STATISTICAL ANALYSIS OF THE ADEQUACY OF EXISTING RISK ASSESSMENT RESULTS FOR HIGH LEVEL NUCLEAR WASTE REPOSITORIES

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Introduction

The importance of radiological performance assessment to the successful licensing of any nuclear facility can hardly be overstated. This is particularly true for a high-level nuclear waste repository because of its being the first deep geologic nuclear facility and the first with such a long time span of concern. The ONWI performance assessment approach relative to postclosure safety focuses on continuous processes and superimposes the discrete events on process behavior. This approach is used because nuclear waste isolation systems in salt are composed of components which degrade slowly rather than fail suddenly, and isolation system performance at suitable sites is likely to be dominated by continuous processes rather than discrete events.

The primary purpose of this study was to determine whether the present literature contains risk analyses of discrete events of scope and depth sufficient for licensing preparation. The sufficiency criterion used was the presence of enough completely developed events to represent, in sum, essentially the total risk posed by the repository as evaluated using a full-range consequence/probability (risk) matrix technique. Data were extracted from literature citing assessments based both on scenario development and fault-tree techniques.[1,2]

Following a brief description of the postclosure risk matrix, the available assessment literature will be discussed and its sufficiency determined. Similar data for the preclosure phase will then be developed and combined with that from the postclosure to make possible a comparison of relative risk of postclosure vs. that from preclosure. Finally, results from these analyses are used as a basis of recommending priorities for future scenario development work.

Associated with the primary purpose of this study were several technical objectives. These included the provision of guidance for future scenario development work; design basis accident scenarios, in particular; and secondly, estimation of the total risk associated with the operation and existence of a high level nuclear waste repository. Historically, both the total risk and design basis accident concepts have been extremely important in nuclear power plant licensing activities in the U.S. Present indications are that similar importance will be given these concepts at least in the public sector of nuclear waste repository licensing.

Risk

Risk is classically defined as a consequence times a probability. A quick scan of postclosure performance assessment literature indicates that analyses have been made for events of probabilities 10^{-8} to 10^{-1} and consequences ranging over seven orders of magnitude.

Thus, to a first approximation, the postclosure risk posed by a repository can be represented by a 7x8 matrix. Quantitatively, the total risk is the sum of the probability/consequence products of all elements of the matrix. Undoubtedly, multiple events will fall into many of the elements, but this is expected to happen most often in the lower consequence events where hundreds of events would be needed to affect the total risk estimate.

Figure 1 indicates the percent contribution each matrix element makes to the total risk estimate. Elements, for which events have been analyzed in the literature, are also indicated. The initial intent was to analyze the entire probability/consequence matrix and quantify the uncertainty in risk as well as developing a risk estimate. Classical and/or Bayesian techniques could be used if the matrix was not so sparse. Due to the paucity of scenarios presently analyzed, such methodological approaches are not feasible. Therefore, a more basic approach must be utilized. It might be noted that the sum of the percent contributions of those elements which have been analyzed is only 0.81% which can be increased substantially if high risk elements are engineered out of the system.

FIGURE 1

Contribution of Matrix Elements to Total Risk [%]

Postclosure

Relative Consequence of Occurrence	10^{-8}–10^{-7}	10^{-7}–10^{-6}	10^{-6}–10^{-5}	10^{-5}–10^{-4}	10^{-4}–10^{-3}	10^{-3}–10^{-2}	10^{-2}–10^{-1}	10^{-1}–10^{-0}
10^{6}–10^{7}	(8.1E-6)	8.1E-5	8.1E-4	8.1E-3	8.1E-2	8.1E-1	8,1E-0	8.1E-1
10^{5}–10^{6}	8.1E-7	8.1E-6	8.1E-5	8.1E-4	8.1E-3	8.1E-2	(8.1E-1)	8.1E-0
10^{4}–10^{5}	8.1E-8	8.1E-7	(8.1E-6)	(8.1E-5)	8.1E-4	8.1E-3	8.1E-2	8.1E-1
10^{3}–10^{4}	8.1E-9	8.1E-8	8.1E-7	8.1E-6	8.1E-5	8.1E-4	8.1E-3	8.1E-2
10^{2}–10^{3}	8.1E-10	8.1E-9	8.1E-8	8.1E-7	8.1E-6	8.1E-5	8.1E-4	8.1E-3
10^{1}–10^{2}	8.1E-11	8.1E-10	8.1E-9	8.1E-8	8.1E-7	8.1E-6	8.1E-5	8.1E-4
10^{0}–10^{1}	8.1E-12	8.1E-11	(8.1E-10)	(8.1E-9)	(8.1E-8)	(8.1E-7)	8.1E-6	8.1E-5

Probability of Occurrence

Figure 2 shows the risk matrix for the preclosure repository phase. In this case the sum of the contributions from those elements which have been analyzed is 1.8%. Here, as in the case of the postclosure matrix, the total risk is dominated by the highest risk matrix element. It is highly likely that events portrayed in this portion of the matrix can be effectively precluded through engineering design. If such means were used to eliminate any contributions from the top three risk elements, the 1.8% sum would rise significantly to 64%.

Examination of both the preclosure and postclosure risk matrices indicates that 97% of the total risk comes from events characterized in the top three risk elements. This fact would tend to indicate the need to identify events, if any, which fall into these elements and engineer them out of the system. The next tier of elements may be either treated similarly to the higher risk elements or may be developed into the "design basis accidents" which were referred to earlier as a need for successful licensing. Major efforts are needed in this area in the postclosure phase since few events in

FIGURE 2

Contribution of Matrix Elements to Total Risk [%]

Preclosure

Relative Consequence of Occurrence	10^{-7}–10^{-6}	10^{-6}–10^{-5}	10^{-5}–10^{-4}	10^{-4}–10^{-3}	10^{-3}–10^{-2}	10^{-2}–10^{-1}	10^{-1}–10^{-0}
10^3–10^4	8.1E-5	8.1E-4	8.1E-3	8.1E-2	8.1E-1	8.1E-0	8.1E-1
10^2–10^3	8.1E-6	8.1E-5	8.1E-4	8.1E-3	8.1E-2	8.1E-1	8.1E-0
10^1–10^2	8.1E-7	8.1E-6	8.1E-5	8.1E-4	8.1E-3	8.1E-2	8.1E-1
10^0–10^1	8.1E-8	8.1E-7	8.1E-6	8.1E-5	8.1E-4	8.1E-3	8.1E-2

Probability of Occurrence

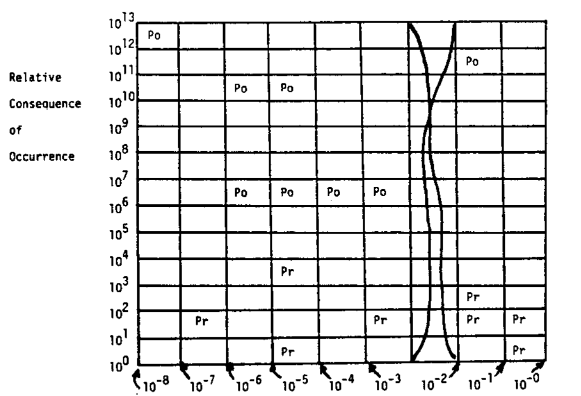
this region of the matrix have been analyzed. In both postclosure and preclosure cases, significant progress toward meeting these needs are anticipated as repository designs develop over the next few years. Since it may be difficult to determine the proper cell of the probability/consequence matrix for a given discrete event, the theory of fuzzy sets may be utilized in the development of cell membership in the database. When sufficient data have been developed by the application of fuzzy set theory and/or other decision theoretic approaches, sensitivity/uncertainty analyses can be performed to determine which areas still need further development.

The question might be asked which repository phase warrants greater emphasis if characterization of risk is the objective. Figure 3 shows the preclosure and postclosrue matrices merged with common probability and consequence scales. Similarly to the development of the matrices in Figures 1 and 2, this merger was accomplished by normalizing the combined pre and postclosure consequence set to the magnitude of its lowest member. It is immediately evident that the total risk over all time from a repository is dominated by the postclosure phase risks. Therefore, it is only logical

FIGURE 3

Available Repository Risk Data

Preclosure and Postclosure



Probability of Occurrence

Po = postclosure

Pr = preclosure

that this phase receive the priority attention. However, to reiterate an earlier point, in both phases the spectrum of accidents in the probability/consequence context must be expanded if the true picture of repository performance is to be projected. The specific scenarios which are needed are those with matrix coordinates such that they contribute significantly to overall risk. Preliminary indications are that this type of guidance makes the development of needed scenarios much more efficient than is ordinarily the case with a more random approach. Perhaps the efficiency of this process could be even further enhanced if any development efforts were delayed until the appropriate designs were available. However, history has shown that many times the scenario development can have a more significant effect on design than vice versa. Therefore, the strategy to be followed in the ONWI program is to go as far as possible with the information now in hand and refine the results and interpretations as more detailed data become available.

Conclusions

The low overall percentages of risk represented by the scenarios which have been analyzed could be interpreted to mean that little work has been done in this area; such is definitely not the case. On the contrary, such results are what would be expected from the random selection/reanalysis mode in which we have been operating for the last several years. Only if a more systematic approach to scenario development is employed in the next few years will a sufficient database be available on which to do the statistical analyses required for licensing.

References

(1) Koplik, C.M., M.F. Kaplan and B. Ross, 1982. "The Safety of Repositories for Highly Radioactive Wastes", Review of Modern Physics, 54, 269, January.

(2) Science Applications, Inc., 1980. Repository Accident Scenarios, ONWI/Sub/80/E513-02105 R-1, Office of Nuclear Waste Isolation, Battelle Memorial Institute, September.