UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

DEC 03 1991

Ms. Margo T. Oge, Acting Director
Office of Radiation Programs, ANR-458
U.S. Environmental Protection Agency
Washington, D.C. 20460

Dear Ms. Oge:

On August 27, 1990, the staff of the U.S. Nuclear Regulatory Commission (NRC) commented on Working Draft No. 2 of the U.S. Environmental Protection Agency's (EPA's) high-level waste (HLW) standards. Included were recommendations to (1) provide comparisons with other regulations and risks as part of the support for the standards and (2) reword the probabilistic containment requirements. When we met on July 12, 1991, our discussions centered on these two topics, and your follow-up letter of July 18 raised a number of questions about them. Enclosure 1 to this letter responds to your July 18 questions.

Enclosure 2 is a short bibliography that might be useful for developing a perspective on the risk level allowed by EPA's HLW standards. Of particular interest are the papers by Kocher which compare EPA's standards to the risks allowed by other radiological standards. Kocher appears to have converted EPA's population impact goal into an individual risk by averaging over the entire U.S. population. Since this approach causes significant "risk dilution," EPA might wish to make its own estimate of the risk within the smaller population actually affected by a release from a repository.

Enclosure 3 presents several example calculations illustrating how compliance might be evaluated for EPA's 1985 containment requirements and for the NRC staff's proposed alternative. I think that most or all of your questions about the proposed alternative wording for the containment requirements (the "three-bucket approach") will be answered by the examples of Enclosure 3.

I hope the enclosed information will answer the questions of your July 18 letter. Please let me know if we can be of further assistance.

Sincerely,

Robert M. Bernero

Robert M. Bernero, Director
Office of Nuclear Material Safety
and Safeguards

Enclosures:
1. Staff's views on EPA's questions
2. Bibliography
3. Example calculations

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Enclosure 1

NRC STAFF VIEWS ON EPA'S
JULY 18 QUESTIONS

Three-bucket alternative

1. What technical analysis is there to support the contention that the level of protection is equivalent for the three-bucket methodology and the 1985 presentation of the containment requirements?

The example calculations of Enclosure 3 illustrate how an applicant might demonstrate compliance with the 1985 EPA standards and with the NRC staff's proposed alternative. For these examples, the two standards are of identical stringency when a scenario screening criterion of 1E-3 is used for the NRC staff's alternative and when 1E-4 is used for EPA's standards. If a screening criterion of 1E-4 were used for both standards, the NRC staff's alternative would be somewhat more stringent because it would apply to a broader range of scenarios than would EPA's 1985 standards.

It should be noted that differences in the two alternatives are probably more theoretical than real. Probabilities in the range of 1E-3 to 1E-4 (over 10,000 years) are very difficult to project with any real accuracy. Therefore, it will seldom be possible to produce probability estimates of the precision suggested in these examples. Indeed, that is the reason for the NRC staff's proposed alternative -- to allow a meaningful regulatory examination of unlikely disruptive scenarios while avoiding the difficulties involved in trying to predict the probabilities of unlikely processes and events.

Classification of human-initiated events as "unlikely" is not an inherent part of the NRC staff's alternative. Nevertheless, Example No. 3 illustrates how the NRC staff's alternative would be applied if human-initiated events were to be classified as "unlikely." The effect would be a ten-fold increase in allowable releases (compared to classification as "likely"), the same as would be the case with EPA's 1985 standards. Since both formulations for the standards have the same effect on the allowable size of releases, the NRC staff views classification of human-initiated events as a separate issue from possible adoption of the staff's proposed alternative wording for the standards.

2. Why is the use of a deterministic analysis preferable at scenarios with a probability below 0.1? How would the uncertainties in the consequences be handled in the second bucket in order to consider the different possible orders of occurrence and the change in their probability over time, (what are the options and rationale for recommended method)?

A major difficulty in implementing EPA's 1985 standards is the need to produce both consequence and frequency estimates for unlikely releases. There is often no good statistical basis to use for the frequency estimates, so they must rely heavily on subjective judgments. Such judgments are expected to be speculative, controversial, and difficult to evaluate during a licensing review. A standard that requires only a consequence analysis (which may include an estimate of uncertainties in projected releases) is preferable to a risk-based standard because it avoids the difficulties involved in attempting to project the frequencies of occurrence for unlikely events while still providing protection for the public.

Consequence analyses for the NRC staff's proposed alternative would be no different than for EPA's 1985 standards. In either case, it would be necessary to consider the order of occurrence of events by, for example, selecting the order that causes the largest releases, or by treating the times of occurrences of all events as random variables.

3. To what extent (either quantitative or qualitative) is the three-bucket methodology felt to reduce the uncertainty of the analysis and make it more meaningful, and how can this be shown?

The NRC staff's proposed alternative makes a repository safety analysis more meaningful by focusing attention on the estimates of the sizes of potential releases rather than on the highly uncertain frequencies with which those releases are projected to occur. As demonstrated in the enclosed example calculations, the level of safety imposed by the NRC staff's alternative is essentially the same as that of EPA's 1985 standards.

4. What kind of statistical analysis and presentation would be appropriate for determining compliance for analyses in the second bucket?

The enclosed example calculations illustrate the NRC staff's concepts.

5. What criteria should be used to decide at what probability level the development of the CCDF for the first bucket should be started?

The NRC staff anticipates including all scenarios with frequencies greater than 0.01 over 10,000 years, as illustrated in the enclosed example calculations.

6. How would one develop the analysis without definitive quantitative probability value boundaries between the buckets?

The NRC staff anticipates that numerical guidance would be provided to assist in classification of processes, events and scenarios. This guidance could be a single numerical value, as suggested in the enclosed example calculations, or could be a more complex formulation that would include consideration of the number of scenarios to be screened and, possibly, qualitative estimates of the sizes of the releases associated with screened scenarios.

7. What would be the rationale for a predetermination that no intrusion events were to fall into bucket 1, as might be inferred by the Commission's definition of "anticipated" events? Would this approach also preclude using intrusion events in developing the bucket 1 CCDF while at probabilities at less than 0.1 probability?

First, the NRC staff notes that potential classification of human intrusion as "unlikely" is an entirely separate issue from adoption of the staff's alternative language for EPA's containment requirements. A determination of the likelihood of intrusion would be necessary for either EPA's 1985 standards or for the NRC staff's alternative.

If the NRC were to classify human intrusion as "unlikely," such classification would be based on a recognition of the differences between the NRC's regulatory requirements for a repository and the assumptions made by EPA when deriving its standards. As EPA noted in the Background Information Document for the standards,

> The Agency . . . has estimated drilling rates that are intended to be upper bounds on the future likelihood of drilling at a repository site. In estimating these values, no credit has been taken for the communication to future generations of the presence of the repository, except . . . for 100 years after disposal . . .

EPA's estimated drilling rates are apparently derived by assuming that the drilling rates of the recent past can be extrapolated for 10,000 years into the future. Such an extrapolation would clearly be an upper bound estimate for an unmarked, unrecorded repository since past random drilling practices have already been largely replaced by targeted drilling aimed at known or inferred resource locations. Thus, even for a "stealth" repository of the type assumed by EPA, actual drilling rates are likely to be lower than the upper bounds estimated by EPA.

The NRC's repository regulations (10 CFR Part 60) would not permit licensing of a repository of the type assumed by EPA. Part 60 requires an extensive site characterization program, including identification and evaluation of potential resources at the repository site. Part 60 also requires Federal government ownership of land and mineral rights within the controlled area, and establishment of such controls outside the controlled area as are necessary to prevent human interference with waste isolation. Finally, Part 60 requires use of monuments and land-use records to warn potential future intruders of the existence and dangers of a repository. These regulatory requirements were judged to be adequate to classify human intrusion as "unanticipated" in Part 60, and could also serve as a basis to classify intrusion as "unlikely" for purposes of implementing EPA's standards. Such classification would exclude intrusion from the CCDF for "likely" releases.

8. What are the alternative rationales for having the analysis cut off at a low probability of one in one thousand vs. one in ten thousand? Which should be used and why?

The enclosed example calculations suggest that one in one thousand would generally impose the same level of safety as EPA's 1985 standards since "unlikely" events would be assigned a conservatively high probability of $\leq$.01. Nevertheless, if there were a large number of scenarios with releases exceeding ten times the table of release limits, a cut-off of one in ten thousand might be needed. The NRC staff prefers a qualitative criterion, as suggested in our Working Draft No. 2 comments, with a numerical guideline offered by EPA in its Supplementary Information. A qualitative regulatory criterion would allow the NRC the flexibility to develop an appropriate numerical value for each specific repository.

Alternative Risk Basis for EPA Standard

1. What would be the proper basis to use for the present acceptable risk to present generations, and how would this be expressed?

As noted by both the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP), risks which are less than 1/100,000 per year and which are also "as low as reasonably achievable" (ALARA) can be considered acceptable for current non-occupational radiation exposure (exclusive of medical and natural background exposure). The ICRP, the Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) all recommend that future radiation exposures be limited to this same level of risk. These organizations further recommend apportionment of a suitable fraction of this risk level for a specific activity such as disposal of high-level wastes. As stated by the ICRP:

> To allow for dose contributions from present practices and to provide a margin for unforeseen future activities, the [ICRP] recommends that national authorities select a fraction of the dose limits as a source upper bound for each source of exposure to ensure that the exposure of individuals will remain below the relevant dose limit.

Determination of the appropriate fraction of the overall limit to be allocated to disposal of HLW would include consideration of the existing level of non-medical, anthropogenic radiation exposures and of the fraction to be reserved for future activities.

2. EPA staff have reviewed some assessments of the uranium fuel cycle and its collective risk, but such evaluations seem to be quite old. Does NRC have a more current assessment of the collective risk of the uranium fuel cycle that reflects dose commitment, current dose conversion, and emission estimates?

The most recent information of which we are aware is that of NCRP Reports 92 and 93. This information is relatively old (late 70's and early 80's) and is derived primarily from models of facility performance rather than from actual measurements. The NCRP estimates that the total annual effective dose equivalent per person in the U.S. is 3.6 mSv (360 mrem), of which 0.014% is attributable to the nuclear fuel cycle. The nuclear fuel cycle is also estimated to cause an annual population exposure to regional populations of 1.36 person-Sv (136 person-rem) per gigawatt, 87% of which results from uranium mining and milling.

3. Since both the commercial sector and the DOE will be using the repository would you think that the present releases and impacts of both these activities should be analyzed in order to arrive at intergenerational equity?

To the extent that both commercial and defense activities are expected to contribute to long-term radiation exposures, either through continued operations or through discharges of long-lived radioactive materials, their impacts are relevant for determining the fraction of the overall risk limit to be allocated to disposal of HLW.

The important concept advanced by the ICRP and others is establishment of an overall limit on allowable radiological impacts for the future. In order to ensure that the activities of future societies are not unduly constrained, the ICRP recommends that a suitable fraction of the recommended limit be allocated for each specific type of activity or facility. Factors to consider when determining the fraction of the limit to be allocated to a specific activity or facility would include the number of people likely to be affected by a release and the duration of expected releases. For example, if a release is likely to be wide-spread and long-lasting, as with gaseous release of C-14, a small fraction would be appropriate to allow an ample margin for future activities. On the other hand, releases that are more restricted in time and/or space can be somewhat larger because such releases will impose fewer restrictions on future societies. In particular, sources of exposure located in relatively isolated areas where future radiological activities are unlikely (e.g., uranium mill tailings in the U.S.) can be allocated a larger fraction of the limit than could similar facilities located in or near urban areas. Since repository locations in the U.S. are likely to be in relatively isolated areas, allocation of a reasonably large fraction of the recommended limit (perhaps 10%) would not seem unreasonable.

4. Initial considerations of this approach indicate that it might not provide a basis to discern a "good" repository. Is it the NRC belief that this should not be a role for the EPA standard?

EPA's standards should provide a basis for distinguishing an acceptable repository from an unacceptable one. The NRC staff does not object to the notion that EPA's standards might be based, in part, on a desire to keep releases ALARA. However, the NRC staff would object to any standards that would require a quixotic search for "the best" repository.

As noted in our comments on Working Draft No. 2, we recommend that EPA "place increased emphasis on comparisons with other regulatory standards and guidance, and with other risks experienced by society" when deriving the release limits of the standards. We do not think that the technical achievability rationale used by EPA to support the 1985 standards are inherently inappropriate.

Rather, we note that those analyses were relatively simple and may not adequately represent the level of performance to be expected from a real repository. Supplementing those analyses with the recommended comparisons with other standards and risks would provide a stronger basis of support for the standards.

Enclosure 2

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EXAMPLES OF COMPLIANCE DEMONSTRATIONS FOR 40 CFR PART 191 CONTAINMENT REQUIREMENTS AND THE NRC STAFF'S PROPOSED ALTERNATIVE

1. INTRODUCTION

Most radiation protection standards are non-probabilistic -- that is, the standards contain no explicit statement of the probabilities of the conditions to which the standards apply. Examples are the uranium fuel cycle standards of the U.S. Environmental Protection Agency (EPA). Those standards simply require that uranium fuel cycle facilities be operated "in such a manner as to provide reasonable assurance" that certain dose limits will not be exceeded. The term "reasonable assurance" is not defined, nor do the standards provide a probabilistic definition of the range of operating conditions to which the dose limits are to be applied.[1]

Parts of EPA's high-level radioactive waste (HLW) standards[2] are also stated non-probabilistically. EPA's standards for operations (Subpart A) essentially extend EPA's uranium fuel cycle standards to include operations at an HLW repository. Similarly, EPA's post-closure standards for protection of individuals and groundwater are applicable only to "undisturbed performance." Thus, for these sections of the standards, there is no need to evaluate the likelihood of processes and events that might disrupt the performance of a repository.

EPA could have used a similar format for its environmental standards for the disturbed performance of a repository. For example, EPA could have simply required that disturbed performance not cause projected impacts greater than some multiple of the level of impacts allowed for undisturbed performance. This type of standard would have directly limited the impacts that might be caused by a repository without requiring a numerical estimate of the likelihood that any specific level of impact would occur. However, EPA chose instead to formulate its standards in a way that requires numerical estimates of both the sizes of possible releases from a repository and the probabilities that those releases will occur. Specifically, EPA's standards require that:

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[1]It is implicitly understood that EPA's uranium fuel cycle standards apply only to "normal" operations, and that there is no requirement to design a facility to comply with those standards in the event of an unlikely accident.

[2]EPA's HLW standards, 40 CFR Part 191, were promulgated in 1985, but were partially remanded by a Federal court decision in 1987. In this paper, references to EPA's HLW standards mean the standards as promulgated in 1985.

> Disposal systems . . . shall be designed to provide a reasonable expectation. . . . that the cumulative releases . . . for 10,000 years after disposal . . . shall:
>
> (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 . . .; and
>
> (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 . . . .

Evaluating compliance with these "containment requirements" would require numerical estimates of the probabilities of processes and events with likelihoods as low as 10^{-7} to 10^{-8} per year. Probabilities this low are very difficult to estimate, and any estimates produced will be very uncertain. In fact, EPA's requirement for numerical estimates of probabilities this low has caused many observers to question whether EPA's standards would be workable in the NRC's formal licensing process.

On August 27, 1990, the NRC staff recommended that EPA consider an alternative formulation for its containment requirements. The NRC staff's proposal retained EPA's probabilistic formulation for relatively likely releases, but substituted a non-probabilistic consequence limit for unlikely releases. The following text for EPA's containment requirements was suggested to implement the staff's proposal:

> Disposal systems . . . shall be designed to provide a reasonable expectation that, for 10,000 years after disposal:
>
> (1) anticipated performance will not cause cumulative releases of radionuclides to the accessible environment to have a likelihood greater than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix B); and
>
> (2) the release resulting from any process, event, or sequence of processes and events that is sufficiently credible to warrant consideration will not exceed ten times the quantities calculated according to Table 1 (Appendix B).

EPA solicited public comment on the NRC staff's proposal after substituting the phrase "have a likelihood between one chance in 10 and one chance in 10,000" for "is sufficiently credible to warrant consideration." Questions have arisen regarding the NRC staff's proposal, including:

> (1) How would an applicant demonstrate compliance with the NRC staff's alternative standards?
>
> (2) Would the NRC staff's alternative require an identical (or nearly equivalent) level of repository safety?
>
> (3) Should the scope of regulated repository disruptions be defined qualitatively, as in the NRC staff's proposal, or would EPA's numerical

modification be more appropriate? If a number is desired, what should it be?

The example calculations presented in this paper are intended to help answer these questions. Section 2 provides some background information on the distinction between the repository system and its environment, the use of modified "event trees" for scenario analyses, and the use of the "complementary cumulative distribution function" (CCDF) to display the estimated uncertainties in repository performance. Section 3 then presents several example calculations comparing EPA's probabilistic standards to the NRC staff's proposed alternative.

2. BACKGROUND INFORMATION

2.1 The Repository System and its Environment.

As illustrated in Figure 1, the entire regulated repository system, including engineered and natural components, can be treated as a system that exists within, and responds to, an evolving external environment. Possible

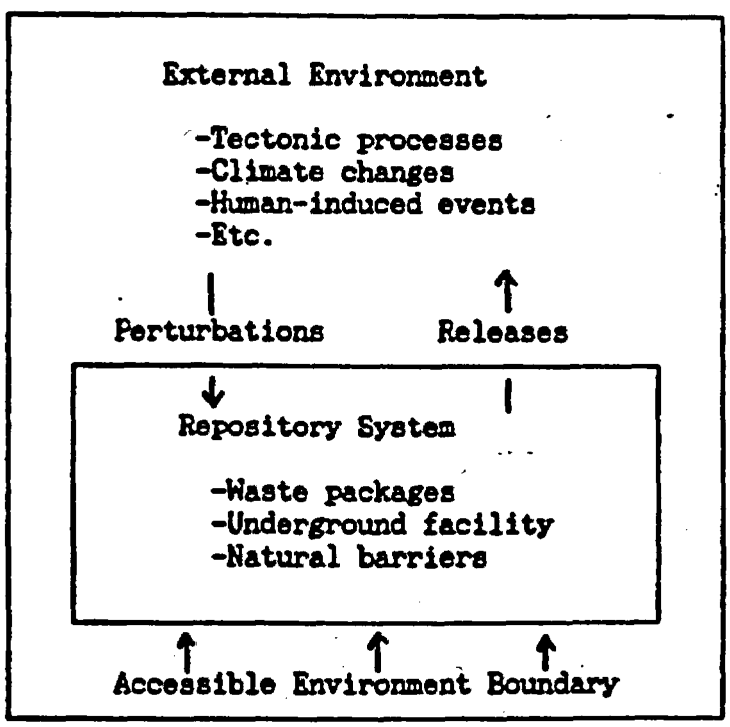

Figure 1. Conceptual representation of repository system and its environment.

evolutions of the repository environment are identified as "scenarios," while uncertainties about the performance of the system within its environment (e.g., corrosion of waste packages) are assumed to be incorporated into the models of the system. Thus, in the example calculations presented in this document, the term "scenario" refers only to external processes and events in the repository environment that could perturb repository performance. Uncertainties about the initial conditions of the repository system and about its response to external perturbations are not included in scenario analyses because they are assumed to be incorporated into the models of the system.

2.2 Scenario Analyses.

In these example calculations, scenarios are constructed using diagrams similar to the event trees used in probabilistic risk assessments. Figure 2 illustrates an example of such a diagram.

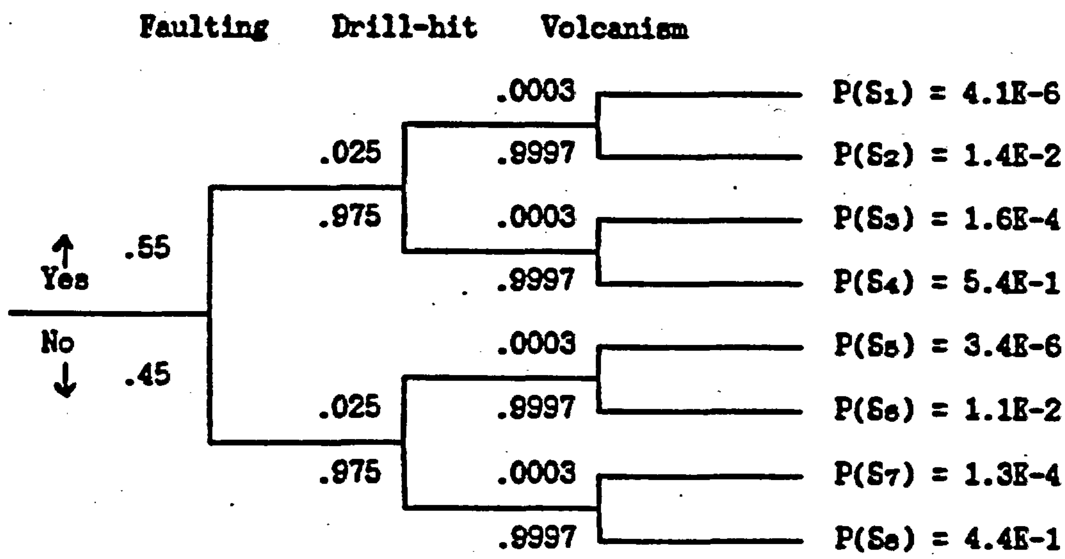

Figure 2. Example of a scenario analysis.

In Figure 2, each branch point represents the potential for a disruptive process or event to occur. The numbers above and below the branch point indicate the probability that the process or event does or does not occur. In Figure 2, the left branch point represents the potential for fault movement, .55 is the probability (over 10,000 years) that fault movement does occur, and .45 is the probability of no fault movement. Similarly, the center and right branches illustrate the potential for, and the probabilities of, drilling that hits a waste package and volcanism.

Each path from left to right through Figure 2 represents a potential evolution of the repository environment, or a "scenario." Multiplication of the event probabilities along each path gives the probability that the scenario will occur. For example, the top scenario (S_1) represents the sequential occurrence of all three events, and has a probability of 4.1E-6 over 10,000 years. No disruptive events occur in the bottom scenario (S_8) where the estimated probability is 4.4E-1. Scenarios S_2-S_7 involve other possible combinations of the three potentially disruptive events.

One step in a scenario analysis is identification of potentially disruptive processes and events. Possible variations in locations, magnitudes, and other characteristics could cause the number of processes and events to become so large that a scenario analysis would be unmanageable. It is necessary, therefore, to use a single process or event to represent a larger class of similar processes or events. For example, movement of a specified magnitude on a particular fault could be taken as an approximation of all other potential fault movements near a site. Approximations of this type clearly involve trade-offs between the realism (or accuracy) of a scenario analysis and its complexity. As iterative performance assessments are carried out for a particular repository, the number of processes and events needed to achieve a desired degree of realism can be determined.

2.3 Complementary Cumulative Distribution Function (CCDF).

Estimates of projected releases from a repository will contain many uncertainties, some of which can be quantified in a meaningful way. One format for displaying the quantifiable uncertainties is the "complementary cumulative distribution function" (CCDF). The CCDF is a curve showing, on the vertical axis, the probability that releases will exceed the values on the horizontal axis. Figure 3 is an example of a CCDF where the size of a projected release is measured in multiples of EPA's table of release limits. Also shown in Figure 3 is a "stair-step" limit representing the maximum releases allowed by EPA's HLW standards.

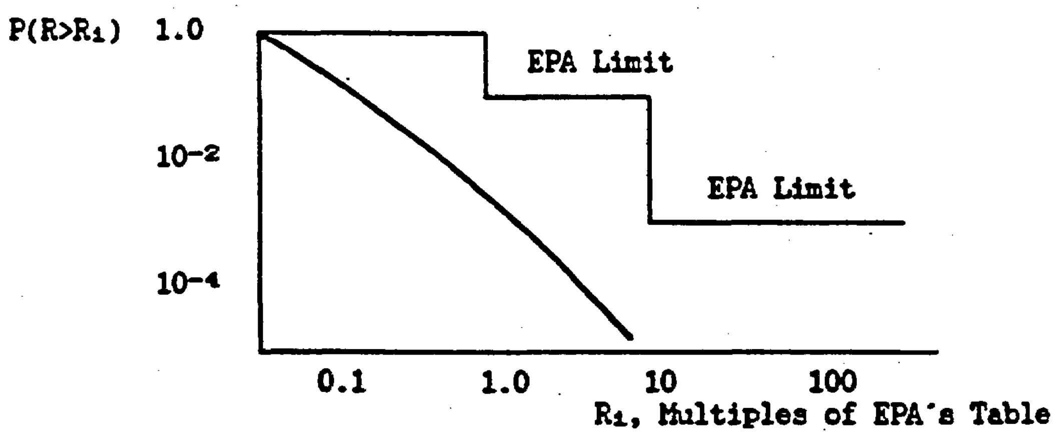

Figure 3. Example of a Complementary Cumulative Distribution Function (CCDF).

In Figure 3, the vertical axis displays the probability that releases will be larger than the values on the horizontal axis. Release probabilities are obtained by summing the probabilities of processes and events that could cause releases. If the regulatory limit applies to releases with probabilities of 1E-3, as illustrated in Figure 3, it will be necessary to include in the summation all processes and events with probabilities greater than about 1E-4 to assure completeness of the CCDF.

2.4 Conditional CCDF.

The releases projected for an individual scenario can be displayed using a "conditional CCDF." A conditional CCDF represents uncertainties in projected releases, assuming the occurrence of a scenario. If conditional CCDF's are calculated for each scenario, a composite CCDF for a repository can be formed using the relationship

$$P(R>R_i) = \Sigma\, P(S_j)P(R>R_i|S_j)$$

where $P(S_j)$ is the probability that scenario S_j will occur and $P(R>R_i|S_j)$ is the conditional probability that releases will exceed R_i assuming that S_j occurs.

3. EXAMPLE CALCULATIONS

An evaluation of compliance with EPA's 1985 standards would involve six steps, as follows.

Step 1 -- Identify disruptive processes and events. All potentially disruptive processes and events that could occur external to the repository system would be identified. In general, processes and events occurring within the repository system, such as waste package corrosion, would be included in models of repository performance. However, when processes and events are initiated outside the repository system, or result from phenomena occurring outside the repository system, they would be considered to be "external." Examples would include drilling that penetrates a repository and movement of a fault that intersects the repository system.

Step 2 -- Screen processes and events. Processes and events could be eliminated from the list of Step 1 on the basis of low probability (including physical impossibility) or the insignificance of estimated releases. EPA's 1985 standards suggest elimination of processes and events with probabilities less than 1/10,000 over 10,000 years.

Step 3 -- Form scenarios. Processes and events would be combined into scenarios as discussed previously in Section 2.2.

Step 4 -- Screen scenarios. Scenarios could be eliminated from further analysis using the same screening criteria as in Step 2.

Step 5 -- Estimate scenario releases. Releases from all processes and events included in each scenario would be estimated.

Step 6 -- Form CCDF. The probability and release estimates for all scenarios would be combined into a CCDF of the form described in Section 2.3. This CCDF would be compared to the two release limits imposed by EPA's standards.

Evaluating compliance with the NRC staff's proposed alternative standard would be virtually identical, except for Step 6. With the staff's alternative, Step 5 would be followed by a test for compliance with the requirement that the release associated with each scenario be less than ten times EPA's table of release limits. If that requirement were met, all likely scenarios (those with probabilities >.01) would be combined into a CCDF to determine the cumulative likelihood of releases larger than EPA's table.

The example calculations presented here start with a "baseline example." This is largely a reproduction of one of the analyses included in EPA's "Background Information Document" (BID) which provides the technical support for EPA's standards.[3] The baseline example uses single value estimates of the probabilities and consequences of three potentially disruptive events to illustrate construction of a CCDF and comparison of that CCDF with the release limits of EPA's HLW standards. A second example then shows how the information from the baseline example would be used to evaluate compliance with the alternative standards proposed by the NRC staff. Additional examples consider variations from the baseline example and illustrate application of the two standards to those variations. Finally, the single value estimates of probabilities and releases are replaced by distributed estimates to illustrate how uncertainties might be incorporated into an evaluation of compliance.

EPA's BID presents analyses of the projected performance of hypothetical spent fuel repositories in four geologic media: basalt, bedded salt, tuff and granite. Five disruptive events were considered: fault movement, breccia pipe formation (salt only), drilling (does not hit a canister), drilling (hits a canister), and volcanic activity. For most events in most media, EPA estimated probabilities much higher or much lower than would be of interest for these example calculations. Only brecciation in salt and volcanic activity in tuff were estimated to have probabilities in the range of interest (10^{-7} to 10^{-8} per year). Brecciation in salt either caused no releases or the estimated releases were not reported by EPA. Therefore, EPA's hypothetical tuff site was chosen for the example calculations presented below.

The following probability and release estimates for EPA's tuff repository were inferred from information in Tables 8.9.1 and 8.10.1 of EPA's BID.

Table 1. Estimates of probabilities of disruptive events and resulting releases.

Event	Probability in 10,000 yr	Release over 10,000 years (Multiples of EPA's Table)
Fault Movement	5.5E-1	5.4E-3
Drilling (hits Canister)	2.5E-2	8.6E-2
Volcanic Activity	3.0E-4	8.0E0

[3] "Background Information Document: Final Rule for High-Level and Transuranic Radioactive Wastes," U.S. Environmental Protection Agency Report Number EPA 520/1-85-023, August, 1985.

Table 8.9.1 of EPA's BID estimates the frequency of fault movement to be 8E-5/yr. Treating fault movement as a Poisson process, the probability of at least one occurrence of fault movement in 10,000 years would be 1 - exp-(8E-5)(10,000) = 0.55. The probabilities that drilling and volcanic activity will occur within 10,000 years are simply 10,000 times the annual estimates in EPA's BID.

Table 8.10.1 of EPA's BID lists EPA's estimates of the expected number of fatal cancers over 10,000 years due to fault movement and drilling. It is important to note that Table 8.10.1 gives expected value estimates which are the product of the actual estimate of fatal cancers and the probability that the disruptive event will occur. In Table 1, above, the release estimates are based on actual fatal cancer estimates derived by dividing EPA's expected value estimates by the probabilities of Table 1.

Tables 8.9.1 and 8.10.1 of EPA's BID do not provide an estimate of the number of fatal cancers that would result from volcanic activity. However, Table 8.9.1 does estimate that the fraction of the repository inventory that would be dispersed to the environment would be 4E-4. At 1,000 years, the repository inventory is about 2E4 times EPA's table of release limits. Assuming 4E-4 as the fraction released, the release would be 8 times Table 1.

Example 1 -- Baseline Example.

This example attempts to reproduce EPA's evaluation of the projected performance of a spent fuel repository in unsaturated tuff.

Step 1 -- Identify disruptive processes and events.

For this example, it is assumed that the only conceivable disruptive processes and events are the five identified by EPA: fault movement, brecciation, drilling (misses waste packages), drilling (hits waste package), and volcanic activity.

Step 2 -- Screen processes and events.

Brecciation is eliminated from further consideration because of physical impossibility in a tuff medium. Drilling (misses waste packages) is also eliminated on the basis of EPA's estimate that no releases would occur.

Step 3 -- Form scenarios.

The eight scenarios for this example are illustrated in Figure 4.

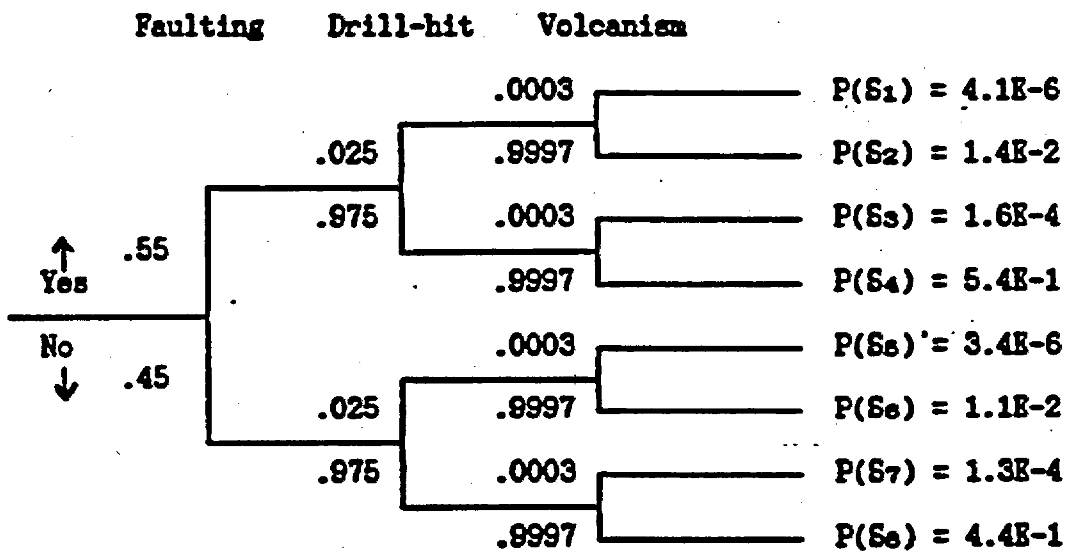

Figure 4. Scenarios for Example 1.

Step 4 -- Screen scenarios.

In this example, scenarios S_1 and S_5 would be eliminated from further consideration because the estimated probabilities are below EPA's specified cut-off of 1E-4.

Step 5 — Estimate scenario releases.

The release estimates for disruptive events are assumed to be those of Table 1. If a scenario includes more than one event, the scenario release is assumed to be the sum of the releases caused by the constituent events.

Step 6 — Form CCDF.

Table 2 illustrates how a CCDF is constructed by listing the scenarios in order of decreasing size of releases, and by calculating the cumulative probability that the release exceeds the value for each scenario.

Table 2. CCDF data for Example 1.

Scenario	Probability	Release	Cumulative Probability
S_3 F,V*	1.6E-4	8.005**	1.6E-4**
S_7 V	1.3E-4	8.000	2.9E-4
S_2 F,D	1.4E-2	.091	1.429E-2
S_5 D	1.1E-2	.086	2.529E-2
S_4 F	5.4E-1	.005	5.6529E-1
S_8 Undisturbed	4.4E-1	0	1.0***

*Notation indicates Scenario S_3 in which faulting and volcanism occur.
**Digits are not all significant, but are presented to illustrate summations of releases and probabilities.
***Rounding may cause a sum slightly different from 1.0.

Plotting the third and fourth columns of Table 2 gives the curve of Figure 5.

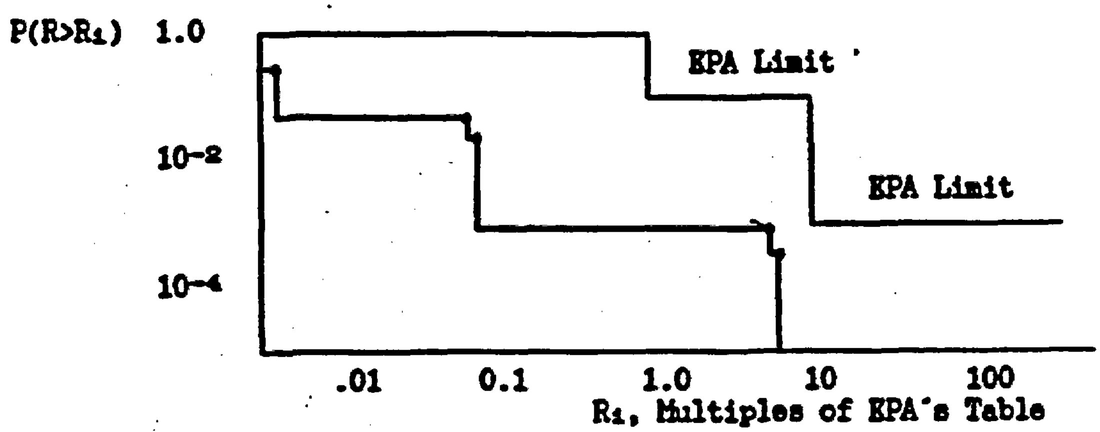

Figure 5. CCDF for Example 1, showing compliance with EPA's release limits.

Figure 5 is a reasonable approximation of the CCDF presented by EPA in Figure 8.10.3 of EPA's BID.

Example 2 -- NRC Staff's Alternative.

This example uses the same data as Example 1 to illustrate the similarities and the differences between EPA's 1985 standards and the NRC staff's proposed alternative.

Step 1 -- Identify disruptive processes and events.

Same as Example 1.

Step 2 -- Screen processes and events.

Same as Example 1.

Step 3 -- Form scenarios.

The eight scenarios for this example are illustrated in Figure 6. The scenarios are essentially the same as in Example 1, except that only a bounding probability estimate of <.01 is provided for the unlikely volcanism event. A probability of .01 over 10,000 years, or 10^{-6}/yr, is often considered to be at the lower range of probability values that can be meaningfully quantified.

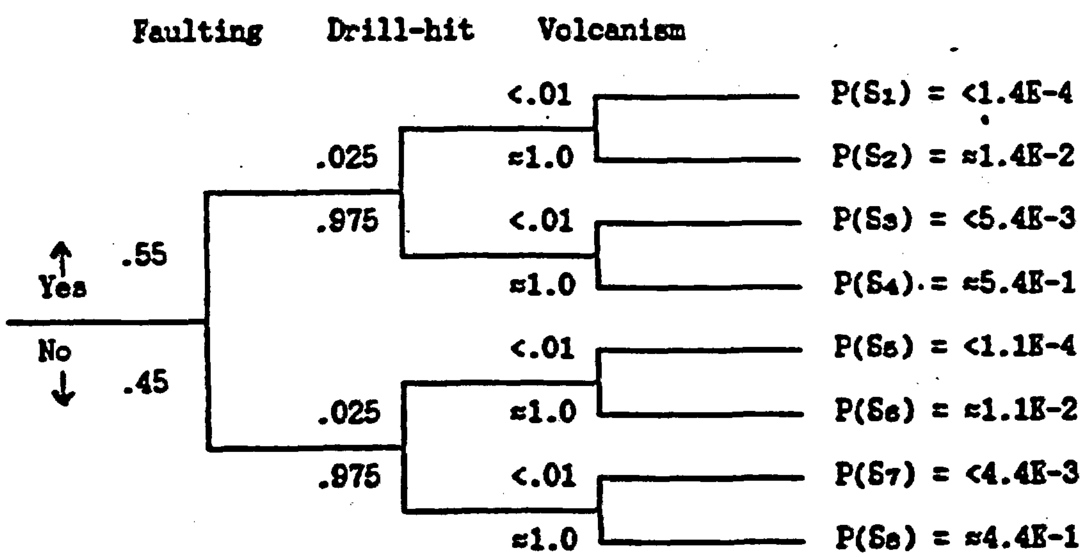

Figure 6. Scenarios for Example 2.

Step 4 -- Screen scenarios.

Because it is so difficult to meaningfully quantify probabilities in the range of 1E-7 to 1E-8 per year, the NRC staff's proposed alternative suggested a qualitative screening criterion (sufficiently credible to warrant consideration) to determine which scenarios should be retained for further analysis. Nevertheless, if a bounding value of <.01 is assigned to unlikely events as in Figure 6, it would be possible to use a numerical screening criterion. Using EPA's suggested numerical value of 1E-4, scenarios S_1 and S_5

would be retained, even though they were eliminated in Example 1. Thus, a value of 1E-4 would make the NRC staff's alternative somewhat more stringent than EPA's current standards. 1E-3 is used in this example, eliminating scenarios S_1 and S_5.

Step 5 — Estimate scenario releases.

Same as Example 1.

Step 6 — Test releases for compliance.

The NRC staff's alternative requires that the release from each scenario be less than ten times EPA's table of release limits. In this example, all scenarios meet this requirement.

Step 7 -- Form CCDF for anticipated performance.

Table 3 illustrates construction of a CCDF only for those scenarios with probabilities >.01, i.e., those scenarios likely to contribute significantly to the CCDF in the region of P = 0.1.

Table 3. CCDF data for Example 2.

Scenario	Probability	Release	Cumulative Probability
S_2 F,D	1.4E-2	.091	1.4E-2
S_6 D	1.1E-2	.086	2.5E-2
S_4 F	5.4E-1	.005	5.65E-1
S_8 Undisturbed	4.4E-1	0	1.0

Plotting the data of Table 3 gives the curve of Figure 7.

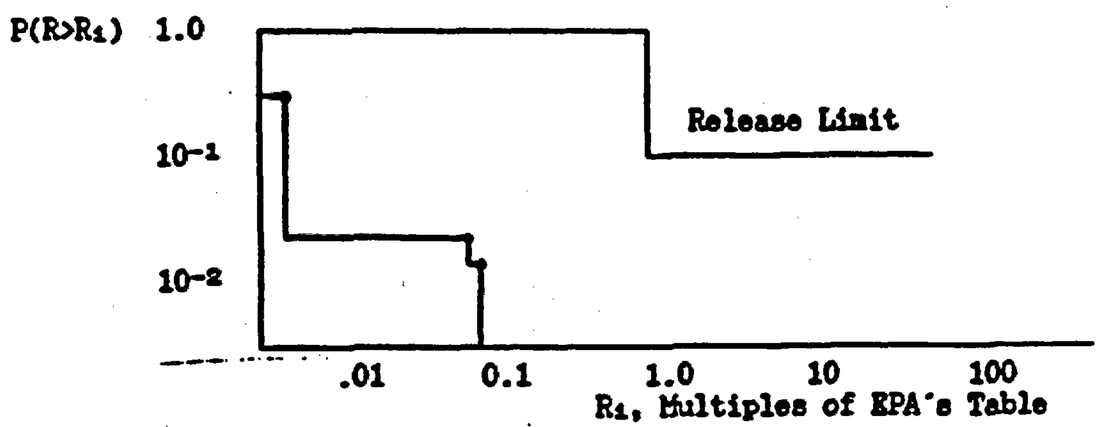

Figure 7. CCDF for Example 2, showing compliance with the NRC staff's alternative standard for anticipated performance.

Example 2 illustrates the importance of the screening criterion for excluding scenarios from further analysis. Use of bounding probability estimates (<.01) for unlikely events produces bounding estimates for scenario probabilities as well. Because scenario probabilities are overestimated, highly unlikely scenarios may be retained in the analysis if EPA's screening criterion of 1E-4 is used. In this example, a criterion of 1E-3 retains the same scenarios that were retained in Example 1.

Example 3 — Human Intrusion Classified as "Unlikely."

The NRC's HLW repository regulations, 10 CFR Part 60, now classify human-initiated disruptions as "unanticipated." An equivalent treatment under the NRC staff's proposed alternative would classify human intrusion as "unlikely." This example illustrates the significance of such classification.

Step 1 — Identify disruptive processes and events.

Same as Example 1.

Step 2 — Screen processes and events.

Same as Example 1.

Step 3 — Form scenarios.

The eight scenarios for this example are illustrated in Figure 8. The scenarios are essentially the same as in Example 1, except that bounding probability estimates of <.01 are provided for both volcanism and drilling (hits waste package).

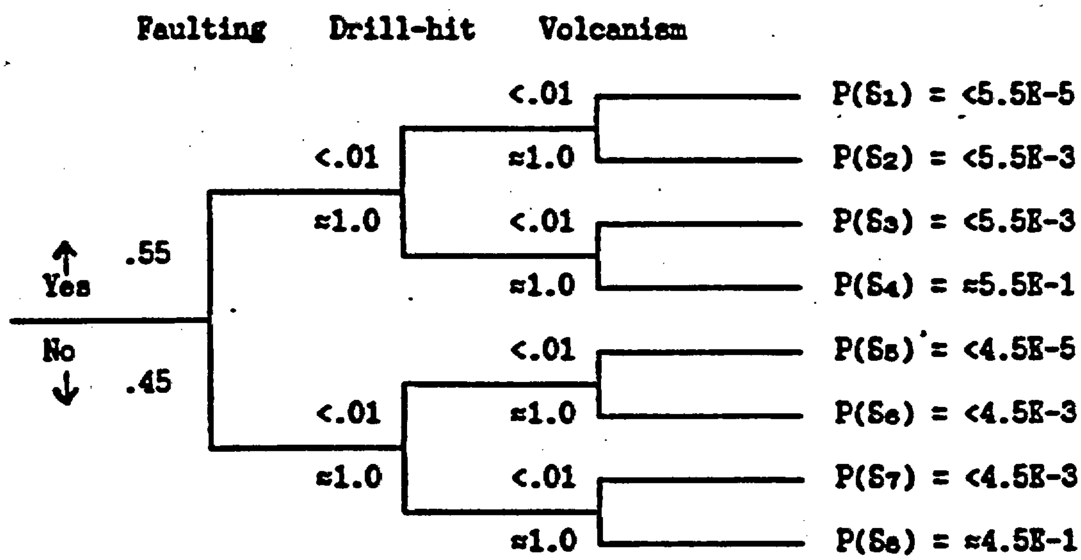

Figure 8. Scenarios for Example 3.

Step 4 — Screen scenarios.

Scenarios S_1 and S_5 are eliminated because the estimated probabilities are much less than 1E-3.

Step 5 — Estimate scenario releases.

Same as Example 1.

Step 6 — Test releases for compliance.

The NRC staff's alternative requires that the release from each scenario be less than ten times EPA's table of release limits. In this example, all scenarios meet this requirement.

Step 7 -- Form CCDF for anticipated performance.

Table 4 illustrates construction of a CCDF only for those scenarios with probabilities >.01, i.e., those scenarios likely to contribute significantly to the CCDF in the region of P = 0.1. In this example, only two scenarios are included in the CCDF.

Table 4. CCDF data for Example 3.

Scenario	Probability	Release	Cumulative Probability
S_4 F	5.4E-1	.005	5.5E-1
S_8 Undisturbed	4.4E-1	0	1.0

Plotting the data of Table 4 gives the curve of Figure 9.

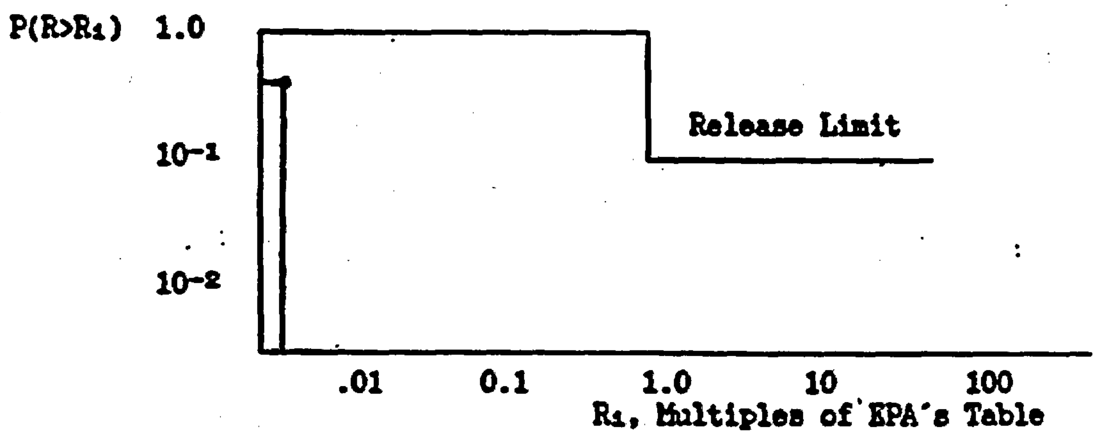

Figure 9. CCDF for Example 3, showing compliance with the NRC staff's alternative standard for anticipated performance.

Classification of human-initiated events as "unlikely" would remove human intrusion scenarios from the CCDF of Figure 9. Instead, releases from human intrusion scenarios would be compared scenario-by-scenario to a limit of ten times EPA's table of release limits. The effect would be to allow a ten-fold increase in releases from human intrusion scenarios. It is important to note, however, that the change in the allowable size of release does not result from adoption of the NRC staff's alternative wording for the standards. Using EPA's 1985 standards, the NRC could also specify a probability for human intrusion of <0.01. Doing so would have the same effect of allowing a ten-fold increase in releases from human intrusion.

Example 4 -- Higher Probability and Larger Release for Volcanism - Evaluation of Compliance with EPA's HLW Standards.

In this example, the probability of volcanism and the estimated release are increased by a factor of ten. The increases are sufficient to cause a marginal violation of EPA's 1985 standards, as illustrated in this example.

Step 1 -- Identify disruptive processes and events.

Same as Example 1.

Step 2 -- Screen processes and events.

Same as Example 1.

Step 3 -- Form scenarios.

The eight scenarios for this example are illustrated in Figure 10. The scenarios are the same as in Example 1 except that the probability estimate for volcanic activity is increased by a factor of ten.

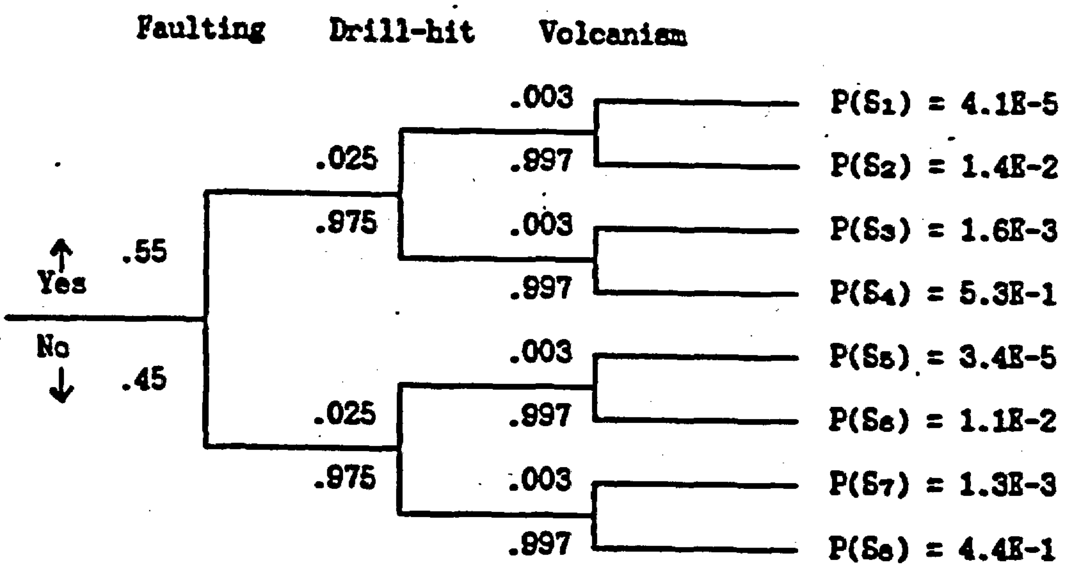

Figure 10. Scenarios for Example 4.

Step 4 -- Screen scenarios.

In this example, scenarios S_1 and S_5 would be eliminated from further consideration because the estimated probabilities are below EPA's specified cut-off of 1E-4.

Step 5 -- Estimate scenario releases.

Same as Example 1 for fault movement and drilling (hits waste package). For this example, the release from volcanism is postulated to be ten times larger than in Example 1. Therefore, the release from scenario S_3 is estimated to be 80.005 times EPA's table of release limits and the release from scenario S_7 is estimated to be 80.0 times EPA's table.

Step 6 — Form CCDF.

Table 5 illustrates construction of a CCDF for this example.

Table 5. CCDF data for Example 4.

Scenario	Probability	Release	Cumulative Probability
S_3 F,V*	1.6E-3	80.005	1.6E-3
S_7 V	1.3E-3	80.000	2.9E-3
S_2 F,D	1.4E-2	.091	1.69E-2
S_6 D	1.1E-2	.086	2.79E-2
S_4 F	5.4E-1	.005	5.679E-1
S_8 Undisturbed	4.4E-1	0	1.0

Plotting the data of Table 4 gives the curve of Figure 11, illustrating a violation of EPA's release limit.

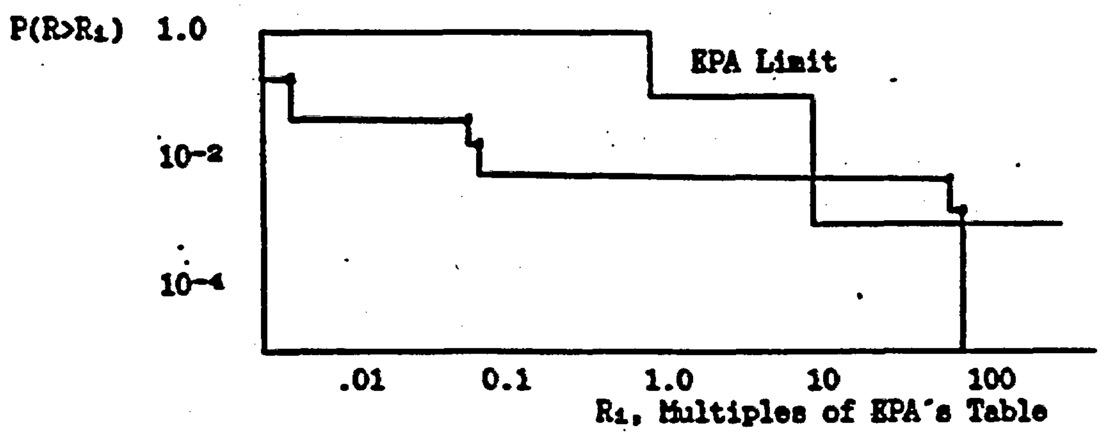

Figure 11. CCDF for Example 4, showing a violation of EPA's release limits.

Example 5 — Higher Probability and Larger Release for Volcanism - NRC Staff's Alternative.

This example uses the same probability and release estimates as Example 4 to determine whether the NRC staff's proposed alternative will also identify a violation.

Step 1 — Identify disruptive processes and events.

Same as Example 1.

Step 2 — Screen processes and events.

Same as Example 1.

Step 3 — Form scenarios.

The scenarios for this example are illustrated in Figure 12. The scenarios are essentially the same as in Example 1, except that only a bounding probability estimate of <.01 is provided for the unlikely volcanism event.

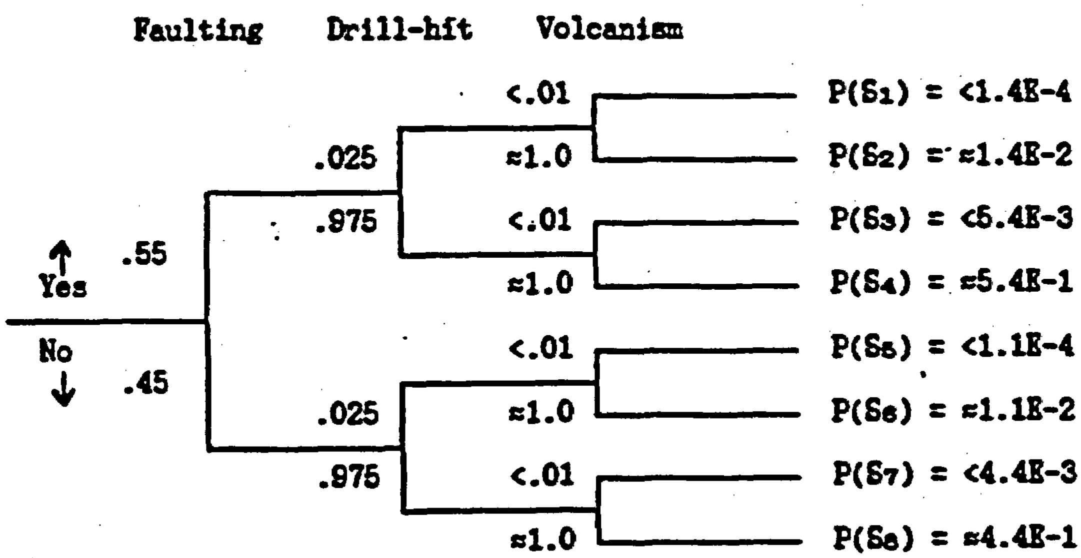

Figure 12. Scenarios for Example 5.

Step 4 — Screen scenarios.

This example again illustrates the importance of the screening criterion for excluding scenarios from further analysis. Using EPA's value of 1E-4, scenarios S_1 and S_5 would be retained, making the NRC staff's alternative somewhat more stringent than EPA's current standards. For this example, a criterion of 1E-3 is used, eliminating scenarios S_1 and S_5.

Step 5 — Estimate scenario releases.

Same as Example 4, where the release from volcanism is postulated to be ten times larger than in Example 1. The release from scenario S_3 is estimated to be 80.005 times EPA's table of release limits and the release from scenario S_7 is estimated to be 80.0 times EPA's table.

Step 6 — Test releases for compliance.

The NRC staff's alternative requires that the release from each scenario be less than ten times EPA's table of release limits. In this example, scenarios S_3 and S_7, which include volcanism, fail to meet this requirement.

Step 7 — Form CCDF for anticipated performance.

For this example, there is no need to develop a CCDF for anticipated performance since individual scenario releases already indicate non-compliance with the NRC staff's proposals. If a CCDF were to be plotted for anticipated performance, it would be identical to that for Example 2.

In this example, the requirement that no scenario cause a release greater than ten times EPA's table is equivalent to EPA's CCDF formulation for identifying the unacceptable release from volcanism. This example again shows that a scenario screening criterion of 1E-4 would make the NRC staff's proposed alternative more stringent than EPA's 1985 standards, although for this example there would be no practical effect since the release limit is exceeded even with a criterion of 1E-3.

Example 6 -- Additional Low-Probability, High-Release Event - Evaluation of Compliance with EPA's HLW Standards.

The potential for differences between EPA's 1985 standards and the NRC staff's proposed alternative is greatest when more than one low-probability, high-release event must be evaluated. Examples 6 and 7 provide a comparison.

Step 1 -- Identify disruptive processes and events.

A sixth event is added to the five events of Example 1 -- a very unlikely, but very severe climate change capable of causing significant releases.

Step 2 -- Screen processes and events.

Brecciation and drilling (misses waste packages) are deleted. Fault movement, drilling (hits waste package), volcanism and climate change are retained.

Step 3 -- Form scenarios.

The sixteen scenarios for this example are illustrated in Figure 13.

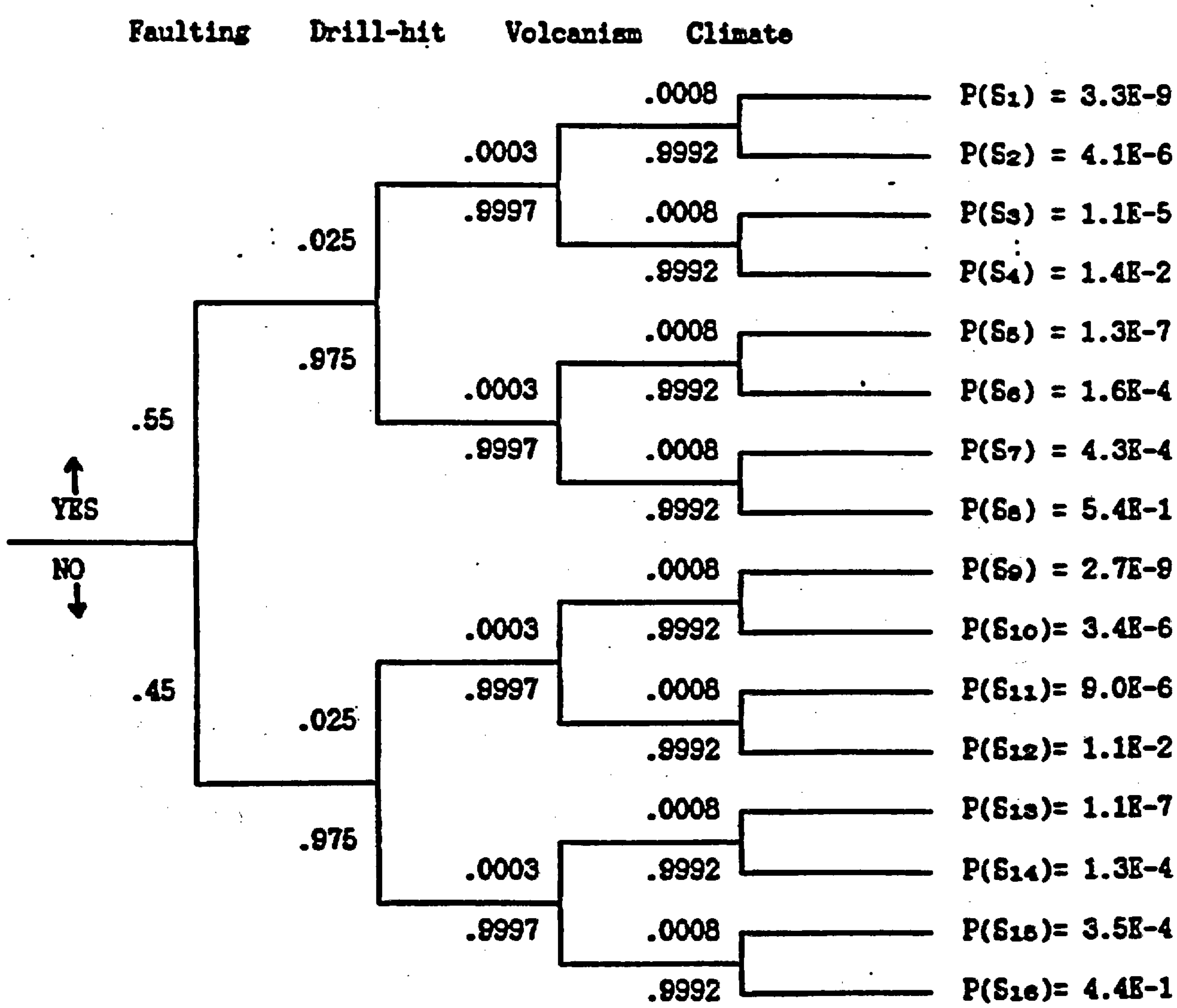

Figure 13. Scenarios for Example 6.

<u>Step 4</u> — Screen scenarios.

Scenarios S_1, S_2, S_3, S_5, S_9, S_{10}, S_{11}, and S_{13} would all be eliminated because the estimated probabilities are less than EPA's criterion of 1E-4.

<u>Step 5</u> — Estimate scenario releases.

Releases associated with fault movement and drilling (hits waste package) are the same as in Example 1. For volcanism, the higher release of Example 4 is assumed. The release postulated for severe climate change is 20 times EPA's table of release limits.

<u>Step 6</u> — Form CCDF.

Table 6 illustrates construction of a CCDF for this example.

Table 6. CCDF data for Example 6.

Scenario	Probability	Release	Cumulative Probability
S_8 F,V	1.6E-4	80.005	1.6E-4
S_{14} V	1.3E-4	80.0	2.9E-4
S_7 F,C	4.3E-4	20.005	9.2E-4
S_{15} C	3.5E-4	20.0	1.07E-3
S_4 F,D	1.4E-2	.091	1.507E-2
S_{12} D	1.1E-2	.086	2.707E-2
S_6 F	5.4E-1	.005	5.6707E-1
S_{16} Undisturbed	4.4E-1	0	1.0

Plotting the data of Table 6 gives the curve of Figure 14, illustrating a violation of EPA's release limits.

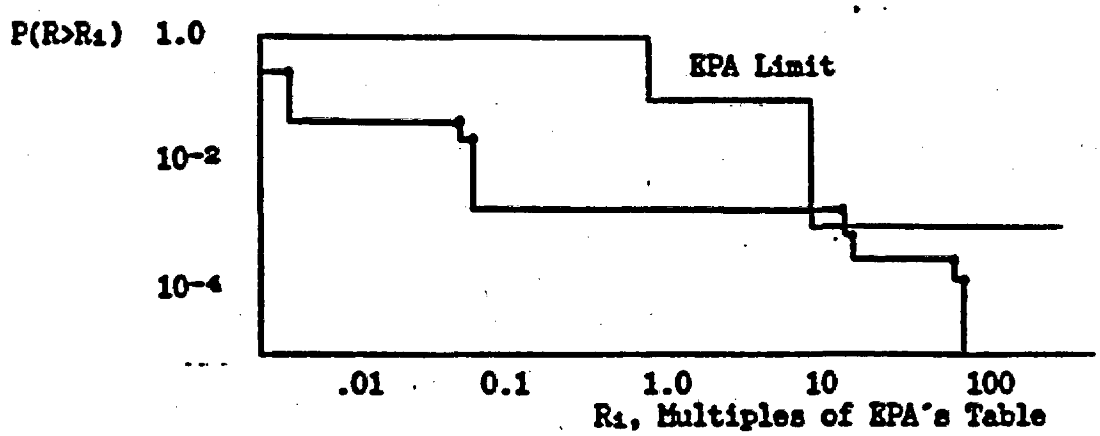

Figure 14. CCDF for Example 6, showing a violation of EPA's release limits.

It is important to emphasize that the releases from volcanism and from climate change are <u>not</u> summed when constructing a CCDF because it is not credible that both events will occur. Instead, the probabilities are summed to determine the cumulative probability that either event will occur.

Example 7 — Additional Low-Probability, High-Release Event - NRC Staff's Alternative.

This example uses the same data as Example 6 to determine whether the NRC staff's proposed alternative will identify the marginal violation of EPA's release limits illustrated in Figure 14.

Step 1 — Identify disruptive processes and events.

Same as Example 6.

Step 2 — Screen processes and events.

Same as Example 6.

Step 3 — Form scenarios.

The sixteen scenarios for this example are illustrated in Figure 15.

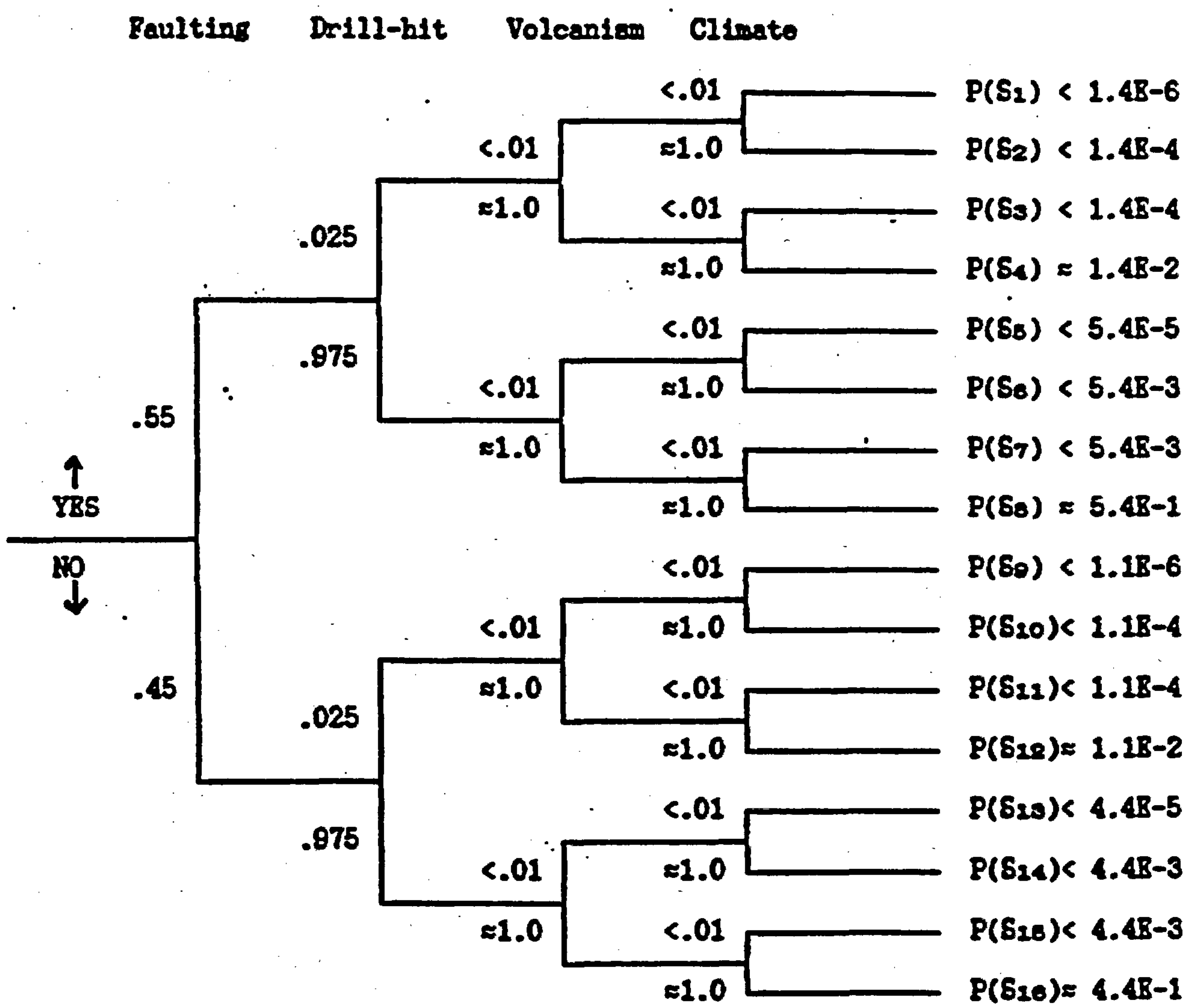

Figure 15. Scenarios for Example 7.

Step 4 -- Screen scenarios.

Scenarios S_1, S_2, S_3, S_5, S_9, S_{10}, S_{11}, and S_{13} would all be eliminated from further consideration if the screening criterion were 1E-3, but scenarios S_2, S_3, S_9, and S_{10} would be retained if the screening criterion were 1E-4. For this example, a criterion of 1E-3 is used.

Step 5 -- Estimate scenario releases.

Same as Example 6.

Step 6 -- Test releases for compliance.

The NRC staff's alternative requires that the release from each scenario be less than ten times EPA's table. Scenarios S_6 and S_{14}, which include volcanism, have higher releases. Scenarios S_7 and S_{15}, which include severe climate change, also fail to meet the criterion.

Step 7 -- Form CCDF for anticipated performance.

Since Step 6 already identified a violation, there is no need to construct a CCDF for likely release. However, Table 7 illustrates how a CCDF would be constructed using those scenarios with probabilities >.01.

Table 7. CCDF data for Example 7.

Scenario	Probability	Release	Cumulative Probability
S_4 F,D	1.4E-2	.091	1.4E-2
S_{12} D	1.1E-2	.086	2.5E-2
S_8 F	5.4E-1	.005	5.65E-1
S_{16} Undisturbed	4.4E-1	0	1.0

Plotting the data of Table 7 gives the curve of Figure 16.

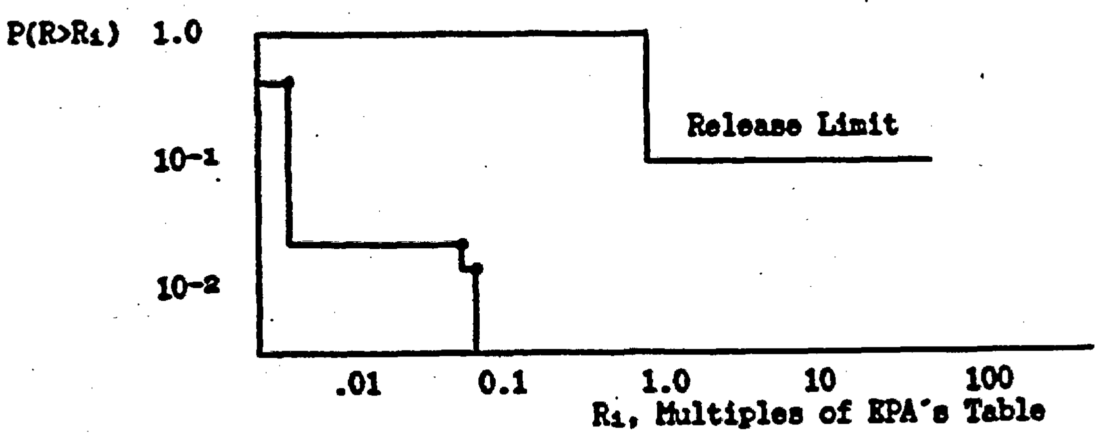

Figure 16. CCDF for Example 7.

Example 7 again shows that the NRC staff's proposed alternative is at least as stringent as EPA's 1985 standards for evaluating the acceptability of scenarios with releases exceeding ten times EPA's table of release limits. If a scenario screening criterion of 1E-4 were used, the NRC staff's alternative would be somewhat more stringent than EPA's standard because more scenarios would be retained in the analysis.

<u>Example 8 — Uncertainties in Release and Probability Estimates</u>
<u>Evaluation of Compliance with EPA's HLW Standards</u>

Examples 1 - 7 used single-valued estimates of both probabilities and releases associated with disruptive scenarios. This example first illustrates how uncertainty (or variability) in release estimates could be incorporated into an analysis of compliance with EPA's HLW standards. Then, incorporation of uncertainties in probability estimates is illustrated.

First, it should be noted that the single-valued estimates of previous examples can be displayed in CCDF format. Figure 17 represents the conditional CCDF for Scenario S_3 of Example 1.

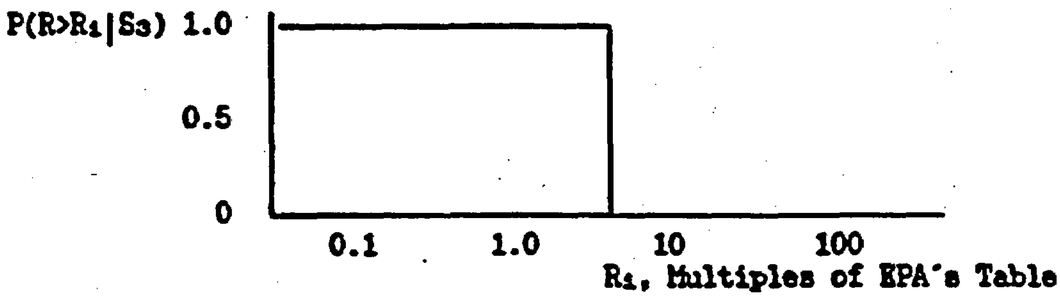

Figure 17. Conditional CCDF for Scenario S_3 of Example 1.

The contribution of each conditional CCDF to the total CCDF for a repository is then obtained by multiplying the vertical axis of Figure 17 by the scenario probability. Figure 18 gives the result for Scenario S_3 of Example 1.

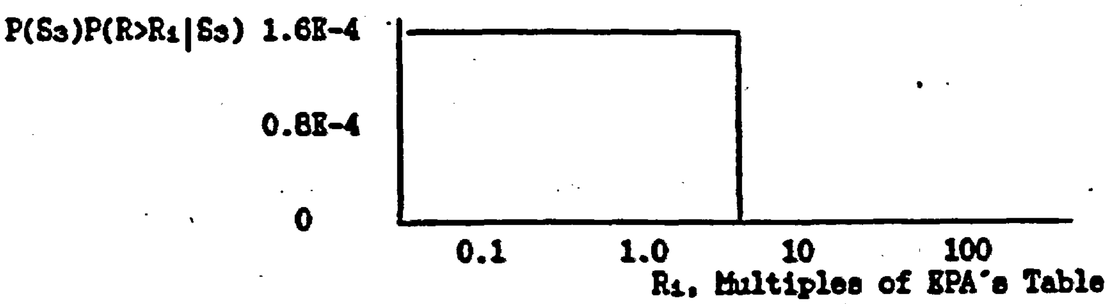

Figure 18. Probability-weighted conditional CCDF for Scenario S_3.

The overall CCDF for a repository is constructed by summing the probability-weighted conditional CCDFs for all scenarios or, conceptually, by stacking them one on top of another, as illustrated in Figure 19.

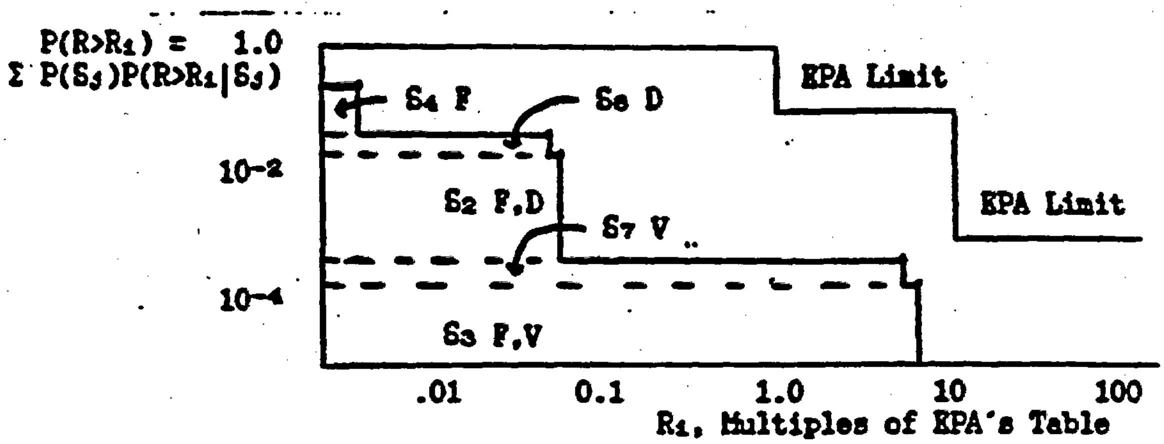

Figure 19. Overall CCDF for Example 1 Constructed by Summing Probability-Weighted Conditional CCDFs.

When conditional CCDFs include estimates of uncertainties in releases, an overall CCDF would be constructed in the same way as indicated in Figures 17 - 19. The overall CCDF for Example 1 might appear as illustrated in Figure 20.

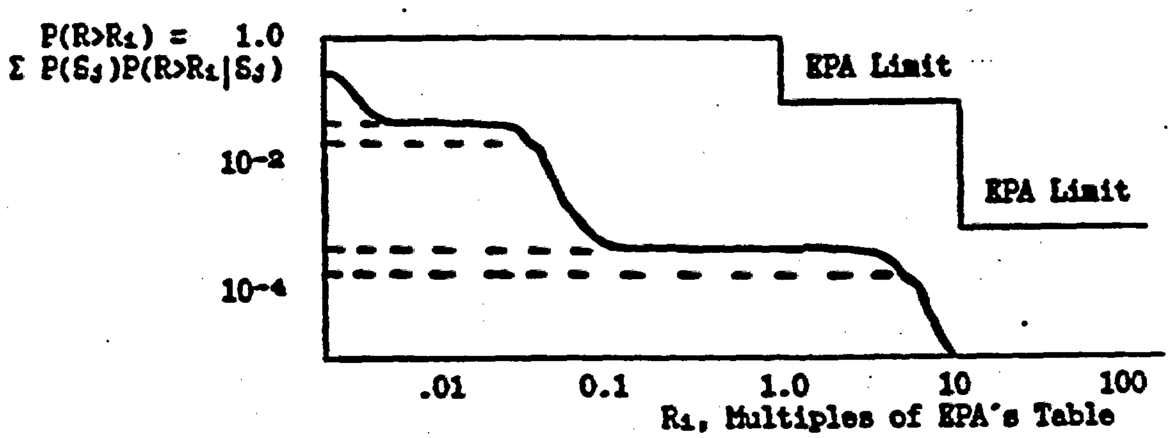

Figure 20. Overall CCDF Including Uncertainties in Releases for Example 1 Constructed by Summing Probability-Weighted Conditional CCDFs.

Uncertainties in the estimated probabilities of disruptive events can be incorporated into an analysis by applying the Monte Carlo technique to the scenario analysis. To illustrate, suppose that the probability estimates for the events of Example 1 were the following:

Table 8. Uncertainty estimates for the probabilities of the disruptive events of Example 1.

Event	Distribution	Mean	Range*
Fault Movement	Uniform	5.5E-1	4.0E-1 to 7.0E-1
Drilling (hits waste package)	Normal	2.5E-2	2.5E-1 to 2.5E-3
Volcanic Activity	Lognormal	3.0E-4	3.0E-2 to 3.0E-6

*For normal and lognormal distributions, the range is from the 5th to the 95th percentiles.

A single probability value for each event would be randomly selected from within the range for that event. The values obtained might be 4.7E-1 for fault movement, 3.3E-2 for drilling, and 5E-3 for volcanism. These values would then be used for a scenario analysis, as illustrated in Figure 21.

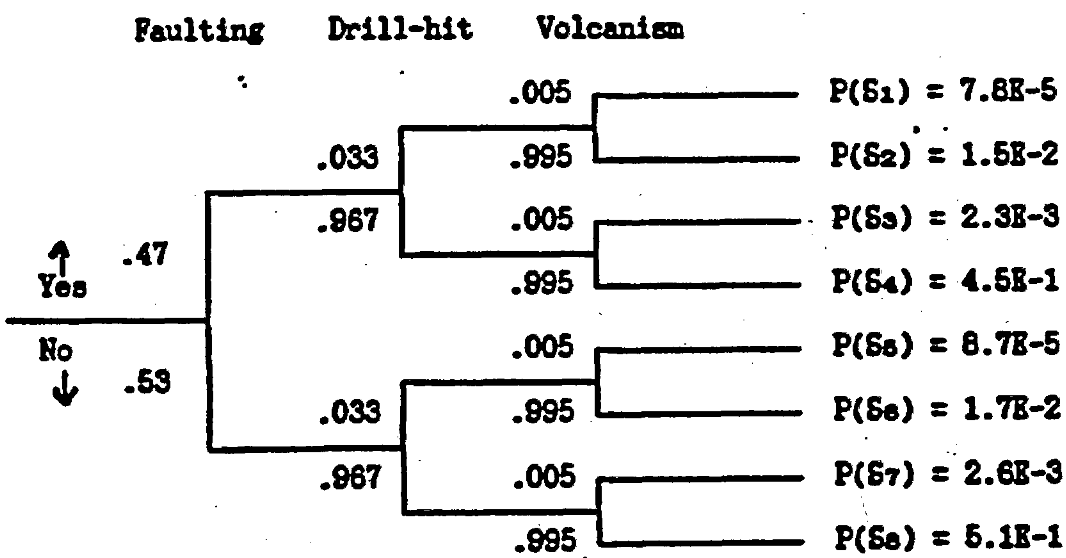

Figure 21. Scenario analysis for randomly selected probability values.

The scenario probabilities of Figure 21 would be combined with estimates of releases to produce a CCDF of the type illustrated in Figure 19 or Figure 20. Then, another set of probability values would be obtained by random sampling, another scenario analysis would be performed, and the resulting scenario probabilities would be used to construct a second CCDF. The process would be continued to produce a "family" of CCDFs of the type shown in Figure 22. The acceptability of a repository for which several CCDFs exceed EPA's release limit would need to be determined in light of the significance of the unquantifiable uncertainties not represented in the CCDFs, any conservatism in the parameters incorporated into the CCDFS, and any other information relevant to a finding of "reasonable assurance" of compliance with EPA's standards.

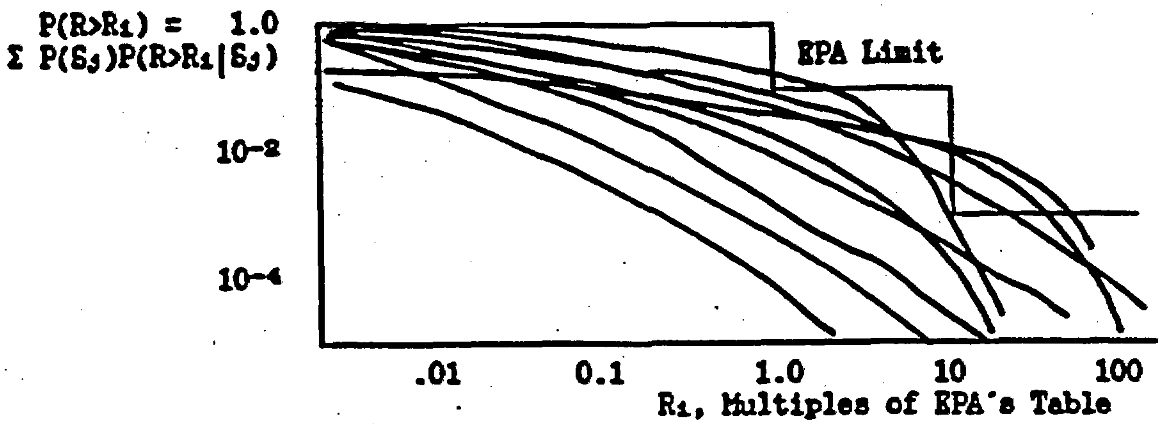

Figure 22. "Family" of CCDFs illustrating uncertainties in the probabilities of disruptive events.

Example 9 -- Uncertainties in Release Estimates - NRC Staff's Alternative.

Evaluation of compliance with the NRC staff's proposed alternative standards would involve two tests. The release estimates for relatively likely scenarios (those with probabilities >.01) would be assembled into a CCDF using the techniques illustrated in Example 8. Such a CCDF might appear as indicated in Figure 23.

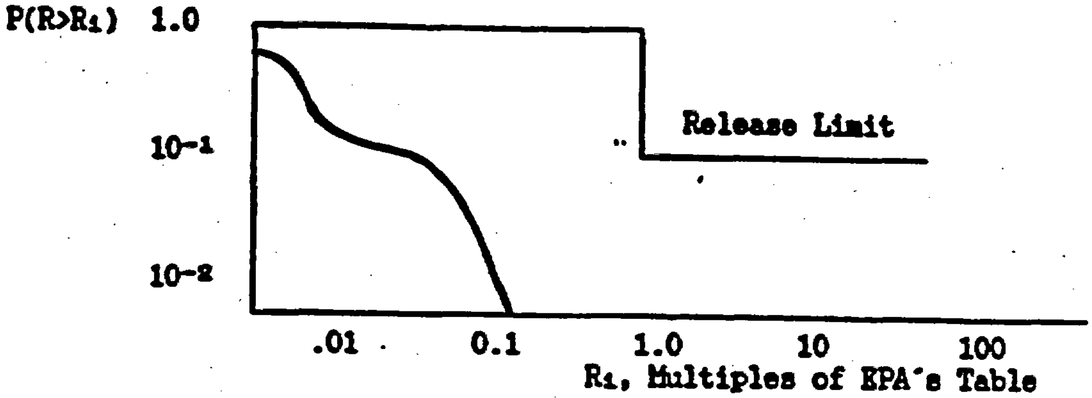

Figure 23. CCDF for likely releases, including estimates of uncertainties in releases.

If information is available about uncertainties in the probabilities of disruptive events, a "family" of CCDFs could be produced as discussed in Example 8.

The estimated release from each unlikely scenario would be compared to a consequence limit of ten times EPA's table of release limits. When uncertainties in releases are estimated, a question arises regarding the fraction of the release estimates that would be required to meet the release criterion, as illustrated by the conditional CCDFs of Figure 24.

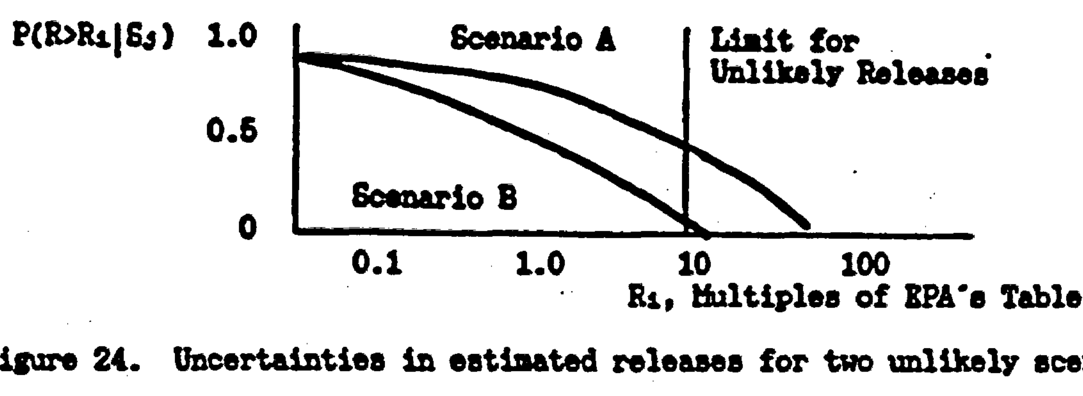

Figure 24. Uncertainties in estimated releases for two unlikely scenarios.

Decisions about the acceptability of the releases illustrated in Figure 24 would need to consider the significance of unquantifiable uncertainties not represented by the curves of Figure 24 as well as any other information relevant to a finding of "reasonable assurance" of compliance with the proposed alternative release limit. No generally applicable numerical confidence level would be specified for acceptance or rejection of curves such as those of Figure 22.

4. SUMMARY

The example calculations presented here illustrate how an applicant might demonstrate compliance with the 1985 EPA standards and with the NRC staff's proposed alternative. For these examples, the two standards are of identical stringency when a scenario screening criterion of 1E-3 is used for the NRC staff's alternative and when 1E-4 is used for EPA's standards. If a screening criterion of 1E-4 were used for both standards, the NRC staff's alternative would be somewhat more stringent because it would apply to a broader range of scenarios than would EPA's 1985 standards.

The reason for the increased stringency of the NRC staff's alternative when using a screening criterion of 1E-4 is the use of bounding (<.01) probability estimates for unlikely processes and events. The bounding probability estimates in these examples are more than ten times higher than the "true" probability values. Therefore, use of a screening criterion of 1E-4 tends to retain scenarios in an analysis that would be eliminated if more precise probability estimates were available. Use of a screening criterion of 1E-3 tends to offset the conservatism imposed by the bounding probability estimates.

It should be noted that differences in the two alternatives are probably more theoretical than real. Probabilities in the range of 1E-3 to 1E-4 (over 10,000 years) are very difficult to project with any real accuracy. Therefore, it will seldom be possible to produce probability estimates of the precision suggested in these examples. Indeed, that is the reason for the NRC staff's proposed alternative -- to allow a meaningful regulatory examination of unlikely disruptive scenarios while avoiding the difficulties involved in trying to predict the probabilities of unlikely processes and events. If any numerical screening criterion is to be specified by EPA, the regulatory language should reflect the lack of precision expected for probability estimates. A criterion to eliminate scenarios with probabilities "on the order of 1E-3 or less" would be preferable to specification of an unqualified number.