CONF-910215 16

BNL-NUREG--45370

DE91 004752

COMPARISON OF RISK SENSITIVITY TO HUMAN ERRORS IN THE OCONEE AND LASALLE PRAS*

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ABSTRACT

This paper describes the comparative analyses of plant risk sensitivity to human errors in the Oconee and LaSalle Probabilistic Risk Assessment (PRAs). These analyses were performed to determine the reasons for the observed differences in the sensitivity of core melt frequency (CMF) to changes in human error probabilities (HEPs). Plant-specific design features, PRA methods, and the level of detail and assumptions in the human error modeling were evaluated to assess their influence on risk estimates and sensitivities.

INTRODUCTION AND METHODOLOGY

As part of ongoing studies on sensitivity of nuclear power plant risk parameters to human errors, Brookhaven National Laboratory (BNL) conducted sensitivity evaluations to assess the impact of human errors on the risk parameters of the Oconee (NUREG/CR-5319)[1] and LaSalle (NUREG/CR-5527)[2] nuclear plants. These two studies show that the sensitivities of CMF and accident sequence frequencies to hypothetical changes in HEPs were significantly different for the two plants. Thus, comparative analyses were performed to determine the underlying reasons for the observed differences in risk sensitivity to human errors. The objectives of these comparative analyses were to identify the differences in plant-specific design features (e.g., BWR versus PWR), and PRA/HRA methods that could affect the sensitivity study results, and to evaluate the extent of human-interaction considerations in the plant PRA models that potentially affect observed results. The methodology developed to perform the comparative analysis consisted of first identifying any between-plant and between PRA/HRA differences that could possibly affect the results of the earlier sensitivity studies.[1,2] Any differences that were amenable to quantitative evaluation were then analyzed to determine their effect on HE sensitivity. Other differences were analyzed qualitatively.

PREVIOUS SENSITIVITY STUDIES

The top-level results of the Oconee and LaSalle sensitivity studies, shown in Figure 1, depict a large difference in the sensitivities of CMF to variation in HEP, when all HEPs were changed together over theoretically derived ranges.

Within a similar range of hypothetical HEP changes, the full range of the Oconee CMF variation is over four orders of magnitude compared to less than 2 orders of magnitude observed for the LaSalle CMF variation. One simple method of measuring the sensitivity of risk to HE variation is with the Risk Increase Ratio which is defined as:

*Work performed under the auspices of the U.S. Nuclear Regulatory Commission.

$$\text{Risk Increase Ratio (RIR)} = \frac{\text{Risk (HEP at Upper Bound Value)}}{\text{Risk (HEP at Base Case Value)}}$$

The RIR for Oconee is 394, while for LaSalle, it is only 10.

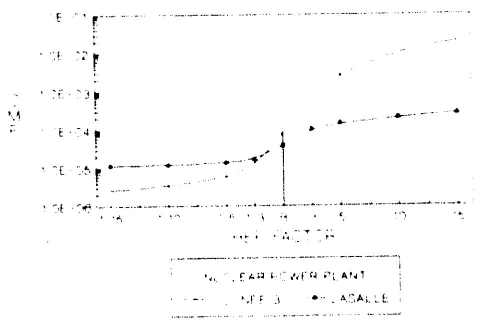

FIG 1. Sensitivity of Oconee and LaSalle plant CMF to HEP variations.

SUMMARY OF RESULTS

The results of the evaluations conducted in this study indicate that the major differences in the risk sensitivity to human errors between the Oconee and LaSalle nuclear plants are due to a number of factors, including plant-specific design features, the construction of the PRA models, and the human reliability analyses (HRAs) performed for the PRAs. In particular, the following areas were observed to notably affect the risk sensitivity results: (i) multiple human errors in minimal cutset terms; (ii) use of pre-accident and commission errors; (iii) differences in base case probabilities of human errors; and (iv) plant design differences. The major results of this comparability study are summarized below.

Multiple Human Errors in Minimal Cutsets

In the earlier risk sensitivity studies, analyses of the dominant accident sequences showed that those which were sensitive to HEP variation contain many cutsets with multiple human errors. These implications were quantitatively evaluated by assessing: (i) percentage contribution to risk of cutsets with similar human error combinations (e.g., singles, doubles, triples, etc.), and (ii) "lumping" of human errors in the cutset terms. Figure 2a shows the percentage contribution to accident risks of cutsets with various human error combinations for the three most dominant accident sequences of Oconee and LaSalle. This plot indicates that Oconee sequence cutsets with triple and quadruple human errors contribute a noticeably higher percentage of accident risks than LaSalle. As HEPs are increased, the effect on those cutsets with multiple human errors will cause the accident sequence frequencies (ASFs) and CMF to change more rapidly than would be the case with only single (or no) human errors in the cutsets. Figure 2b shows that doubling HEPs results in very significant increases in the contribution to accident risk from cutsets with triple and quadruple human errors for Oconee.

Another approach used to assess the effects of these multiple human errors on risk sensitivity was to modify the Oconee model slightly by combining or "lumping" selected human errors that appear in the same cutset. The intent of this approach was to adjust the structure of the Oconee cutsets as much as reasonably possible to make it closer to that of the LaSalle model. Only those human errors which describe actions to maintain the same safety function were lumped. This approach reduced both the total number of human errors and cutsets with multiple human errors in the three dominant sequences of Oconee. The RIR for Oconee drops from 394 to 116 when HEs in the three dominant sequences were lumped.

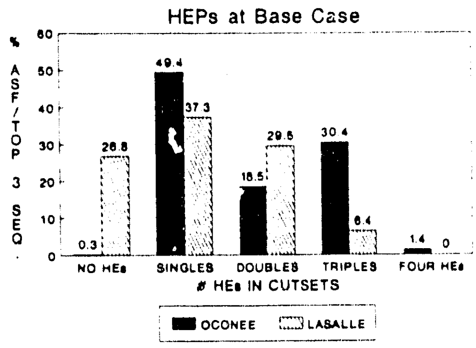

FIG 2a. Percent contribution to risk of cutsets with various human error combinations at base case HEPs (Oconee versus LaSalle).

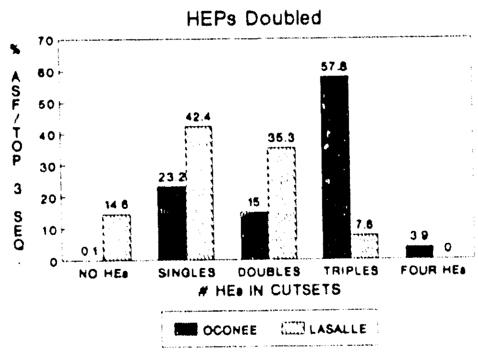

FIG 2b. Effect of doubling human error probabilities on the percent contribution to risk of cutsets with various human error combinations (Oconee versus LaSalle).

Use of Pre-Accident and Commission Errors

One predominant area of HRA modeling difference between the Oconee and LaSalle models is the presence of many more pre-accident and commission errors in Oconee. The impact of these errors on sensitivity was investigated by precluding variation of pre-accident and commission HEPs. In addition, the combined effects of lumped errors and precluding variation in pre-accident and commission HEPs were also analyzed to determine the effect of interaction of different factors. Figure 3 shows the risk variation curves of Oconee as a result of these effects. When the pre-accident and commission human errors were not varied in the sensitivity calculations, the Oconee plant core melt frequency decreased by about one-half order of magnitude over the full range of its risk sensitivity. Further, the Oconee plant sensitivity to human errors is drastically reduced when the effects of "lumping" and precluding variation in the pre-accident and commission HEs are combined. Table 1 summarizes the results of these sensitivity calculations. They indicate that the combined effects of lumped human errors and precluding variation of pre-accident and commission HEPs make the Oconee sensitivity close to the sensitivity of LaSalle. The RIR for the Oconee CMF was lowered from 394 to 52 which is comparatively close to the LaSalle RIR of 10. The underlying reasons for the lack of pre-accident and commission errors in the LaSalle risk model were primarily due to decisions made in the HRA process. Some of these modeling decisions were affected by plant practices; i.e., the LaSalle PRA team noted excellent procedures and multiple independent checks by the plant staff designed to preclude pre-accident errors.

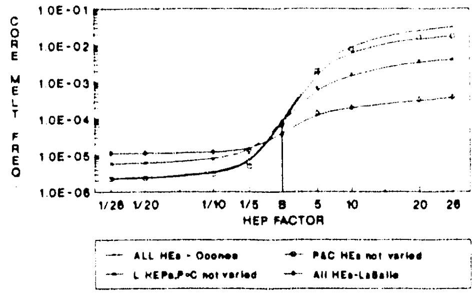

FIG 3. Sensitivity of Oconee 3 core melt frequency due to effects of pre-accident (P), commission (C), and lumped (L) HEs.

TABLE 1. Sensitivity of Oconee core melt frequency to groups of HEs.

Groups of Human Errors	HEP FACTOR BaseCase	HEP FACTOR Upper Bnd	RIR
All Human Errors	7.87E-5	3.10E-2	394
All HEs except no vari. of Pre-Acc./Comm. HEPs	7.87E-5	1.81E-2	230
Lumped Human Errors	7.87E-5	9.10E-3	116
Lumped Errors & no variation in Pre-Acc./Comm. HEs	7.87E-5	4.07E-3	52
LaSalle CMF	3.80E-5	3.87E-4	10

<u>Differences in Base Case Probabilities of Human Errors</u>

Another important contributor to the large difference in sensitivity between the Oconee and LaSalle is due to the fact that important human errors driving the LaSalle sensitivity generally have higher base case HEPs (mean = 0.36) than those for Oconee (mean = 0.016). This prevents any significant increase in the LaSalle CMF when the base case HEPs are varied, due to HEPs quickly reaching a value of 1.0.

In order to examine the quantitative effects of this difference in base case HEPs on plant risk sensitivity, the HEPs of 18 dominant human errors in Oconee were changed to the mean value of 0.36 for LaSalle base case HEPs. Naturally, as the mean base case HEPs are increased for Oconee, the base case CMF also increases. But importantly, with higher base case HEPs, it is observed that there is a very rapid ceiling effect in risk sensitivity as the modified HEPs reach a probability cut-off value of 1.0 very quickly. The RIR for Oconee drops from 394 to 22 due to this adjustment in mean base case HEPs (whereas LaSalle's RIR is 10). Thus, it can be inferred that the base case quantification of HEPs in the HRA process has a significant impact on plant risk sensitivity.

Plant Design Differences

The safety systems are significantly different between the Oconee (a PWR) and LaSalle (a BWR) plant and this plays a significant role in specifying the level of operator intervention and the consequences of human errors. Some of these plant differences include the diversity of and automatic features of the LaSalle safety systems, which reduce the level of vulnerability to human errors during abnormal plant conditions. The differences in plant-specific design features result in different types of principal contributors to plant CMF. For example, the Oconee and LaSalle plants have somewhat difference support systems. In the Oconee plant, the important support systems are the instrument air (IA), low-pressure service water (LPSW), and component cooling systems (CCS). For the LaSalle plant, an important support system is the core standby cooling (CSC) system which circulates cooling water from the lake (i.e., ultimate heat sink) to safety-related systems. The recovery of the described support systems after an initiating event involve multiple operator actions which were modeled in the dominant accident sequence cutsets. As pointed out earlier, the HEs in dominant cutsets play an important role in driving the risk sensitivity of the two plants. In particular, the sensitivity of the Oconee plant is driven by triple HEs more than the LaSalle plant, and the structure of the HE combinations in minimal cutsets is a reflection of the plant-specific design differences.

Comparison of Human Error Impact on Similar Sequences

An additional method to isolate the reasons for differences in risk sensitivity to human errors was an analysis of similar accident sequences. The loss of offsite power/station blackout sequences (LOOP/SBO) were judged to have the best potential for being very similar; thus, the T8 sequence of the LaSalle model and the T5QUs sequence of the Oconee model were selected. The T8 accident sequence for LaSalle is primarily characterized by a transient event which is a loss of offsite AC power event, failure of all diesel generators (DG), and failure of all high and low pressure injection systems, after successful scram and SRV operation. There are five human errors in the top 25 cutsets of this sequences which involve failure to reopen RCIC valves, failure to recover offsite power, and failure to repair the DGs. The T5QUs sequence at Oconee is initiated by a LOOP caused by a grid upset or switchyard fault. The emergency power from Keowee Hydro Station also fails, creating a station blackout. This is followed by a loss of offsite power system heat sink (i.e., loss of main feedwater and emergency feedwater). Reactor coolant system integrity is lost as either the PORV or the safety relief valves (SRVs) become stuck open. Finally, there is no HPI available due to the loss of all AC power (station blackout), resulting in core melt. There are four human errors in the top 25 cutsets of the T5QUs sequence which involve improper restoration of the turbine-driven EFW pump, closure of the PORV block valves, failure to transfer EFW suction, and failure to provide feedwater from the Safe Shutdown Facility (SSF).

The risk sensitivity curves for the two selected LOOP sequences are somewhat similar in shape; however, the Oconee sequence has a lower base case frequency and is somewhat more sensitive than the LaSalle sequence. The lower base case frequency of the Oconee sequence is primarily due to the inclusion of the failure event of either a stuck-open PORV or SRV in each sequence cutset. The differences between the human errors in the two sequences result in the Oconee sequence being more sensitive. Reference 3 discusses the major differences in HEs between these two similar sequences which illustrate the difference in modeling between the two plant PRAs.

Thus, in overview, the sequences and human errors are somewhat similar in function but when examined in detail, there are many plant-related and model-related differences. Among the HEs in the top 25 cutsets, not a single one is directly comparable between Oconee and LaSalle. Similarly, among the total HEs included in the sequences, the only comparable ones are a few unimportant pre-accident restoration errors. It is somewhat surprising that, on the two sequences selected as most likely to be similar, so many differences were identified. However, it does illustrate the fundamental difference between the PRAs.

CONCLUSIONS

The detailed comparative analysis of the risk sensitivity to HEs between the Oconee and LaSalle PRA models was performed to analyze the large differences in risk sensitivity between the two plants. These reasons can be classified under two general headings: (a) structural reasons, and (b) underlying reasons. A number of structural reasons, relating to the structure of both the PRAs and the HRAs of the two plants, were identified. The most important structural reasons identified are:

(i) the presence of multiple HEs (three or four) in cutsets of the dominant accident sequences of Oconee,

(ii) an overall larger number of HEs in the Oconee PRA,

(iii) higher base case HEPs in the LaSalle PRA, and

(iv) notably different HEs, even for similar accident sequences.

It was also determined that these various factors interacted to result in larger sensitivity differences than would be observed if the factors only affected risk sensitivity individually.

The underlying reasons causing these structural differences in the two PRAs were also explored. The two main reasons found to cause the PRA structural differences were plant design differences and PRA/HRA modeling differences. In the plant design area, general PWR versus BWR plant differences were found to be important, as well as several Oconee-specific design features, such as the Standby Shutdown Facility (SSF) and an Emergency Feedwater (EFW) System requiring manual transfer. PRA and HRA modeling decisions made during the PRA development process were also found to be important to the differences in sensitivity. An example is the decision that resulted in very few pre-accident errors and no during-accident commission errors in the final LaSalle model. Also, the detailed sequence and basic event level modeling were found to be different enough to cause notable effects on the plant risk sensitivities. This conclusion means that any plant-to-plant comparison of baseline risk or risk sensitivity must be done with caution and with knowledge of the underlying modeling decisions that were incorporated in the studies. Further risk sensitivity studies for other plants would be worthwhile, especially because of the large differences noted between the Oconee and LaSalle sensitivity studies.

REFERENCES

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