MAXIMUS

CONCEPT PAPER PREPARED FOR THE
DIVISION OF SYSTEMS AND RELIABILITY RESEARCH
ON THE DEVELOPMENT OF A MEASURE OF SERIOUSNESS

I. OBJECTIVES OF STUDY

The safety status of a nuclear reactor is a dynamically changing condition that varies as equipment malfunction, operators make errors, and natural events occur. The seriousness or importance of these events varies from insignificant to potentially extremely dangerous. The objective of this study is to provide a methodology for quantifying the seriousness of events and event sequences that occur in actual practice. In addition, the tools necessary to implement the methodology would be provided along with a sample application.

II. APPROACH

Fault Tree Analysis is a standard technique to quantify the safety of a reactor in terms of the probability that an accident occurs. Bayesian statistical approaches have been used to quantify the probability of occurrence of the various events in the fault trees, and Monte Carlo simulation and moment matching techniques have been used to combine these individual event probabilities and their attendant uncertainty to an overall safety assessment.

The probability of an accident, Pr(Z), can be estimated from the structure of the fault tree leading to the accident and the estimated probabilities of occurrences of the events in the three. For example, for independent events, A, B, and

C, if (A or B) and C must occur for an accident to occur, then, the probability of an accident is:

$$Pr(Z) = \left[1-(1-Pr(A))*(1-Pr(B))\right]*Pr(C).$$

We propose to relate the seriousness of the occurrence of an event sequence to the resultant increase in the probability of an accident, given the event sequence occurs. In the above example, if the event A or the event B were to occur, then the probability of an accident would increase to:

$$Pr(Z|A) = Pr(Z|B) = Pr(C).$$

If the event C were to occur, the probability would increase to:

$$Pr(Z|C) = 1-(1-Pr(A))*(1-Pr(B)).$$

The actual relation between change in accident probability and seriousness is not immediately apparent. It is clear, however, that this relation is not linear. For example, suppose $Pr(Z) = 1x10^{-8}$ and $Pr(Z|C) = 2x10^{-8}$. One would not wish to claim that the occurrence of event C resulted in a situation twice as serious as existed before C occurred. On the other hand, if $Pr(Z|C) = 1x10^{-4}$, could one credibly claim that the occurrence of C resulted in a situation 10,000 times as serious as existed prior to the occurrence of C?

A more promising relation involves the use of logarithms to focus attention on order of magnitude changes in accident probability. One such relational measure that we propose to investigate, which conveniently produces values of seriousness within the range of 0 to 100%, is as follows.

$$\text{Seriousness} = \frac{\log_{10} \Pr\{Z\} - \log_{10} \Pr\{Z|\underline{X}\}}{\log_{10} \Pr\{Z\}} * 100\%$$

where $\underline{X}$ is the event sequence that occurred.

This expression, gives a measure of the degradation in safety that occurs as a result of the event sequence $\underline{X}$ occurring. If an accident actually occurred, the seriousness would be 100%. With no events occurring, the seriousness remains at 0%.

An Example

To illustrate this measure, consider the independent events listed below and their probabilities of occurrence.

Hypothetical Example

Event	Probability of Occurrence
A	9.1×10^{-3}
B	5.2×10^{-3}
C	7.6×10^{-3}
D	4.1×10^{-3}
E	2.4×10^{-2}
F	3.1×10^{-3}

Assume that the fault tree indicates an accident, Z, will occur if:

Z = (A <u>or</u> B) <u>and</u> (C <u>or</u> D) <u>and</u> E <u>and</u> F occur.

Using these estimates, the probability of a reactor accident can be estimated to be $Pr(Z) = 1.24*10^{-8}$.

Assume that events A and E took place in a real situation, but no accident occurred. How serious was the sequence? The probability of an accident after A and E occurs is calculated to be $3.62*10^{-5}$. Using the unconditional probability of an accident and the expression given earlier, the seriousness of the event sequence is calculated as 43.8%. This figure indicates that the logarithm of the probability of failure decreased in magnitude by 43.8% as a result of events A and E occurring.

In addition to the point estimate of seriousness calculated above, it is also possible to provide interval assessments using Monte Carlo simulation or moment matching techniques. Thus, event sequences can be distinguished both by the estimated change in the logarithm of failure probability and by the uncertainty attendant in that estimate.

This approach can also be adapted to different accident outcomes, such as releases of varying amounts of radioactive material in the atmosphere. This would be accomplished by multiplying the seriousness of the event sequence by the outcome value and would provide a further refinement of the concept. Moreover, the approach can be adapted to dependent event sequences by appropriate clustering of events and event sequences. These ideas would be explored further in the study.

Calibration of Measure

In selecting and refining a measure of seriousness, we could also calibrate the measure against informed opinions. We would interview knowledgeable personnel and obtain data reflecting opinions about the relative seriousness of various possible event sequences. We would use these data to refine the selected measure to assure consistency between the measure and opinion consensus, where it existed. For example, if the consensus was that a change in the probability of an accident to 10^{-2} was four times as serious as a change to 10^{-4}, then we would refine the measure to show this. An appropriate function would be used to map increases in accident probability into a measure of seriousness.

An alternative to a continuous measure of seriousness, as in the previous examples, is a discrete measure. It may be preferable to categorize event sequences into distinct classes or levels of increasing seriousness. A discrete measure that maps event sequences into, say, ten discrete levels consistent with informed opinions can also be searched for, developed, and refined.

III. POSSIBLE TASK PLAN

The tasks that could be accomplished in the study are as follows.

TASK 1: SELECT A REPRESENTATIVE FAULT TREE

In this initial task, an actual reactor fault tree would be selected for analysis. The fault tree should represent the range of complexity possible so that the methodology would be tested against a wide range of situations. Possibly we could work with the staff of a civilian licensee on a real problem.

TASK 2: TEST DIFFERENT MEASURES FOR SERIOUSNESS AND EVALUATE THE RESULTS

The measure proposed in this concept paper represents our initial idea. We would like to explore other possibilities and the notion of linking event sequences to outcomes of varying importance, again in the context of a specific, real situation. In this task we would define different measures, interview selected officials to gain their opinions, and present the candidate measures to the NRC staff for review and comment.

TASK 3: DEVELOP APPROACH FOR CLASSIFYING EVENT SEQUENCES

For a large fault tree, there are probably hundreds of thousands of possible event sequences to explore. In this task we would develop an approach for systematically identifying the most likely sequences of events and classifying them for further analysis.

TASK 4: PREPARE SOFTWARE FOR ANALYSIS

In this task, we would write the computer programs for assessing the seriousness of various event sequences, and the attendant uncertainty. We would document the software so the NRC has access to it and can use it after the study is over. The software would be designed so that any fault tree can easily be entered into the system.

TASK 5: CONDUCT THE ANALYSES

In this task, we would conduct an indepth analysis of the fault tree examined and identify event sequences of particular concern. We would explore the tradeoffs of point estimates and the uncertainty in these estimates in determining the relative seriousness of event sequences. The intent of the analysis would be to make the notion of seriousness a workable and practical tool.

TASK 6: PREPARE FINAL REPORT

Finally, we would document our analyses, and provide recommendations for further use of the concept of seriousness in the field. The report would be of publishable quality.