ENCLOSURE

# SUMMARY OF THE NRC/DOE TECHNICAL EXCHANGE ON NRC'S "THREE-BUCKET APPROACH" FOR THE IMPLEMENTATION OF 40 CFR PART 191

July 22, 1992
Bethesda, Maryland

On July 22, 1992, the Nuclear Regulatory Commission and the U.S. Department of Energy (DOE) conducted a technical exchange to discuss the use of NRC's so-called "three bucket approach" for the implementation of 40 CFR Part 191 -- the U.S. Environmental Protection Agency's (EPA's) radiation protection standard for high-level radioactive waste (HLW). Representatives from the State of Nevada; Nye County, Nevada; EPA; the Nuclear Waste Technical Review Board; and DOE program participants also attended the technical exchange. The agenda is attachment 1; attachment 2 is the list of attendees.

The technical exchange consisted of NRC and DOE providing a discussion and demonstration of the use of the alternative approach by using trial examples for the implementation of EPA's standard. The discussions and demonstrations focused on clarification, implementation, equivalency, and stringency of NRC's alternative. Each presentation was accompanied by questions and discussions.

The first series of presentations were made by NRC. In its opening presentation, D. Fehringer discussed the NRC staff's alternative approach to the implementation of the EPA HLW standard (attachment 3). His presentation began with some general background on how to conduct a performance assessment for a geologic repository (including scenario development and screening) and in doing so, calculate the complementary cumulative distribution function to demonstrate compliance with 40 CFR Part 191. In his second presentation, D. Fehringer discussed NRC's proposed alternative approach to demonstrate compliance with 40 CFR Part 191 using the so-called "three-bucket" approach (see attachment 4) along with examples of how the NRC staff would treat the uncertainties in scenario screening (see attachment 5). It was noted that the principal advantage to NRC's alternative is that it would not require precise probability estimates for unlikely processes and events.

Following the NRC presentation, M. Wilson of DOE (Sandia National Laboratories (SNL)) provided an analysis of NRC's "three-bucket" approach that compared and contrasted NRC's alternative with the original 1985 EPA standard. As part of its analysis, DOE noted some concerns with NRC's proposed approach (see attachment 6), suggesting that it could be more stringent than the original 1985 standard and that DOE would need additional guidance on how to identify and screen scenarios before it could implement the proposed alternative.

In concluding its presentations, DOE expressed doubts about the desirability of the NRC alternative approach and noted that it was concerned that it might have to pursue two approaches -- both EPA's and NRC's. However, DOE noted that it would study NRC's proposal in further detail before reaching any final

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decision. DOE noted that it expected to reach a conclusion regarding the alternative approach by August 10, 1992, as part of a larger response to EPA on its draft standard.

The State of Nevada; Nye County, Nevada; and EPA were invited to present their respective comments, if any, at the technical exchange; however, all declined to comment.

At the closing of the technical exchange, DOE reported that SNL had completed and published its report of a total system performance assessment for a geologic repository at Yucca Mountain, Nevada, and that a subsequent report of parallel efforts by Pacific Northwest Laboratory would be released near the end of the fiscal year.

9.3.92

Michael P. Lee
Repository Licensing and Quality Assurance Project Directorate
Division of High-Level Waste Management
Office of Nuclear Material Safety and Safeguards
Nuclear Regulatory Commission

9/4/92

Priscilla Bunton
Regulatory Integration Branch
Office of Systems and Compliance
Office of Civilian Radioactive Waste Management
U.S. Department of Energy

ATTACHMENT 1

# AGENDA
# NRC/DOE TECHNICAL EXCHANGE ON NRC'S "THREE-BUCKET APPROACH" FOR THE IMPLEMENTATION OF 40 CFR PART 191

July 22, 1992

Phillips Building, Room P-110
Bethesda, Maryland

| *AGENDA ITEM* | | *DISCUSSION LEAD* |
|---|---|---|
| 9:00am | Opening Remarks | NRC, DOE, State |
| 9:15am | Proposed Three-Bucket Concept | NRC |
| | - Follow-up Discussion by NRC and DOE | |
| 10:45am | Examples of Compliance Demonstration with the 40 CFR Part 191 Containment Requirement | |
| | - NRC Example Including Treatment of Uncertainties | NRC |
| | - DOE Example | DOE |
| **LUNCH** | | |
| 1:30pm | Open Discussion | All |
| 2:30pm | Closing Remarks | All |

ATTACHMENT 2

# ATTENDEES AT THE JULY 22, 1992, NRC/DOE TECHNICAL EXCHANGE ON NRC'S "THREE-BUCKET APPROACH" FOR THE IMPLEMENTATION OF 40 CFR PART 191

**DOE**
P. Bunton
J. Boak
D. Valentine
S. Borg
T. Bjerstedt

**SNL**[1]
F. Bingham
H. Dockery
M. Wilson
T. Blejwas

**TESS**[3]
S. LeRoy
S. Pahwa
P. Krishna
M. Lugo
J. Dameron

**Weston**
J. York
R. Palabrica
J. Docka
H. Minwalla

**NRC**
D. Fehringer
N. Eisenberg
D. Brooks
A-B Ibrahim
J. Kotra
D. Loosely
P. Justus
M. Lee
R. Neel
J. Randall
J. Youngblood
M. Federline

**CNWRA**[4]
R. Baca

**ACNW**[6]
H. Larson
L. Deering

**SRA Technologies**
T. Kabele

**GAO**[9]
V. Sgobba

**Nye County, Nevada**
E. Holstein
M. Mindy

**State of Nevada**
S. Frishman

**Winston and Strawn**
S. Echols

**EPA**[2]
C. Petti
W. Russo

**NWTRB**[5]
L. Reiter

**USGS**[7]
R. Wallace

**PNL**[8]
P. Eslinger

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1 Sandia National Laboratories

2 U.S. Environmental Protection Agency

3 TRW Environmental Safety Systems

4 Center for Nuclear Waste Regulatory Analyses

5 Nuclear Waste Technical Review Board

6 Advisory Committee on Nuclear Waste

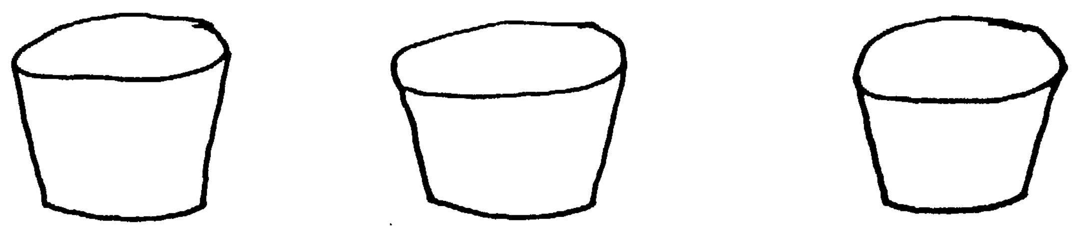
7 U.S. Geological Survey

8 Pacific Northwest Laboratory

9 General Accounting Office

ATTACHMENT 3

# The NRC Staff's Proposed Alternative for Implementing EPA's HLW Standards



Likely Unlikely Very Unlikely

# EPA HLW Standards - Requirements

Containment Requirement

- Limits total activity released over 10,000 years
- Stated probabilistically

Individual Protection Requirement

Groundwater Protection Requirement

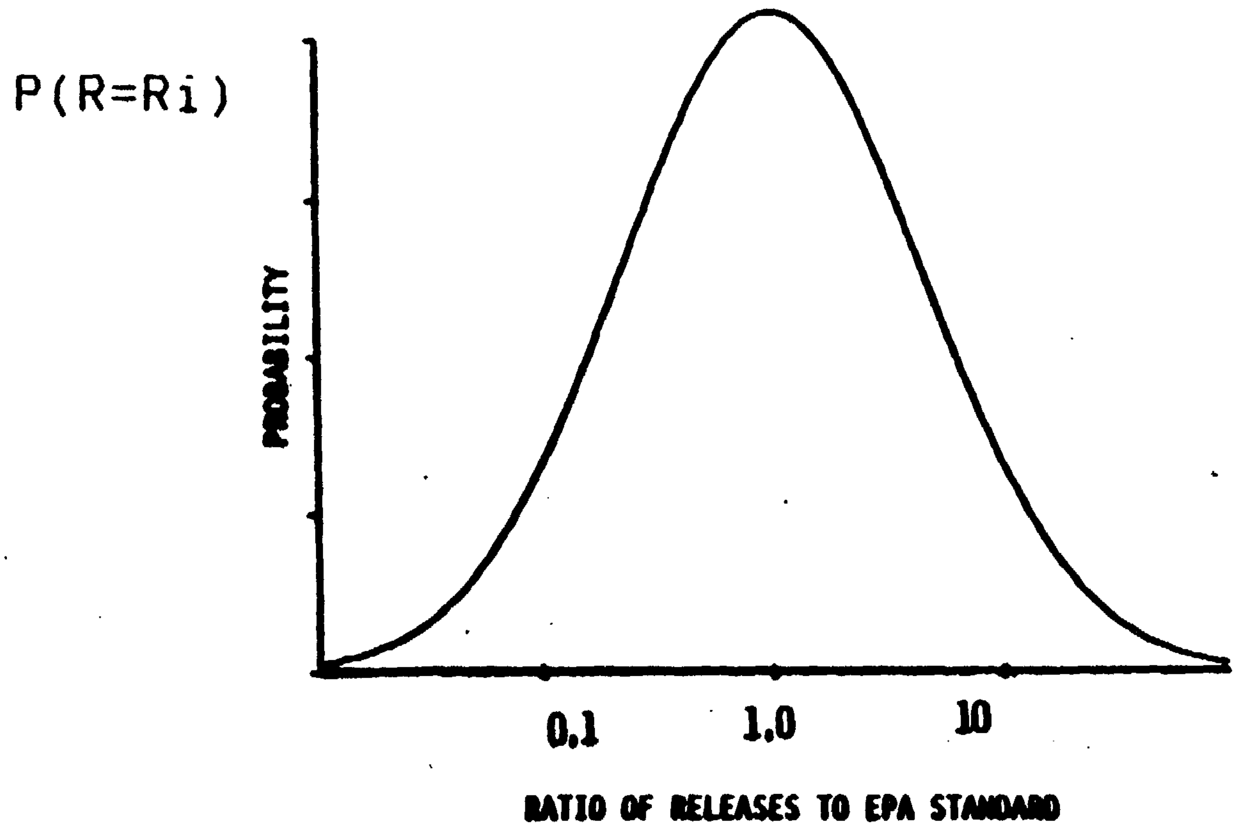
# EPA CONTAINMENT REQUIREMENT

| RADIONUCLIDE | RELEASE LIMIT (CURIES) OVER 10,000 YEARS PER 1000 MTHM OF WASTE |
|---|---|
| C-14 or I-129 | 100 |
| Tc-99 | 10,000 |
| Th-230 or 232 | 10 |
| Any other alpha-emitter | 100 |
| Any other beta-emitter | 1,000 |

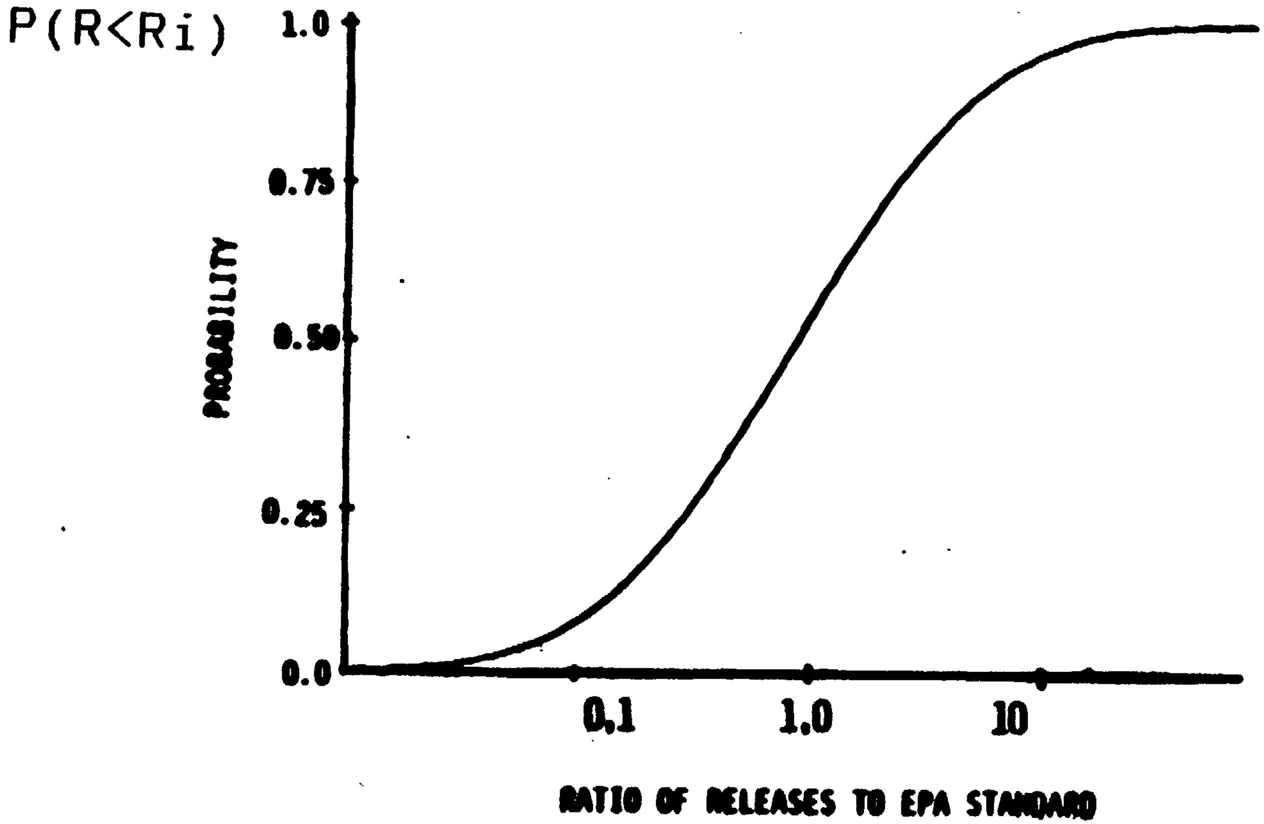
SUM-OF-FRACTIONS RULE: IF MORE THAN ONE NUCLIDE IS RELEASED, THE ACTIVITY OF EACH IS TO BE DIVIDED BY ITS RELEASE LIMIT, AND THE FRACTIONS ARE TO BE SUMMED.

PROBABILISTIC NATURE: RELEASES MORE LIKELY THAN 1/10 IN 10,000 YEARS SHALL NOT EXCEED THE RELEASE LIMIT ABOVE.

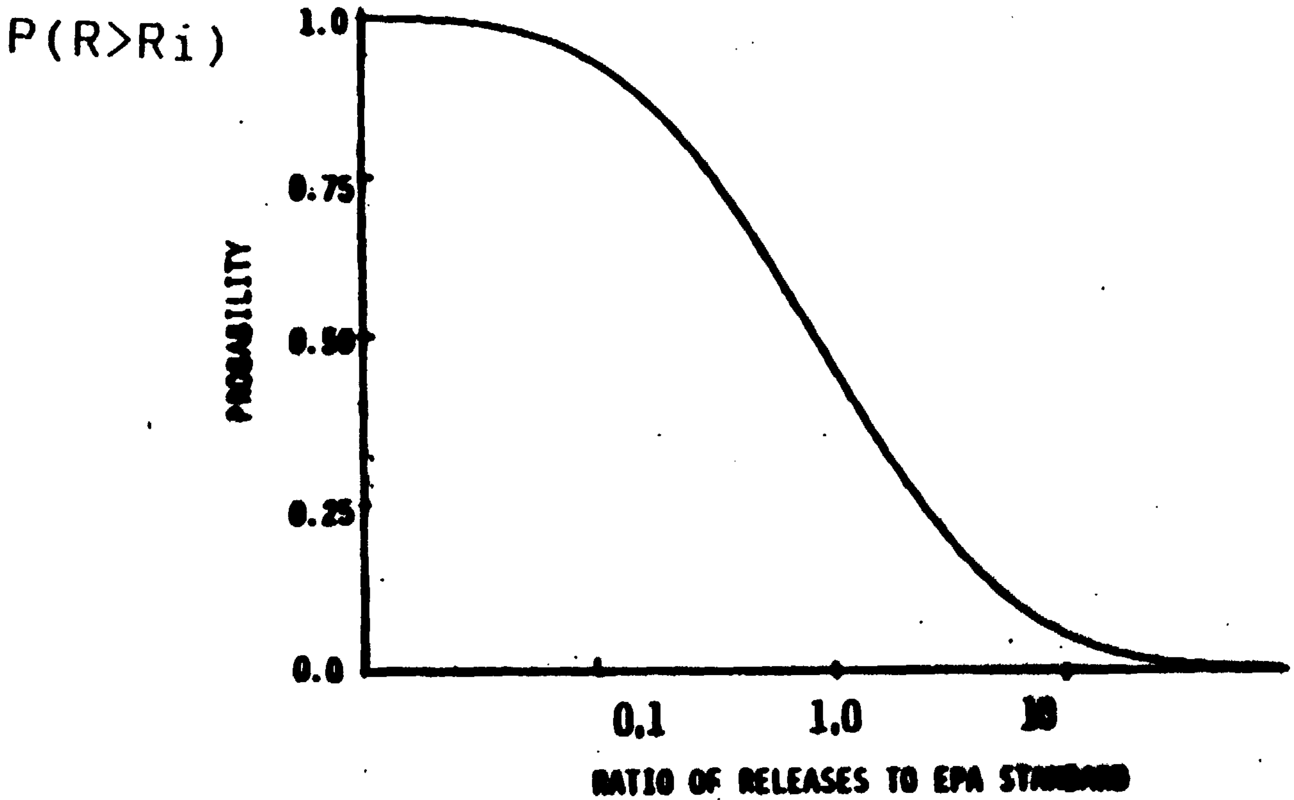
RELEASES MORE LIKELY THAN 1/1000 IN 10,000 YEARS SHALL NOT EXCEED TEN TIMES THIS RELEASE LIMIT.



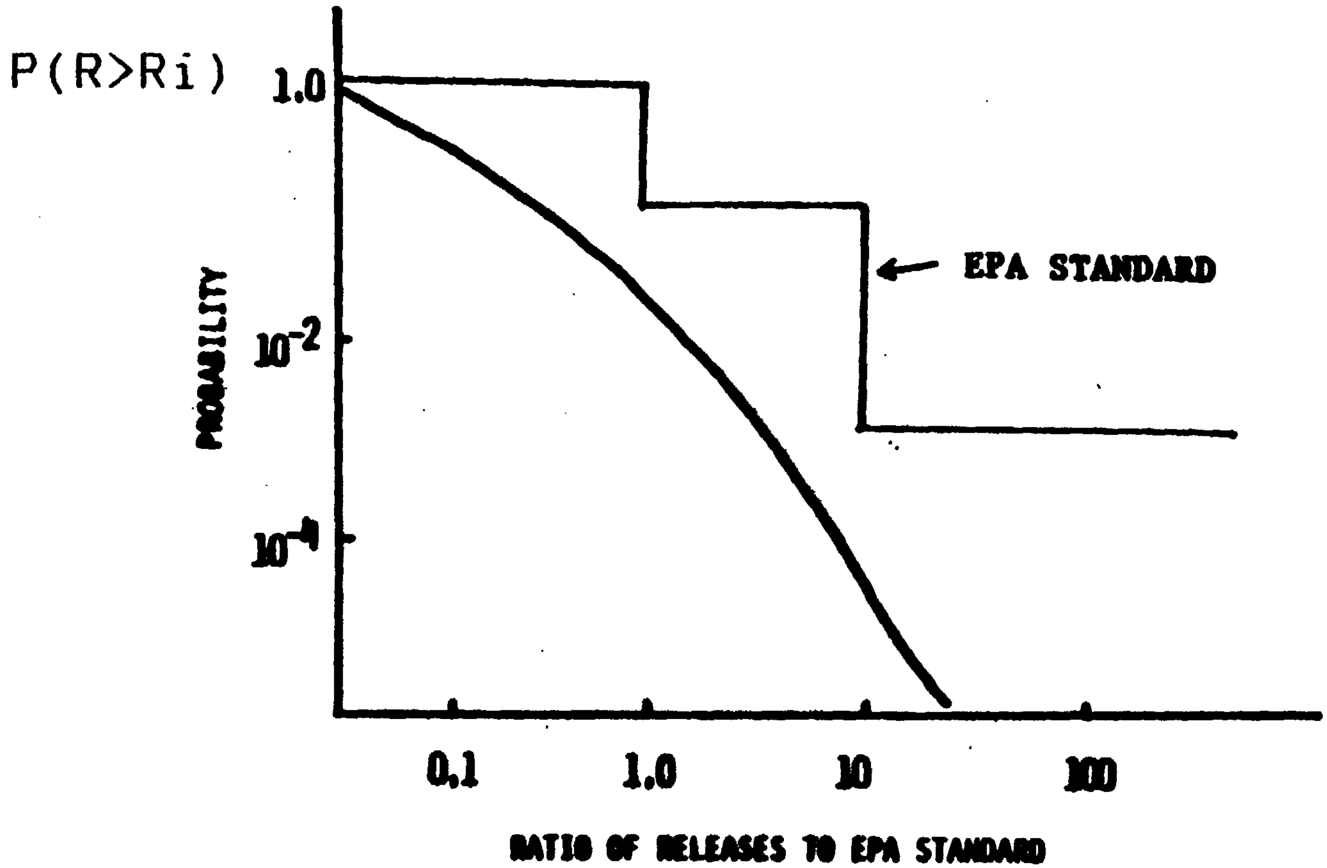

Example of a Probability Density Function




Example of a Cumulative Distribution Function




Example of a Complementary Cumulative Distribution Function.


P(R>Ri)
1.0
$10^{-2}$
$10^{-4}$
PROBABILITY
EPA STANDARD
0.1
1.0
10
100
RATIO OF RELEASES TO EPA STANDARD

# NRC 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).

ATTACHMENT 4

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

JUL 1 1992

J. William Gunter, Director
Criteria and Standards Division, ANR-460
Office of Radiation Programs
U.S. Environmental Protection Agency
Washington, D.C. 20460

Dear Mr. Gunter:

Thank you for the opportunity to review early draft reports of several technical analyses performed for you by the U.S. Department of Energy (DOE) as support for your high-level waste standards. Because of the preliminary nature of these analyses and DOE's obvious intent to continue working on them, we are providing only an informal review at this time as you requested. Enclosed are preliminary NRC staff comments on these early draft reports.

Sincerely,

B. J. Youngblood, Director
Division of High-Level Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure:
As stated

cc: John Roberts, DOE

## Preliminary NRC Staff Comments on Draft DOE Technical Analyses

<u>Human Intrusion</u> The NRC staff has no objection to the general concept proposed by DOE -- i.e., qualitative evaluation of the potential for, and the consequences of, intrusion (and, presumably, other types of human-initiated releases). In our view, the analyses of natural resources required by our own regulation would be quite similar. We note, however, that DOE's proposed text for 40 CFR Part 191 would not constitute an environmental standard since it would not contain "limits on radiation exposures or levels, or concentrations or quantities of radioactive material, in the general environment . . ." Accordingly, if EPA chooses to adopt DOE's recommendation, DOE's text should be incorporated as a non-binding assurance requirement, rather than as part of the containment requirements.

If EPA chooses to adopt DOE's recommendation, EPA might also wish to consider whether adjustments would be needed in the table of release limits of the standards. EPA's release limits were originally intended to apply to all releases from both natural and human-initiated disruptions. If human-initiated releases are to receive a separate, qualitative evaluation, some degree of reduction in the release limits might be appropriate.

<u>Three-Bucket Approach</u> Evaluating the safety of an HLW repository involves projecting its waste isolation capability within an environment that will evolve in an uncertain manner. Because we cannot predict with certainty what the future environmental conditions will be, we must postulate several future conditions that are representative of the full range of conceivable environmental conditions. It is neither possible nor necessary to foresee and evaluate all possible futures. Rather, the "reasonable assurance" (or "reasonable expectation") test of repository licensing requires only that a set of potential future conditions be identified that is reasonably representative of the full range of possible futures.

A convenient way to evaluate possible future environmental conditions for a repository is through use of a scenario analysis in which each "scenario" represents one possible set of future environmental conditions. For example, one scenario might include no disruptive environmental conditions, a second might consist of human intrusion into a repository, fault movement might constitute a third scenario, and the combination of fault movement and human intrusion might be a fourth scenario. As illustrated in the December 3, 1991, letter from Robert M. Bernero to Margo Oge, it is possible to define <u>mutually exclusive</u> scenarios using a technique similar to the event tree method used in probabilistic risk analysis. Defining scenarios to be mutually exclusive is a key concept in understanding the NRC staff's proposed alternative wording for EPA's containment requirements.

EPA's 1985 containment requirements contained two relevant criteria: (1) there must be less than one chance in ten that the cumulative release of radioactive material will exceed EPA's table of release limits, and (2) there must be less than one chance in one thousand that the cumulative release will exceed ten times EPA's table. In addition, EPA's "Guidance for Implementation" suggested that "categories of events or processes" with less than one chance in ten thousand need not be considered when evaluating compliance with the containment requirements. EPA's guidance also suggested that an assessment of repository performance should produce a "complementary cumulative distribution function" (CCDF) indicating the probability of exceeding various levels of cumulative release. Construction of a CCDF would require estimation of the sizes of potential releases and of the probabilities with which those releases are expected to occur.

One effect of EPA's 1985 standards was to limit the size of the permissible release from any credible release scenario to ten times EPA's table. This limit applied to all scenarios, regardless of likelihood, provided the scenario has a probability greater than about $10^{-3}$ to $10^{-4}$. (The exact threshold would depend on the number of scenarios with probabilities in this range.) Importantly, if an applicant could demonstrate that all credible, mutually exclusive scenarios have releases less than ten times EPA's table of release limits, that alone would suffice to demonstrate compliance with the second part of EPA's containment requirements (less than one chance in one thousand that the cumulative release will exceed ten times EPA's table). However, the wording of EPA's 1985 standards also required estimation of the probabilities of unlikely scenarios as well as estimation of the sizes of the releases. Since probabilities on the order of $10^{-3}$ over 10,000 years will be highly uncertain and contentious, and since they are not needed to ensure that any credible release will be less than ten times EPA's table of release limits, the NRC staff developed alternative language for EPA's standards that would eliminate the need for such probability estimates.

The NRC staff's proposed alternative mimicked EPA's 1985 language, making only the minimal changes needed to substitute a deterministic release limit applicable to all scenarios for EPA's probabilistic limit for unlikely releases. In retrospect, it appears that many misunderstandings of the NRC staff's proposal would have been avoided if substantially different language had been suggested. The following regulatory text might better describe the NRC staff's concept.

191.01 <u>Definitions</u>

*　　　*　　　*

"Scenario" means a hypothetical future set of repository environmental conditions including any sequence of potentially disruptive processes and events that is sufficiently credible to warrant consideration.

*　　　*　　　*

191.12a <u>Consequence limit</u>

Disposal systems for radioactive waste shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, the release of radionuclides caused by any scenario will not exceed ten times the quantity calculated according to Table 1 (Appendix A).

191.12b <u>Containment requirement</u>

Disposal systems for radioactive waste shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, there will be at least a 90 percent likelihood that the cumulative release of radionuclides to the accessible environment will not exceed the quantity calculated according to Table 1 (Appendix A).

DOE identifies a number of questions which DOE asserts must be answered before DOE can evaluate the merit of the three-bucket approach. The NRC staff's views on each of these questions is presented below.

-How to determine unambiguously the bucket into which each sequence of events and processes falls. In the NRC staff's view, there would be no need to assign scenarios to "buckets" based on the likelihoods of the scenarios. The NRC staff's proposed alternative would apply two separate criteria to projected repository performance. First, no credible sequence of processes and events (scenario) could cause a projected release greater than ten times EPA's table of release limits. This limit would apply to each scenario, regardless of probability, provided the scenario is "sufficiently credible to warrant consideration." The second criterion would require that there be at least a 90 percent likelihood that the cumulative release, from all credible scenarios, would be less than EPA's table of release limits. When evaluating compliance with this criterion, scenarios would need to be included only to the extent necessary to demonstrate compliance. If, for example, three scenarios have probabilities of 0.5, 0.39 and 0.01, and if the projected release for each scenario is less than EPA's table, compliance would have been demonstrated without need to evaluate any other scenarios, regardless of likelihood.

-The meanings of certain terms used in the statements of the approach (e.g., "sequences," "anticipated," "sufficiently credible to warrant consideration," "scenario"). "Sequence" would have its plain English meaning. If the order in which processes or events occur within a sequence is important for a performance assessment, two options would be available: define separate scenarios for each order, or use the worst (highest release) order as an approximation of all orders containing the same processes and events. As a practical matter, the latter option will need to be used in most cases if the number of scenarios is to be kept manageable.

"Anticipated" was used in the NRC staff's original proposal, but editing of the staff's comments caused the word to lose all meaning. As indicated in the revised wording above, the term is not necessary, and its use in the previous proposal should be ignored.

"Sufficiently credible to warrant consideration" would have the meaning intended by EPA in its 1985 standards, i.e., scenario probabilities on the order of $10^{-3}$ to $10^{-4}$ over 10,000 years. EPA's 1985 standards referred to the release probability (sum of scenario probabilities) in the containment requirements, but seemed to refer to scenario probabilities in EPA's implementation guidance. Therefore, it is impossible to make a direct numerical translation from EPA's 1985 standards to the NRC staff's proposed alternative. In any case, the NRC staff considers it more appropriate to state the concept qualitatively, and to provide numerical guidance in a format (e.g., a Regulatory Guide) that allows some flexibility in application. The important point is that no change is intended in the scope of analyses that would have been required by EPA's 1985 standards.

"Scenario" would be defined as suggested above.

-<u>The logical consistency of comparing incomplete CCDFs to limits originally established for a complete CCDF</u>. When demonstrating compliance with regulatory requirements, a demonstration of compliance must be sufficiently complete to show compliance, but need not be complete in any absolute sense. Even with EPA's 1985 standards, there would have been no need to develop a "complete CCDF." EPA's 1985 standards required only "less than one chance in ten" of exceeding EPA's table, and "less than one chance in one thousand" of exceeding ten times the table. DOE could have demonstrated compliance without constructing a CCDF at all by merely showing that the projected release from each <u>mutually exclusive</u> scenario would be less than EPA's table. Even if that were not possible (if releases from some scenarios were greater than one), a "complete CCDF" would not be necessary. In fact, EPA's own guidance recognized this by acknowledging that scenarios with probabilities less than one in ten thousand could be ignored, and when EPA noted that "performance assessments need not evaluate in detail the releases from all events and processes."

-<u>The uncertainty in knowing how much more restrictive the "three-bucket approach" is, when compared with the original standard</u>. In the December 3, 1991 letter from Robert M. Bernero to Margo Oge, the NRC staff demonstrated the basis for its belief that its proposed alternative would be no more and no less stringent than EPA's 1985 standards.

-<u>Whether the determinations of probabilities must be more accurate, or less accurate, than those required for showing compliance with the original standard</u>. The NRC staff's alternative would require significantly less precision for probability estimates for most "unlikely" scenarios since those scenarios would not need to be included in a CCDF. If the consequence of an "unlikely" scenario were greater than 10X EPA's table, it would only be necessary to demonstrate that the scenario is not "sufficiently credible to warrant consideration." (If the consequence is less than 10X EPA's table, no probability estimate would be needed at all.) For "likely" scenarios, i.e., those that significantly influence the overall probability of exceeding 1X EPA's table, there would be no difference between the two concepts.

-<u>Whether the probability limits for the buckets take parameter variabilities into account</u>. As noted in the response to DOE's first "question," the NRC staff's alternative does not define "buckets" into which scenarios must be placed. The staff's alternative establishes a deterministic release limit (ten times EPA's table) which applies to all credible scenarios, regardless of scenario probability. An additional, probabilistic requirement would also be applied to the more likely scenarios -- i.e., at least a 90 percent likelihood that the projected release would be less than EPA's table. DOE's demonstration of compliance with the latter requirement would need to include as many scenarios as necessary to demonstrate a likelihood of at least 90 percent.

DOE's question may indicate a different concern -- i.e., treatment of uncertainties in release estimates when evaluating compliance with the deterministic release limit (ten times EPA's table). The NRC staff recognizes that any estimate of release will be uncertain, and that only a relative few of the sources of uncertainty can be quantified with any precision. The NRC's regulations accommodate such uncertainties, both those that can be quantified and those that cannot, by requiring a demonstration of "reasonable assurance" of compliance. EPA's standards use a similar term, "reasonable expectation," for the same purpose. In the NRC staff's view, the "reasonable assurance" concept will allow an appropriate regulatory evaluation of the uncertainties in DOE's demonstrations of compliance with EPA's standards, whether those standards adopt the staff's proposal or retain EPA's 1985 language.

In summary, DOE's analysis of the NRC staff's proposal indicates no reason to change the fundamental concepts originally proposed. The revised wording suggested above may prove easier to understand since it more clearly articulates the concepts of a scenario-based analysis of repository performance, and it more clearly imposes two separate regulatory criteria on repository performance. Also, formulating the containment requirement in CDF, rather than CCDF, language might help observers to better understand this alternative. In particular, "completeness" of an analysis is not required. It is only necessary to include a sufficient number of scenarios to demonstrate the required 90 percent likelihood that releases will be less than EPA's table. Once that level of likelihood has been demonstrated, incorporation of additional scenarios into a CDF would not be necessary.

Multimode Release Limits The NRC staff has no strong objection to the general concept of using different tables of release limits for evaluation of releases to different points in the environment. In fact, it may be an attractive compromise between the simplicity of the single table of EPA's 1985 standards and the desire for greater realism evident in DOE's suggestion for use of a limit on collective doses resulting from releases. The multiple table approach would eliminate some of the potential conservatism inherent in EPA's 1985 standards while avoiding the significant difficulties inherent in projections of collective doses over long time periods. The NRC staff notes, however, that additional explanation will be needed regarding application of multiple tables of release limits. Some releases may enter more than one environmental compartment, as when a release to the land surface is transported to a river through erosion, and then to the ocean. EPA will need to explain whether such pathways were considered when deriving the tables of release limits, or whether pathway modeling is to be done on a site-specific basis when implementing the standards.

The NRC staff anticipates substantial difficulty in implementing DOE's "point of compliance" concept for evaluating potential releases. The effect of this concept would be to treat portions of the environment as "barriers" to release of wastes. The NRC staff objects to this concept since it may be difficult for DOE to exercise effective, long-term control over any portion of the environment outside of the controlled area. Of greatest concern is DOE's suggestion that releases to groundwater be ignored except to the extent that radionuclides are projected to be withdrawn through a well. Projecting the locations of wells and the amount of water withdrawn from them for 10,000 years after disposal may prove to be as difficult as projecting population sizes and locations for collective dose estimates. The NRC staff recommends that EPA reject DOE's "point of compliance" concept and, instead, retain the "accessible environment" definition used in the 1985 standards.

The NRC staff objects to DOE's proposed use of "site adjustment factors." DOE states that "[EPA] assumed, in deriving the release limits for the river and well releases . . . that the entire drainage system of all rivers . . . and all aquifers . . . are contaminated by the released radionuclides." The NRC staff questions both the accuracy of this statement and its relevance. In EPA's environmental transport model, EPA estimated collective impacts by determining the fraction of released radionuclides that would enter various pathways leading to humans. The concentrations of these radionuclides were not determined and were, in fact, irrelevant since individual impacts were not estimated. In EPA's model, potential releases would be transported by groundwater to a river. Then, withdrawals of water from the river for irrigation and for drinking water use would cause 10% of released radionuclides to enter food pathways and would cause 0.013% to be directly ingested with drinking water. In EPA's model, these fractions are not sensitive to the size of the river or to the location of discharge of contaminated groundwater. DOE's suggested use of "site adjustment factors" appears to be an attempt to estimate the likelihood that any individual person would be affected by a repository release. Since EPA's containment requirements are based on collective, rather than individual, risk, DOE's "site adjustment factors" seem to be inappropriate, and the NRC staff recommends that EPA not incorporate them into the standards.

The NRC staff would not consider it advisable to use duplicate tables of release limits for traditional and SI units of radioactivity. A single table, perhaps with a footnote indicating the conversion factor for the alternate system of units, should be sufficient.

Collective Dose The NRC staff has no objection to a collective dose formulation for EPA's standards, provided that such a formulation is accompanied by specification of a "standard biosphere," much like that suggested by DOE. As noted above, however, multiple tables of release limits may prove to be a more workable way to remove some of the potential conservatism inherent in EPA's 1985 standards while avoiding the problems inherent in projecting collective doses over long periods of time.

The NRC staff does not recommend that EPA allow the option of selecting from a suite of alternative standards (release limits or collective dose). The complexity of such standards, as well as the appearance of allowing the applicant to select the least stringent standards for a particular repository, would both be serious drawbacks to the alternative standards concept proposed by DOE. Instead, EPA should select a single, preferred formulation of its standards, and require compliance with those standards for all repositories.

TRU Waste Equivalency Unit The NRC staff has previously stated its view that the technical achievability basis underlying EPA's standards should be supplemented by comparisons with other radiation protection standards and other accepted risks. Using technical achievability alone, it is not clear that EPA can develop any defensible basis for a TRU waste equivalency unit, since EPA has not evaluated the waste isolation capabilities of conceptual TRU waste disposal facilities.

Assuming that EPA adopts our previous recommendation for supporting the standards, the NRC staff wishes to voice its support for the general concept presented, at different times, by Neil Numark (EPA contractor), Jim Channell (New Mexico EEG), and Bill Russo (EPA staff). Using this approach, equivalent units of waste would be derived by considering both the half-lives of the radionuclides present in different types of wastes and the "environmental dose conversion factors" for those radionuclides. In effect, this approach would consider two units of waste to be equivalent if release to the environment of the average activity present during 10,000 years would cause an equivalent number of health effects.

Uncertainty Propagation The NRC staff has previously expressed its reservations about any requirement to project repository impacts longer than 10,000 years. We continue to believe that such projections would be highly uncertain, and would not likely provide a firm basis for judging the acceptability of a repository.

DOE argues that the time period for application of the individual and groundwater protection standards should be maintained at 1,000 years, rather than extending it to 10,000 years. In our view, DOE has not provided convincing justification for its recommendation. We see no reason why projections of individual doses or of groundwater contamination levels should be significantly more difficult than projections of cumulative releases. If cumulative releases can be projected for 10,000 years, it seems that the other measures of impact could be projected for that period of time also.

Carbon-14 DOE's presentation of the "carbon-14 issue" appears to the NRC staff to be one-sided and misleading. DOE correctly notes that potential gaseous releases from an unsaturated zone repository would be rapidly diluted to concentrations so low that individual impacts would be only a very small percentage of natural background radiation levels. However, DOE fails to mention that collective impacts from such releases could be substantial. Suppose, for example, that the 10,000-year release of carbon-14 would be 8,000 curies, as estimated in DOE's presentation. It is well known that the projected global collective dose commitment is about 400-500 person-rem per curie. Thus, 3 to 4 million person-rem would result from an 8,000 curie carbon-14 release. If these person-rem were valued at $1,000 each, as suggested in the NRC's regulations for nuclear power plants, the U.S. should be willing to pay as much as 3 to 4 billion dollars to prevent such a release. Coincidentally, DOE's estimate of the cost to prevent release of carbon-14 falls within this range.

The collective dose estimate of the preceding paragraph raises a fundamental question which the NRC staff urges EPA to face head-on. That question is whether a collective dose estimate composed of tiny doses over thousands of years to billions of people is a meaningful basis for standard-setting. In the NRC staff's view, it is not. Uncertainties regarding the health risks of tiny doses are so great as to make this type of collective dose estimate virtually meaningless. In addition, the long times over which doses would be incurred raises questions about a possible need to discount either the doses projected or the value of current expenditures for prevention of future doses. As EPA is well aware, discounting is a subject whose philolophical basis has uncertainties at least as large as the uncertainties about the health significance of the dose estimates. Thus, the NRC staff urges EPA to accept DOE's proposal, even though the staff does not completely agree with DOE's rationale.

# 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 <u>The Repository System and its Environment</u>.

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

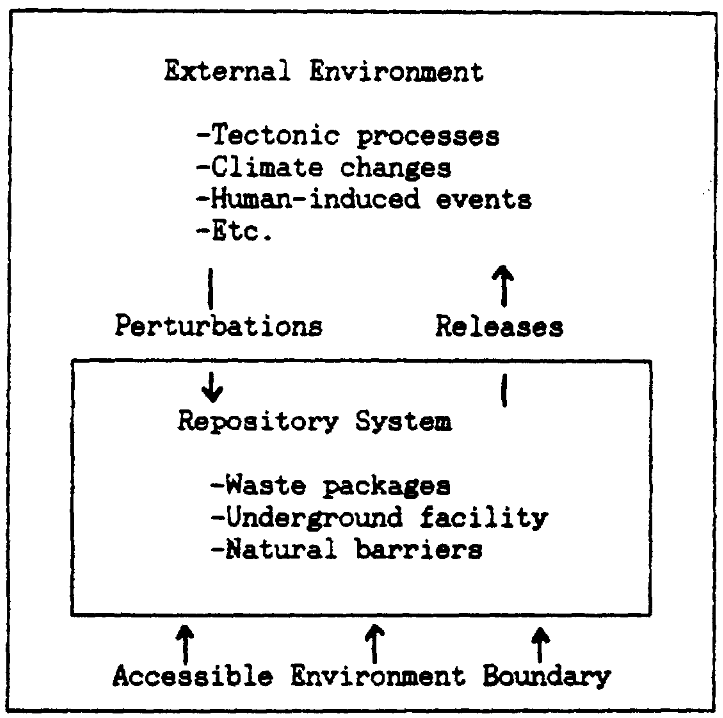


Figure 1. Conceptual representation of repository system and its environment.

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.

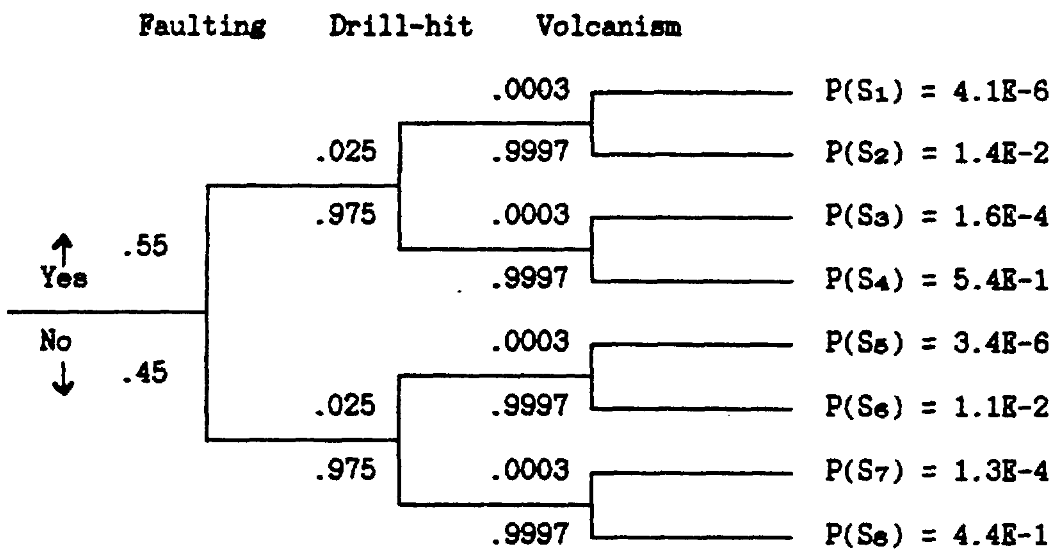


Figure 2. Example of a scenario analysis.

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.

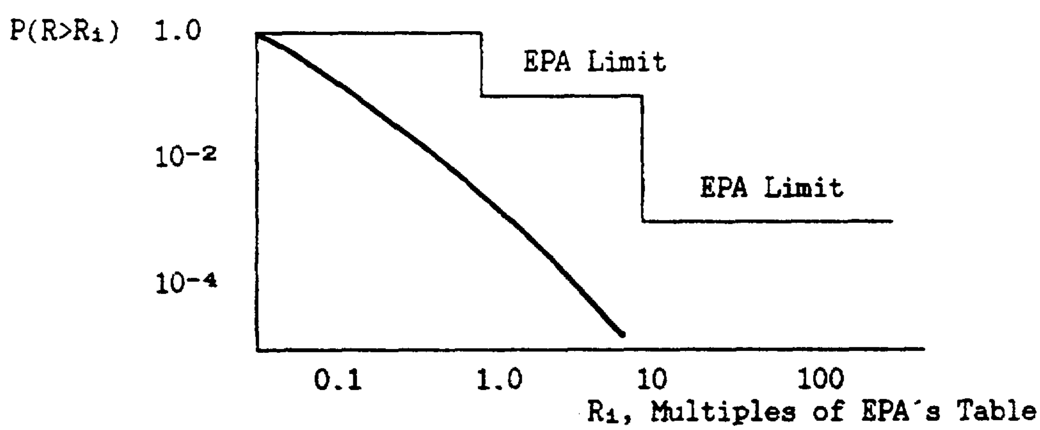


Figure 3. Example of a Complementary Cumulative Distribution Function (CCDF).

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.

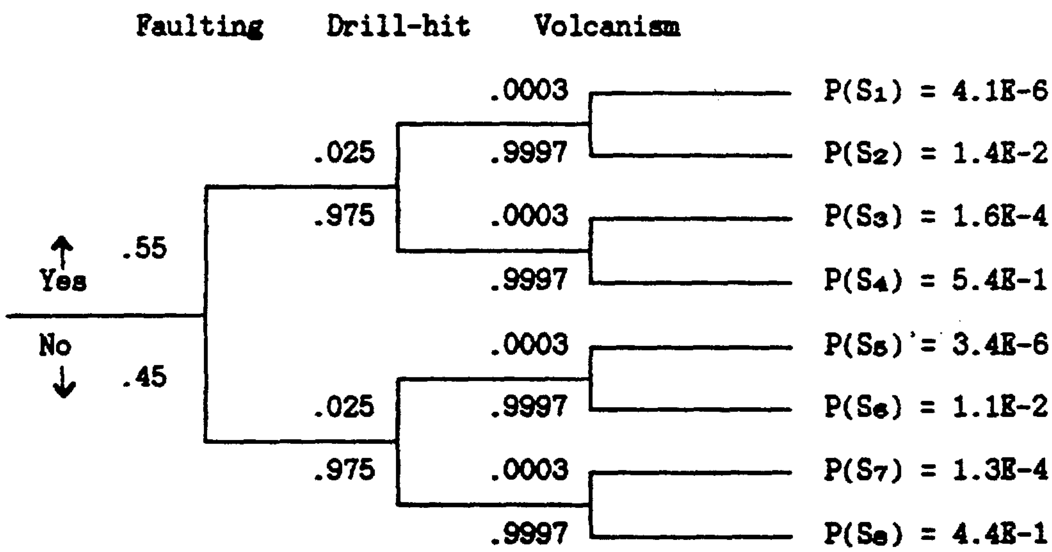


Figure 4. Scenarios for Example 1.

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 |
| $S_6$ 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.

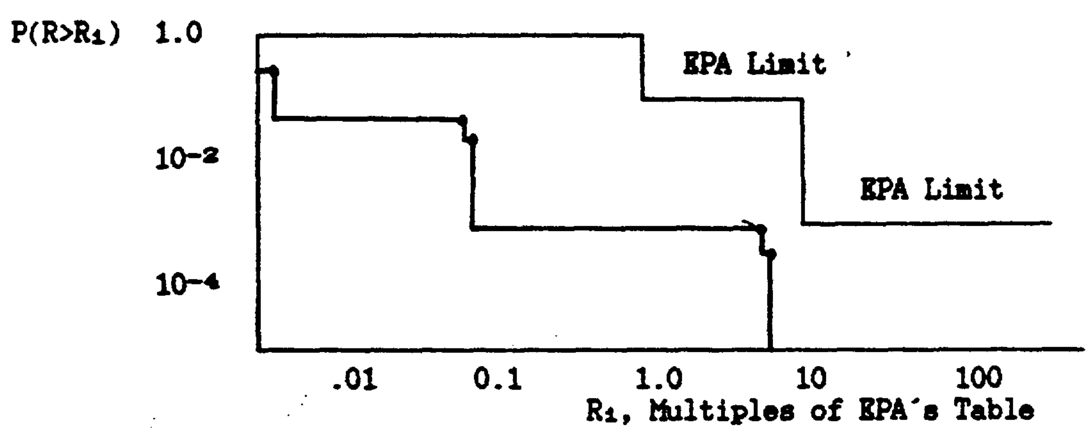


Figure 5. CCDF for Example 1, showing compliance with EPA's release limits.

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.

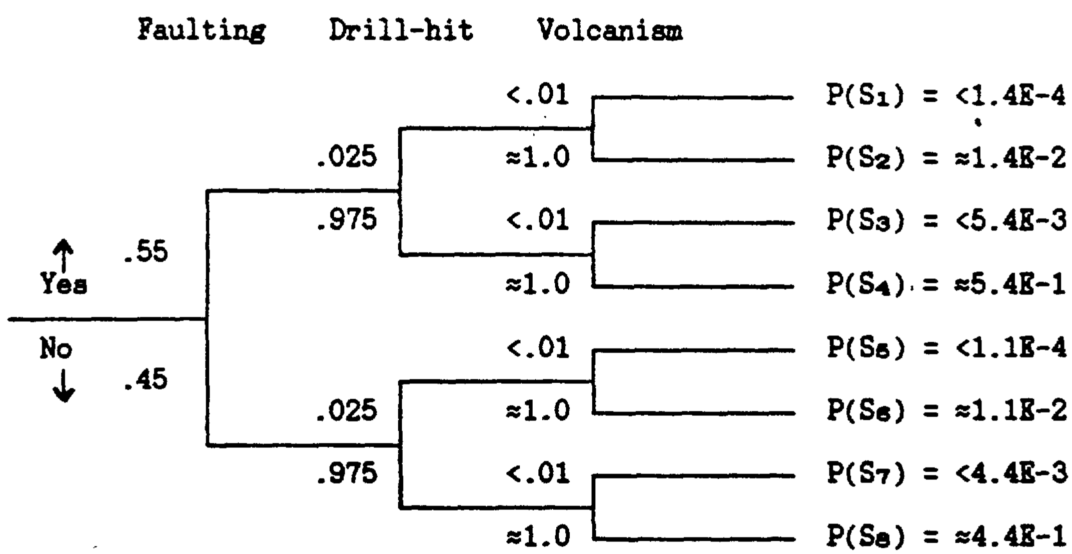


Figure 6. Scenarios for Example 2.

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.

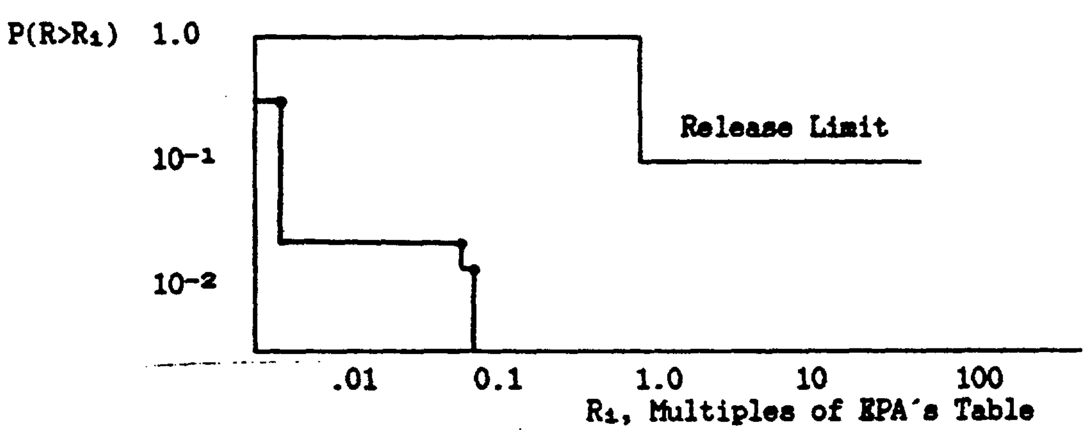


Figure 7. CCDF for Example 2, showing compliance with the NRC staff's alternative standard for anticipated performance.

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).

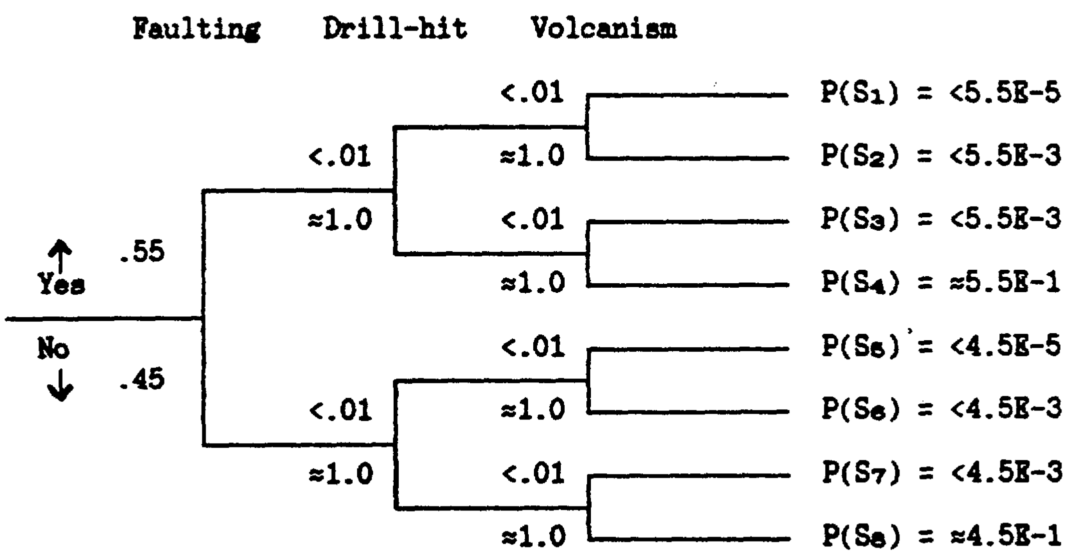


Figure 8. Scenarios for Example 3.

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.

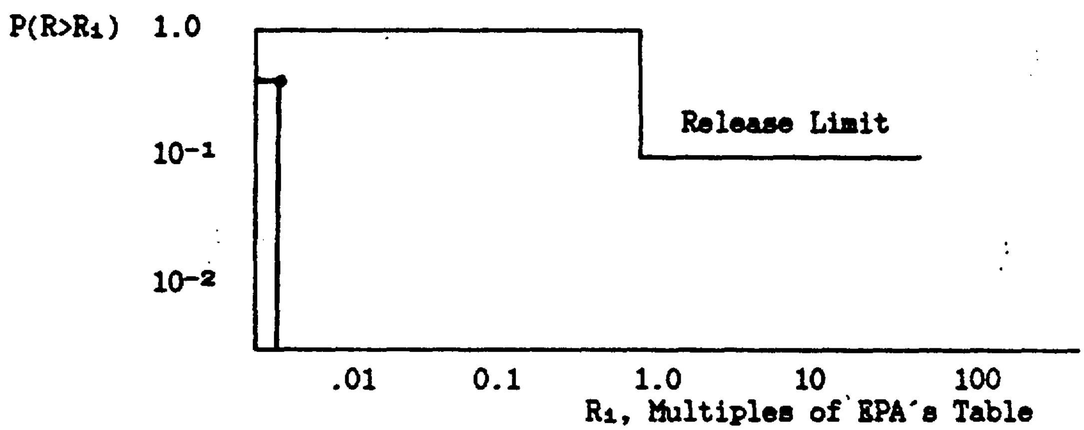


Figure 9. CCDF for Example 3, showing compliance with the NRC staff's alternative standard for anticipated performance.

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.

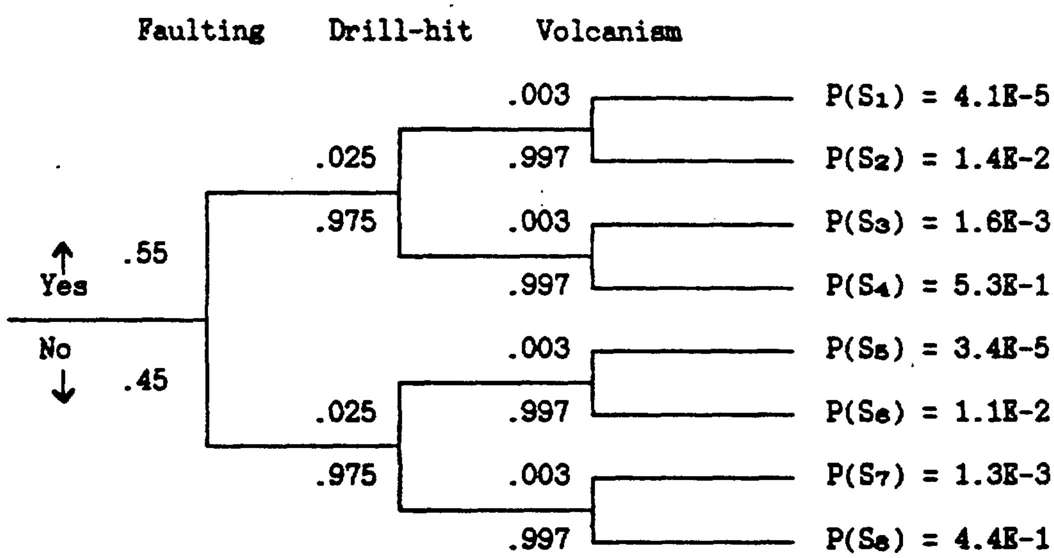


Figure 10. Scenarios for Example 4.

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.

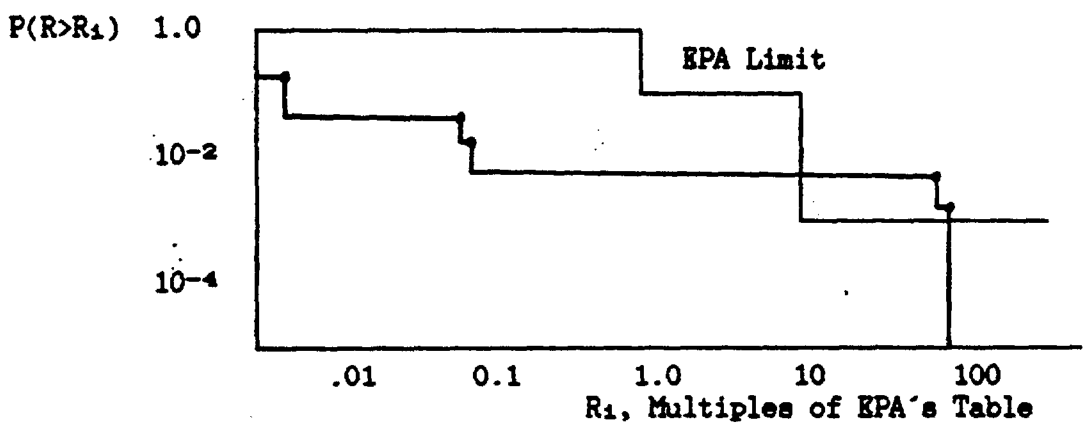


Figure 11. CCDF for Example 4, showing a violation of EPA's release limits.

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.

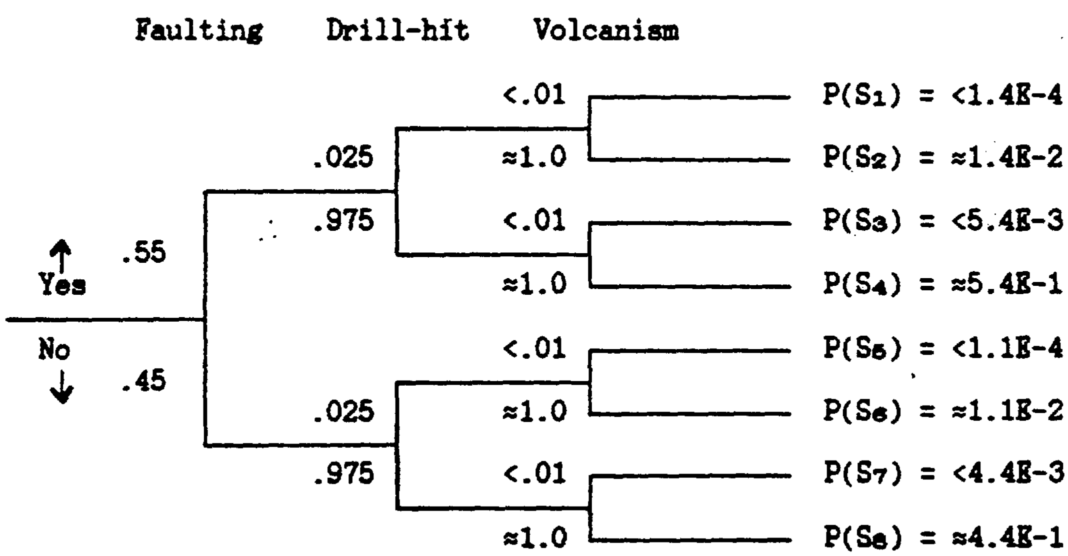


Figure 12. Scenarios for Example 5.

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.

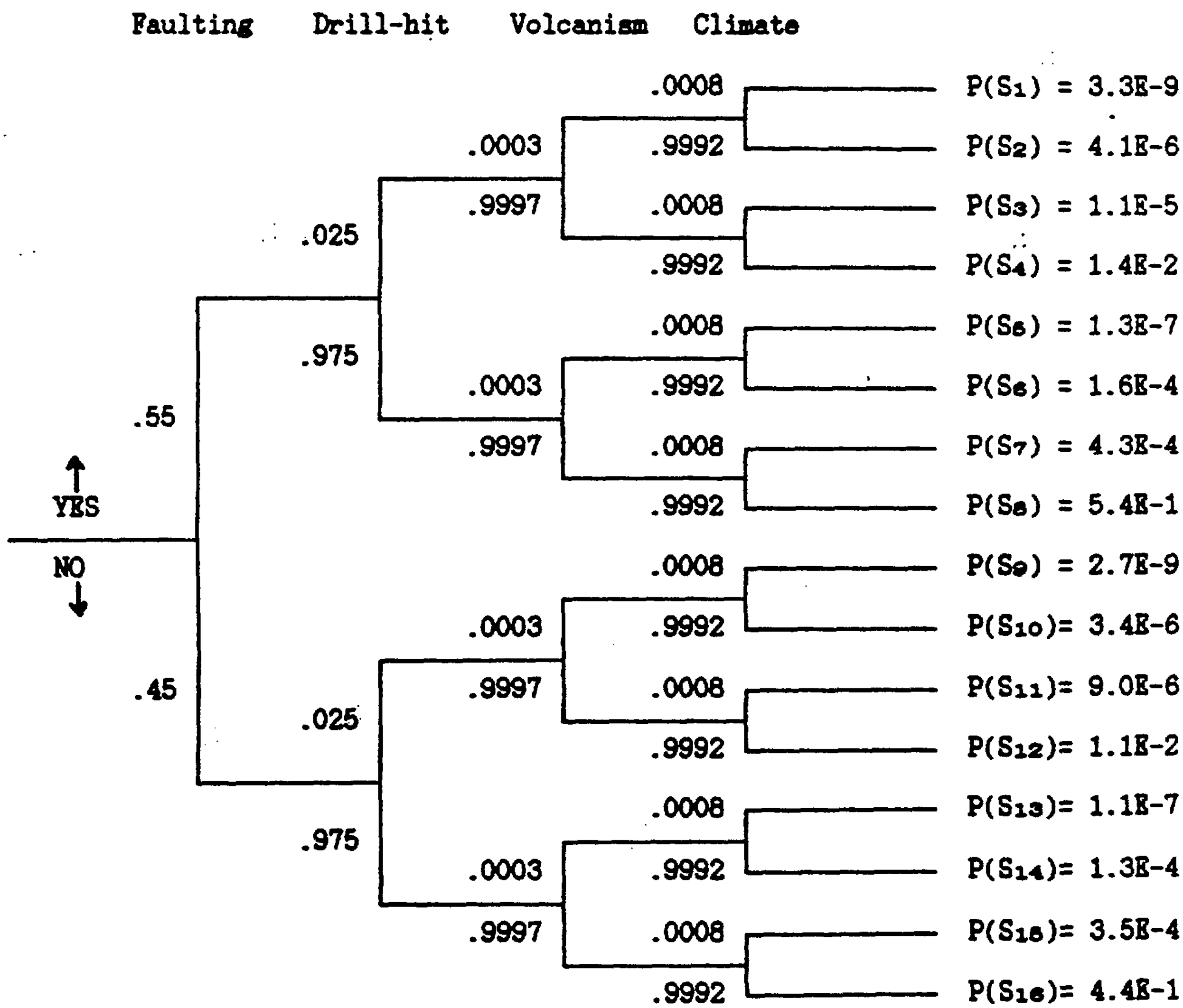


Figure 13. Scenarios for Example 6.

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 because the estimated probabilities are less than EPA's criterion of 1E-4.

Step 5 -- 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.

Step 6 -- Form CCDF.

Table 6 illustrates construction of a CCDF for this example.

Table 6. CCDF data for Example 6.

| Scenario | Probability | Release | Cumulative Probability |
|---|---|---|---|
| $S_6$ 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 |
| $S_8$ 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.

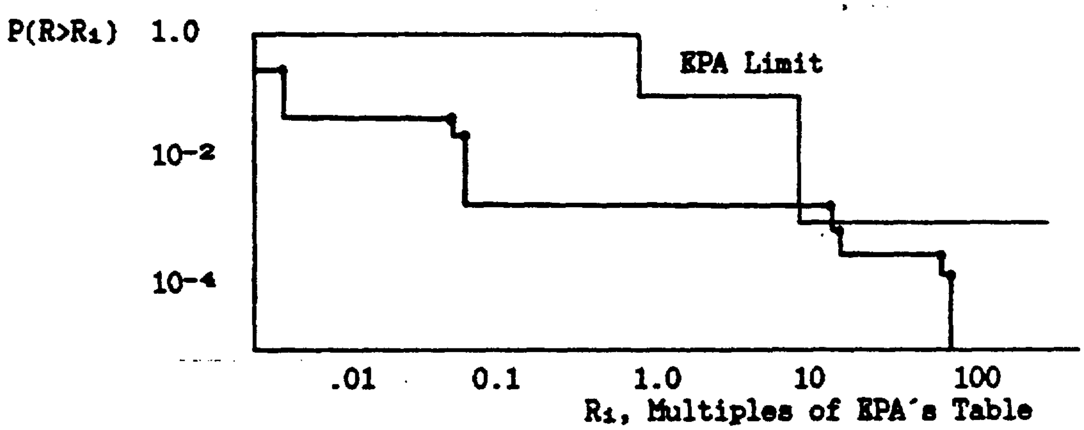


Figure 14. CCDF for Example 6, showing a violation of EPA's release limits.

It is important to emphasize that the releases from volcanism and from climate change are not 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.

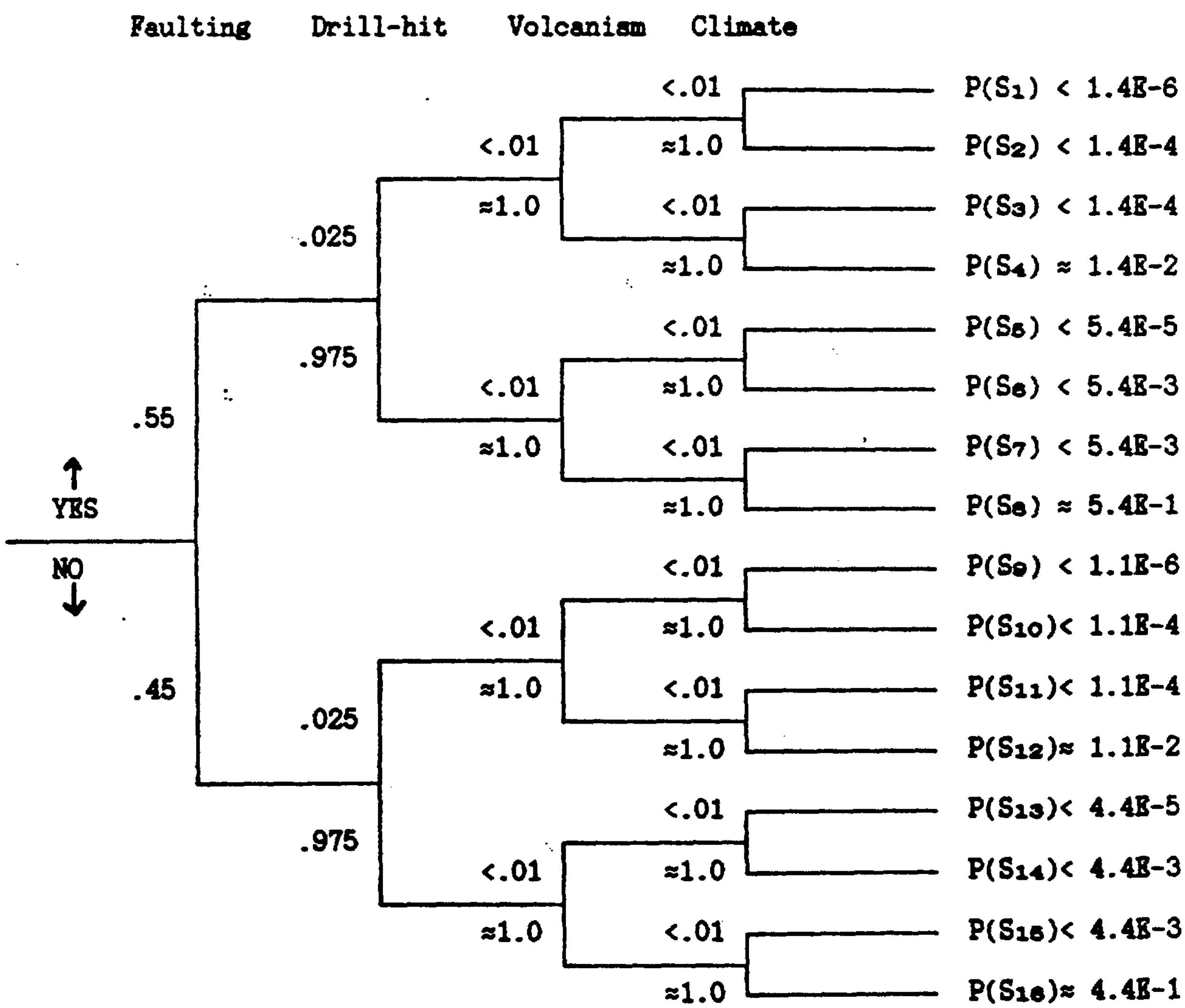


Figure 15. Scenarios for Example 7.

<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 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.

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

Same as Example 6.

<u>Step 6</u> -- 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.

<u>Step 7</u> -- 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.

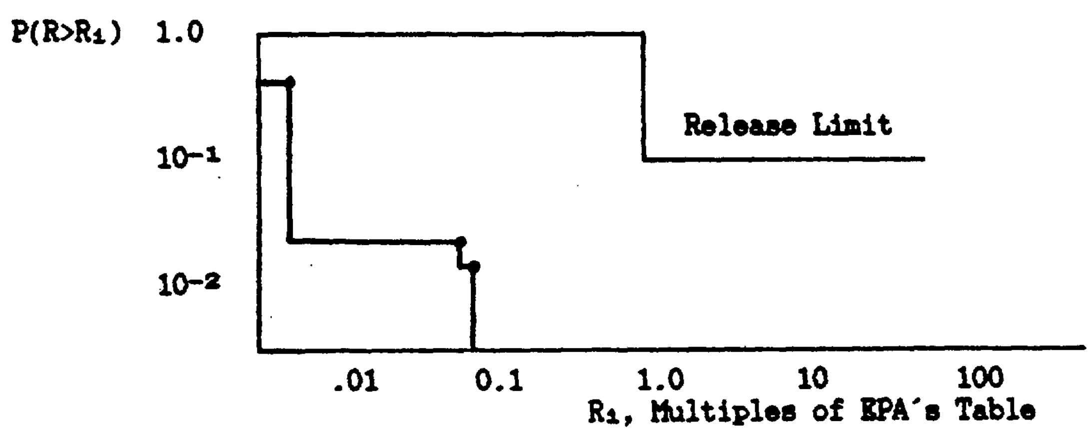


Figure 16. CCDF for Example 7.

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.

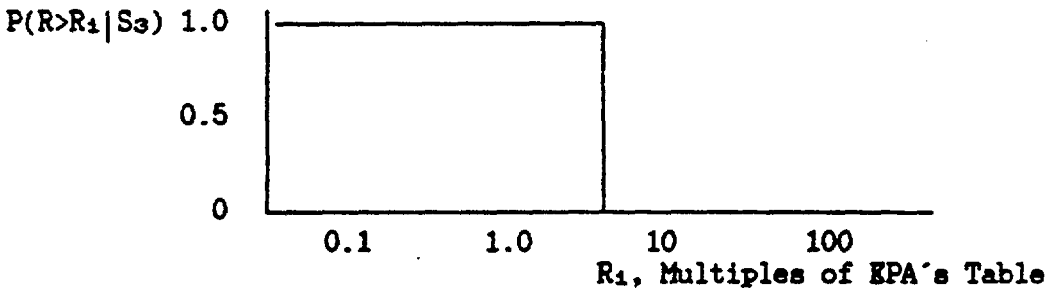


Figure 17. Conditional CCDF for Scenario $S_3$ of Example 1.

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.

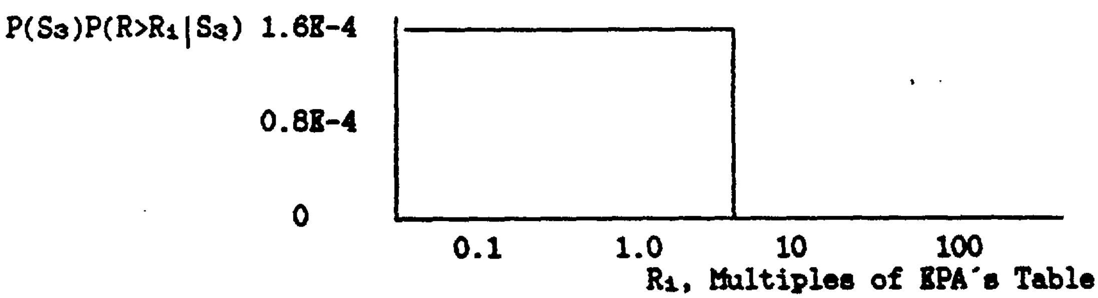


Figure 18. Probability-weighted conditional CCDF for Scenario $S_3$.

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.

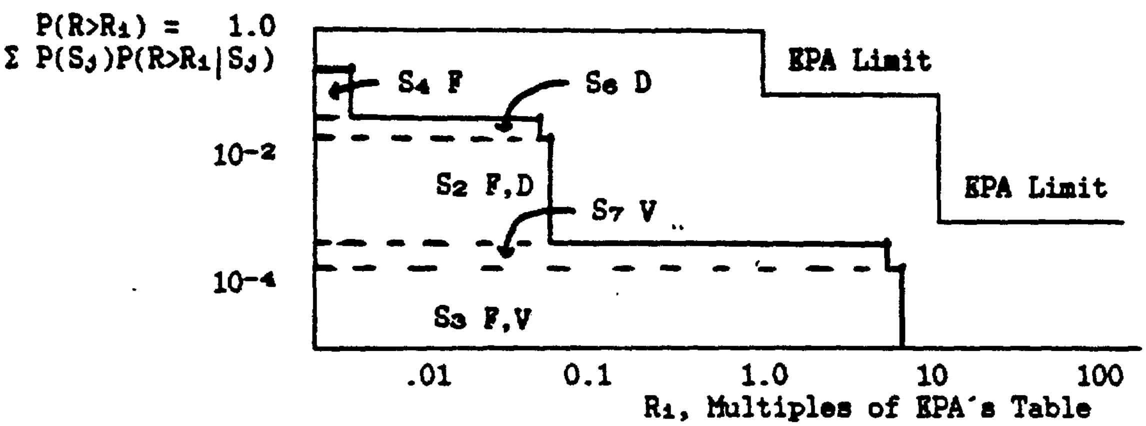


Figure 19. Overall CCDF for Example 1 Constructed by Summing Probability-Weighted Conditional CCDFs.

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.

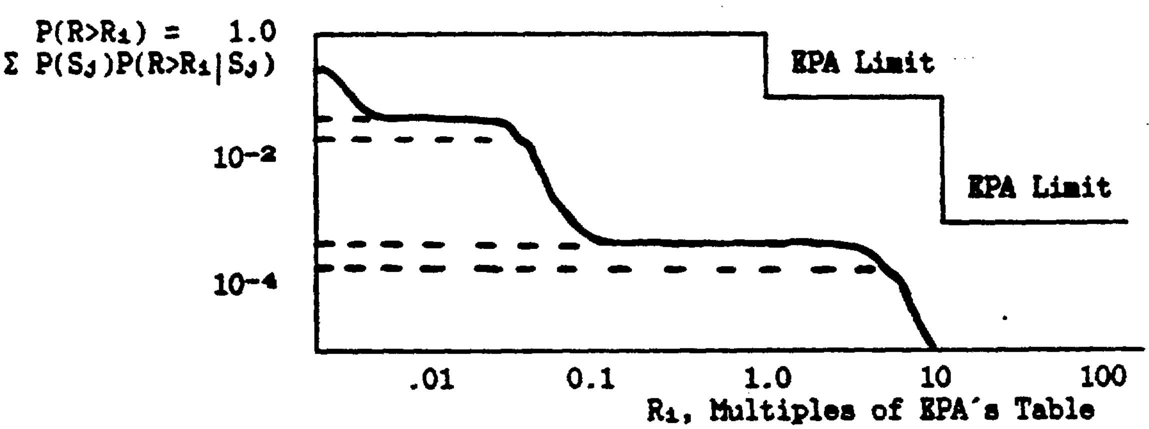


Figure 20. Overall CCDF Including Uncertainties in Releases for Example 1 Constructed by Summing Probability-Weighted Conditional CCDFs.

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.

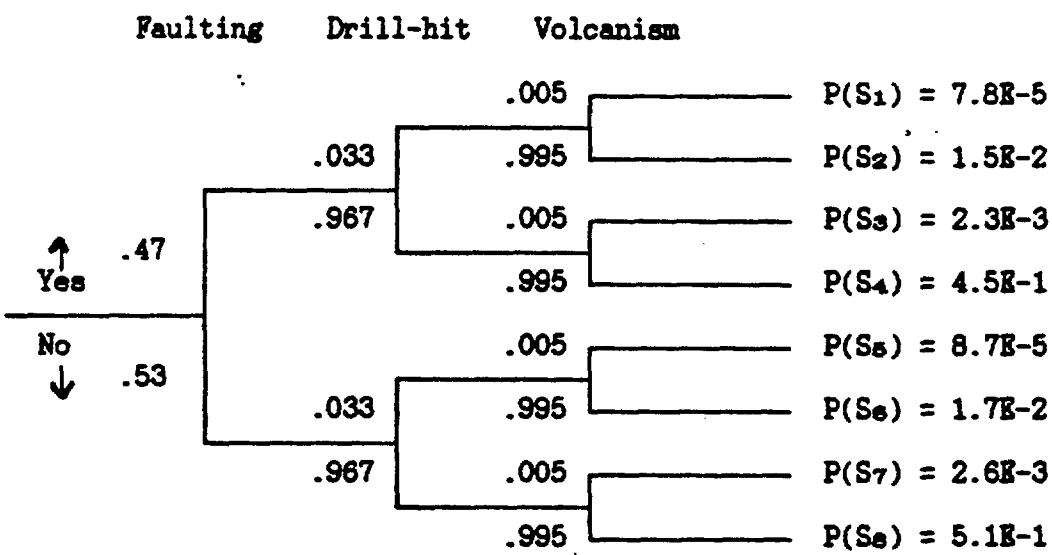


Figure 21. Scenario analysis for randomly selected probability values.

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.

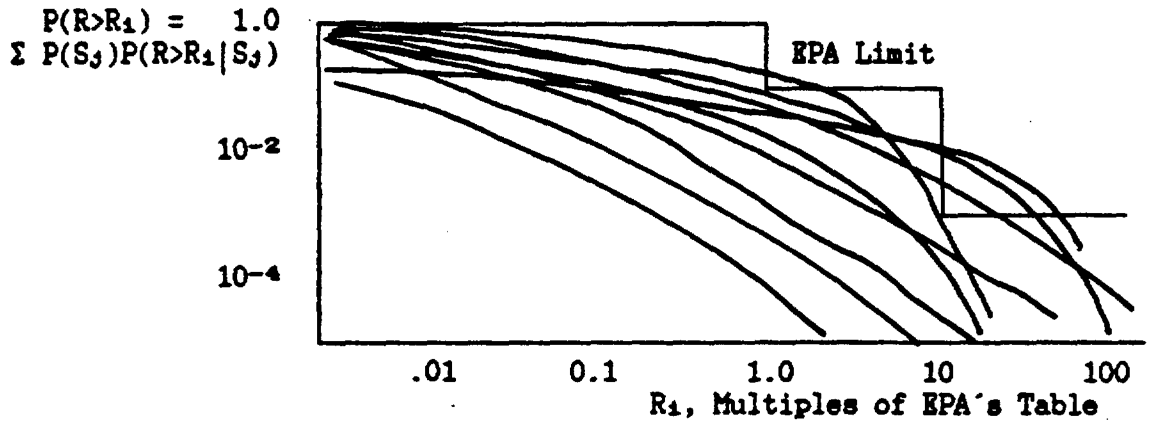


Figure 22. "Family" of CCDFs illustrating uncertainties in the probabilities of disruptive events.

<u>Example 9 -- Uncertainties in Release Estimates - NRC Staff's Alternative</u>.

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.

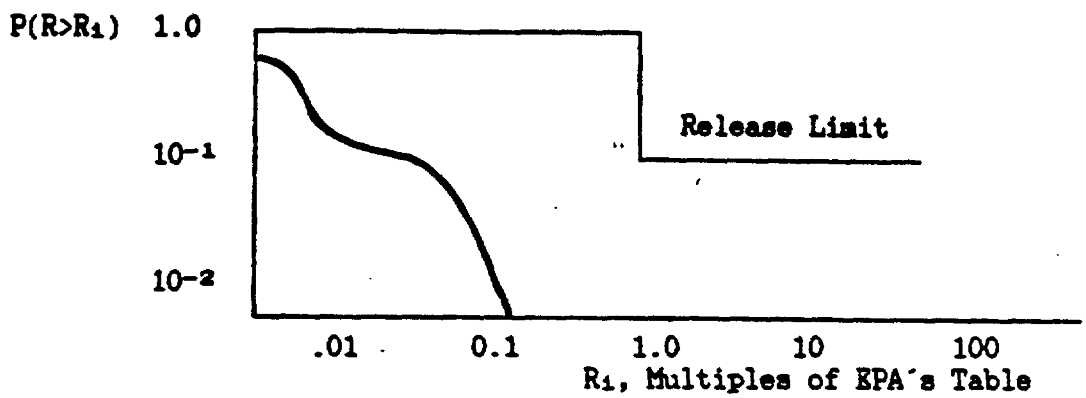


Figure 23. CCDF for likely releases, including estimates of uncertainties in releases.

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.

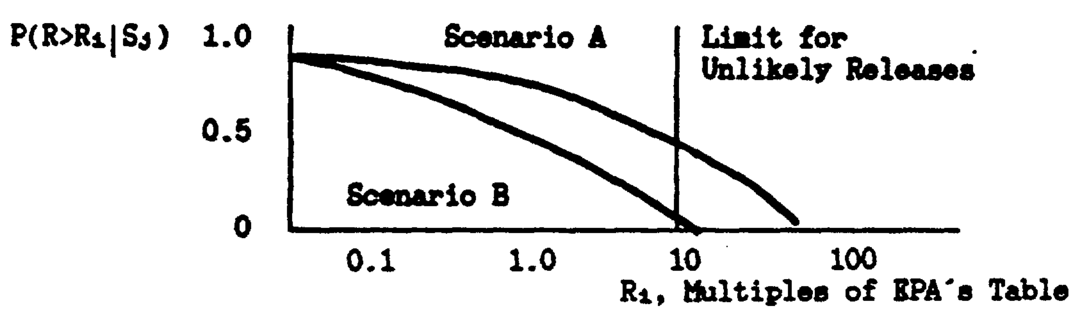


Figure 24. Uncertainties in estimated releases for two unlikely scenarios.

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.

# An Analysis of the Three-Bucket Approach

Michael L. Wilson
Sandia National Laboratories

**PRELIMINARY DRAFT**

**PRELIMINARY DRAFT**

## Advantages of the original EPA approach

- It is understood. Methods have been developed for showing compliance with it.
- It is clear. Specific numbers are given for release limits and probability cutoffs.
- It places restrictions on the system as a whole in a concise, consistent manner rather than requiring treatment of subsystems in any particular way.

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## Disadvantages of the original EPA approach

- It requires calculation of the probability distribution of normalized releases (the CCDF) down to one part in 1000. This may require thousands of Monte Carlo realizations for statistical significance.

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## Advantages of the three-bucket approach

- It is easier, at least in principle. The CCDF only has to be calculated down to one part in 10, which only requires tens of Monte Carlo realizations.

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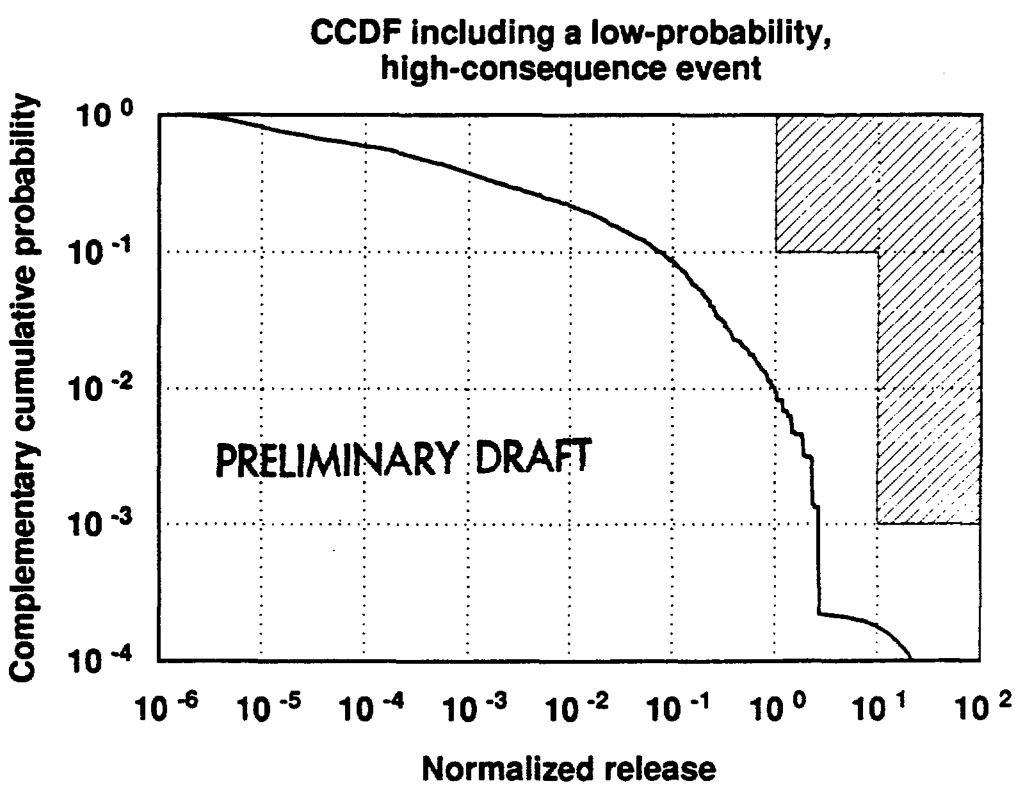
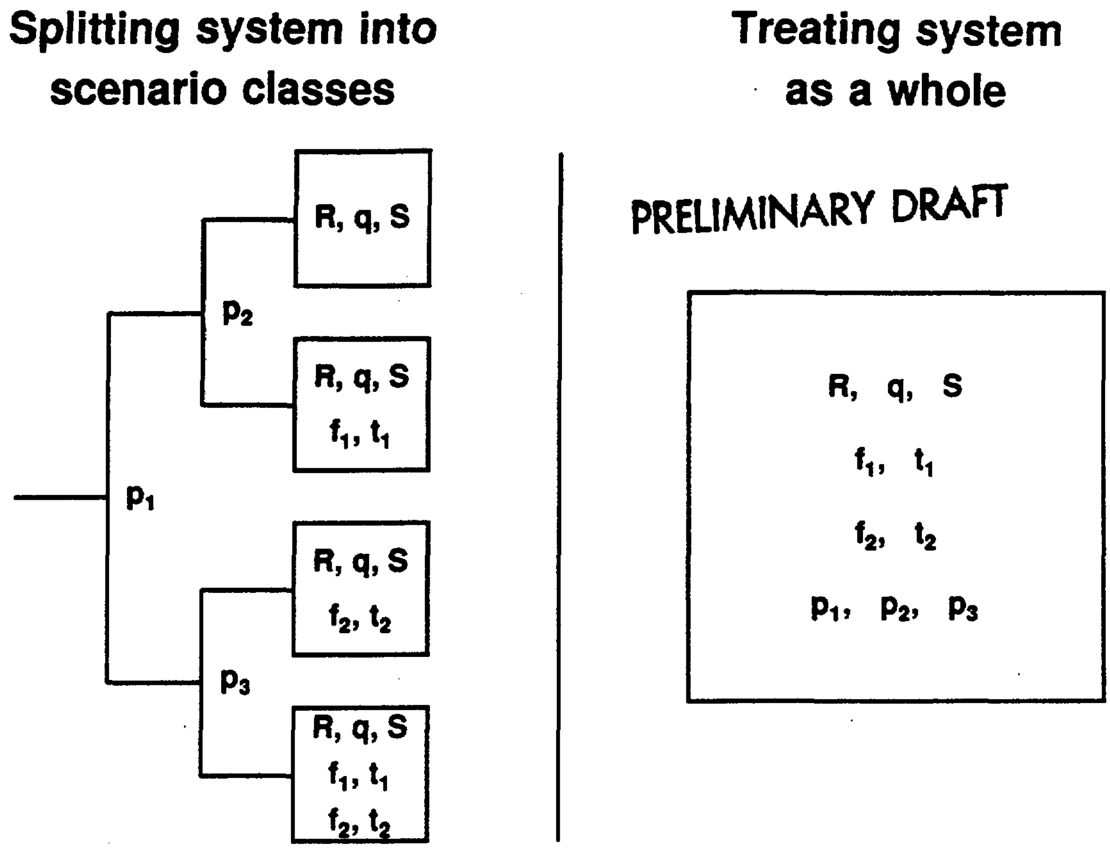
# Disadvantages of the three-bucket approach, as now stated

- The statement of the three-bucket approach is vague.
- It is more stringent. Releases are restricted down to probabilities of one part in 10,000 rather than down to one part in 1000.
- How do you assign a single number for the normalized release of a scenario class?
- How do you split the system up into scenario classes?




Splitting system into scenario classes
Treating system as a whole
R, q, S
p2
R, q, S
f1, t1
p1
R, q, S
f2, t2
p3
R, q, S
f1, t1
f2, t2
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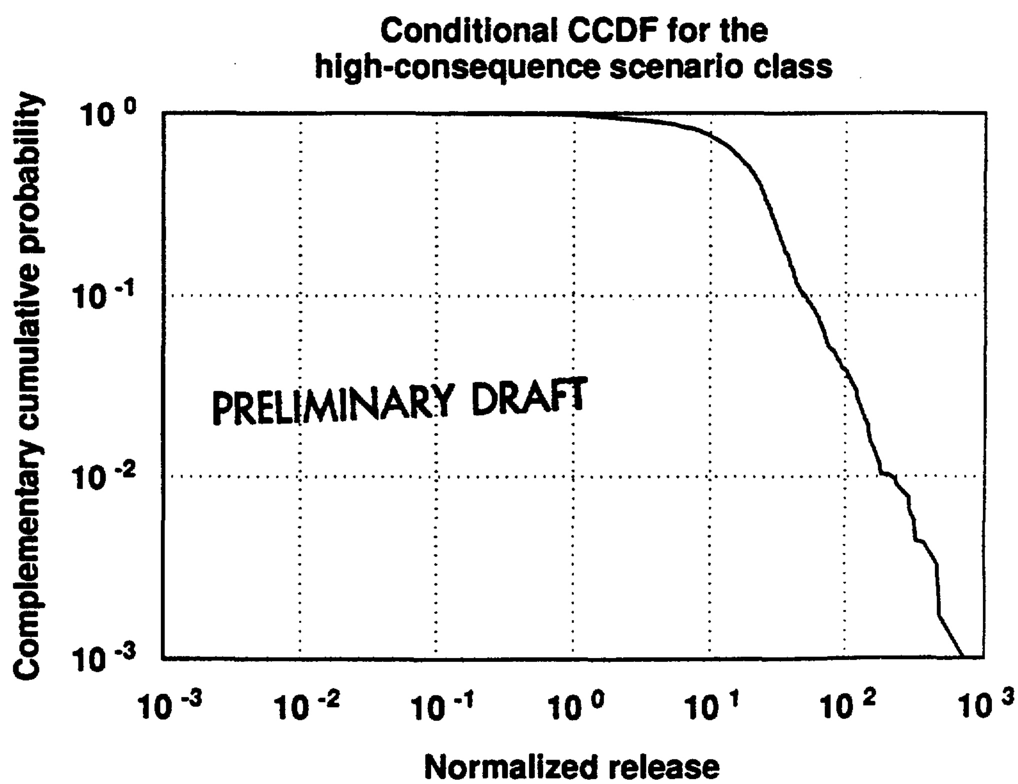
R, q, S
f1, t1
f2, t2
p1, p2, p3


Conditional CCDF for the high-consequence scenario class
Complementary cumulative probability
10 0
10 -1
10 -2
10 -3
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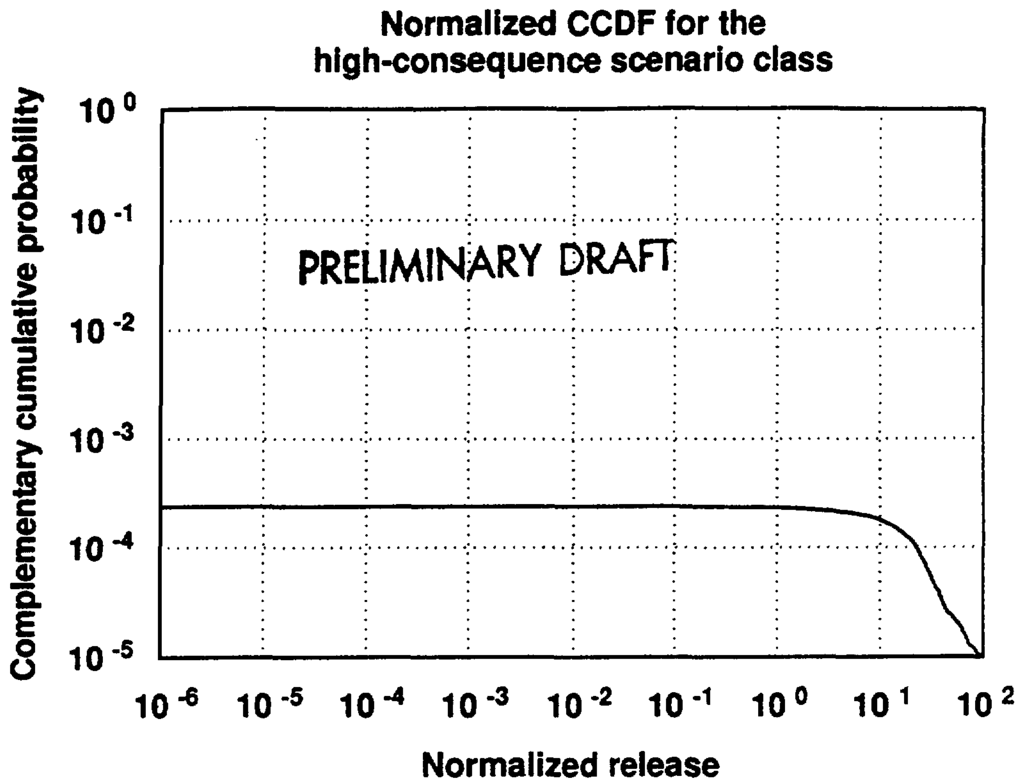
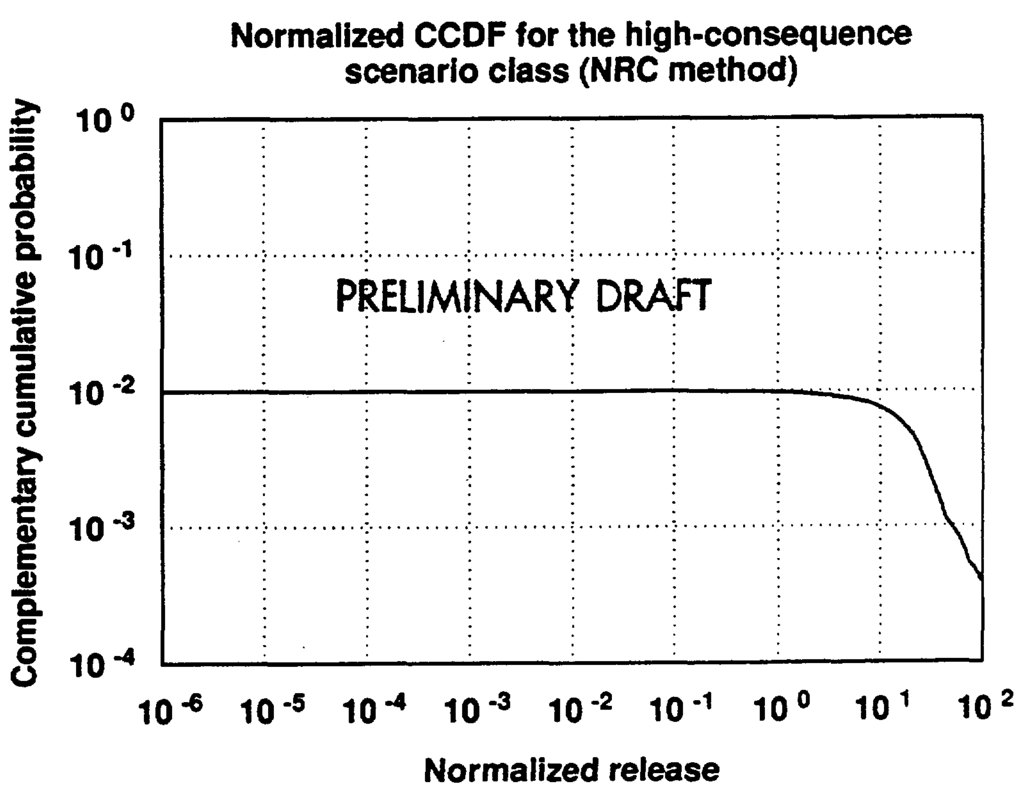
10 -3
10 -2
10 -1
10 0
10 1
10 2
10 3
Normalized release


Normalized CCDF for the
high-consequence scenario class
Complementary cumulative probability
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
PRELIMINARY DRAFT
$10^{-6}$ $10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ $10^{0}$ $10^{1}$ $10^{2}$
Normalized release


Normalized CCDF for the high-consequence
scenario class (NRC method)
Complementary cumulative probability
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
PRELIMINARY DRAFT
$10^{-6}$ $10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ $10^{0}$ $10^{1}$ $10^{2}$
Normalized release

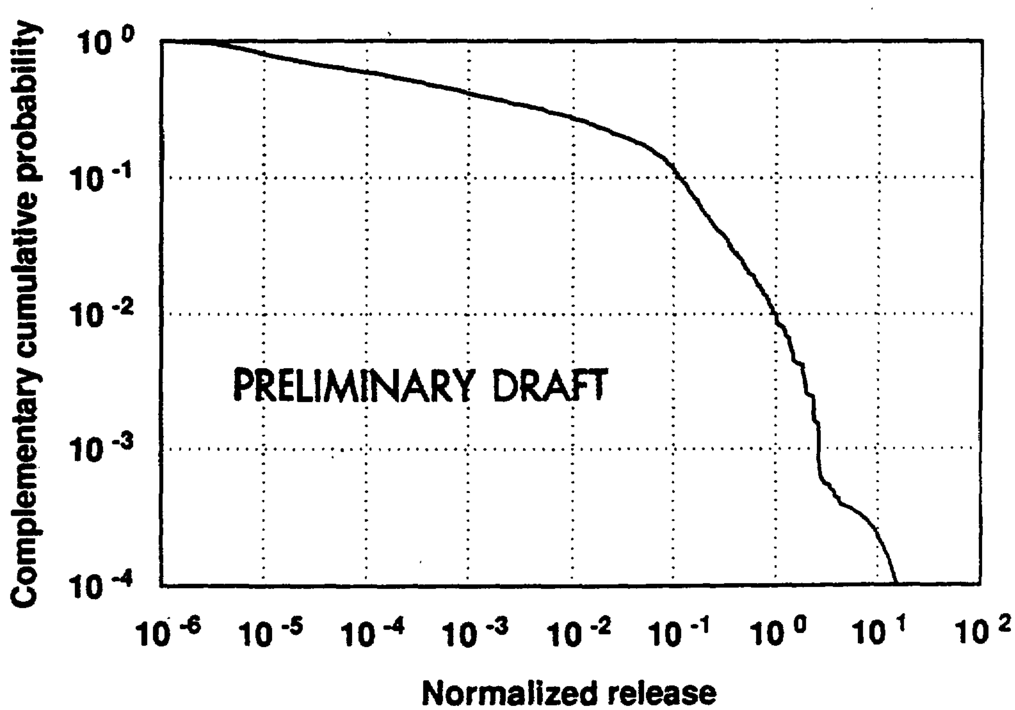
## Logic-tree diagram with one scenario class

PRELIMINARY DRAFT

Probability

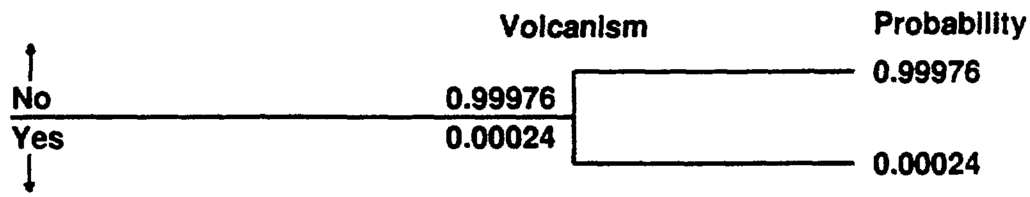
1.0

Example total-system CCDF

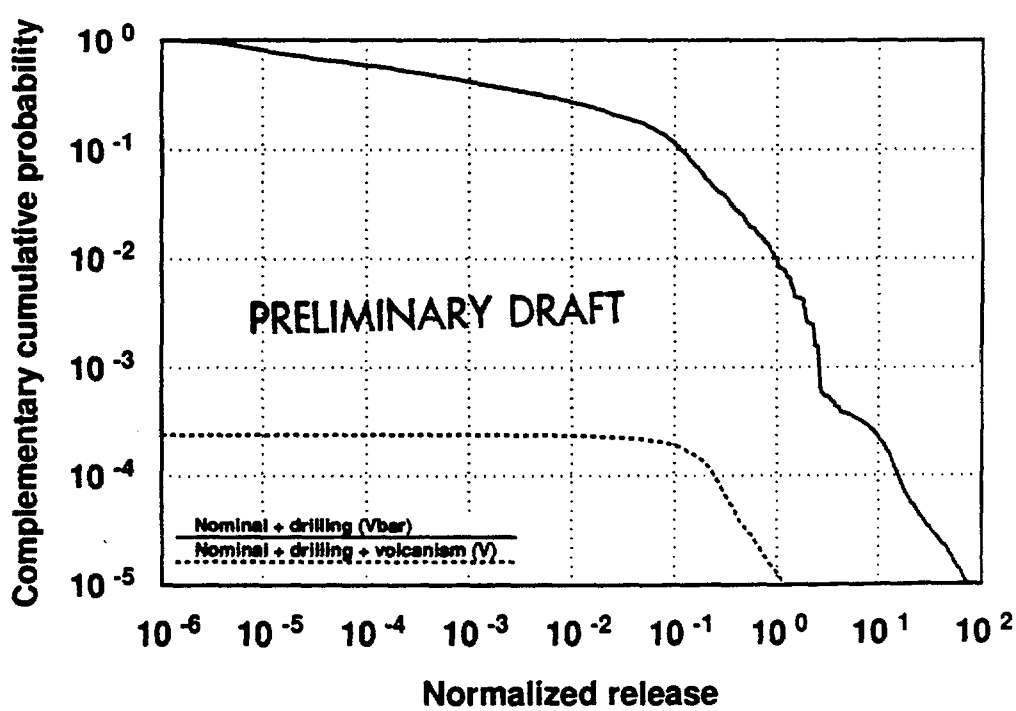


# Logic-tree diagram with two scenario classes

PRELIMINARY DRAFT

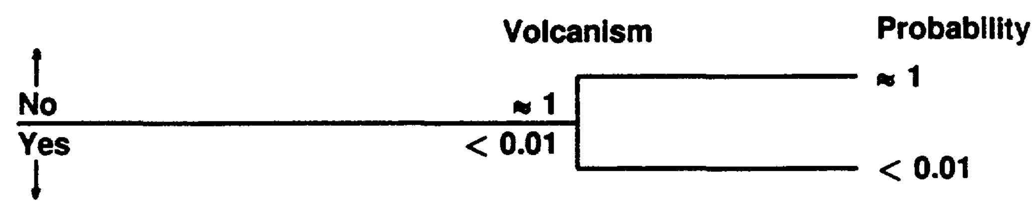


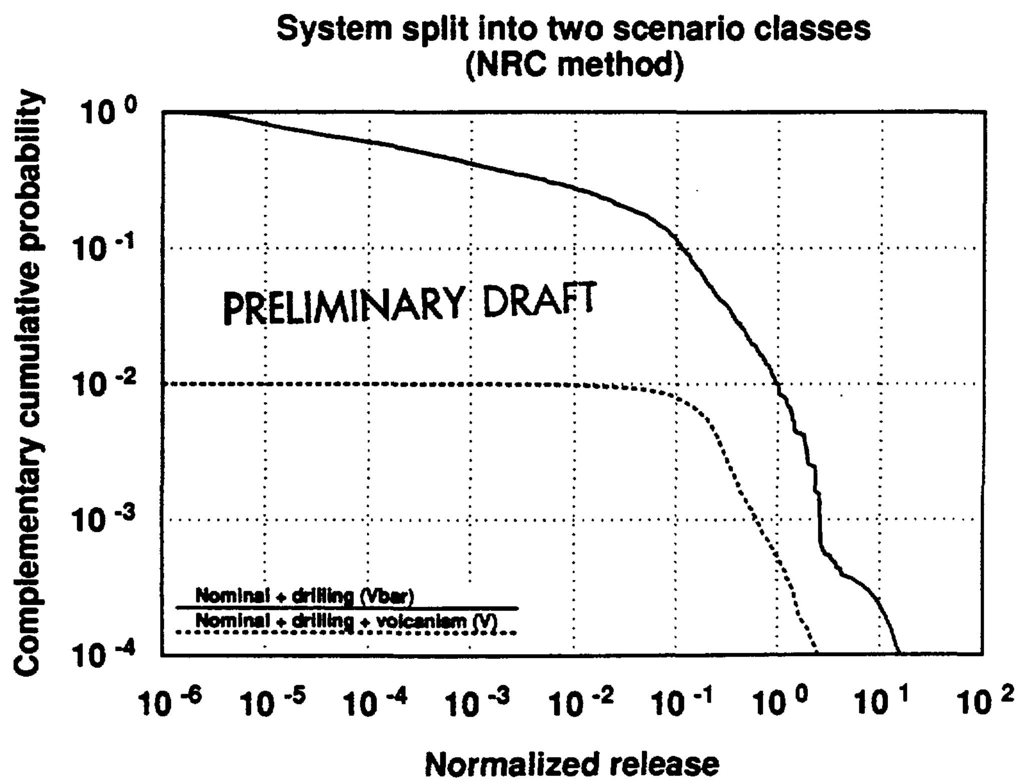

System split into two scenario classes



# Logic-tree diagram with two scenario classes (NRC method)

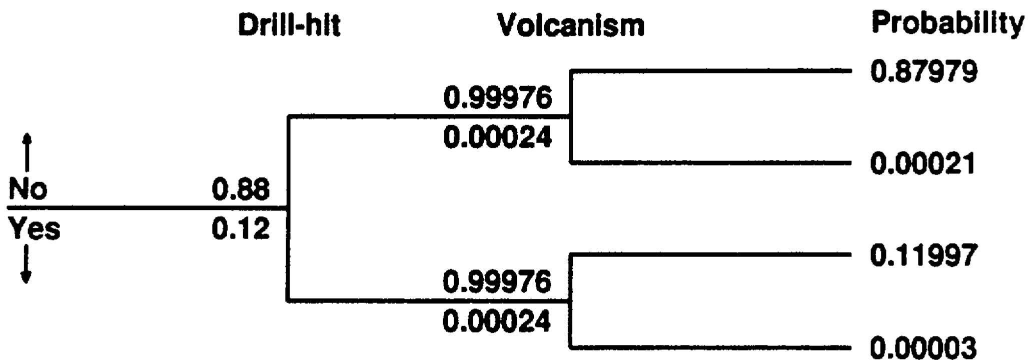
PRELIMINARY DRAFT



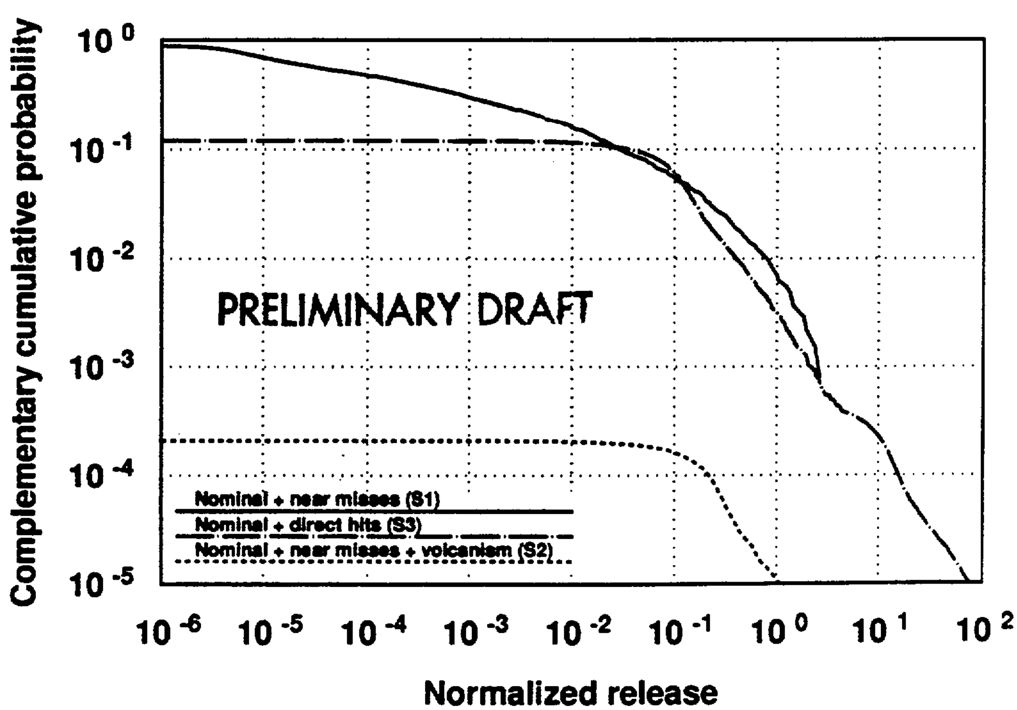



# Logic-tree diagram with four scenario classes

PRELIMINARY DRAFT

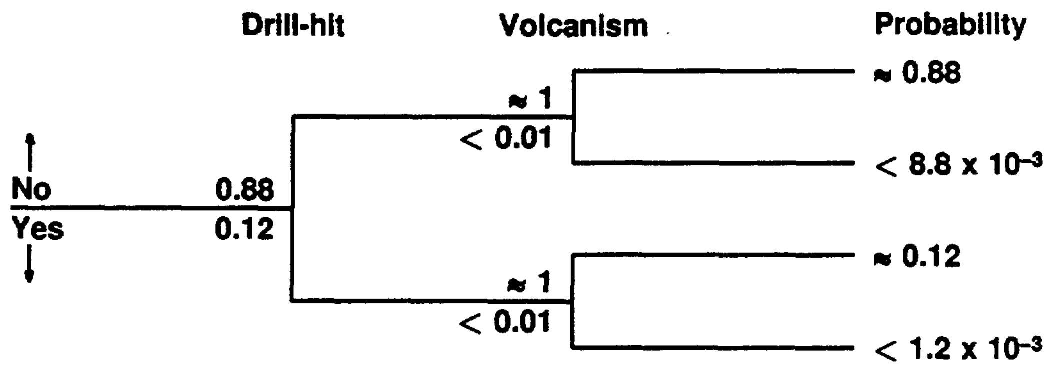



## System split into four scenario classes

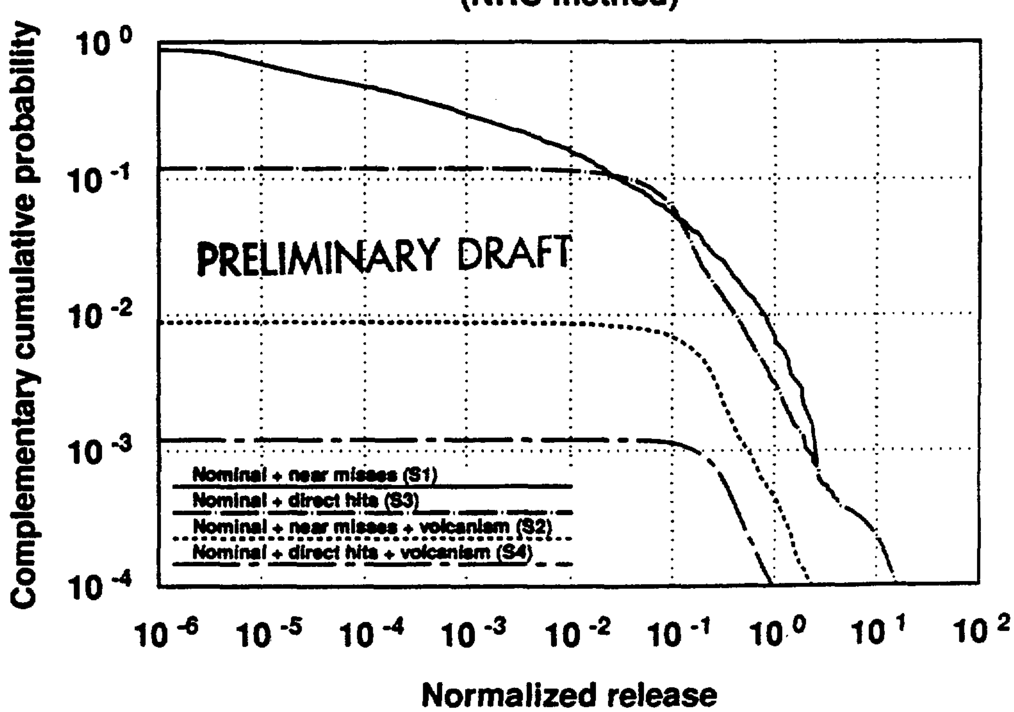


# Logic-tree diagram with four scenario classes (NRC method)

PRELIMINARY DRAFT

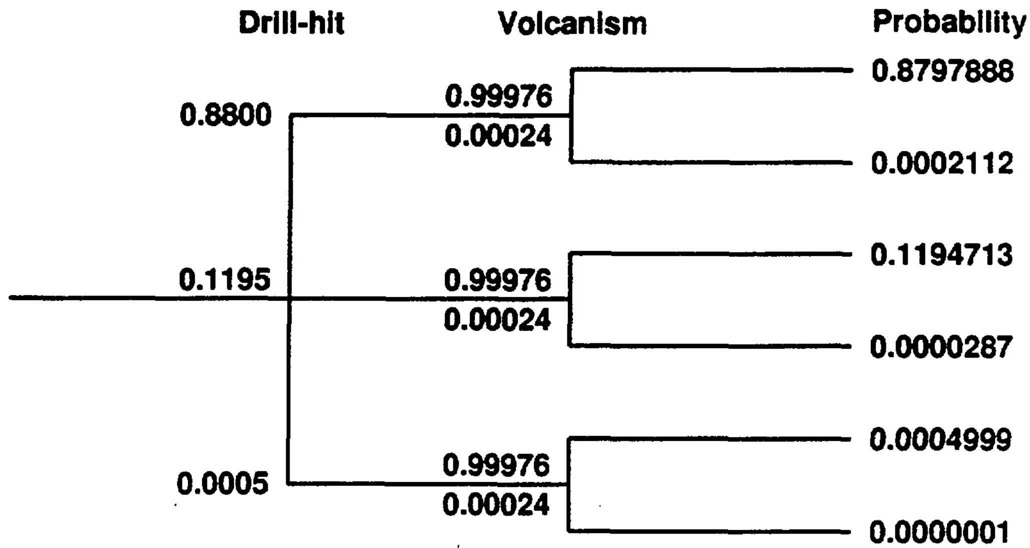



## System split into four scenario classes (NRC method)

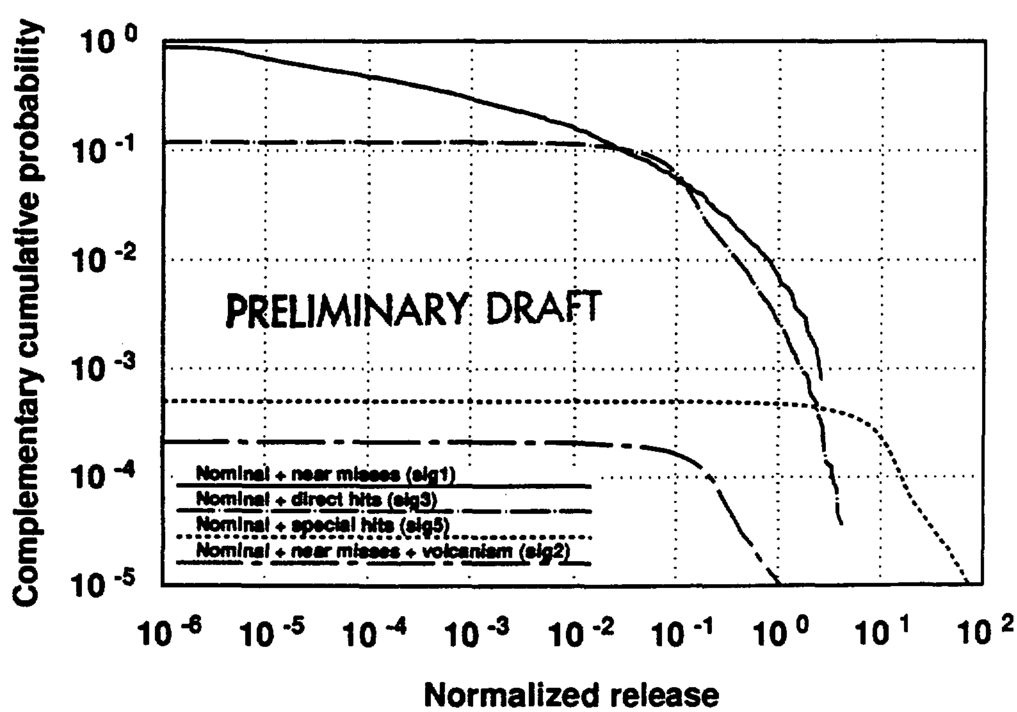


# Logic-tree diagram with six scenario classes

PRELIMINARY DRAFT

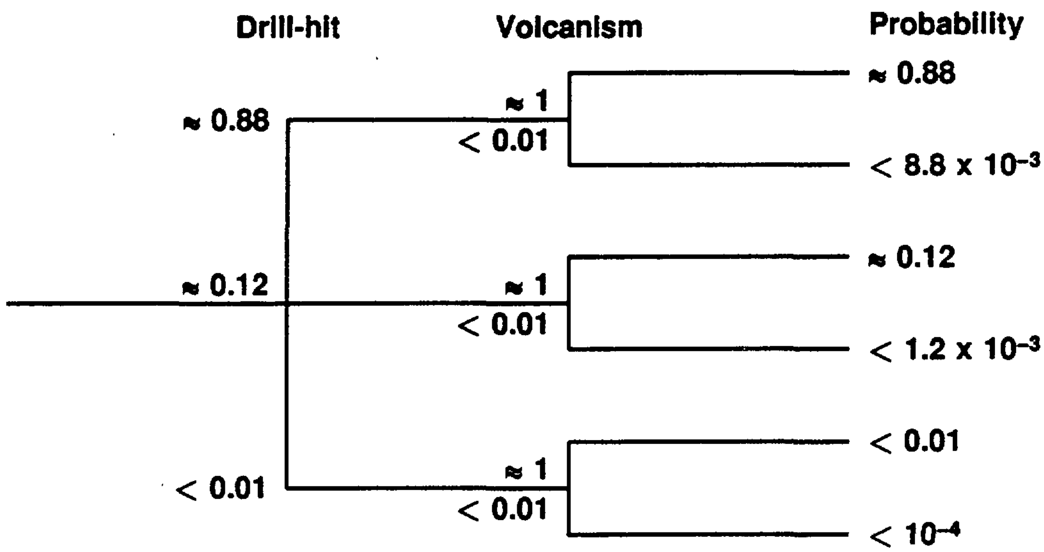



System split into six scenario classes

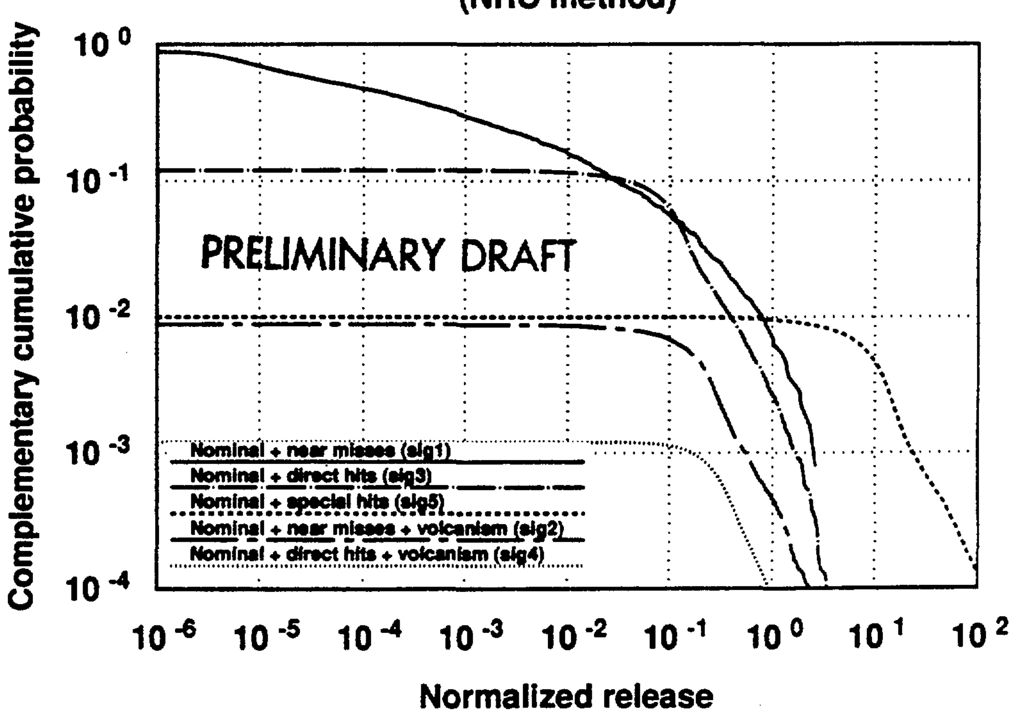


## Logic-tree diagram with six scenario classes (NRC method)

PRELIMINARY DRAFT




### System split into six scenario classes (NRC method)



## Summary of scenario-class sensitivity

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| | mean | 90% conf. | $10^{-4}$ cutoff | $10^{-3}$ cutoff (NRC method) |
|---|---|---|---|---|
| 1 scenario class | 0.057 | 0.11 | 16 | 2.6 |
| 2 scenario classes | 0.33 | 0.62 | 16 | 2.6 |
| 4 scenario classes | 0.31 | 0.60 | 16 | 2.5 |
| 6 scenario classes | 14 | 23 | 16 | 23 |

PRELIMINARY DRAFT

## Conclusion

- Additional guidance is needed to resolve the ambiguities of the three-bucket approach.