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A WORKING DEFINITION OF SCENARIO AND A METHOD OF SCENARIO CONSTRUCTION[a]

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ABSTRACT

The event-tree method of scenario construction has been chosen for the Yucca Mountain performance assessment. Its applicability and suitability to the problem are discussed and compared with those of the Nuclear Regulatory Commission (NRC) method. The event-tree method is appropriate for an incompletely characterized site, where there must be an evolving understanding, over time, of the processes at work, for a site that may require analysis of details in specific context, and when the scenario functions to guide site characterization. Anticipating the eventual requirement for using the NRC method, we show that the event-tree method can be translated to the NRC format after final scenario screening.

INTRODUCTION

The Yucca Mountain system performance assessment uses an event-tree method for scenario development. This method of constructing scenarios leading to radionuclide release from a potential repository at Yucca Mountain appears to depart from the method developed by the NRC[1]. The two methods share the same ultimate purpose, namely to show that a site is suitable or unsuitable for licensing a nuclear-waste repository. They differ in the definition and function of scenario and in the method used for scenario construction. We will show in the ensuing discussion that the differences are due to the maturity of understanding of the site implicit in each method and its definitions. Because we must meet NRC requirements in the license application, we show how to translate to the required form, currently anticipated to be that of Cranwell et al.[1].

SCENARIO CONSTRUCTION USING EVENT TREES

The first step in the event-tree method is to identify all features, events, and processes (FEPs) imagined to influence radionuclide releases to the accessible environment from a repository at a specific site. We accomplish this step using information, interpretations, and speculations provided by principal investigators (PIs) working on the Yucca Mountain Project (YMP).

The collected information is combined into a logical structure we call a "generalized event tree"--generalized because it uses FEPs and not just events. The structure of the tree is developed around five fundamental pieces of information:

1. a definition of the initiating event or process,
2. interaction of the initiating event or process with the fluid flow system,
3. interaction of the initiating event or process with the waste,
4. release of waste from the engineered barrier system (EBS),
5. transport of contaminants to the water table, the surface, or the accessible environment.

The next step is construction of scenarios. We define a scenario as a well-posed problem, starting from an initiating event or process and proceeding through a logically connected and physically possible combination or sequence of FEPs to the release of contaminants to the accessible environment or to the water table. Event trees provide a tool for systematic construction of scenarios. A sample portion of an event tree is shown in figure 1.[2] In our method, each scenario is defined by a single, connected path through the tree, accompanied by sketches (e.g., figure 2) illustrating possible details that may need to be included in modeling the FEPs in the path. The tree includes all FEPs that the PIs have suggested are physically possible at the site and their connections. At this point there is no attempt to distinguish whether scenarios are independent, competing, sequential, or simultaneous; such important distinctions are developed later. There is also at this point no implication about the relative probabilistic or consequential importance of the different scenarios.

This construction method and definition of scenario separates an extremely large and complex problem into many parts, each a solvable problem. The event tree and scenarios defined in it serve multiple, interrelated purposes toward gaining a solution to the whole problem:

1. The scenario defines solvable problems. Furthermore, since some sequences of FEPs have common members until some branching, or are identical to sequences found other places in the event tree, it helps to associate problems whose solutions may be accomplished with similar analyses.
2. Together event tree and scenarios provide a framework and details to help determine priorities and redirection in site characterization when site characterization is not complete.
3. Scenarios retain the work of PIs in context. FEPs cannot be

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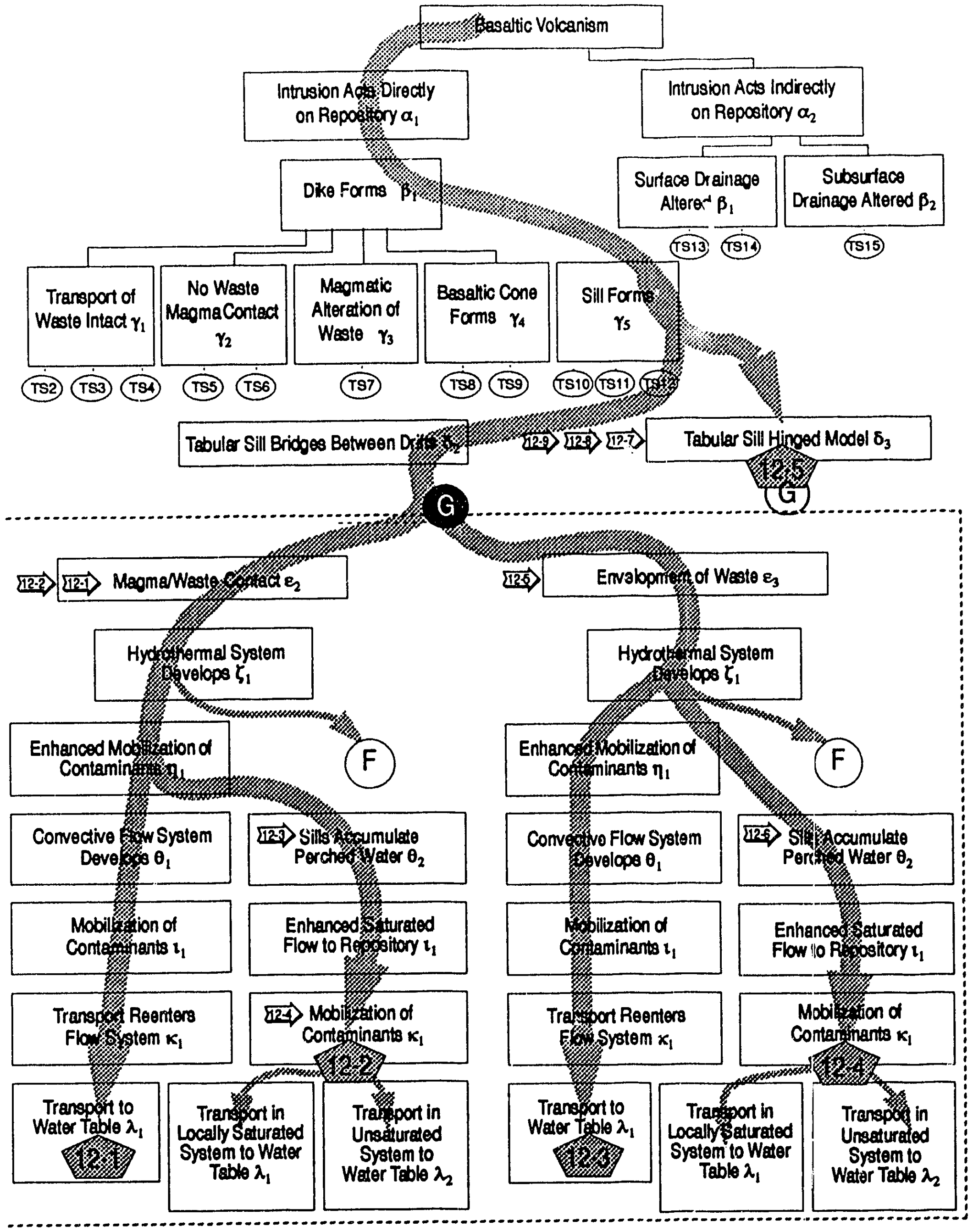

Figure 1. An example of a segment of an event tree showing paths connecting sequences of FEPs that define scenarios. (from Barr et al.[2])

satisfactorily analyzed out of the context of the study defined by the PI; therefore, we construct scenarios to the level of detail at which the PIs are working in order to include their results and their insights. As we attempt to visualize details, other details and accompanying questions become apparent.

4. The event tree suggests a bookkeeping system to keep track of which scenarios have been adequately analyzed, which are in progress, and which remain to be investigated. A log of progress is important because participants and the public at large have many technical concerns with regard to a nuclear-waste repository and require assurance of rigorous examination of these concerns.

5. The event tree and scenarios retain alternative interpretations of data and alternative conceptual models. We work with real data--incomplete and inexact data--that support alternate interpretations by different PIs. These alternative interpretations are retained until it is established whether the differences are important and testable.

Two examples are given, one to illustrate the scale of detail retained in the construction of scenarios in this method, and another to illustrate the retention of alternative conceptual models and alternative interpretations of data.

Figure 2 shows a dike as it passes through the repository, intersecting a number of emplacement drifts. Each drift, as a result of construction, has developed a stress-altered region around it out to about three drift diameters. Further stress-alteration from waste-heating of the rock will be superimposed. How the intruding dike responds to the presence of this stress-altered region is an open question. These stress-induced alterations, suggested by PIs in rock mechanics, could profoundly influence contaminant release and transport.

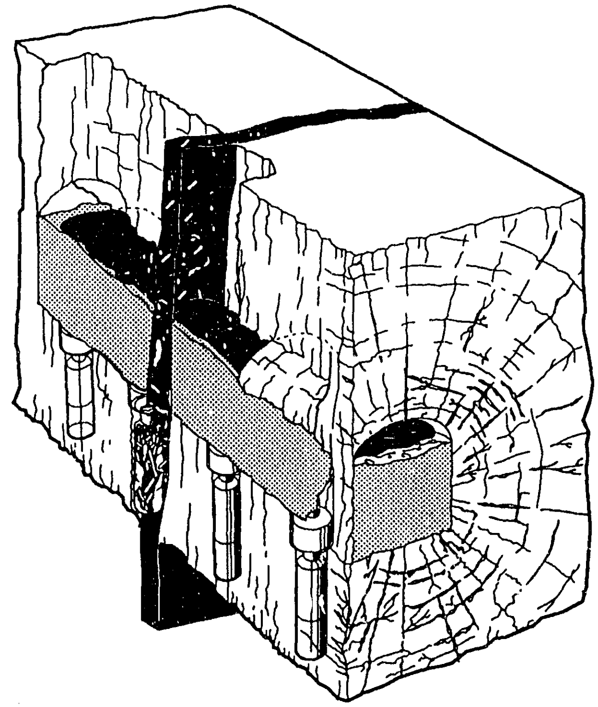

Figure 2. Possible stress altered region around drift may influence dike insertion. (from Barr et al.[2])

Figure 3 shows two alternative conceptual models for formation of a sill from a dike intersecting the repository drifts. The first mode is for a fingered sill that fills the void space in the intersecting drifts. The second mode is a sill that bridges adjacent drifts as if the drifts produced a plane of preferential weakness. The second sill type displaces rock between drifts, bending and fracturing the immediate overburden. Figure 4 shows a variation of the second type of sill formation (suggested by Dr. D. Borns) where the insertion occurs without bending and fracturing of the overburden. Instead the overburden is lifted intact with a nearby fault acting as a hinge. The reader can construct other variations that depend on the location of the sill being emplaced above or below the drifts and including or missing the waste containers. Each model requires a separate branch in the tree until it can be determined that the releases due to each can be incorporated into a single model. Theses analyses will support each other, however, as they contain common FEPs.

Other examples of alternative conceptual models are the interpretations of Fridrich[3], Czarnecki[4], and Sinton[5] of the hydraulics

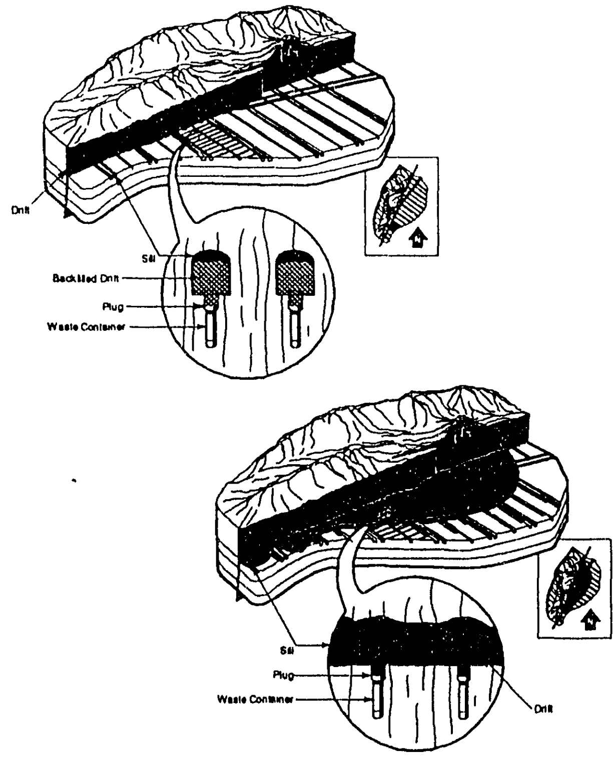

Figure 3. Alternative sill insertion models. (from Barr et al.[2])

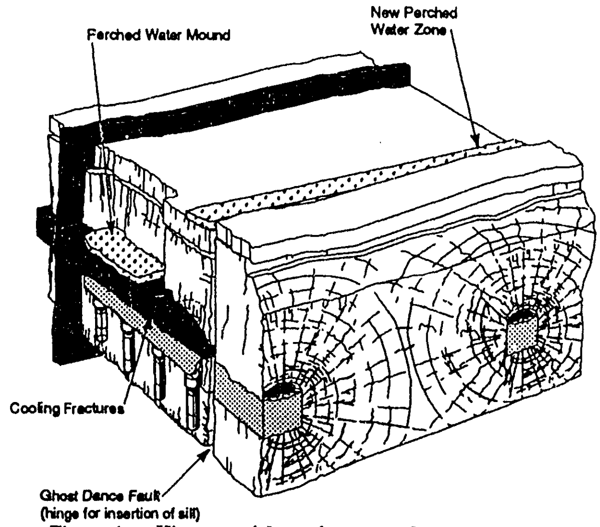

Figure 4. Hinge model produces no fractures above the sill. (from Barr et al.[2])

of the high-gradient region in the saturated zone north of the proposed Yucca Mountain site. Testing can demonstrate which parts, if any, of these models are reasonable. Testing will be done during site characterization if the divers models produce significantly different consequences.

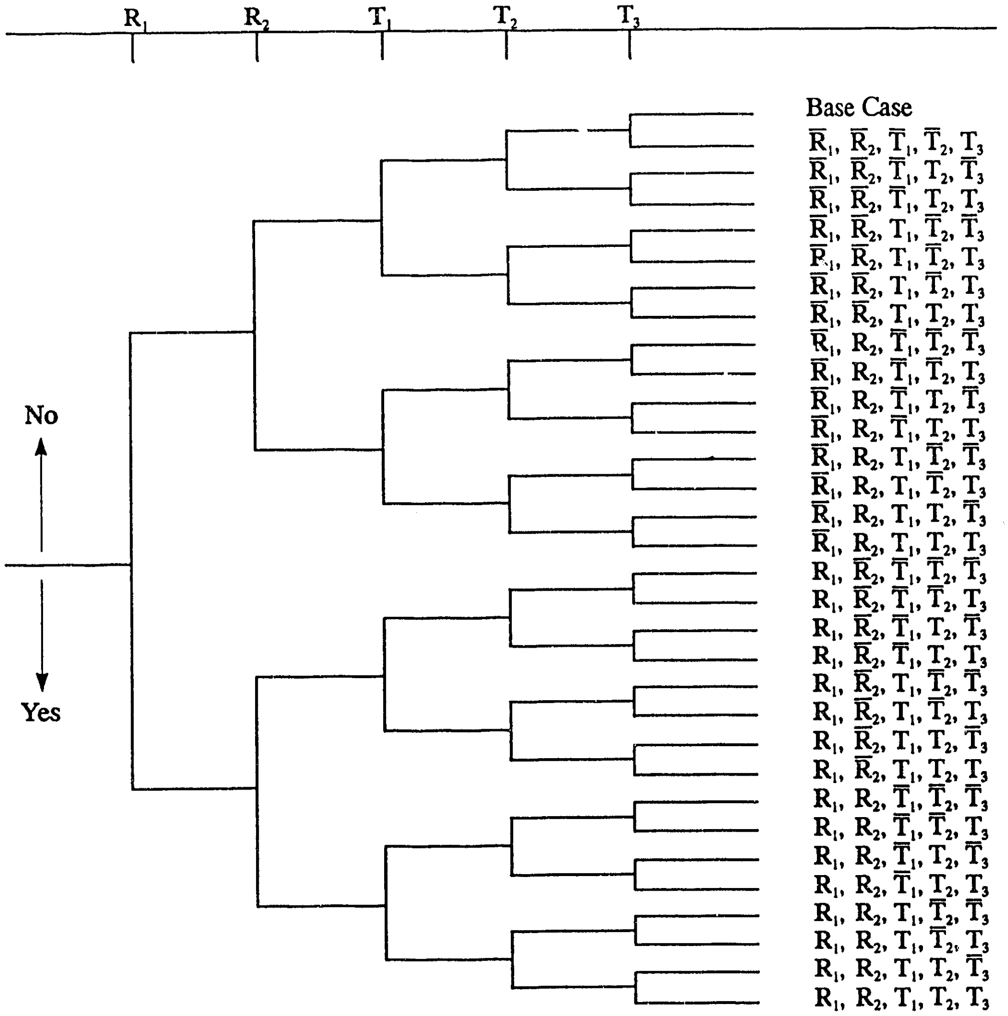

Figure 5. A sample bifurcation diagram used in the NRC scenario construction method. Each subscripted R at the top of the diagram stands for a release process and each subscripted T for a transport process. The right hand column is a summary of which processes are and are not (indicated by a bar, e.g., $\bar{T}$) included in each horizontal path. (Cranwell et al.[1])

SCENARIO CONSTRUCTION BY THE NRC MENTOD

As in the event-tree method, the first step in the NRC method is to identify FEPs. The second step is an iterative process of investigating, analyzing, eliminating, and combining FEPs, until the original collection is pruned and lumped into a few release processes and a few transport processes. A release process may include mechanisms by which the waste container is degraded and contaminants are mobilized in addition to thermal processes. A transport process may include thermally driven flow as well as retardation of contaminants.

The NRC model organizes the release processes and the transport processes into a logical structure in the form of a bifurcation diagram (figure 5). In this diagram, each subscripted R at the top of the diagram stands for a release process (lumped processes may include several FEPs), and each subscripted T stands for a transport process. Branching in this tree is determined by whether or not the process above the branching occurs. Each level, that is, each bifurcation, is built on a question about a lumped process. The right-hand column summarizes the processes included and excluded in each separate path. A bar over a letter is used to negate the process, that is to say it does not occur. Construction of the bifurcation diagram using all combinations of lumped processes ensures local completeness. Local completeness means that every combination among processes is included. (We maintain that global completeness, meaning inclusion of every process including those yet unknown, is not possible). Once all recognized and possible combinations have been constructed, the results must be examined to remove physically impossible combinations of the retained, lumped processes. A scenario is defined as a continuous path from left to right through the resulting diagram.

DIFFERENCES

The method we are using organizes FEPs in a logical structure in the form of multiple branching paths (figure 1). The criterion for multiple branches is that a PI identifies competing, sequential, simultaneous, or independent processes. For example, figures 3 and 4 show three alternative conceptual models for formation of a sill from a dike. These types of sills could be competing, sequential, or simultaneous, and each model occupies a branch in the tree. Two of theses branches are shown in figure 1.

Each branch tries to reflect the level of detail at which the PIs are doing their experiments and analyses, either directly in the tree or indirectly in the explanatory sketches. In figure 6, a dike

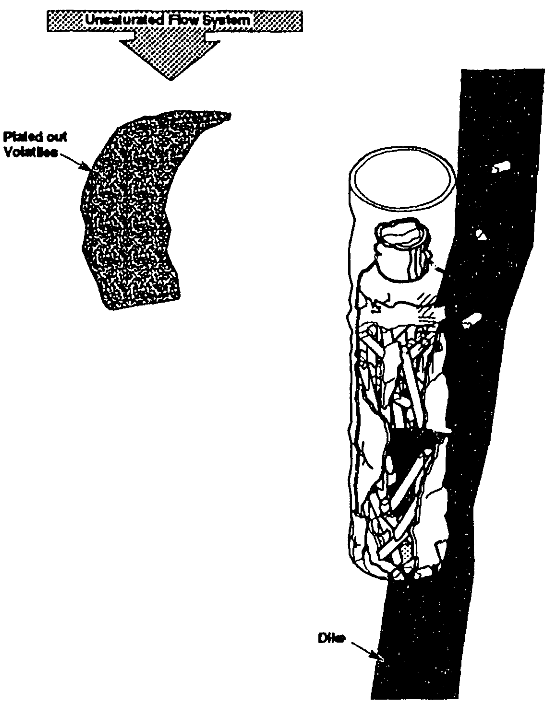

Figure 6. Volatiles driven from a container by a hot dike plate-out in the surrounding cooler rock and become available for mobilization and transport. (from Barr et al.[2])

has intruded through the repository and intersected a waste container. Since the magma temperature is approximately 1100 to 1200°C, any fragile or broken containers could reasonably be expected to leak any fission products that happen to be volatile at these temperatures. Such volatiles would plate out (condense) in the cooler surrounding rock, forming a halo of contaminants separate from the waste container--in effect partitioning the source and putting part of the contaminants into a different flow field. The point of this example is that the sketches, which are at the level of detail at which PIs are working, give a more complete picture of the FEPs that should be included. It is likely that some of these details would escape notice and be omitted from a lumped calculation if they have not been previously examined and explicitly included.

Our current objective is to include all the ideas, results, and speculations offered by the PIs. Local completeness has not yet been examined; we are still trying to sort out the problem to the PIs' satisfaction.

Any multiple branching tree can be reorganized into a bifurcation diagram by sorting and proper identification of branching questions; the real difference between the methods is in the level of detail required by each expansion. The considerable detail we build on must also be implicitly required in the lumped processes of the NRC method, however. One could not adequately model release or transport, for example, without knowing what mechanistic details are included as lumped processes. This implicit inclusion of details means that the NRC method demands a complete, mature understanding of the proposed site. If there is no lumping of processes in the NRC method, the number of possible scenarios becomes impossibly large to analyze. We do not expect this to be the case, because we expect massive pruning of the trees on physical and probabilistic bases to reduce the number to manageable terms. Pruning is determined by the details of the FEPs involved; without that detail it is difficult to judge the importance of any scenario. Our analyses of igneous activity generate more than 130 scenarios; we expect few to survive detailed scrutiny.

TRANSLATING BETWEEN METHODS

A further implication in our use of trees has been mentioned, but requires explanation. Notice in figure 1 that scenarios appear without regard to whether they are competing, independent, sequential, or simultaneous. Scenario 12-1 of figure 1 includes "Convective Flow System Develops", a FEP active during the hot phase of the sill. Upon sill cooling, water driven outward by the sill heat may return and accumulate atop the sill as in scenario 12-2 (and shown in the ponding in figure 4). Path 12-2 is parallel to 12-1 in the tree, but it occurs after 12-1 in time. To be more consistent with the NRC method we must examine each occurrence of the initiating event or process and decide which tree branches are consistent with each conceptual model of the occurrence. This remark will be illustrated. Cranwell et al.[2] developed scenarios for several release modes and transport modes from one conceptual model of the representative site. For Yucca Mountain, we have a number of conceptual models of the site and two different kinds of alternative conceptual models. The first kind of alternative conceptual model results from different interpretations of the same data, as in the conflicting interpretations[3,4,5] of the high-gradient data. We must carry such alternatives in the analysis until they are resolved. The second kind of alternative conceptual model involves alternative effects produced by the same initiating event. For example, if basaltic volcanism is the initiating event, a cinder cone above the repository is accompanied by an intruding dike. A dike that reaches the surface presents a different risk to the repository from a dike that terminates below the surface. These alternative conceptual models for the same initiating event cannot be distinguished by further data--although probabilities of occurrence may be quite different. Both must be carried in the analyses as independent events.

In addition to establishment of the conceptual model in which the initiating event or process occurs and collection of FEPs to work from, translation still requires some systematic lumping of FEPs into groups consistent with those of Cranwell et al.[1] Much of the lumping of FEPs in the event trees is transparent; some choices for grouping into release or transport modes are arguable, but do not affect the calculational results for release. There are, however, subtleties in lumping when the FEP is important to both release and transport. A feature important to both release and transport--because it affects the flow system--is discussed in the stress-altered region example of figure 2. In this case, the rock condition must become part of the conceptual model. We would apply this lumping procedure to every branch of the tree produced by an initiating event or process for each conceptual model of the site.

To be specific, we will translate the tree of figure 1 to the form of figure 5. The example in figure 5 treats two release modes and three transport modes. We must reorganize the tree because we need to specify the contents of each release mode and each transport mode.

Two release and two transport modes will be constructed. As suggested above we need a particular conceptual model--we pick the model with a tabular sill (lower sketch of figure 3). The release modes and transport modes will be assembled from the components of paths 12-2 and 12-4 on figure 1. Release mode R_1 consists of the coupling of the FEPs ε_2, ζ_1, η_1, θ_2, ι_1, κ_1, along path 12-2, and R_2 consists of the coupling of FEPs ε_3, ζ_1, η_1, θ_2, ι_1, κ_1, along path 12-4. Coupling of these FEPs specifies a flow field and chemical behavior of container and contaminants leading to releases from the container.

Transport mode T_1 consists of the coupling of FEPs η_1, ι_1, κ_1, λ_1 along 12-2 and T_2 of FEPs η_1, ι_1, κ_1, λ_2 along 12-4. Combinations of these FEPs is intended to define transport modes by specifying the flow field to the accessible environment and the chemical behavior of contaminants in the rock. In some cases a given FEP can appear in both the release mode and in the transport mode: e.g., convective flow affects both container failure and transport. Figure 7 shows the tree with this reorganization.

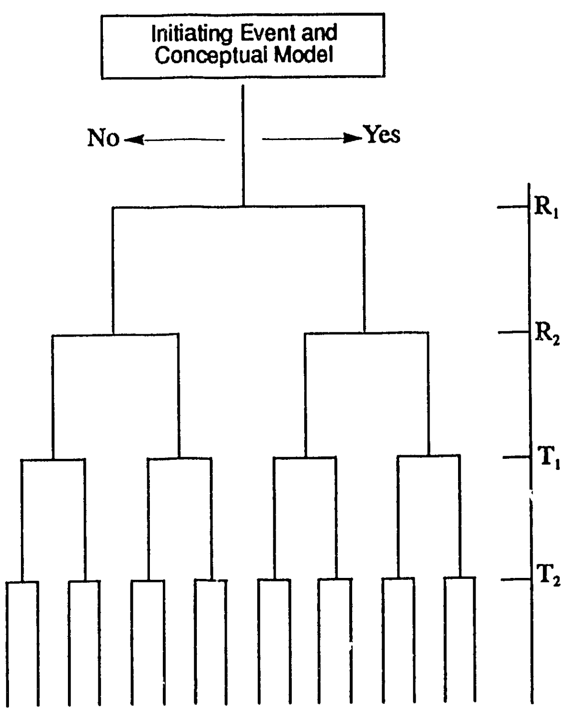

Figure 7. Translation to a bifurcation diagram with R_1 and R_2 lumped release processes, and T_1 and T_2 lumped transport processes.

SUMMARY

We can, with a fair amount of labor, translate our current scenarios to the form the NRC uses. It does not seem prudent to do so at this time; our understanding of Yucca Mountain is not yet mature enough to lump processes in this manner. Site characterization would be unnecessary if our current understanding would suffice. As site characterization proceeds, we will be able to successively prune the generalized event trees, and scenario calculations will become less unwieldy.

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