An Event Tree Screening Approach for Transportation Risk Analysis

W.R. Rhyne
H&R Technical Associates, Inc.

INTRODUCTION

Event trees are often used in transportation risk analyses to generate accident scenarios and to quantify the frequency of the scenarios. The purpose of the event tree is to provide a systematic, logical development of the many potential outcomes of a specific event. The emphasis is on completeness, and the result is often complex. Some accident scenarios will not contribute significantly to the risk result because either the scenario frequency is insignificant, the scenario consequence is insignificant, or both. If the event tree is constructed with completeness as the goal, then many insignificant scenarios will likely be identified. Screening methods can be used to eliminate the insignificant scenarios that have been generated; however, the analyst will have invested considerable effort to generate a complex tree. Avoiding the generation of insignificant scenarios would be much more cost effective.

EVENT TREE ANALYSIS

An event tree is a graphical model for identifying and evaluating potential outcomes from a specific initiating event. The event tree depicts the chronological sequence of events (that is, accident scenarios) that could result from the initiating event. The first step in constructing an event tree is to identify the initiating event; for example, "accident occurs producing mechanical force." The analyst then asks what protective system action, operator action, normal system function, and so forth is expected to occur next. Each event following the initial event is conditional on the preceding event. The outcomes of the events are usually binary; that is, the outcomes are described by the success or failure of an action or, alternatively, "yes, the action was successful," or "no, it was not."

To construct the tree, a horizontal line is drawn starting at the left-hand side of a page, and the accident initiator is identified directly above at the top of the sheet (see Figure 1). The next event is listed at the top and to the right of the initiating event, and the binary outcome of the event is indicated by a branch point that splits the initiating event into two states indicated by two horizontal lines. As shown in Figure 1, the "mechanical force fails package" condition is the upper branch, and the "mechanical force does not fail package" condition is the lower branch. Accident data indicate that fire can occur after events involving mechanical force. Although the package has failed from mechanical force, the fire can still affect the release characteristics. If the package did not fail from the mechanical force, it can fail from the thermal force. At this point, five accident scenarios have been defined, one for each of the five branches. Two branches are for package mechanical failure scenarios, one is for package failure from fire, and two are for the scenarios in which package integrity is maintained. Note that a column has been provided for quantifying the likelihood of each scenario. Additional fault tree construction details and examples can be found in standard references such as the Center for Chemical Process Safety guidelines (1989).

At this point in the analysis, all release scenarios are grouped into three outcomes. The mechanical forces arising from a transportation accident are frequently characterized as impact, puncture, or crush, and the release characteristics produced by these forces on the various package components can be quite dissimilar. The preferred way to handle the release characteristic dissimilarity is to construct a more complex event tree that explicitly shows impact, puncture, and crush failures because (1) the analysts determining package failure thresholds work with these forces and (2) the conditional probabilities of these force magnitudes are readily available (Clarke et al. 1976 and Dennis et al. 1978). (The event trees do not include branches for the type of object struck, the impact angle, etc., and the use of probabilistic force magnitudes that include these considerations is assumed.)

Addition of three mechanical force outcomes to Figure 1 will increase the complexity of the tree. If further additions are needed, for example, to distinguish between large and small openings or instantaneous and continuous releases, then the event tree complexity could rapidly become unmanageable, particularly because these attributes may not apply uniformly to all forces. An alternative approach is presented in Figures 2 through 5 (Rhyne 1994); each force is treated in a separate tree. The approximation inherent in using the fault trees in Figures 2 through 5 is that failures are overcounted because once a package is considered failed by one force, it is not removed from consideration for failure by another force. The overcounting is less than 1% for a typical Type B package, and the simplicity of the approach warrants this level of conservatism. If additional scenario distinctions, e.g., for large or small openings, are needed, they are more easily incorporated in a force-specific tree. This approach is most effective for situations with only a few release types.

The conditional probability of the "impact force fails package" is usually evaluated by using a fault tree, as are the corresponding branches for the other three forces. The fault tree evaluation is indicated by the I, C, P, and F symbols shown on Figures 2 through 5, respectively. Thus, Figures 2 through 5 represent accident scenarios that arise from many package failure modes involving four types of forces. A major objective of the event tree analysis is to identify all significant release scenarios. Screening methods are used to eliminate scenarios that are insignificant from either a frequency or a consequence perspective.

Figure 1. Event tree analysis of truck or train accidents.

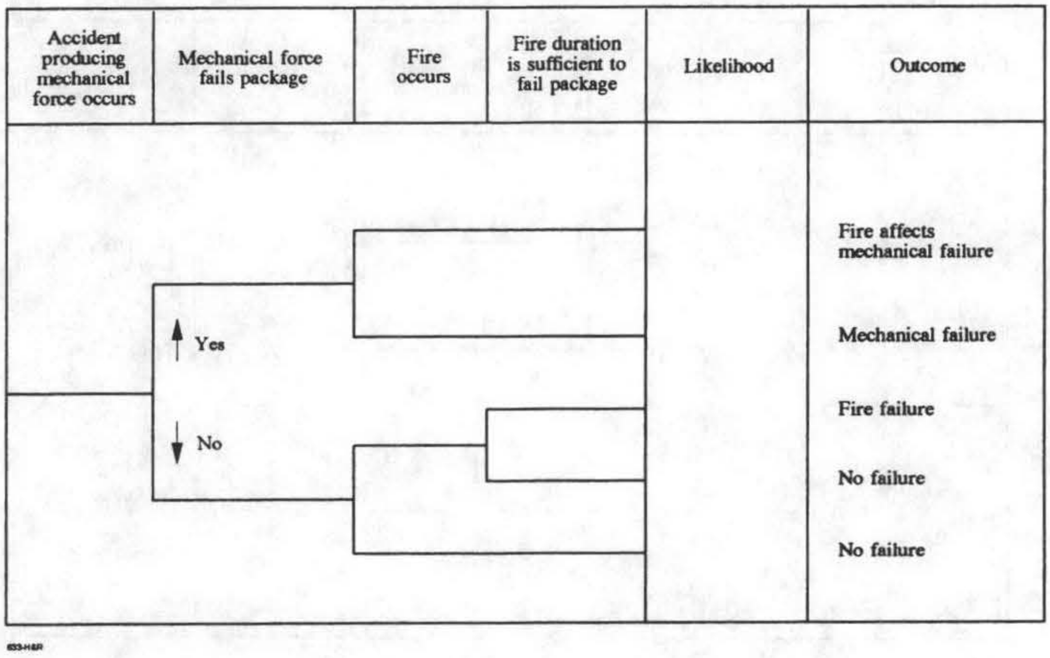


Figure 2. Event tree analysis of impact accidents.

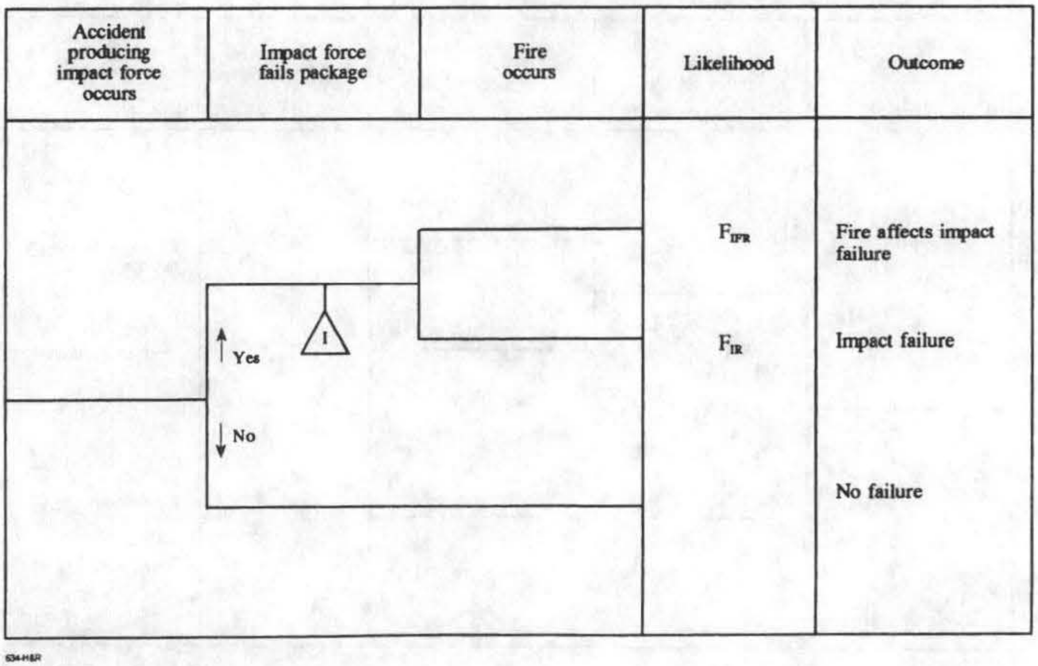


Figure 3. Event tree analysis of crush accidents.

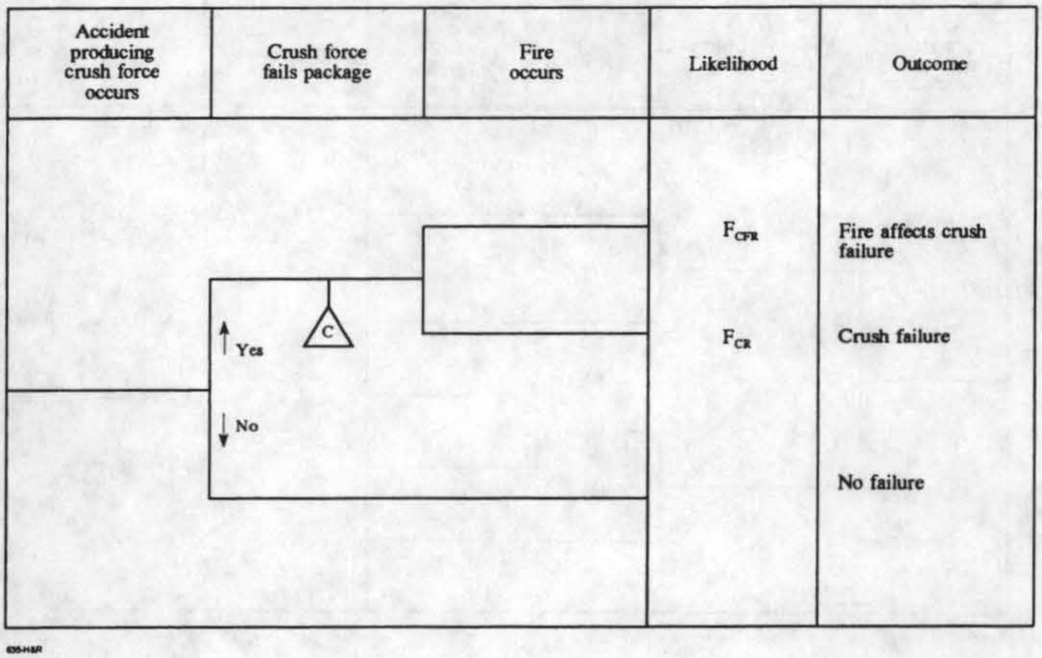
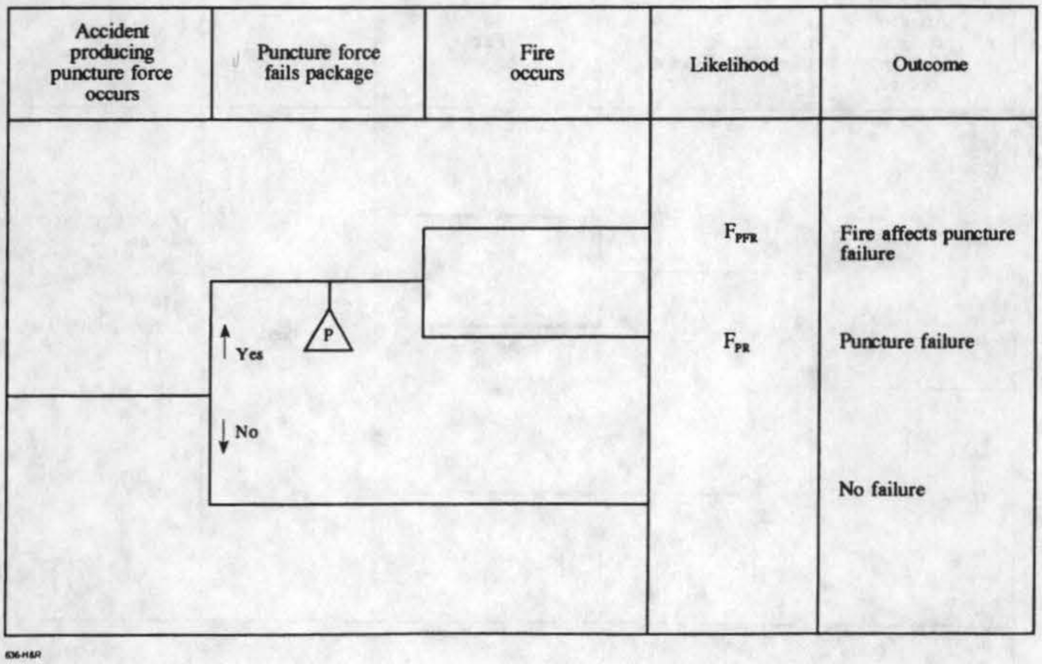


Figure 4. Event tree analysis of puncture accidents.



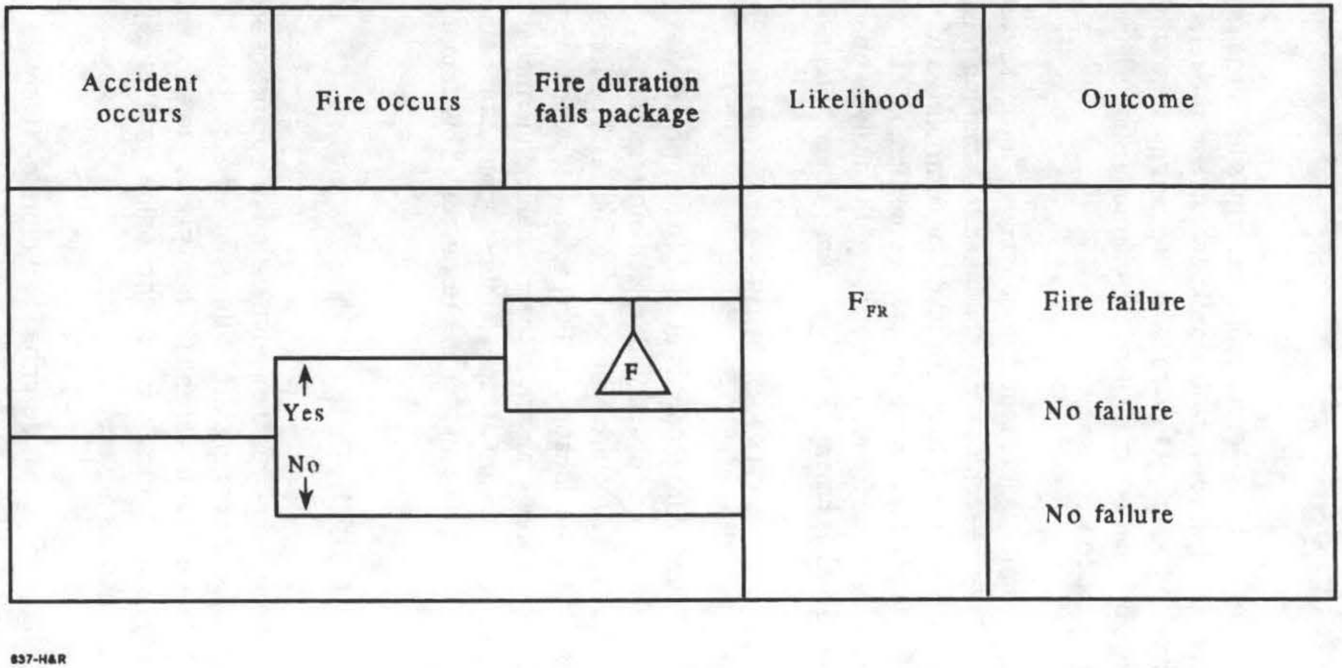


Figure 5. Event tree analysis of fire accidents.

CONSERVATIVE RELEASE ANALYSIS

The approach used for many analyses for U.S. Department of Energy sites is to assume that, given a failure in the package, all of the dispersable package contents are released regardless of the size or location of the failure. Once released, the contents are subject to dispersion depending on their physical, and perhaps chemical, characteristics. This approach is recognized as a significant conservatism.

The effect of this conservative approach is that (1) the consequences of many release scenarios are treated as identical, (2) these scenarios are combined by summing their frequencies, and (3) some scenarios become relatively insignificant contributors to risk due to their small frequency value. The analyst may have invested a considerable effort to generate a number of release scenarios in the frequency portion of the analysis only to have many of these scenarios considered as having an insignificant frequency contribution.

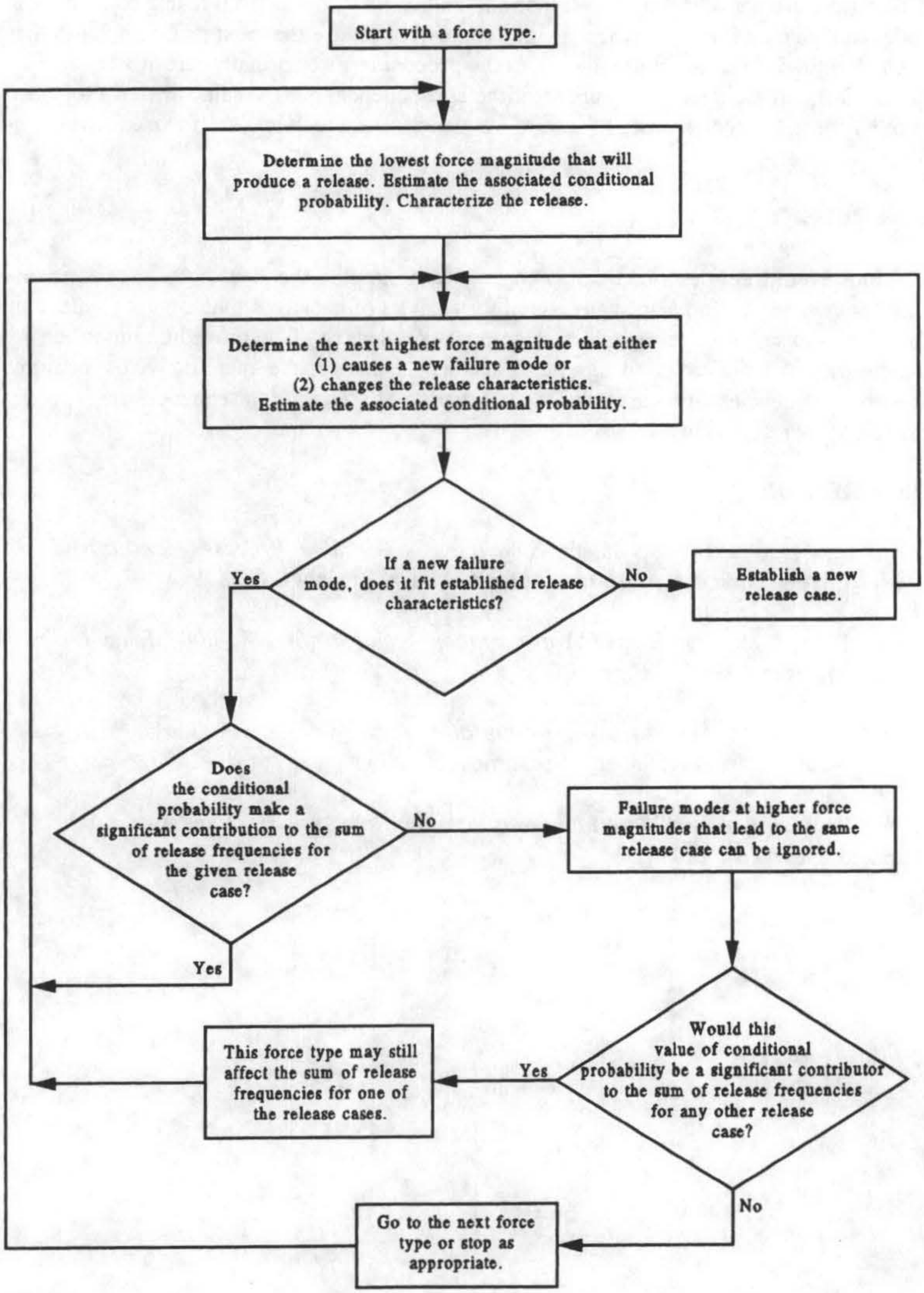
PRACTICAL ANALYSIS OF FAILURE THRESHOLDS

Some qualitative knowledge of package failure modes is needed to identify release scenarios. Quantification of the frequency associated with a scenario requires quantification of the magnitude of the force required for package failure. The force magnitude will depend on factors such as the location on the package at which the force is applied. As a practical matter, the event tree analyst and the mechanical/thermal analyst(s) will have to compromise on the number of failure modes and force application points that can reasonably be addressed, given project time and budget resources. This compromise is a form of screening.

SCREENING DURING SCENARIO IDENTIFICATION

The procedure described in this section formalizes the identification of significant accident scenarios that can be used to (1) reduce the complexity of the event tree analysis, (2) reduce the need for calculation of failure thresholds, and (3) help prevent overlooking a significant release scenario. This approach is most practical for complex packages for which conservative release rates or amounts are desired.

The scenario identification/screening procedure is described by Figure 6. (Only the primary logic steps are given to simplify the presentation.) Note that the release characterization step can be very qualitative, depending on the nature of the packaging and packaging contents. Release and dispersion of contents is one example characterization and loss of shielding without dispersion is another. Similarly, the determination of the next highest force magnitude to cause either a new failure mode or changes in the release characterization can be approximate. Engineering judgment is an appropriate tool for this estimate; detailed analyses are performed later to the extent needed to validate the estimates.



540-H&R

Figure 6. Event tree screening procedure.

This procedure helps prevent the scenario identification process from failing to identify a significant release scenario by terminating too early because the most probable failure has been identified. Another potential use of the procedure is to formally screen all scenarios arising from an accident force initiator if the consequences are the same as those for another force but the estimated scenario frequencies are much less than those for the other force.

CONCLUSION

The four event trees described in this paper greatly simplify the identification of accident scenarios. The trees are especially useful for analysis of packages that are very simple and for which conservative release rates or amounts are desired. The procedure described integrates the identification of significant accident scenarios, the quantitative estimation of scenario frequencies, and the qualitative estimation of scenario consequences (as expressed by release characteristics).

REFERENCES

Center for Chemical Process Safety, *Guidelines for Chemical Process Quantitative Risk Analysis*, New York: American Institute of Chemical Engineers (1989).

Clarke, R.K., et al. *Severities of Transportation Accidents, SLA-74-0001*, Sandia National Laboratories (1976).

Dennis, A.W., et al. *Severities of Transportation Accidents Involving Large Packages, SAND77-0001*, Sandia National Laboratories (1978).

Rhyne, W.R. *Hazardous Materials Transportation Risk Analysis,* Van Nostrand Reinhold, New York (1994).