SCENARIO EVOLUTION: INTERACTION BETWEEN EVENT TREE CONSTRUCTION AND NUMERICAL ANALYSES

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ABSTRACT

Construction of well-posed scenarios for the range of conditions possible at any proposed repository site is a critical first step to assessing total system performance. Event tree construction is the method that is being used to develop potential failure scenarios for the proposed nuclear waste repository at Yucca Mountain. An event tree begins with an initial event or condition. Subsequent events are listed in a sequence, leading eventually to release of radionuclides to the accessible environment. Ensuring the validity of the scenarios requires iteration between problems constructed using scenarios contained in the event tree sequence, experimental results, and numerical analyses. Details not adequately captured within the tree initially may become more apparent as a result of analyses. To illustrate this process, we discuss the iterations used to develop numerical analyses for PACE-90 using basaltic igneous activity and human-intrusion event trees.

INTRODUCTION

The objective in constructing scenarios for performance assessment is to provide a suite of well-posed problems. The scenarios will provide a basis for calculating the consequence and probability of occurrence of each feature, event, and process (FEP) that might result in radionuclide escape from a repository. There are a number of forms of logic diagrams (such as fault trees, event trees, and the matrix method) that can be used to develop scenarios. All these logic diagrams types will lead to the same consequences, given the same initiating event, even though different paths are constructed to reach the same point. The method of scenario development discussed here is construction of event trees. We also discuss the iterative development of scenarios by comparison between selected event trees and PACE-90 (Performance Assessment Calculational Exercises) analyses.
Briefly, the first phase of PACE-90 resulted in calculations of groundwater transport of nuclides in a "nominal configuration" (see Barnard and Dockery, 1991) describing Yucca Mountain. The second phase involved development of perturbed configuration problems, including those initiated with the occurrence of basaltic igneous activity and human intrusion. For both igneous activity and human intrusion, problems were defined that were subsequently identified as scenarios within the appropriate event tree. Details of PACE-90 are reported in Barnard and Dockery, 1991 (this volume).

This paper discusses the process for developing detailed scenarios using a problem statement and an event tree. The process is used interactively and iteratively to identify deficiencies in event trees and to provide sufficient detail to perform calculations. Evolution of scenarios as a result of this process as applied to the PACE-90 problems is described in the following sections.

The process can begin by using scenarios from event trees to pose numerical problems. When difficulty is encountered in formulating the calculation because of a lack of detail or consistency in a scenario, the discrepancy must be resolved and the event tree altered. Conversely, the process can begin with an initial problem statement that defines a general sequence of events to be modeled. Then, the problem is identified within the event tree and the details for the analysis are drawn from within a specific scenario. The second method is the one that was used in conjunction with PACE-90. The consequence of several such iterations between event trees and calculations is a suite of credible scenarios.

DEFINING SCENARIOS USING EVENT TREES

We define a "scenario" as a single, continuous path through an event tree, from the primary event or process, to the release of contaminants (in the cases considered here, by means of groundwater transport to the water table or gaseous release to the atmosphere). Multiple initiating events, such as the combined effects of simultaneous (or sequential) basaltic eruption and human intrusion, are not considered. A scenario leading to the potential failure of a repository to contain contaminants must contain five components. The sequence of events described in each event tree is initiated by 1) an initial event or process (such as a basaltic intrusion) that ultimately results in a radionuclide release. To this basic event or process are added, in sequence: 2) a driving mechanism able to move radionuclides, 3) contaminants existing in a form that can be mobilized, 4) a pathway for release, and 5) a time for initiation of the scenario to establish the initial conditions for the release and transport processes.

Construction of an event tree further requires groups of FEPs that can be used in any systematic and physically reasonable combination to describe the transport of radionuclides as a result of changes caused by an initiating event. The event tree is formed when the FEPs are arranged in a logical hierarchy. Each FEP may be followed by a single FEP, or may branch into multiple FEPs.
These succeeding FEPs may be the direct consequence of the previous FEP, or may follow the previous FEP in a time sequence. Although the tree may split into multiple branches at any given point to reflect several possible FEPs, this does not imply that the FEPs at that branch are necessarily mutually exclusive.

Once a scenario upon which a numerical problem will be based is located within an event tree, the implicit and explicit assumptions can be identified for an analysis that incorporates the FEPs contained in that scenario. For each specified problem, alternative conceptual models may be identified at any level in the event tree. They may occur within a single element, within nearby elements at the same level, or within the entire path of the scenario.

The structure of any event tree is dependent upon the interpretation of the investigator concerning the most probable ordering of the sequence of events and the relative importance of the FEPs that are candidates for inclusion in the tree. The sequence presented here is not a unique representation. Other investigators might have different interpretations in terms of sequencing or relative importance. However, assuming all the FEPs have been considered, the range of outcomes should be the same for any configuration of event trees with a common initiating event. The scenarios identified in these trees will not necessarily all be used in the final stages of performance assessment. Some of the paths will be judged technically implausible and will be "pruned" from the trees when sufficient technical arguments are provided. The result will be a shortened list of scenarios that will then be published to form a foundation for performance assessment of Yucca Mountain. Ultimately, expert judgment will be used to provide probabilities for each of the FEPs. These values will be incorporated into total-system performance-assessment calculations.

EVENT TREE FOR BASALTIC IGNEOUS ACTIVITY

An event tree is being developed to describe the effect of basaltic igneous activity on radionuclide release from a repository in volcanic tuff. The portion of that tree used in the problem discussed here focuses on effects on the groundwater flux system that might reasonably occur as a result of intrusion of a basaltic dike into Yucca Mountain. This discussion of scenario development will cover the general sequence of FEPs; the PACE-90 problem is more narrowly defined and will not include all the possibilities shown in the event trees. For calculations associated with this problem, a dike is presumed to intersect the repository horizon at 5000 years after-closure. Values adopted for parameters such as dike orientation, temperature, composition, etc. are based on observations of basaltic intrusions occurring in the Yucca Mountain area. This problem further assumes that the intrusion does not move waste containers to the surface.

The initial section of the basaltic-intrusion event tree is shown in Figure 1. This event tree shows two main branches: the basaltic intrusion either does or does not interact directly with the repository. The PACE-90 problem addresses only the direct interaction branch. Direct interaction with the repository is then followed by two possibilities. In the first, a cinder cone is formed at a point
Figure 1.
Initial portion of event tree for basaltic igneous activity. Path followed by the PACE-90 problem is denoted by the unshaded boxes.

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where a single conduit for magma reaches the surface. In the second, the eruption occurs along the length of a linear fissure. The first branch is the one followed in PACE. Volcanology studies on eruptive styles in the southern Basin and Range indicate that, if the intrusion reaches the repository horizon, the likelihood that the dike will continue to the surface is virtually assured. Therefore, there is no element in the tree indicating that the dike does not propagate to the surface. The three FEPs shown at the next level include 1) a dike passing alongside or through the repository, but not intersecting waste; 2) the envelopment of waste in magma; and 3) a sill filling the repository, but not reaching, the buried waste. The PACE igneous-activity problem assumes no magma-waste mechanical contact (such as envelopment or entrainment); the interaction of waste (container and spent fuel) with the magma is restricted to thermal effects.

The codes and models available for calculating the PACE problem are currently only capable of analyzing contaminant transport due to vapor and groundwater flow. However, the branch of the tree showing entrainment indicates a requirement to develop specific tools to model that FEP. This is an example of how event trees can be used as indicators of deficiencies in numerical capabilities.

Next, the damage to waste packages due to microseismic activity (Figure 1) associated with the intrusion is considered. The PACE scenario assumes that the packages have been degraded by essentially continuous, low-magnitude tremors that occur over several months. This degradation allows escape of volatile nuclides from waste packages affected by the thermal pulse from the dike. The next branching of the tree shows transport of volatiles by thermal effects of the magma, formation of a hydrothermal system, or development of a nonlocal, multiphase thermal system. The PACE problem follows the hydrothermal branch. Included in the hydrothermal FEP are such processes as heat-pipe formation, condensation reflux, etc. These processes are assumed to occur while the dike forms a detectable heat source. Corrosive volatiles from the magma, if incorporated into a hydrothermal system, could accelerate degradation of the waste packages, as indicated by the FEP in Figure 2. Relatively soon after the dike solidifies, the country-rock temperature decreases below the boiling point of water. At this point, a local convective-flow regime or an enhanced saturated flow regime (depending on the amount of water present in the rock) could be established.

For the convective-flow branch, leaching or other mobilization of waste by convection or by groundwater flow would permit the waste to be transported to the water table. For the enhanced-saturated-flow branch it is recognized that alteration of the flow field by the dike might cause the previously unsaturated rock to become saturated by mechanisms such as the development of a condensation cap or the ponding of water near the dike. Thus, mobilization of the waste would result in transport through either saturated or unsaturated rock.

Having traced the entire PACE-90 problem can be traced through the event tree, we next illustrate how the detailed assumptions for a model of this
particular scenario can be developed. For example, some of the assumptions that are underlying the conceptual model for the FEP "hydrothermal system develops" are these: water content of the surrounding rock is sufficient to permit establishment of a hydrothermal system, thermal gradient is sufficient to initiate hydrothermal processes, and that paths exist to allow flow of the hydrothermal fluids. At a different level, alternative conceptual models are also represented by branches beneath a single element. At each step described above in the definition of the scenario, alternatives among conceptual models could be identified. For example, instead of following the "convective flow develops" path (Figure 2), the problem could be changed to investigate the saturated-flow branch. This change would require the development of a different source-term release profile to reflect the greater amount of water present in the repository. It would also require using a different transport model. Similarly, the problem could take the "nonlocal multiphase thermal system" branch (Figure 1), requiring a different source term to reflect the change in hydrologic conditions.

Finally, we illustrate how the event tree has changed as a result of iteration between calculational problem development and the form of the scenario in the tree. Figure 1 originally omitted the "basaltic cinder cone forms ..." branch. After discussions with geologists, the branch and the subsequent release modes (not shown in this figure, i.e., ash-cloud fallout, weathering of encapsulated waste at the surface, etc.) were added to the tree to make the tree consistent with current understanding of volcanic processes. The event tree was also changed to reflect the relationship between dikes and sills. Before this iteration, dikes and sills were considered to occur independently. Therefore, the dike and the sill-formation FEPs were drawn in at the same level in the tree. However, a dike must form first in order to provide a source for sill formation. This logic was reflected by changing the position of the "intrusion fills repository as sill" FEP so it now lies below the dike intrusion FEP. Also, as a result of the analyses done to define the PACE-90 problem, the FEP covering disturbance of the container due to microseisms was relocated higher in the tree. This was necessary to identify those containers damaged by ground motion and consequently unable to contain the volatile fraction of the waste.
**Human-Intrusion Event Tree**

The second scenario represented by a specific PACE calculation involves human intrusion via exploratory drilling for hydrocarbons 3000 years post-closure. Because we have already explained how to move through an event tree using the volcanism tree, we will only discuss the specific assumptions of the human-intrusion problem. Current drilling technology is assumed because projecting changes in drilling methods into the future is beyond the scope of this problem. The drill string penetrates a backfilled drift. Drilling fluid is lost upon intersecting the drift, filling the void space (approximately 40%) within the entire drift. This scenario is shown in Figure 3.
Two variations of a problem are proposed (Figure 4). For the first variation of the scenario, we assume that the drillhole continues approximately 15 m below the drift floor. Future modeling of the hydrologic processes will involve simulating the lateral dispersion of the drilling fluids accumulated in the drift, followed by imbibition of the fluid into the wall-rock matrix. The radionuclide source term for this problem will assume the drill bit intercepts the waste package, exposing the entire contents to the fluid in the drift. Transport modeling will simulate the consequences of the mobilization of uncontained waste by locally saturated flow conditions. The continuation of this scenario is shown in Figure 4. The second variation assumes that drilling stops when the bit penetrates the drift. All the containers in that drift are subjected to flooding by the drilling fluid. Hydrologic modeling addresses the impact of the saturated-flow plume on groundwater travel time. Since it is assumed that no waste containers are damaged by drilling, the source term reflects the effects of saturated-flow conditions on containers degraded only by their age. Releases from this source are modeled to the water table in the variably saturated environment.

Both problem variations branch from the FEP "contaminated fluids enter locally saturated flow system" (Figure 4). The assumptions made about the dispersion of drilling fluids controls the subsequent description of the processes. As an illustration of how refining scenarios has identified alternative conceptual models for this problem, note that the FEP "drilling fluids mobilize contaminants" above branches to four possibilities: 1) "contaminated fluids enter locally saturated flow system", 2) "contaminated fluids alter flow field", 3) "contaminated drilling fluids flow down drillhole", and (4) "contaminated fluids enter enhanced unsaturated flow system". The effects on radionuclide transport due to breaching (or not breaching) of containers are not shown explicitly in the event tree. Instead, the effects are a matter of degree for all of the FEPs shown. The relative importance of the degree of breaching must be established by calculations similar to those in PACE-90. Other details, such as type of drilling fluid, duration of drilling, and total depth of penetration are also not specified in the event tree. Many such details must be investigated to determine whether the tree should be expanded to include them. Alternately, these details may be more reasonably treated as a sensitivity or uncertainty study within a given branch. Calculational exercises will help differentiate among these options.
Figure 3.
Initial portion of the human-intrusion event tree. Path of the PACE-90 problem denoted by unshaded boxes.
Figure 4.
Final portion of the human-intrusion event tree. Paths followed by the PACE-90 problems denoted by the unshaded boxes.
OBSERVATIONS AND CONCLUSIONS

Currently, event trees are not sufficiently detailed to provide more than an outline for calculational modeling. However, specific calculations, expert opinion, or experiments can provide this detailed information. Moreover, the tree does not indicate the relative importance or the probabilities of occurrence of the branches, which are ultimately necessary for a risk assessment. In the absence of appropriate field data, iteration between event trees (or other forms of logic diagram) and the calculational problems derived from them can only indicate relative importance of alternative scenarios. Performing calculations defines the details necessary to construct physically consistent and complete scenarios, and will help set the priorities for acquiring field data. For example, the original event tree constructed for basaltic igneous activity was found to be incomplete in certain FEPs needed to adequately calculate the PACE-90 problem. The necessary refinements were then incorporated into the scenario, allowing development of a more credible event tree. The event trees constructed for Yucca Mountain will continue to change as the iterative process continues until the scenarios are judged technically credible and until they contain sufficient detail to perform adequate numerical analyses for assessing performance.

REFERENCES


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