uncertainty bands than would be the case if substantial experimental information was available. As has been observed in many such applications since the reactor safety study [3], the presence of wide uncertainty bands is not necessarily troubling. In fact, many such analyses have shown that the conclusions are tolerant of substantial uncertainties. Therefore, once a phenomenon is identified and included, its use in this study may result in a conclusion that a detailed accounting, or physical modeling, of the physical process may not be needed and large uncertainty bands are acceptable.

This of course assumes that all of the relevant phenomena have been identified and herein lies the most important aspect of expert judgement. Since the use of detailed calculational models are limited to the phenomena that have been identified, these, by themselves, do not provide the needed insights that certain physical processes may be missing. Therefore, the three major areas that must be addressed by the experts are:

1. Have all the relevant phenomena been identified and if not, what is missing?

2. For those which have not been identified, how can the uncertainties associated with these processes be quantified?

3. For the phenomena which have been identified, is sufficient information known to make reasonable assessments on the uncertainty bounds with respect to the reactor design and the spectrum of accidents to be considered?

Each of these relates to somewhat different needs from the experts. In the following sections, we will explore these needs and thereby give a framework on how expert judgement should be constructed and used. Fundamental to the success of such an effort is how the experts are selected.

3. HAVE ALL OF THE RELEVANT PHENOMENA BEEN CONSIDERED?

In the 1979 crash of an American Airlines DC10 in Chicago, the accident occurred because an engine mount failed during takeoff; ripping open the leading edge of the wing and destroying all of the hydraulic control systems as a result. This tragic common mode failure had been analyzed in terms of its likelihood of occurrence and was stated in the newspapers as having a frequency of 10^{-11} per takeoff; so low as to be considered incredible. During the investigation that followed, it surfaced that the engine mount failed as a result of a technique used to check the engine during maintenance. This technique had not been considered in assessing the likelihood of failure of the engine mount on takeoff. Hence, this enormous misrepresentation of the failure frequency occurred because all of the relevant phenomena were not considered.

This is a tragic example, but one which strikes to the heart of the issue. Specifically, when expert judgement is used as a substitute for extensive experience or experimental information, how should an expert team be formulated such that the relevant questions are asked? Perhaps more to the point, how should the group of experts be selected (what should their qualifications be) to assure that reasonable assessments are performed? Typically technical experts are selected as individuals who have worked in a field for a number of years, written papers on issues related to the principle subject, performed experiments, carried out analyses, etc. While this is an important consideration, much of what is written is on issues, physical processes, etc. which have already been considered. Thus, a selection based on the number of papers in journals may be inadequate when dealing with an area where there is only limited information.

To provide confidence that the fundamental questions would be asked, it is essential that an expert team have individuals who have demonstrated the capability for “finding problems”. Even more important, the team leader must have demonstrated this capability. How can a team be formed to assure that these capabilities exist? This is the key question.

In this regard, those who are creating the team need to search the backgrounds of the team leader in particular, and hopefully all members of the expert group, to select a group of individuals who have demonstrated such accomplishments. Thus, in addition to reviewing the resumes of such individuals, people who have worked with the individuals should be interviewed to determine if those being considered have demonstrated the capabilities of “finding problems” in the past. This capability of probing and asking meaningful questions is truly what is being asked for when expert judgement is the only means available. It is essential that the team leader, the one steering the evaluation, has a track record of being able to uncover issues when they have not previously been considered. Of equal importance, the team leader must be able to select what issues are reasonable and which are unreasonable in such a context. As will be discussed in the next section, the team leader must have the capacity to perform simplified, independent analyses to access whether individual contentions of team members are appropriate. Without such a capability, the use of expert judgement is generally restricted to retreading the available literature and perhaps some recasting of limited experimental information. In short, not much would be gained from expert judgement without the capability to “find the problem areas”.

Examples of probabilistic risk assessments where substantial areas were uncovered that had not previously been considered are the Zion Probabilistic Safety Study (ZPSS) [4] and the Indian Point Probabilistic Safety Study (IPPSS) [5]. In these, the original approach was to use an analytic capability similar to that used for the reactor safety study. However, as the individual phenomena were examined, particularly in light of the TMI-2 accident experience, several other issues became apparent. These resulted in questions related to:

- How could the vessel be expected to fail if the debris were not cooled in-vessel?
- Considering a spectrum of accident conditions, would the reactor coolant system pressure influence the debris behavior in containment?
- If the debris were discharged to the containment, what is the extent of cooling that could be expected for the core material?
- For the extent of core oxidation observed in the TMI-2 accident considering reasonable uncertainties with respect to the accident sequence, what potential loadings could be imposed on the containment boundary.

As a result of these considerations, several phenomena surfaced that had to be evaluated, principally through expert judgement using hand calculations. Subsequently, these became the subject of numerous experiments. These included issues related to the mode of vessel failure, in particular the response of in-vessel lower head penetrations, including the in-core instrument tubes when molten debris accumulates in the lower plenum, direct containment heating (DCH), ex-vessel debris coolability and hydrogen combustion. Of these, the areas of hydrogen combustion had been investigated immediately after the TMI-2 accident, but the results of these PRA studies increased the awareness that the variety of accident conditions in such studies could substantially alter the way in which combustion would occur. Certainly the ZPSS and IPPSS substantially altered the way in which probabilistic risk assessments were done and in particular altered the way in which the Level II assessments were performed. More to the point, they substantially altered the way in which calculational models were developed to support Level II activities. In this way, they are a prime example of demonstrating how expert judgement can/should be used to determine if there are substantive issues which have not been surfaced by previous evaluations.

4. ONCE THE PHENOMENA ARE IDENTIFIED, HOW CAN REALISTIC UNCERTAINTIES BE ESTIMATED?

It is one thing to convene a group of experts who have the ability to find relevant phenomena, conditions, situations, etc. where they have not been previously considered but another thing to provide reasonable estimates of uncertainty bounds once such issues have been found. In this situation, it is always tempting to hedge ones bets by making the uncertainty ranges large. In some cases, this may be sufficient to answer the question at hand because the decision may be tolerant of large uncertainties. However, this may also result in the inability to make any decision. Thus, the use of expert judgement must involve a combination of individuals with a track record of finding problems, situations, etc. and a track record of solving problems.

How do you formulate such a group? First and foremost, the decisions for a team leader should not rely solely on the information given in a resume. Positions held and journal publications offer no insights to either of the questions on whether one can find problems and whether one can find solutions. It should be noted that finding solutions also means comprehending and addressing reasonable uncertainties in the solution process. Here again it is necessary to interview colleagues of those being considered and specifically ask questions related to what problems have been solved by the individual, has the proposed solution withstood the test of time, how is the solution documented, etc. Only through this type of probing can it be determined whether those chosen are experts in the sense of providing realistic insights into issues to be considered and the spectrum of uncertainties that would accompany such conditions. In this regard, it is also important to ask whether the individual in question can develop uncertainty bands related to issues through simplified hand calculations. By definition, detailed computer models represent those details which have already been considered, hence, the formulation of expert judgement and the associated uncertainties likely are not easily addressed by detailed models. On the other hand, meaningful hand calculations are necessary when a new situation, condition, phenomenon, etc. is uncovered.

Once a specific phenomena has been identified and meaningful hand calculations have been performed, but have failed to narrow the uncertainty bands to acceptable levels, then the processes for issue resolution need to be used. One such process [6] was used to resolve the issue related to the likelihood that a Mark-I containment liner would fail under severe accident conditions if molten debris was released from the reactor pressure vessel. This process, which was derived from a general approach defined by Theofanous [7], was effective in focusing the agreements and disagreements between various individuals. Furthermore, this process enables the uncertainty bands to be narrowed by focusing on those issues that needed to be examined further to eliminate some of the perceived uncertainties. A similar process has been used to address issues related to direct containment heating [8]. In both of these approaches, the structured analyses and discussions between experts were used to focus additional discussions and experiments on those issues that would lead to a narrowing of the uncertainty bands. This is of course necessary for a regulatory agency to make decisions related to public health and safety, including severe accidents. In both cases, the approaches were successful in focusing the available resources to answer the outstanding questions. These evaluations would follow the assessment where expert judgement has been used to determine if there are relevant phenomena, situations, conditions, etc. that are yet to be considered.

5. HOW SHOULD EXPERTS BE SELECTED?

The discussions in this paper are not meant to suggest that resumes (curriculum vitae) should not be an important part of an evaluation. Clearly, those experts which are chosen must have worked in the field for a number of years. To this end, the curriculum vitae enables a selection team to quickly find those which have been working in the area of interest. However, it is also possible that those working in an area for a number of years may have begun to narrow their interest to specific problems, provided refinements of specific areas in a given field that are not relevant to the discussions at hand, etc. Therefore, it is crucial to any expert judgement assessment to have team members with a track record of “finding problems”. Certainly for the selection of a team leader, this is essential for a valid assessment. To accomplish this, the selection committee should interview the suggested list of experts (and alternates) to look for those who have asked the probing questions related to whether all relevant phenomena have been considered. It is necessary that this evaluation comes from other people.

It is equally important that the capabilities of the individuals be assessed with respect to their propensity for “solving problems”. Without this evaluation, there is no assurance that reasonable bounds can be set on the uncertainty values. Clearly uncertainty bounds can be set easily on those issues where substantial experience and experiments are available. All those working in a given field can utilize data where it exists. However, expert judgement is required when there is a lack of relevant experimental information. The ability to formulate a meaningful set of hand calculations is essential to address areas where detailed experimental basis is unavailable.

These two aspects, both of which involve interviews of colleagues of possible team members, are necessary to assure that all the elements of an inquiring study are exercised. If this isn’t done, there is no closure that the study has attempted to evaluate whether important unknown phenomena exist. Use of expert judgement is the only way to provide closure for this part of the evaluation.

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