The role of sensitivity analysis in Probabilistic Safety Assessment

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ABSTRACT

Nuclear power plant Probabilistic Safety Assessment (PSA) studies utilise many models, simplifications and assumptions. Also subjective judgement is widely applied due to lack of data. This results in significant uncertainties. Three general types of uncertainties have been identified: (1) parameter uncertainties, (2) modelling uncertainties, and (3) completeness uncertainties. The significance of some of the modelling assumptions and simplifications cannot be investigated by assignment and propagation of parameter uncertainties. In such cases the impact of different options may (and should) be studied by performing sensitivity analyses, concentrating on the most critical elements. This paper describes several items suitable for close examination by means of application of sensitivity analysis, when performing a level 1 PSA. Sensitivity analyses are performed with respect to: (1) boundary conditions, (2) operator actions, and (3) treatment of common cause failures (CCFs). The items of main interest are identified continuosly in the course of performing a PSA, as well as by scrutinising the final results. The practical aspects of sensitivity analysis are illustrated by several applications from a recent PSA study. It is concluded that sensitivity analysis leads to insights important for analysts, reviewers and decision makers.

1 INTRODUCTION

The objective of this paper is to describe how sensitivity analysis can be applied in a nuclear power plant PSA, with the purpose of indicating the vulnerability of the study results to various sources of uncertainty, and to locate modelling weaknesses. The main focus is placed on applications taken from a recent Swedish PSA performed by ASEA-ATOM on an ASEA-ATOM BWR75 plant. The concept of the "living PSA" is highly favoured in Sweden. PSAs are continuosly extended and modified in order to keep them up to date with plant changes. PSAs are also used in day-to-day safety work, concerning e.g.

- pointing out weak points in plant safety and proposing design modifications,
- evaluating the consequences of proposed construction changes,

- transferring adequate knowledge to operation and maintenance personnel,
- evaluating the impact of testing and preventive maintenance.

The use of probabilistic methods implies by definition that the results are subject to uncertainties. This will influence both the performance of the PSA, and the interpretation of its results. The remainder of this paper will deal with uncertainties; ways to identify them and ways to assess the influence they have on PSA results.

2 SOURCES OF UNCERTAINTY

The various sources of uncertainty encountered in a PSA quite naturally fall into one of the following categories, given in PRA Procedures Guide (1983) and in an overview by Vesely and Rasmuson (1984):

Parameter Uncertainties
Concern failure data in PSA; uncertainty due to e.g.

- limitations of the data base,
- diverging expert opinions,
- limited applicability of available data,
- interpretation of the analyst,
- applicability of data analysis methods used.

Modelling Uncertainties
Due to limitations in either

- coverage of model, or
- representativity of model.

Completeness Uncertainties
Completeness uncertainties are closely related to modelling uncertainties. They are mainly a concern during the identification activities of a PSA, and may originate from:

- contributor uncertainty (identification)
- relationship uncertainty (interaction).

Traditionally, the main focus has been on the treatment of parameter uncertainties; the methods for such analyses are therefore relatively well developed. However, experiences have shown that uncertainties related to modelling and completeness have a major impact on total analysis results. The completeness problem touches upon the limits of our knowledge which in practice makes rigorous treatment impossible, while modelling uncertainties are best studied by the application of sensitivity analysis.

Two important reasons for performing sensitivity analyses are that:

- They are used to estimate the firmness of the conclusions, or rather, of the foundation upon which the conclusions are built. Sensitivity analysis will shake this foundation and assess the effects.

- They are necessary in order to give a many-faceted picture of PSA results to decision-makers. Although sometimes practised, it is definitely not advisable to make use of a PSA without acquainting oneself with the models and assumptions upon which the conclusions are founded. A study of the impact which changes in models and assumptions may have on final results usually gives a better perspective on conclusions.

Examples of phenomena in PSA to be studied with sensitivity analysis are:

- effects of excessive conservatism with respect to system capacities, credited systems etc,
- effects of credited/not credited operator actions,
- common cause failures (CCF).
- effects of simplifications introduced.

3 SENSITIVITY ANALYSIS IN A PSA

The sensitivity analysis described in this chapter, is part of a recent PSA, performed by ASEA-ATOM on a BWR plant designed by ASEA-ATOM. The plant is characterised by a strict division of safety systems into four well separated trains.

Most of the sensitivity analyses were performed using the computer programme SENS. Input data to the programme is the cut-set list from an accident sequence evaluation. The programme makes it possible to vary failure data of individual basic events and to change CCF parameters. Starting from the cut-set list of the sequence evaluation, a modified list is generated and a new total failure probability is given as well as an importance ranking of the basic events that appear in the cut-sets.

The phenomena considered could quite naturally be divided into three categories:

1. Boundary conditions of the PSA.
2. Operator actions.
3. Treatment of Common Cause Failures (CCFs).

Boundary Conditions.

Two kinds of sensitivity analyses fall into this main category:

- Impact of uncredited favourable conditions (conservatively chosen system success criteria or uncredited systems).
- Effect obtained by crediting more realistic boundary conditions during the final part of the PSA.

Five cases were analysed:

1. System demands after LOCA-similar situations.
2. Crediting of continuous condensation pool cooling.
3. Modelling of electrical power supply.
4. Gas turbines and return of external grid.
5. Decay heat removal.
   This function was conservatively modelled in the first phase of PSA. The impact of a more realistic crediting for additional heat removal possibilities is shown in Figure 1.

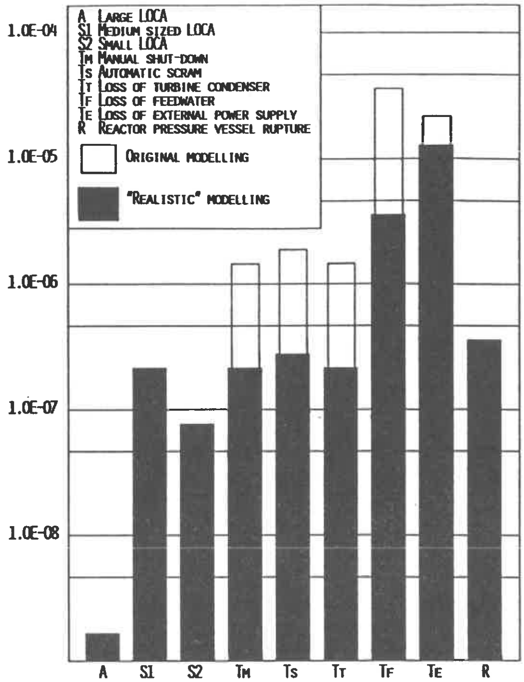

Figure 1. Accident frequencies with two different decay heat removal models.

Operator actions. Three critical cases were covered:

1. Actuation of depressurisation system.
2. Manual scram.
3. Restart of feedwater system.

In cases 1 and 2 the available time is a critical parameter for making right decision in the control room, while complexity of the task in case 3 has a major impact on the successful performance of local manual actions. The final results of the PSA where shown to be highly dependent on the assumptions made in modelling manual depressurisation.

Treatment of Common Cause Failures. CCFs have crucial influence on the quantitative results of a PSA. This is particularly true for plants characterised by a high level of redundancy (the analysed plant has four parallel trains in all safety systems). The significance of CCF contributors is illustrated in Figure 2. The sensitivity analysis has been concentrated to two problem areas, namely dependency aspects of human interactions and variation of CCF parameters. The results of the study were not too sensitive to the choice of high-order CCF parameters. This conclusion is essential, since a rather limited experience material has been used when estimating these parameters.

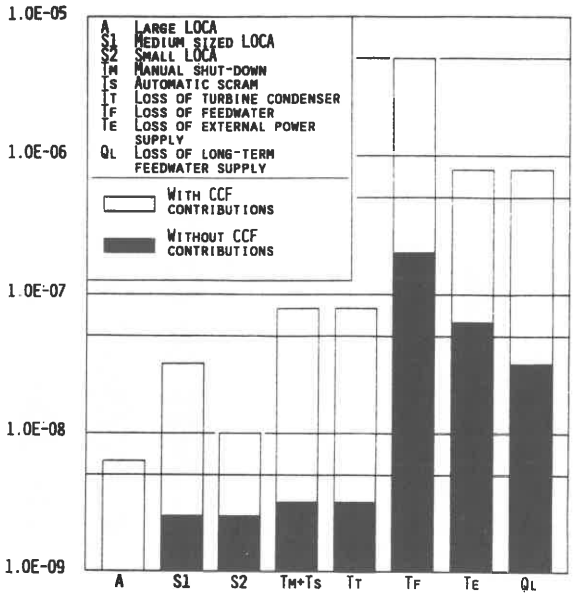

Figure 2. Accident frequencies with and without CCF contributions.

Comparing the results of two PSAs. Direct comparison of the results of two different PSAs is extremely difficult. The problem was highlighted in the sensitivity analysis by recalculating the results of the reference PSA, using the models and assumptions of another contemporary Swedish PSA. Figure 3 summarises the comparison.

4 CONCLUSIONS

Sensitivity analysis plays an important role in probabilistic safety assessment. Its task is twofold:

- During the PSA it is used as a decision aid by giving a rough estimate of the impact of alternative models on the total PSA results. In this way, sensitivity analysis may indicate the relative importance of safety systems at an early stage of the PSA (Knochenhauer 1985).

- In the final phase of the PSA, the obvious task of sensitivity analysis is to estimate the sensitivity of the final results to changes in basic assumptions. Thus, the relative importance to the total results of the models, parameters, and assumptions chosen, is underlined.

Another interesting insight was demonstrated when sensitivity analysis was used to make possible the comparison of two different PSAs by adapting the reference PSA to the models and assumptions of another PSA. In fact, this is the only way to compare PSAs - by thorough examination of fundamental modelling differences and their impact on the final re-

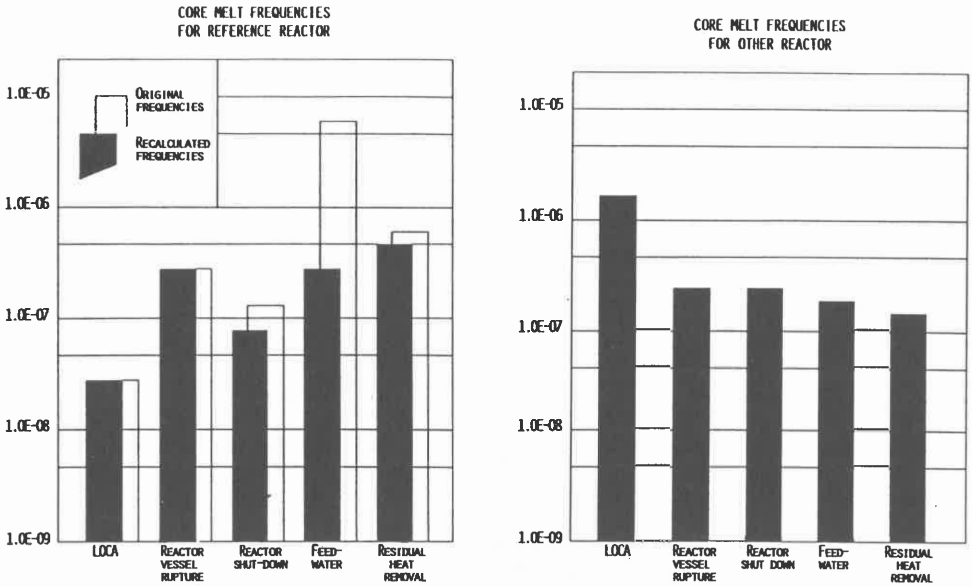

Figure 3. Comparison of results from two different PSAs.

sults. This type of approach should be attractive to reviewers and to decision makers, being a helpful tool for interpretation of PSA results and for obtaining a better perspective on findings with relevance to safety.

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