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Quantitative Analysis of Potential Performance Improvements for the Dry PWR Containment

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ABSTRACT

This report calculates the risk benefit associated with potential performance improvements for the large dry pressurized water reactor (PWR) containment. The analysis is based on the June 1989 draft NUREG-1150 results for the Zion commercial nuclear reactor. Simplified containment event trees and the large accident progression event trees from draft NUREG-1150 are used to evaluate the effects of potential improvements on the response of the Zion containment to dominant severe accident sequences. Source terms are generated parametrically using the ZISOR code and offsite consequences are calculated with the MELCOR Accident Consequence Code System (MACCS). These results give point estimates of the risk reduction associated with each containment improvement identified by Brookhaven National Laboratory in their draft Issues Characterization Report.

FIN No. A6890—Quantitative Analysis of Potential Performance Improvements for the Dry Pressurized Water Reactor Containment

EXECUTIVE SUMMARY

This report provides a quantitative analysis of the risk reduction potential associated with the containment performance improvements identified in the draft Issues Characterization Report for the dry PWR containment. These improvements are as follows: (1) enhanced reactor depressurization to mitigate direct containment heating (DCH), (2) addition of a cavity flooding system to ensure that the reactor cavity is flooded at the time of vessel breach, (3) improvements in the hydrogen control system, (4) containment venting, and (5) modifications to reduce the frequency of the interfacing systems loss-of-coolant accident (LOCA). The last two improvements [items (4) and (5)] are not evaluated in this report.

The quantitative analysis in this report relied exclusively upon the June 1989 draft NUREG–1150 analysis of the Zion plant. Therefore, the findings in this report are necessarily specific to the Zion plant. These results should not be applied to other dry PWR containments without further analysis, with due consideration given to plant–specific and site–specific features that can affect the results.

Simplified containment event trees were used wherever possible to analyze the containment response. They were derived from the large accident progression event trees used for the June 1989 Zion draft NUREG–1150 analysis. In some cases, dependencies among questions in the accident progression event trees made the use of simplified event trees impracticable. In these cases, the draft NUREG–1150 computer codes were used to analyze the improvements, with the Zion accident progression event trees used as input files.

Table ES–1 presents a summary of the calculated results of the risk benefit analysis.

Table ES–2 shows the relative contribution of the various modes of containment failure to two of the offsite risk measures in the base case, the 50– and 1000–mile population doses. These contributions are a weighted average of the contributions from each plant damage state group.

The following conclusions can be drawn from the analysis performed for this report. The above caveat about the plant–specific nature of the results should be kept in mind.

The benefits to risk of intentional operator depressurization cannot be judged conclusively. Vessel depressurization appears to have both positive and negative effects. First, vessel breach may be prevented in some

Table ES– 1. Composite annual risk results

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (Person–Rem)	Mean 1000–Mile Dose (Person–Rem)	Mean Offsite Costs ($)
Base case	3.31E–05	1.39E–02	26.3	84.6	5.99E+04
Depressurization via PORVs	3.18E–05	1.38E–02	26.2	83.9	5.93E+04
Full depressurization #1 (no HPME)	4.12E–05	1.39E–02	26.3	84.4	5.98E+04
Full depressurization #2 (no HPME)[a]	1.60E–05	1.09E–02	18.7	65.2	5.23E+04
Cavity flooding	3.12E–05	1.28E–02	24.0	76.5	5.58E+04
H_2 control	3.31E–05	1.39E–02	26.3	84.6	5.99E+04

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a. This case includes the use of a point estimate α mode failure probability of 8.0E–04.

Table ES–2. Containment failure mode contribution to offsite dose (base case)

Containment Failure Mode	Contribution to 50–Mile Dose (%)	Contribution to 1000–Mile Dose (%)
DCH	2.1	1.7
α	71.5	75.0
Bypass	26.1	23.1
Late overpressure	ε	ε
Basemat melt–through	ε	ε

ε = negligible

sequences by intentional depressurization, because depressurization may allow injection from available low pressure systems. This is the case, for example, in sequences where AC power is available. Depressurization also eliminates temperature–induced steam generator tube ruptures, which bypass the containment. However, depressurization reduces but does not eliminate DCH failures for Zion, because the capacity of the pressurizer pilot–operated relief valves (PORVs) has not been shown to be sufficient to fully depressurize the reactor (<200 psig). Finally, if the conditional probabilities of α mode failure (containment failure as the result of an in–vessel steam explosion) developed for draft NUREG–1150 are used, then the benefits of depressurization may be offset by an increased probability of early containment failure, because NUREG–1150 has judged α mode failure to be more likely at low reactor coolant system (RCS) pressures.

The addition of a cavity flooding system yields a slight reduction in risk but may increase the probability of DCH failure in some sequences. The effect of a flooded cavity on the threat from DCH is not known. The discussion in the draft Issues Characterization Report for the dry PWR containment appears to indicate that the effect may be plant–specific, enhancing the threat at some plants while mitigating it at others. At any rate, *the risk reduction is not significant for Zion.* Flooding the cavity does increase the conditional probabililty of an ex–vessel steam explosion; however, because ex–vessel steam explosions are an insignificant threat to containment integrity at Zion, this effect does not increase offsite risk.

Improvements in the hydrogen control systems are of no benefit in terms of risk. This result is very specific to Zion. Other plants, particularly those with smaller subatmospheric containments, might realize a more significant risk reduction from hydrogen control improvements.

Improvements to reduce the frequency of containment bypass sequences would provide the greatest tangible risk reduction benefit. Containment bypass sequences, both the so–called interfacing systems LOCA and steam generator tube rupture (SGTR), contribute very significantly to the annual offsite risk at Zion. "Front–end" improvements to reduce the incidence of bypass initiators have not been analyzed. However, any reductions in bypass frequency would provide a corresponding reduction in all risk measures. In addition, a preliminary report from Sandia National Laboratory (SNL) mentions two possible mitigative strategies, based on a plant visit to Surry. The first of these strategies is to ensure that the break location in the interfacing systems LOCA is submerged. The second is a suggestion to reflood the steam generators in the case of SGTR, to ensure that the release from the RCS is scrubbed through a volume of water. Neither of these suggestions has been evaluated in this report, because the means to do so were unavailable. A preliminary evaluation of these improvements for Surry by SNL found a significant reduction in the early and latent fatality risk (no doses or offsite costs were calculated). Both may have the potential to generically reduce the bypass sequence risk. However, the efficacy and cost–effectiveness of these strategies is best determined on a plant–specific basis.

Gradual overpressurization by noncondensible gases (including steam) is not a threat to containment integrity for Zion. Containment failure by eventual overpressurization (time scale of one or more days) was predicted only in the APET runs made for the LOCA plant damage state group. Even in these cases, the conditional probability of eventual overpressurization was very small. Again, this result is Zion–specific. A relatively high probability of containment failure attributable to basemat melt–through (BMT) was found; however, these failures are negligible contributors to offsite risk.

FOREWORD

SECY–88–[illegible]47, dated May 25, 1988, presented the NRC staff's program plan to evaluate generic severe accident containment vulnerabilities via the Containment Performance Improvement (CPI) program. This effort was predicated on the assumption that there are generic severe accident challenges for each light water reactor (LWR) containment type that should be addressed to determine whether additional regulatory guidance or requirements concerning needed containment features are warranted, and to confirm the adequacy of the existing Commission policy. The bases for the assumption that such assessments were needed included the uncertainty in the ability of some LWR containments to successfully survive some severe accident challenges, as indicated in draft NUREG–1150. All LWR containment types have been assessed beginning with the boiling water reactors (BWRs) with Mark I containments. This effort was closely integrated with the Individual Plant Examination (IPE) program and is intended to focus on resolution of hardware and procedural issues related to generic containment challenges.

This report documents the results of NRC–sponsored research related to severe accident challenges and potential enhancements that could improve containment performance. The purpose of this report is to provide pressurized water reactor (PWR) dry containment owners with information they may find useful in their IPE. No requirements are contained in this report; it is provided for information only.

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A number of people made significant contributions to this project. Foremost among them is Carrie Grimshaw, formerly of Brookhaven National Laboratory, who supplied the source codes for EVNTRE and ZISOR, along with the input files for the Zion plant. Without her cooperation in supplying these files, this project could not have been completed on schedule. We would also like to thank Bill Galyean, who always had time to discuss problems when they arose. Finally, we would like to thank Doug Woody of Westinghouse Savannah River Co. for supplying us with a copy of ET-LOAD for use in this project.

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FIGURES

TABLES

ACRONYMS

AFWS	Auxiliary feedwater system
APET	Accident progression event tree
ATWS	Anticipated transient without scram
BMT	Basemat melt–through
BNL	Brookhaven National Laboratory
BWR	Boiling water reactor
CCI	Core–concrete interaction
CPI	Containment performance improvement
DCH	Direct containment heating
EDG	Emergency diesel generator
EVSE	Ex–vessel steam explosion
HPME	High pressure melt ejection
LHS	Latin hypercube sampling
LOCA	Loss–of–coolant accident
LPIS	Low pressure injection system
LWR	Light water reactor
MACCS	MELCOR Accident Consequence Code System
PDS	Plant damage state
PORV	Pilot–operated relief valve
PWR	Pressurized water reactor
RCP	Reactor coolant pump
RCS	Reactor coolant system
S2	Medium LOCA
SAIC	Science Applications International Corporation
SBO	Station blackout
SCET	Simplified containment event tree
SGTR	Steam generator tube rupture
SNL	Sandia National Laboratory
STCP	Source Term Code Package

QUANTITATIVE ANALYSIS OF POTENTIAL PERFORMANCE IMPROVEMENTS FOR THE DRY PRESSURIZED WATER REACTOR CONTAINMENT

1. INTRODUCTION

In SECY-88-147, dated May 25, 1988, the NRC staff presented to the Commission its program plan to evaluate generic severe accident containment vulnerabilities in the Containment Performance Improvement (CPI) program. This effort is predicated on the presumption that there are generic severe accident challenges to each light water reactor (LWR) containment type that should be assessed to determine whether additional regulatory guidance or requirements concerning needed containment features are warranted, and to confirm the adequacy of the existing Commission policy. The bases for the presumption that such assessments are needed include the uncertainty in the ability of LWR containments to successfully survive some severe accident challenges, as indicated by draft NUREG-1150.[1]

This report focuses on dominant severe accident challenges, as identified by the most recent NUREG-1150 research, which can conceivably threaten dry PWR containment integrity. Potential improvements from the draft Issues Characterization Report[2] are evaluated for their ability to arrest core damage, prevent or delay containment failure during postulated severe accidents, or mitigate the offsite health consequences of a fission product release. Accordingly, a risk analysis has to be performed to correlate containment challenges, resulting consequences, sequence frequencies, and potential improvement benefits. Potential improvements and benefits are considered for each containment challenge.

A quantitative risk analysis is presented to correlate severe accident sequence frequencies, containment failure mode probabilities, and the magnitude of the offsite consequences. As seen in Equation 1.1, the risk from operation of a nuclear power plant stems from all these factors:

$$\mathrm{RISK}_k = \sum_{i=1}^{m} \sum_{j=1}^{n} \Big[\mathrm{FREQ}_i \, * \, \mathrm{CRMP}_{ij} \, * \, \mathrm{CONS}_k \, (\mathrm{FP}_{ij})\Big] \qquad (1.1)$$

where,

RISK_k = the risk associated with consequence measure k

FREQ_i = the frequency of accident sequence i

CRMP_{ij} = the conditional probability of containment release mode j, given accident sequence i

FP_{ij} = fission product source term for containment release mode j of accident sequence i

CONS_k = mean magnitude of consequence k, given fission product source term (FP_{ij}) for release mode j and sequence i.

Consequently, all factors affecting plant risk should be considered in a program to improve containment performance.

Because of time and budget constraints, this report analyzes only PWR containments that operate at atmospheric pressure, with Zion being chosen as the reference plant. Subatmospheric containments such as Surry are not specifically analyzed in this report, although some of the conclusions reached may also be applicable to this type of PWR containment as well. The fact that Zion was used as the reference plant for the atmospheric PWR containment should also be stressed. As a result of this choice, some of the results may be specific to Zion; applicability to other sites would have to be verified on a plant-specific basis.

The analyses in this report are based on the June 1989 draft NUREG-1150 analysis of the Zion plant.[1,3,4] The methodology used is explained in detail in Section 2. Briefly, simplified containment event trees (SCETs), each consisting of 10-15 top events, were developed from the large 72-question accident progression event trees (APET) used to analyze the Zion containment response for draft NUREG-1150. A base case SCET was constructed for each of the dominant Zion plant damage states: (1) loss-of-coolant accidents (LOCAs), (2) station blackout (SBO), (3) transients (including anticipated transients without scram), and (4) containment bypass. Each of these plant damage states is defined in draft NUREG/CR-4550 for Zion.[3] The SCETs were utilized to the greatest extent possible in analyzing the effects of the potential improvements on containment response. The details of how this was done are provided in Section 2.

To reduce the number of source term calculations, the end states of the SCETs were grouped into accident progression bins in accordance with the binning scheme presented in draft NUREG/CR-4551 for Zion.[4] This scheme groups together end states that have similar characteristics of containment failure mode, type of reactor vessel breach, amount of core-concrete interaction (CCI), etc. The details of the scheme used to bin the SCET end states are presented in Section 2.

For each accident progression bin produced by grouping the SCET end states, a source term must be calculated so that offsite consequences can be determined. As in the draft NUREG-1150 analysis of Zion, the ZISOR parametric source term generation code was used to do this.[4] For each accident progression bin, ZISOR parametrically calculates important characteristics of the containment release. Examples of these characteristics are the time and duration of the release, the release fractions of the various nuclide groups, and the energy of the release. In all of the cases in this report, *point estimates* of the source terms were obtained using ZISOR. This is an important technicality that will be discussed in more detail in later sections.

The source terms generated with the ZISOR code are input to the MELCOR Accident Consequence Code System (MACCS), along with site data from the Zion draft NUREG-1150 MACCS deck. The MACCS code generates conditional offsite consequences for each set of source terms input from ZISOR, generally for each accident progression bin. These conditional consequences are the last input needed to calculate risk using Equation 1.1. For this report, five risk measures are reported: (1) the mean number of early (acute) fatalities per reactor-year of operation, (2) the mean number of latent cancer fatalities per reactor-year of operation, (3) the mean dose (in person-rem per reactor-year) within 50 miles of the plant, (4) the mean dose (in person-rem per reactor-year) over the entire 1000-mile MACCS calculational grid, and (5) the mean offsite costs ($ per reactor-year).

The authors would like to emphasize that *point estimates* of risk were calculated for this report. There is an uncertainty range associated with each of these numbers, either because of stochastic variations or lack of knowledge. These uncertainties have not been fully evaluated for this report, since a full uncertainty analysis was beyond the specified scope of work. In some instances, sensitivity cases have been run in an attempt to provide an estimate of uncertainty. However, the reader should keep this limitation in mind when using any of the risk estimates in this report.

A word of caution should likewise be added about the number of significant figures associated with the values in this report. In most cases, the codes used in the analysis provide two or more significant figures. The authors generally have reported all values using two or three significant figures. However, this does not signify high confidence in these values to this level of precision. On the contrary, our level of knowledge is limited to, at most, one significant figure. The important point is that the reader should not take the values in this report literally to the second or third place after the decimal, because the values are not really accurately known to that level. As an example, a reported value of 0.167 should probably be interpreted as 0.2.

2. METHODOLOGY

This section describes in some detail the methodology used to construct and quantify the SCETs. It also describes the process used to bin the SCET end states into accident progression bins, the use of the ZISOR code to generate source terms, and the use of the MACCS code to calculate consequences. Readers interested primarily in the results of the analysis rather than the details of the analysis itself may omit this section.

2.1 Construction of SCETs

The EVNTRE event progression analysis code[5] provided the essential tool for developing SCETs from the large APETs used for Reference 4. The Zion APET consists of 72 questions or top events, with most questions having multiple branches (see Appendix A for a listing of a representative Zion APET). Because the APET is so large and complex, it cannot be graphically represented; it exists only as a computer input file. The APET's complexity makes it very useful for detailed evaluations of containment response but the analysis is similarly complicated and the results can be difficult to interpret without highly detailed knowledge of the analysis. One of the goals of this analysis was to condense the information contained in the APET into a form that can be graphically displayed so that individual paths through the event tree can be visually traced out. Thus, there was a need to construct SCETs.

Rather than the 72 questions in the Zion APET, the SCETs each have at most 10–20 questions. In addition, all branching in the SCETs is binary. Tertiary and higher order branching was eliminated in order to simplify the paths through the tree to the greatest possible extent.

2.1.1 Branching Structure Determination. The skeletal structure of each SCET was developed by using the sorting feature in the EVNTRE code. This feature allows the user to select summary questions displaying the relevant accident progression phenomenology from the APET and sort the output of the APET on these questions. The result of this sorting is a greatly simplified event tree, whose top events are simply the summary questions arranged according to the order specified in the sort. The sorted output file from EVNTRE provides the branching structure for the SCET. To make this concept more concrete, the base case SCET for the LOCA plant damage state (PDS) is developed in this section as an example.

The full 72–question APET for the Zion LOCA PDS is listed in Appendix A for reference. The first step in constructing the SCET is to select the summary questions from the APET that will represent the top events in the SCET. For the LOCA PDS, the following questions were chosen (the question numbers refer to the APET listed in Appendix A).

1. CI – #11: Event CI questions whether there is pre–existing containment leakage.
2. VB – #23: Event VB questions whether reactor vessel breach occurs.
3. E–SPRY – #24: Event E–SPRY questions whether containment sprays are available prior to vessel breach.
4. FLD – #31: Event FLD questions whether the reactor cavity is flooded or dry at the time of vessel breach.
5. HPME – #35: Event HPME questions whether high pressure melt ejection occurs at the time of vessel breach.
6. EVSE – #40: Event EVSE questions whether a significant ex–vessel steam explosion occurs following vessel breach.
7. E–CF – #42: Event E–CF questions whether containment failure occurs at, or shortly after, vessel breach.
8. SPRY – #43: Event SPRY questions the availability of containment sprays following vessel breach.
9. CCI – #50,55: Event CCI questions whether there is either a prompt or delayed core–concrete interaction (CCI) following vessel breach.
10. L–OP – #64: Event L–OP questions whether late overpressure containment failure occurs.
11. BMT – #68: Event BMT questions whether basemat melt–through occurs.

To obtain the sorted output file that contains the branch structure information for the SCET, the EVNTRE code is run using the LOCA APET as the tree input file, with a binning input file constructed to sort the output on the above 11 questions. The EVNTRE code initially had to be run in the point estimate mode (mode 2), because the post-processors needed to evaluate output from the sampling mode were not available at the beginning of this project. This can be a fairly severe limitation, because the results of a point estimate run can be drastically different from results obtained in the sampling mode. However, this limitation was overcome to a degree, as will be explained shortly. The binning input file and the sorted output from the point estimate run for the LOCA PDS will be presented first.

Zion LOCA Input Binning File

```
11          CI     VB         E-SPRY      FLD        HPME       EVSE     E-CF      SPRY
            CCI    L-OP       BMT
2      2    CI        No-CI                                     $ Pre-existing cont. leakage
1      1    11
             1
            CI
1      2    11
            /1
            No-CI
2      2    VB        No-VB                                     $ Vessel breach
1      1    23
            /1
            VB
1      2    23
             1
            No-VB
2      2    E-SPRY  noE-SPRY                                    $ Early sprays
1      1    24
             1
            E-SPRY
1      2    24
            /1
            noE-SPRY
2      2    FLD        Dry                                      $ Amount of water in cavity
1      1    31
             1
            Wet
1      2    31
            /1
            Dry
2      2    HPME     No-HPME                                    $ High pressure melt ejection
1      1    35
             1
            PrEj
1      2    35
            /1
            nPrEj
2      2    EVSE   nEVSE                                        $ Ex-vessel steam explosion
1      1    40
             1
            EVSE
1      2    40
            /1
            nEVSE
```

Zion LOCA Input Binning File (continued)

```
2     2     E-CF      noE-CF                                  $ Early Cont. Failure
1     1     42
            /4
            E-CF
1     2     42
             4
            noE-CF
2     2     SPRY                noSPRY                  $ Sprays after vessel breach
1     1     43
             1
            SPRY
1     2     43
            /1
            noSPRY
2     2     CCI                 NoCCI                   $ Core-concrete interaction
2     1     50                    55
             1      +             1
            PrmCCI                  DldCCI
2     2     50                      55
            /1                      /1
            noPrmptCCI              noDelydCCI
2     2     L-OP                  noL-OP                  $ Late overpressure cont. failure
1     1     64
            /5
            OP-CCI
1     2     64
             5
            noOP-CCI
2     2     BMT                     noBMT                 $ Basemat melt-through
1     1     68
            /3
            BMT
1     2     68
             3
            noBMT
1
11          1    2    3    4    5    6    7    8    9    10    11
            CI    VB    E-SPRY    FLD    HPME    EVSE    E-CF    SPRY
            CCI   L-OP    BMT
```

Sorted Output for LOCA PDS

```
CI          VB          E-SPRY      FLD         HPME        nEVSE       noE-CF      SPRY        CCI         noL-OP      noBMT
                                                                                            1.4323E-04  1.4323E-04  1.4323E-04
CI          VB          E-SPRY      FLD         HPME        nEVSE       noE-CF      SPRY        NoCCI       noL-OP      noBMT
                                                2.8646E-04  2.8646E-04  2.8646E-04  2.8646E-04  1.4323E-04  1.4323E-04  1.4323E-04
CI          VB          E-SPRY      FLD         No-HPME     EVSE        noE-CF      SPRY        CCI         noL-OP      noBMT
                                                                                            1.1598E-03  1.1598E-03  1.1598E-03
CI          VB          E-SPRY      FLD         No-HPME     EVSE        noE-CF      SPRY        NoCCI       noL-OP      noBMT
                                                            2.3196E-03  2.3196E-03  2.3196E-03  1.1398E-03  1.1598E-03  1.1598E-03
CI          VB          E-SPRY      FLD         No-HPME     nEVSE       E-CF        noSPRY      CCI         noL-OP      noBMT
                                                                        3.6333E-05  3.6333E-05  3.6333E-05  3.6333E-05  3.6333E-05
CI          VB          E-SPRY      FLD         No-HPME     nEVSE       noE-CF      SPRY        CCI         noL-OP      noBMT
                                                                                            2.0925E-03  2.0925E-03  2.0925E-03
CI          VB          E-SPRY      FLD         No-HPME     nEVSE       noE-CF      SPRY        NoCCI       noL-OP      noBMT
                                    4.9716E-03  4.6852E-03  2.3655E-03  2.3292E-03  2.3292E-03  2.3674E-04  2.3674E-04  2.3674E-04
CI          VB          E-SPRY      Dry         No-HPME     nEVSE       E-CF        noSPRY      CCI         noL-OP      noBMT
                                                                        2.2624E-07  2.2624E-07  2.2624E-07  2.2624E-07  2.2624E-07
CI          VB          E-SPRY      Dry         No-HPME     nEVSE       noE-CF      SPRY        CCI         noL-OP      noBMT
            4.9999E-03  4.9999E-03  2.8280E-05  2.8280E-05  2.8280E-05  2.8054E-05  2.8054E-05  2.8054E-05  2.8054E-05  2.8054E-05
CI          No-VB       E-SPRY      FLD         No-HPME     nEVSE       noE-CF      SPRY        NoCCI       noL-OP      noBMT
                                    7.3904E-08  7.3904E-08  7.3904E-08  7.3904E-08  7.3904E-08  7.3904E-08  7.3904E-08  7.3904E-08
CI          No-VB       E-SPRY      Dry         No-HPME     nEVSE       noE-CF      SPRY        NoCCI       noL-OP      noBMT
5.0000E-03  8.4088E-08  8.4088E-08  1.0184E-08  1.0184E-08  1.0184E-08  1.0184E-08  1.0184E-08  1.0184E-08  1.0184E-08  1.0184E-08
No-CI       VB          E-SPRY      FLD         HPME        nEVSE       noE-CF      SPRY        CCI         noL-OP      BMT
                                                                                                                    5.7005E-03
No-CI       VB          E-SPRY      FLD         HPME        nEVSE       noE-CF      SPRY        CCI         noL-OP      noBMT
                                                                                            2.8502E-02  2.8502E-02  2.2802E-02
No-CI       VB          E-SPRY      FLD         HPME        nEVSE       noE-CF      SPRY        NoCCI       noL-OP      noBMT
                                                5.7005E-02  5.7005E-02  5.7005E-02  5.7005E-02  2.8502E-02 2.8502E-02   2.8502E-02
No-CI       VB          E-SPRY      FLD         No-HPME     EVSE        noE-CF      SPRY        CCI         noL-OP      BMT
                                                                                                                    6.9241E-02
No-CI       VB          E-SPRY      FLD         No-HPME     EVSE        noE-CF      SPRY        CCI         noL-OP      noBMT
                                                                                            2.3080E-01  2.3080E-01  1.6156E-01
No-CI       VB          E-SPRY      FLD         No-HPME     EVSE        noE-CF      SPRY        NoCCI       noL-OP      noBMT
                                                            4.6161E-01  4.6161E-01  4.6161E-01  2.3081E-01  2.3081E-01  2.3081E-01
No-CI       VB          E-SPRY      FLD         No-HPME     nEVSE       E-CF        noSPRY      CCI         noL-OP      noBMT
                                                                        7.2302E-03  7.2302E-03  7.2302E-03  7.2302E-03  7.2302E-03
No-CI       VB          E-SPRY      FLD         No-HPME     nEVSE       noE-CF      SPRY        CCI         noL-OP      BMT
                                                                                                                    1.6637E-01
No-CI       VB          E-SPRY      FLD         No-HPME     nEVSE       noE-CF      SPRY        CCI         noL-OP      noBMT
                                                                                            4.1640E-01  4.1640E-01  2.5003E-01
No-CI       VB          E-SPRY      FLD         No-HPME     nEVSE       noE-CF      SPRY        NoCCI       noL-OP      noBMT
                                    9.8936E-01  9.3235E-01  4.7074E-01  4.6351E-01  4.6351E-01  4.7111E-02  4.7111E-02  4.7111E-02
No-CI       VB          E-SPRY      Dry         No-HPME     nEVSE       E-CF        noSPRY      CCI         noL-OP      noBMT
                                                                        4.5021E-05  4.5021E-05  4.5021E-05  4.5021E-05  4.5021E-05
No-CI       VB          E-SPRY      Dry         No-HPME     nEVSE       noE-CF      SPRY        CCI         noL-OP      BMT
                                                                                                                    2.2331E-03
No-CI       VB          E-SPRY      Dry         No-HPME     nEVSE       noE-CF      SPRY        CCI         noL-OP      noBMT
            9.9498E-01  9.9498E-01  5.6277E-03  5.6277E-03  5.6277E-03  5.5827E-03  5.5827E-03  5.5827E-03  5.5827E-03  3.3496E-03
No-CI       No-VB       E-SPRY      FLD         No-HPME     nEVSE       noE-CF      SPRY        NoCCI       noL-OP      noBMT
                                    1.4707E-05  1.4707E-05  1.4707E-05  1.4707E-05  1.4707E-05  1.4707E-05  1.4707E-05  1.4707E-05
No-CI       No-VB       E-SPRY      Dry         No-HPME     nEVSE       noE-CF      SPRY        NoCCI       noL-OP      noBMT
9.9500E-01  1.6733E-05  1.6733E-05  2.0267E-06  2.0267E-06  2.0267E-06  2.0267E-06  2.0267E-06  2.0267E-06  2.0267E-06  2.0267E-06
```

The SCET branching structure is obtained from this sorted output by tracing lines through the output, starting at the lower left hand corner, with branches at each point where the conditional probability changes. The first several branches for the LOCA SCET have been outlined in the sorted output above to illustrate this procedure. The split fraction at each branch is calculated by dividing the sequence fraction at the branch in question by the fraction at the preceding point in the SCET. For larger SCETs with more top events upon which to sort the APET output, this procedure quickly becomes unwieldy to perform by hand. To automate the construction of the SCETs from the sorted output, use was made of an interface code currently under development by Science Applications International Corporation (SAIC) called ET–LOAD.[6] This code reads the sorted output file from EVNTRE and constructs the SCET using SAIC's ETA–II event tree code.[7] The branching structure and split fractions are determined automatically by ET–LOAD. Note that the sorted output indicates that early containment sprays are always available in the LOCA PDS. Therefore, in order to further simplify the event tree, the column headed by event E–SPRY was deleted.

There is a further limitation in that the EVNTRE code is set up to sort upon at most ten questions. This limitation was overcome by making a modification to the EVNTRE source code to allow use of up to 20 sort parameters. However, this same limitation also exists in the version of ET–LOAD obtained from SAIC. Because the source code for ET–LOAD was unavailable, the allowed number of sort parameters could not be increased. Therefore, for larger SCETs, the branching structure and split fractions for the last few questions had to be input by hand.

2.1.2 Split Fraction Evaluation. As mentioned above, the point estimate split fractions are calculated by dividing the sequence fraction at the branch in question by the fraction at the preceding point in the SCET. However, because these split fractions were obtained from a *point estimate* evaluation of the APET, the SCET with these split fractions may not always accurately model the APET results. An example of this type of problem is seen in the conditional probability of early containment failure attributable to direct containment heating (DCH). The point estimate evaluation of the APET does not predict any failures of this type. On the other hand, Reference 4 indicates that the conditional probability of DCH failure, given the occurrence of the LOCA PDS, is ~1.7×10^{-3}. Because the post–processors needed to extract a composite sorted output from an APET evaluated in the sampling mode were not initially available, a method was developed to reduce the impact of having to sort the APET in the point estimate mode. The key to this method is the use of the EVNTRE frequency output file generated from a sampling mode evaluation of the APET. This file, as discussed in Reference 5, provides the realized split fractions for each question in the APET. A particular split fraction in this file is actually the conditional probability of taking that particular branch of the APET. By referring to the appropriate question in the APET, the conditional probability of DCH failure, vessel breach, basemat melt–through (BMT), and other parameters of interest can be determined. The frequency output file for the base case LOCA PDS is shown in Appendix B.

Figure 2.1 shows the LOCA SCET obtained from the point estimate run. Similarly, Figure 2.2 shows the final base case LOCA SCET obtained by modifying the SCET in Figure 2.1 to obtain agreement with the sampled frequency output.

2.1.3 Binning of SCET End States. The next step in the analysis is to map the end states of the SCET into the set of accident progression bins defined in Reference 4. This mapping is required in using the ZISOR code to generate source terms for the consequence calculations. Binning the SCET end states is a two–step process. First, an EVNTRE input file must be created to describe the SCET. This file is analogous to the APET file listed in Appendix A but it describes the SCET instead of the 72–question APET. The file that describes the LOCA SCET is listed as follows:

Zion Simplified Containment Event Tree (SCET)

```
    10
   NQ
     1          1.000
               LOCA
 1   Is there pre–existing containment leakage?
     2            CL        ncCL
     1             1           2
                0.005       0.995
```

Zion Simplified Containment Event Tree (SCET) (continued)

```
2  Does the reactor pressure vessel fail?
    2            VB          noVB
    1             1             2
          0.9999832     0.0000168
3  Is the reactor cavity flooded?
    2           FLD         noFLD
    2             1             2
    2
    1             2
                  1
                 VB
             0.9943        0.0057
          Otherwise
              0.879         0.121
4  Does HPME occur at vessel failure?
    2          HPME        noHPME
    2             1             2
    2
    2             2             3
                  1           * 1
                 VB           FLD
           5.80E-02      9.42E-01
          Otherwise
              0.000         1.000
5  Does a large ex-vessel steam explosion occur?
    2          EVSE        noEVSE
    2             1             2
    2
    3             2             3             4
                  1           * 1           * 2
                 VB           FLD        noHPME
           4.95E-01      5.05E-01
          Otherwise
              0.000         1.000
6  Does early containment failure occur?
    2          E-CF        noE-CF
    2             1             2
    4
    5             1             2             3             4             5
                  2           * 1           * 1           * 1           * 2
               noCL            VB           FLD          HPME        noEVSE
           2.50E-02      9.75E-01
    4             2             3             4             5
                  1           * 1           * 2           * 2
                 VB           FLD        noHPME        noEVSE
           1.50E-02      9.85E-01
    2             2             3
                  1           * 2
                 VB         noFLD
           8.00E-03      9.92E-01
          Otherwise
              0.000         1.000
```

Zion Simplified Containment Event Tree (SCET) (continued)

```
7   Sprays after vessel breach?
      2        SPRY      noSPRY
      2           1           2
      2
      2           4           6
                  2         * 1
             noHPME        E-CF
              0.000       1.000
          Otherwise
              1.000       0.000
8   Does core-concrete interaction occur?
      2         CCI       noCCI
      2           1           2
      5
      1           4
                  1
               HPME
           5.00E-01    5.00E-01
      1           5
                  1
               EVSE
           5.00E-01    5.00E-01
      5           2           3           4           5           6
                  1         * 1         * 2         * 2         * 2
                 VB         FLD      noHPME      noEVSE      noE-CF
           8.98E-01    1.02E-01
      1           2
                  2
               noVB
              0.000       1.000
          Otherwise
              1.000       0.000
9   Does late containment overpressure failure occur?
      2        L-OP      noL-OP
      [illegible]           1           2

                  1           6           8
                  2         * 2         * 1
               noCL       noE-C         CCI
         9.[illegible]-04  9.991E-01
        [illegible]se
                          1.000
[illegible]hat melt-through occur?
     [illegible]T      noBMT
                  1           2

                  1           2           4           6           8           9
                  2         * 1         * 1         * 2         * 1         * 2
               noCL          VB        HPME      noE-CF         CCI      noL-OP
            2.0E-01     8.0E-01
      7           1           2           4           5           6           8           9
                  2         * 1         * 2         * 1         * 2         * 1         * 2
               noCL          VB      noHPME        EVSE      noE-CF         CCI      noL-OP
            3.0E-01     7.0E-01
      7           1           2           4           5           6           8           9
                  2         * 1           2         * 2         * 2         * 1         * 2
               noCL          VB      noHPME      noEVSE      noE-CF         CCI      noL-OP
            4.0E-01     6.0E-01
          Otherwise
              0.000       1.000
```

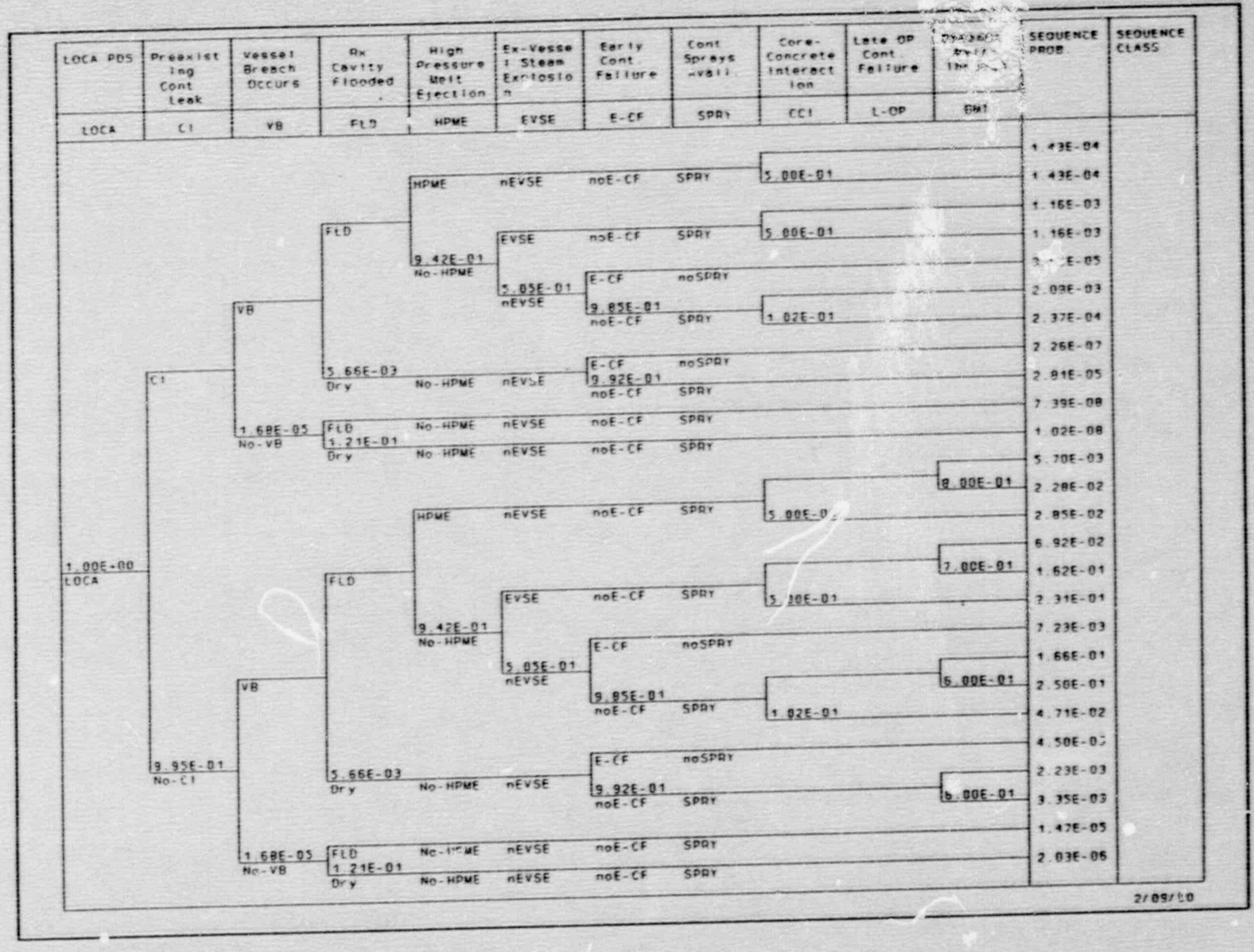


Figure 2.1. Point estimate LOCA SCET.

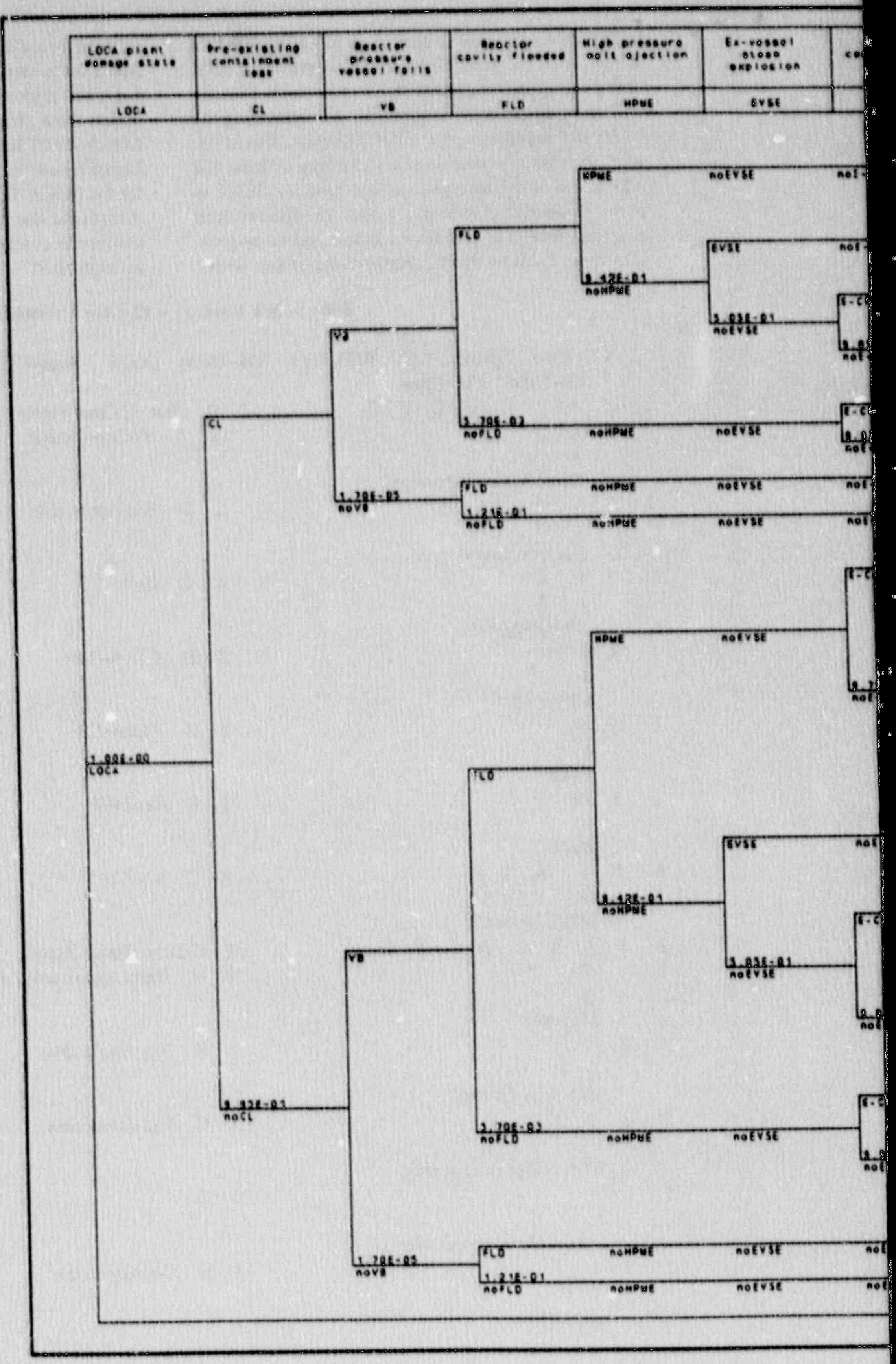
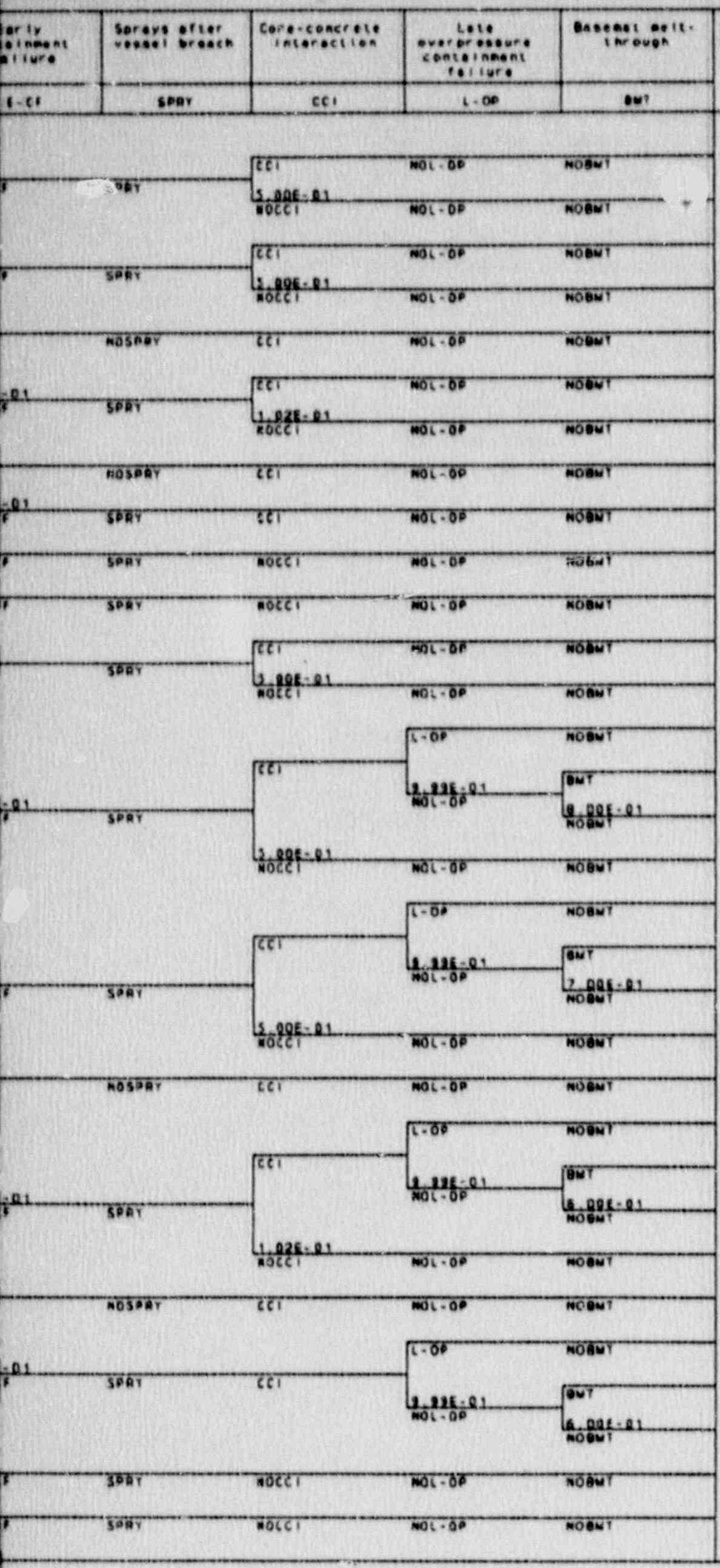


Figure 2.2. Base case LOCA SCET.



SEQUENCE PROB	SEQUENCE CLASS	SEQUENCE DESCRIPTION
1.44E-04	ECF-CL-D	CDDCACABACBB
1.44E-04	ECF-CL-D	CDCCACDBACBB
1.16E-03	ECF-CL	CDDDBCBBDCBB
1.16E-03	ECF-CL	CDCDBCDBDCBB
3.55E-05	ECF-CL-A	DAFDDCBBDBBB
2.09E-03	ECF-CL	CDDDBCABDCBB
2.30E-04	ECF-CL	CDCDBCDBDCBB
2.20E-07	ECF-CL-A	DAADDCBBDBBB
2.83E-05	ECF-CL	CDADBCABDCBB
7.47E-06	ECF-CL	CDCAFCBBDCBB
1.03E-08	ECF-CL	CDCAFCDBDCBB
7.17E-04	ECF-D	DDDCACABACBB
7.17E-04	ECF-D	DDCCACDBACBB
2.52E-05	LCF	EDDCACABACBB
5.59E-03	BMT	FDDCACABAEBB
2.24E-02	NCF	GDDCACABAGBB
2.80E-02	NCF	GDCCACDBAGBB
2.08E-04	LCF	EDDDBCBBDCBB
6.91E-02	BMT	FDDDBCBBDEBB
1.61E-01	NCF	GDDDBCBBDGBB
2.31E-01	NCF	GDCDBCDBDGBB
7.06E-03	ECF-A	DAFDDCBBDBBB
3.73E-04	LCF	EDDDBCABDCBB
1.66E-01	BMT	FDDDBCABDEBB
2.50E-01	NCF	GDDDBCABDGBB
4.73E-02	NCF	GDCDBCDBDGBB
4.54E-05	ECF-A	DAADDCBBDBBB
5.06E-06	LCF	EDADBCABDCBB
2.25E-03	BMT	FDADBCABDEBB
3.37E-03	NCF	GDADBCABDGBB
1.49E-05	NCF	GDCAFCDBDGBB
2.05E-08	NCF	GDCAFCDBDGBB

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The second step is to construct a binning file that assigns each end state of the SCET to one of the accident progression bins defined in Reference 4. This file will serve as the input binning file for evaluating the SCET file above using the EVNTRE code. This is exactly analogous to what was done initially with the full APET. The only difference is that now the SCET is being evaluated. Reference 4 uses 12-dimensional character vectors to identify the Zion accident progression bins. Each of the 12 components of the vector represents a characteristic of the sequence that may affect the source term (see Table 2.4-1 in Reference 4 for a description of these characters). The file used to assign these character vectors to the end states of the LOCA APET in Reference 4 is shown in Appendix C. Listed below is the analogous binning file developed for the LOCA SCET. The question numbers in this file refer to the questions in the SCET, with the questions numbered consecutively from left to right, starting with question 1.

Zion SCET Binning – 12 Characteristics

```
12  CF–Time  Sprays  CCI  RCS–Pres  VB–Mode  SGTR  Amt–CCI  Zr–Ox  HPME  CF–Size
      RCS–Hole  CD–Time
7  7  A  B  C  D  E  F  G                 $  Char. 1, Cont. Failure Time
2  1  1   1                               $  A   Not Applicable
      1   /1
      Event V, not submerged
2  2  1   1                               $  B   Not Applicable
      1   /1
      Event V, submerged
2  3  1   6                               $  C   Early–CF
      1   2
      CF before VB
1  4  6                                   $  D   CF–at–VB
      1
      CF at VB
1  5  9                                   $  E   VLate–CF
      1
      L–OP
1  6  10                                  $  F   Final–CF
      1
      BMT
4  7  1    6   9  10                      $  G   No–CF
      2  *2 *2 *2
      SGTR or NoCF
8  8  A  B  C  D  E  F  G  H              $  Char. 2, Spray Status
1  1  7                                   $  A   Early sprays only; sprays fail at vessel breach.
      2
      ESp only
2  2  1   1                               $  B   Not Applicable
      1   /1
      ESp & ImSp only
2  3  1   1                               $  C   Not Applicable
      1   /1
      ESp, ImSp, & LSp only
1  4  7                                   $  D
      1
      Sprays always available
2  5  1   1                               $  E   Not Applicable
      1   /1
      LSp only
```

Zion SCET Binning – 12 Characteristics (continued)

```
2   6   1   1                              $  F  Not Applicable
        1   /1
        LSp & VLSp only
2   7   1   1                              $  G  Not Applicable
        1   /1
        VLSp only
2   8   1   1                              $  H  Not Applicable
        1   /1
        No sprays
6   6   A  B  C  D  E  F                   $  Char. 3, CCI
2   1   3   8                              $  A  Prmpt CCI in dry cavity.
        2   1
        PrmptDry
2   2   1   1                              $  B  Not Applicable
        1   /1
        Prmpt CCI in shallow pool
1   3   8                                  $  C
        2
        No CCI
3   4   3   7   8                          $  D
        1   1   1
        Prmpt CCI in wet cavity
2   5   1   1                              $  E  Not Applicable
        1   /1
        Short delay CCI–cavity not replenished
3   6   3   7   8                          $  F  CCI occurs after a long delay;  cavity not replenished.
        1   2   1
        LDlyd–Dry
4   4   A  B  C  D                         $  Char. 4, RCS Pressure before VB
1   1   2                                  $  A
        2
        System setpoint pressure
2   2   1   1                              $  B  Not Applicable
        1   /1
        High Pressure
2   3   2   4                              $  C
        1   1
        Intermediate
2   4   2   4                              $  D
        1   2
        Low pressure
6   6   A  B  C  D  E  F                   $  Char. 5, Mode of VB
1   1   4                                  $  A
        1
        PrEj
3   2   2   4   6                          $  B
        1   2   2
        Gravity pour
2   3   1   1                              $  C  Not Applicable
        1   /1
        Gross failure of bottom head
```

Zion SCET Binning – 12 Characteristics (continued)

```
2   4   4   6                                        $  D
        2   1
        Alpha mode
2   5   1   1                                        $  E   Not Applicable
        1   /1
        Rocket failure
1   6   2                                            $  F
        2
        No VB
3   3   A   B   C                                    $  Char. 6, SGTR
2   1   1   1                                        $  A   Not Applicable
        1   /1
        SGTR w/no SORVs
2   2   1   1                                        $  B   Not Applicable
        1   /1
        SGTR w/ SORVs
2   3   1   1                                        $  C   SGTR never occurs for LOCA PDS
        1 + 2
        No SGTR
4   4   A   B   C   D                                $  Char. 7, Amt. of core in CCI
6   1   4   8       4   5   6   8                    $  A
        1   1  + ( 2   2   2   1 )
        70–100% of core in CCI
5   2   5   8       4   5   6                        $  B
        1   1  + ( 2   2   1 )
        30–70% of core in CCI
2   3   1   1                                        $  C   Not Applicable
        1   /1
        0–30% of core in CCI
1   4   8                                            $  D
        2
        No CCI
2   2   A   B                                        $  Char. 8, Zr oxidation
2   1   1   1                                        $  A   Not Applicable
        1   /1
        Low Zr oxidation in–vessel
2   2   1   1                                        $  B
        1 + 2
        Hi Zr oxidation in–vessel
4   4   A   B   C   D                                $  Char. 9, HPME
1   1   4                                            $  A
        1
        >40% of core
2   2   1   1                                        $  B   Not Applicable
        1   /1
        Moderate fraction (20–40%)
2   3   1   1                                        $  C   Not Applicable
        1   /1
        Low fraction ( <20% )
1   4   4                                            $  D
        2
        No HPME
```

Zion SCET Binning – 12 Characteristics (continued)

```
7   7  A  B  C  D  E  F  G                  $  Char. 10, Type of cont. failure
2   1  1    1                 $                A   Not Applicable
       1   /1
       Catastrophic rupture
2   2  4    6                               $  B
       2    1
       Rupture
4   3  1    4  6   9                        $  C
       1+( 1   1)+ 1
       Leak
2   4  1    1                               $  D   Not Applicable
       1   /1
       Shear
1   5  10                                   $  E
        1
       BMT
2   6  1    1                               $  F   Not Applicable
       1   /1
       Bypass (SGTR)
4   7  1    6  9   10                       $  G
       2 * 2 *2 *  2
       No CF
2   2  A  B                                 $  Char. 11, No. of holes in RCS
2   1  1    1                               $  A   Not Applicable
       1   /1
       1 hole
2   2  1    1                               $  B
       1 + 2
       2 holes
2   2  A  B                                 $  Char. 12, Time of core damage
2   1  1    1                               $  A   Not Applicable
       1   /1
       Early CD
2   2  1    1                               $  B
       1 +  2
       Late  CD
0
```

Comparing this file to the APET binning file in Appendix C, it is clear that not all of the characters could be used. The reason for this is that some details of the accident progression are unavoidably lost in the transition from the full 72–question APET to the decidedly smaller SCET (the mapping of end states to accident progression bins is *into* rather than *onto*). Examples where a reduction sometimes had to be made in the number of characters used to describe a vector dimension are the time of core damage, the number of holes in the reactor coolant system (RCS), the amount of zirconium oxidized in–vessel, and the amount of CCI. Wherever possible in these cases, characters were eliminated based on their conditional probability of occurrence in the sampled frequency output file.

Once the binning file is constructed, the EVNTRE code is run, with the file describing the SCET as input, along with the binning file needed to assign character vectors to the SCET end states. The result of this is an output file that lists each accident progression bin (identified by a unique 12–dimensional character vector) and its conditional probability of occurrence.

This file forms the input for the ZISOR source term calculation. The ZISOR base case LOCA input file is shown as follows:

SCET LOCA Accident Progression Bins

Conditional Probability	Vector
2.8272E–05	CDADBCABDCBB
8.4000E–08	CDCAFCDBDCBB
1.4417E–04	CDCCACDBACBB
1.3967E–03	CDCDBCDBDCBB
1.4417E–04	CDDCACABACBB
2.0919E–03	CDDDBCABDCBB
1.1591E–03	CDDDBCBBDCBB
4.5599E–05	DAADDCBBDBBB
7.0949E–03	DAFDDCBBDBBB
7.1725E–04	DDCCACDBACBB
7.1725E–04	DDDCACABACBB
5.0634E–06	EDADBCABDCBB
2.5176E–05	EDDCACABACBB
3.7465E–04	EDDDBCABDCBB
2.0759E–04	EDDDBCBBDCBB
2.2484E–03	FDADBCABDEBB
5.5895E–03	FDDCACABAEBB
1.6636E–01	FDDDBCABDEBB
6.9134E–02	FDDDBCBBDEBB
3.3726E–03	GDADBCABDGBB
1.6716E–05	GDCAFCDBDGBB
2.7973E–02	GDCCACDBAGBB
2.7794E–01	GDCDBCDBDGBB
2.2358E–02	GDDCACABAGBB
2.4954E–01	GDDDBCABDGBB
1.6131E–01	GDDDBCBBDGBB

A description for the first of these vectors, CDADBCABDCBB, is provided here for reference. Further discussion can be found in Reference 4.

Vector Character	Description
C	Containment failure before vessel breach
D	Containment sprays available throughout sequence
A	Prompt core–concrete interaction occurs in dry reactor cavity
D	RCS pressure low (<200 psig) at time of vessel failure
B	Gravity pour of debris from failed reactor vessel
C	No SGTR
A	70–100% of core participates in core–concrete interaction
B	Large amount of zirconium oxidation occurs in–vessel
D	No high pressure melt ejection from the failed reactor vessel
C	Containment rupture
B	Two holes in the RCS
B	Core damage occurs late.

The end state binning process was enhanced near the end of the project when the PSTEVNT post–processor code became available.[8] The use of this code to automatically map the end states of the SCET into ZISOR accident progression bins is described in Section 4.

2.2 Source Term Generation

A source term was calculated for each SCET accident progression bin using the ZISOR parametric source term generation code.[4] As mentioned earlier, the input to this code is the file listing the accident progression bins and their conditional probabilities of occurrence (these probabilities are not actually used in the ZISOR code). As in the previous case of EVNTRE, only point estimates of the source terms could be obtained from ZISOR, since the necessary post–processor (the PARTITION code)[9] was not available. This limitation is discussed further in the paragraphs which follow.

Figures 3.5–1 through 3.5–4 in Reference 4 show a comparison of the ZISOR results with those from the Source Term Code Package (STCP) for four accident sequences. As these figures illustrate, the point estimate isotopic release fractions calculated by ZISOR can differ markedly from the mean release fractions determined with ZISOR when using a Latin Hypercube Sampling (LHS) routine. In most cases, the point estimate is lower than the sampling mean, sometimes by several orders of magnitude. Because of this, the conditional consequences calculated with the MACCS code, using point estimate inputs from ZISOR, tend to be lower than the consequence results published in Reference 4. This is an inescapable problem, though not a severe one, that should be recognized when comparing the CPI results in this report to the Zion results published in the June 1989 draft of NUREG–1150.

For each accident progression bin, ZISOR calculates the characteristics of the release and the isotopic release fractions for each of the two allowable release plumes. The ZISOR output for the LOCA SCET accident progression bins is shown below. Following each 12-dimensional character vector are three rows of numbers, which represent the characteristics of the release. The meaning of each of these numbers (from left to right by row) is listed here for easy reference.

Row 1:
1) Warning time in seconds; usually the time of core collapse.
2) Time of beginning of early release in seconds.
3) Duration of early release in seconds.
4) Time of beginning of late release in seconds.
5) Duration of late release in seconds.
6) Elevation of the release in meters.

Row 2/3:
1) Energy release rate of first/second plume in watts.
2) Fraction of Xe and Kr released in the first/second plume.
3) Fraction of iodine released in the first/second plume.
4) Fraction of cesium released in the first/second plume.
5) Fraction of tellurium released in the first/second plume.
6) Fraction of strontium released in the first/second plume.
7) Fraction of ruthenium released in the first/second plume.
8) Fraction of lanthanum released in the first/second plume.
9) Fraction of cerium released in the first/second plume.
10) Fraction of barium released in the first/second plume.

ZISOR Point Estimate Results for SCET LOCA Accident Progression Bins

```
1 CDADBCABDCBB
1.440E+04   1.800E+04   1.800E+03   1.980E+04   3.600E+04   1.000E+01
3.111E+05   1.000E+00   8.653E-03   8.653E-03   6.972E-03   1.001E-03   7.700E-09   7.700E-10   7.700E-10  1.001E-03
1.606E+06   0.000E+00   0.000E+00   0.000E+00   2.132E-04   3.864E-04   4.037E-08   2.180E-06   2.180E-06  3.864E-04
1 CDCAFCDBDCBB
1.440E+04   1.800E+04   1.800E+03   1.980E+04   3.600E+04   1.000E+01
3.111E+05   1.000E+00   1.188E-03   9.900E-04   6.300E-04   7.150E-05   5.000E-10   5.000E-11   5.000E-11  7.150E-05
1.600E+06   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00  0.000E+00
1 CDCCACDBACBB
1.440E+04   1.800E+04   1.800E+03   1.980E+04   3.600E+04   1.000E+01
3.111E+05   1.000E+00   4.950E-03   4.950E-03   1.680E-04   4.420E-04   3.400E-09   3.400E-10   3.400E-10  4.420E-04
1.600E+06   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00  0.000E+00
1 CDCDBCDBDCBB
1.440E+04   1.800E+04   1.800E+03   1.980E+04   3.600E+04   1.000E+01
3.111E+05   1.000E+00   8.613E-03   8.613E-03   6.972E-03   1.001E-03   7.700E-09   7.700E-10   7.700E-10  1.001E-03
1.600E+06   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00  0.000E+00
1 CDDCACABACBB
1.440E+04   1.800E+04   1.800E+03   1.980E+04   3.600E+04   1.000E+01
3.111E+05   1.000E+00   4.974E-03   4.974E-03   1.680E-04   4.420E-04   3.400E-09   3.400E-10   3.400E-10  4.420E-04
1.600E+06   0.000E+00   0.000E+00   0.000E+00   1.283E-04   2.326E-04   2.431E-08   1.313E-06   1.313E-06  2.326E-04
1 CDDDBCABDCBB
1.440E+04   1.800E+04   1.800E+03   1.980E+04   3.600E+04   1.000E+01
3.111E+05   1.000E+00   8.653E-03   8.653E-03   6.972E-03   1.001E-03   7.700E-09   7.700E-10   7.700E-10  1.001E-03
1.600E+06   0.000E+00   0.000E+00   0.000E+00   2.132E-04   3.864E-04   4.037E-08   2.180E-06   2.180E-06  3.864E-04
1 CDDDBCBBDCBB
1.440E+04   1.800E+04   1.800E+03   1.980E+04   3.600E+04   1.060E+01
3.111E+05   1.000E+00   8.637E-03   8.637E-03   6.972E-03   1.001E-03   7.700E-09   7.700E-10   7.700E-10  1.001E-03
1.600E+06   0.000E+00   0.000E+00   0.000E+00   1.254E-04   2.273E-04   2.375E-08   1.282E-06   1.282E-06  2.273E-04
1 DAADDCBBDBBB
1.440E+04   1.800E+04   9.000E+02   1.890E+04   3.600E+04   1.000E+01
6.222E+05   1.000E+00   1.735E-02   1.735E-02   1.239E-02   1.780E-03   1.369E-08   1.369E-09   1.369E-09  1.780E-03
1.600E+06   0.000E+00   0.000E+00   0.000E+00   1.078E-02   1.955E-02   2.042E-06   1.103E-04   1.103E-04  1.955E-02
1 DAFDDCBBDBBB
1.440E+04   1.800E+04   9.000E+02   1.890E+04   3.600E+04   1.000E+01
6.222E+05   1.000E+00   1.531E-02   1.531E-02   1.239E-02   1.780E-03   1.369E-08   1.369E-09   1.369E-09  1.780E-03
1.600E+06   0.000E+00   2.042E-03   2.042E-03   1.078E-02   1.955E-02   2.042E-06   1.103E-04   1.103E-04  1.955E-02
1 DDCCACDBACBB
1.440E+04   1.800E+04   1.800E+03   1.980E+04   3.600E+04   1.000E+01
3.111E+05   1.000E+00   1.100E-03   1.100E-03   3.733E-05   9.822E-05   7.556E-10   7.556E-11   7.556E-11  9.822E-05
1.600E+06   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00  0.000E+00
```

ZISOR Point Estimate Results for SCET LOCA Accident Progression Bins (continued)

```
1 DDDCACABACBB
1.440E+04  1.800E+04  1.800E+03  1.980E+04  3.600E+04  1.000E+01
3.111E+05  1.000E+00  1.124E-03  1.124E-03  3.733E-05  9.822E-05  7.556E-10  7.556E-11  7.556E-11  9.822E-05
1.600E+06  0.000E+00  0.000E+00  0.000E+00  1.283E-04  2.326E-04  2.431E-08  1.313E-06  1.313E-06  2.326E-04
1 EDADBCABDCBB
1.440E+04  4.320E+04  1.800E+03  4.500E+04  3.600E+04  1.000E+01
1.944E+04  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
1.944E+05  1.000E+00  1.969E-06  1.969E-06  2.140E-04  8.899E-06  4.038E-08  4.955E-08  4.955E-08  8.899E-06
1 EDDCACABACBB
1.440E+04  4.320E+04  1.800E+03  4.500E+04  3.600E+04  1.000E+01
1.944E+04  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
1.944E+05  1.000E+00  1.158E-06  1.158E-06  1.284E-04  5.338E-06  2.431E-08  2.983E-08  2.983E-08  5.338E-06
1 EDDDBCABDCBB
1.440E+04  4.320E+04  1.800E+03  4.500E+04  3.600E+04  1.000E+01
1.944E+04  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
1.944E+05  1.000E+00  1.969E-06  1.969E-06  2.140E-04  8.899E-06  4.038E-08  4.955E-08  4.955E-08  8.899E-06
1 EDDDBCBBDCBB
1.440E+04  4.320E+04  1.800E+03  4.500E+04  3.600E+04  1.000E+01
1.944E+04  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
1.944E+05  1.000E+00  1.573E-06  1.573E-06  1.262E-04  5.283E-06  2.375E-08  2.915E-08  2.915E-08  5.283E-06
1 FDADBCABDEBB
1.440E+04  8.640E+04  1.800E+03  8.820E+04  3.600E+04  0.000E+00
0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
0.000E+00  5.000E-03  1.941E-09  1.941E-09  1.691E-09  4.800E-10  2.863E-14  1.454E-12  1.454E-12  4.800E-10
1 FDDCACABAEBB
1.440E+04  8.640E+04  1.800E+03  8.820E+04  3.600E+04  0.000E+00
0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
0.000E+00  5.000E-03  1.116E-09  1.116E-09  1.229E-10  2.533E-10  1.696E-14  8.751E-13  8.751E-13  2.533E-10
1 FDDDBCABDEBB
1.440E+04  8.640E+04  1.800E+03  8.820E+04  3.600E+04  0.000E+00
0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
0.000E+00  5.000E-03  1.941E-09  1.941E-09  1.691E-09  4.800E-10  2.863E-14  1.454E-12  1.454E-12  4.800E-10
1 FDDDBCBBDEBB
1.440E+04  8.640E+04  1.800E+03  8.820E+04  3.600E+04  0.000E+00
0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
0.000E+00  5.000E-03  1.930E-09  1.930E-09  1.633E-09  3.740E-10  1.754E-14  8.552E-13  8.552E-13  3.740E-10
1 GDADBCABDGBB
1.250E+03  3.650E+03  1.800E+03  1.025E+04  2.160E+04  0.000E+00
3.700E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
1.700E+05  5.000E-03  1.941E-09  1.941E-09  1.691E-09  4.800E-10  2.863E-14  1.454E-12  1.454E-12  4.800E-10
1 GDCAFCDBDGBB
1.250E+03  3.650E+03  1.800E+03  1.025E+04  2.160E+04  0.000E+00
3.700E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
1.700E+05  5.000E-03  2.640E-10  2.200E-10  1.400E-10  1.589E-11  1.111E-16  1.111E-17  1.111E-17  1.589E-11
1 GDCCACDBAGBB
1.250E+03  3.650E+03  1.800E+03  1.025E+04  2.160E+04  0.000E+00
3.700E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
1.700E+05  5.000E-03  1.100E-09  1.100E-09  3.733E-11  9.822E-11  7.556E-16  7.556E-17  7.556E-17  9.822E-11
1 GDCDBCDBDGBB
1.250E+03  3.650E+03  1.800E+03  1.025E+04  2.160E+04  0.000E+00
3.700E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
1.700E+05  5.000E-03  1.914E-09  1.914E-09  1.549E-09  2.224E-10  1.711E-15  1.711E-16  1.711E-16  2.224E-10
1 GDDCACABAGBB
1.250E+03  3.650E+03  1.800E+03  1.025E+04  2.160E+04  0.000E+00
3.700E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
1.700E+05  5.000E-03  1.116E-09  1.116E-09  1.229E-10  2.533E-10  1.696E-14  8.751E-13  8.751E-13  2.533E-10
1 GDDDBCABDGBB
1.250E+03  3.650E+03  1.800E+03  1.025E+04  2.160E+04  0.000E+00
3.700E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
1.700E+05  5.000E-03  1.941E-09  1.941E-09  1.691E-09  4.800E-10  2.863E-14  1.454E-12  1.454E-12  4.800E-10
1 GDDDBCBBDGBB
1.250E+03  3.650E+03  1.800E+03  1.025E+04  2.160E+04  0.000E+00
3.700E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
1.700E+05  5.000E-03  1.930E-09  1.930E-09  1.633E-09  3.740E-10  1.754E-14  8.552E-13  8.552E-13  3.740E-10
```

2.3 Consequence Calculations

A PC-based version of the MACCS code[10] was used to calculate conditional offsite consequences for the source terms generated by ZISOR. In order to limit the computer time required for the consequence analysis to approximately 12 hours for each PDS, accident progression bins with similar source terms were grouped together before running MACCS.

The MACCS code is composed of three modules: ATMOS, EARLY, and CHRONC, which are exercised in sequence. This set of modules has been developed for the purpose of evaluating the severe accident consequences at commercial LWR power plants. MACCS 1.5.11 incorporates several improvements over earlier versions of MACCS and codes like CRAC2 in the treatment of variable and long-term releases, deposition modeling, dosimetry, emergency response, long-term mitigative actions, radiological health effects, and economic impacts.

ATMOS treats the atmospheric transport and deposition of material. EARLY models the effects on the surrounding area during the emergency action period, which can be up to one week in length. CHRONC models the effects of the accident in the time following the end of the emergency action period. Atmospheric transport is modeled in ATMOS using a straight line Gaussian treatment of the plume. Plume depletion occurs during transport as a result of radioactive decay and deposition onto the ground. Wet and dry deposition are treated as independent processes in ATMOS. The same initial seed was used to generate the pseudorandom weather sampling for all of the MACCS calculations performed for this analysis. Thus, the weather pattern imposed by MACCS is the same for each release.

As mentioned earlier, five offsite consequences are used as risk measures in this report: (1) the mean number of early fatalities, (2) the mean number of latent fatalities, (3 and 4) the mean population dose over 50 and 1000 miles, and (5) the mean offsite costs. Each of these risk measures is reported per reactor-year of operation, as calculated using Equation 1.1. The conditional consequences calculated by MACCS form one of the inputs to this equation. The actual calculation is done with a PC-based spreadsheet, using Lotus 1-2-3 software.[11]

2.4 Evaluation of Potential Containment Improvements

There remain two goals of the CPI program that affected the way in which potential containment improvements were evaluated. The first is simplicity: the SCET for each PDS should be small enough to allow the reader to visualize each path through the tree and to perform desired sensitivity calculations more quickly and easily than could be done with the full APET. The second is a desire that the results of the SCET analysis be as close as possible to the published draft NUREG-1150 results. The purpose for the first goal is clear enough. The purpose of the second is to lend a measure of credibility to the CPI analysis, since it is by nature a "simplified" evaluation of a very complex and uncertain problem. However, difficulties can arise in trying to meet both of these goals simultaneously. One such problem, the limitations of point estimate calculations of source terms, has already been discussed. Another closely related problem arises when attempting to determine the risk benefit of a potential containment improvement.

As an example, the authors considered the suggestion of intentional operator depressurization of the reactor to prevent DCH. Because this issue is examined more thoroughly in a later section of the report, it will only be briefly summarized here. The simple approach in evaluating this issue would be to merely eliminate high pressure melt ejection from the SCET by setting the conditional probability of the lower branch of event HPME to 1.0 for all cases. By doing this, vessel failure at other than low pressure is eliminated and early containment failure as a result of DCH is eliminated. The conditional probability of early containment failure from in-vessel steam explosion (α mode failure) increases, because α mode failure is judged by most experts to be more likely at low vessel pressure. However, the complete elimination of DCH by depressurization through the pressurizer pilot-operated relief valves (PORVs) is generally not predicted by the Zion APET constructed for the draft NUREG-1150 analysis. The reason for this is that opening the PORVs to depressurize the reactor vessel does not always reduce the vessel pressure sufficiently to prevent DCH. There must also be an accompanying break in the reactor coolant system (RCS) equivalent in size to a medium LOCA (S2 break), such as an S2 initiating event or induced failure of the pressurizer surge line. Another result predicted by the APET is that induced steam generator tube rupture (SGTR) is eliminated by operator depressurization. In addition, opening the PORVs can significantly affect the conditional probability of vessel breach for some PDS groups.

The first means of coping with discrepancies between the SCET results and those predicted by the APET is once again the frequency output file showing the realized split fractions for each event in the APET, which is obtained by evaluating the APET in the sampling mode. For operator depressurization, Question 16 in the Zion APET was modified as follows (refer to Appendix A for the base case APET). First, the split fraction for this event was changed to allow a constant conditional probability of 1.0 for depressurization. Secondly, the sampling input file was modified so that Question 16 was not sampled (refer to Reference 5 for the details of how to modify the sampling input file). This modification was necessary to prevent the sampling routine from overriding the split fraction specified in the APET. The modified APET was then evaluated with EVNTRE in the sampling mode (mode 3). The frequency output file generated by this evaluation was then used to adjust the split fractions in the SCET so that the results matched those from the APET evaluation as closely as possible. For example, in the LOCA PDS, the APET evaluation predicted that depressurization during core melt would eliminate induced SGTR. The split fraction for event SGTR in the SCET used to evaluate vessel depressurization was appropriately modified to reflect this. When the PSTEVNT post–processor code[8] became available, it provided a second, more automated, approach for handling this problem. The use of PSTEVNT is discussed further in Section 4.

3. LOSS–OF–COOLANT ACCIDENTS

The LOCA PDS group at Zion is generally characterized by a loss of RCS integrity prior to the time of core uncovery.[4] However, two sequences initiated by a station blackout (SBO) are included in the SBO PDS even though they lead to induced failure of the reactor coolant pump (RCP) seals. Not all of the breaks depressurize the RCS enough to allow the low pressure injection system (LPIS) to inject. Therefore, some LOCA sequences will involve vessel failure at a pressure above the shutoff head of the LPIS pumps unless a temperature–induced break of the RCS occurs or the RCS is intentionally depressurized.

3.1 LOCA Core Damage Frequency

For this analysis, we have used the LOCA core damage frequency of 2.6 x 10^{-4} per reactor–year reported in Table 2.2–3 of Reference 4.

3.2 LOCA SCET Results

The base case LOCA SCET is shown in Figure 3.1. This SCET was constructed using the methodology outlined in Section 2. Table 3.1 shows the containment failure probabilities, conditional on the occurrence of the LOCA PDS, calculated from this SCET and compares them with the probabilities from Reference 4.

As this table shows, the conditional containment failure probabilities predicted by the SCET agree quite well with the published Zion results. Note that the most probable end states of the SCET involve either no containment failure or basemat melt–through (BMT). The conditional probability of early containment failure (at or near the time of reactor vessel breach) is low, with the majority of early failures caused by α mode steam explosions.

3.3 Base Case LOCA Consequence Results

The SCET end states were binned into accident progression bins and the ZISOR code was used to generate source terms for these bins as described in Section 2. The ZISOR source terms were then further binned in order to reduce the required number of MACCS calculations. Conditional consequences were then obtained for each accident progression bin group using the MACCS code. The Zion site data and meteorological files were used for these calculations. The conditional consequences for each accident progression bin are shown in Table 3.2.

These conditional consequences are now used in Equation 1.1 to obtain the annual LOCA risk for Zion. Table 3.3 compares the calculated annual risk from the SCETs with the published values in Reference 4.

As shown in Table 3.3, the risk calculated from the SCET is significantly less than that obtained in Reference 4. Recall, however, that the conditional containment failure probabilities from the SCET do not differ greatly from the published values. Therefore, the reason(s) for the difference lie in one or more of the following areas. First, there could be a loss of information in binning the SCET end states into accident progression bins. Secondly, ZISOR could be underestimating the source terms. Finally, a later revision of the MACCS code was used for this report which differed from that used for Reference 4. This disparity could possibly lead to lower values for the chosen risk measures. Each of these possible causes is examined below.

The possibility that crucial source term information was lost in the binning process was examined by performing sensitivity studies on the cases where a choice had to be made from among allowed values of the binning parameters. This choice eliminated some of the parameters used in Reference 4. An example would be the time of core damage (dimension 12). In the Reference 4 binning scheme, this dimension had two allowable parameter values: early or late core damage (A or B, respectively). Since the SCET does not model the time of core damage, a choice had to be made between these two allowed values for this report. The decision was made to assign all end states a value of B in dimension 12 in the vector describing the accident progression bin. In the sensitivity study for this case, the opposite choice was made; all end states were binned with a value of A in dimension 12. The difference in binning for this case, as well as the others that were run, was found to have little or no effect on the annual LOCA risk. Thus, the limitations of the SCET binning scheme do not appear to significantly influence the annual risk for the LOCA PDS.

The next possibility is that ZISOR could be underestimating the source term for the dominant accident progression bins. As discussed in Section 2.2, only point estimates of the source terms could be obtained from ZISOR. This leads to the use of source terms that

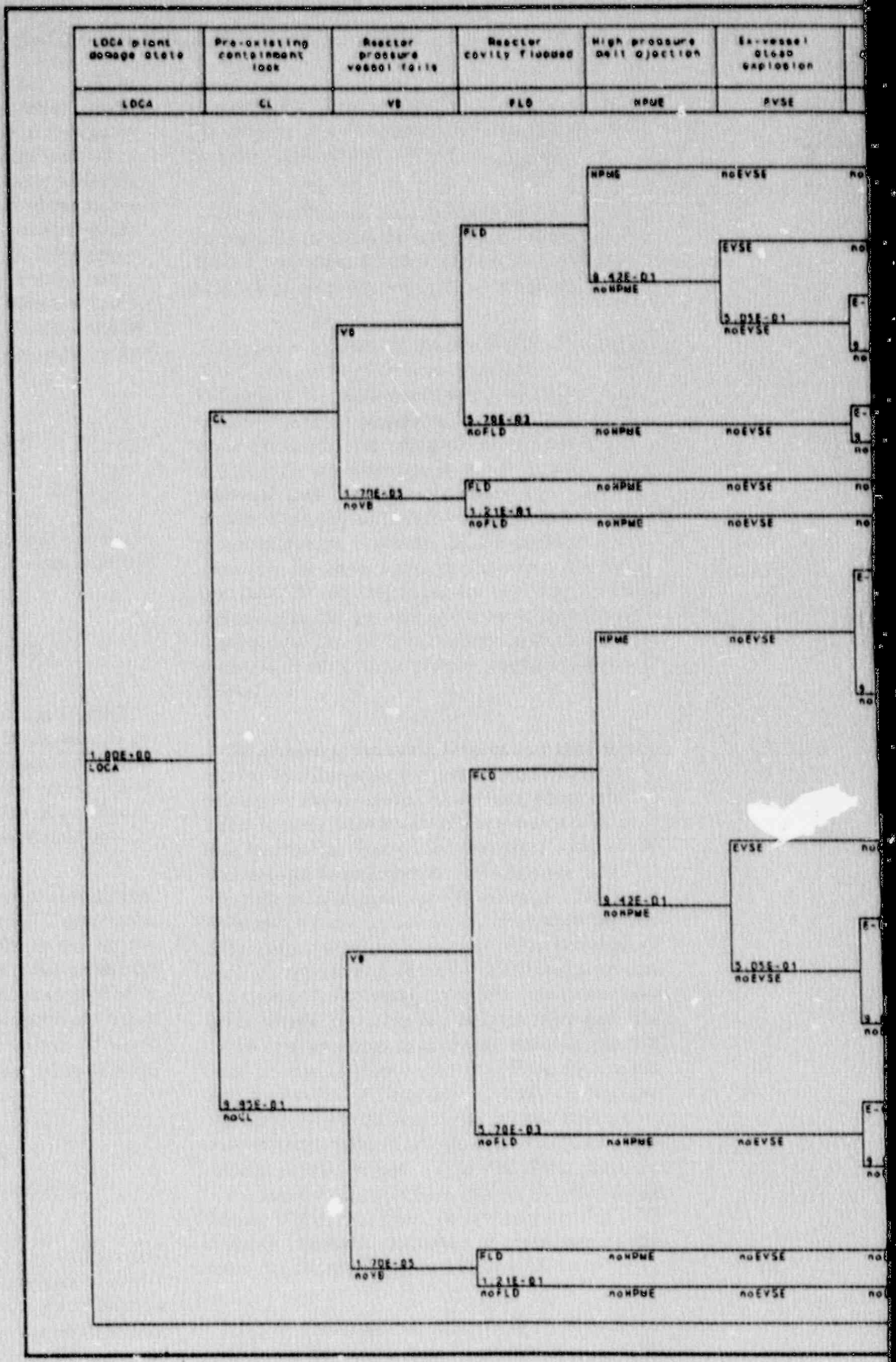
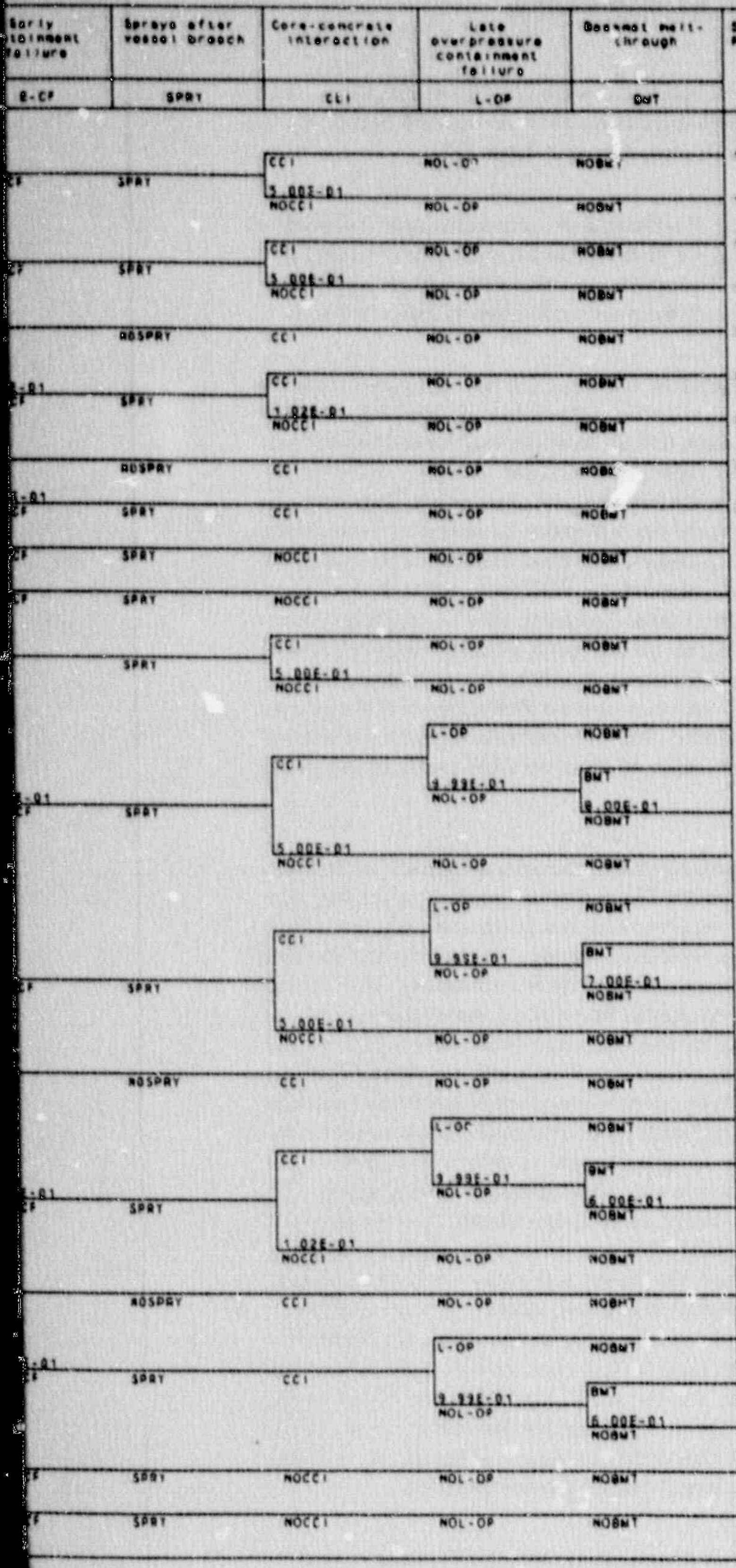


Figure 3.1. Base case LOCA SCET.



SEQUENCE PROB.	SEQUENCE CLASS	SEQUENCE DESCRIPTION
1.44E-04	ECF-CL-D	CDDCACABACBB
1.44E-04	ECF-CL-D	CDCCACDBACBB
1.15E-03	ECF-CL	CDDDBCBBDCBB
1.18E-03	ECF-CL	CDCDBCDBDCBB
3.55E-05	ECF-CL-A	DAFDDCBBDBBB
2.09E-03	ECF-CL	CDDDBCABDCBB
2.38E-04	ECF-CL	CDCDBCDBDCBB
2.28E-07	ECF-CL-A	DAADDCBBDDBB
2.83E-05	ECF-CL	CDADBCABDCBB
7.47E-08	ECF-CL	CDCAFCDBDCBB
1.03E-08	ECF-CL	CDCAFCDBDCBB
7.17E-04	ECF-D	DDDCACABACBB
7.17E-04	ECF-D	DDCCACDBACBB
2.52E-05	LCF	EDDCACABACBB
5.59E-03	BMT	FDDCACABAEBB
2.24E-02	NCF	GDDCACABAGBB
2.80E-02	NCF	GDCCACDBAGBB
2.08E-04	LCF	EDDDBCBBDCBB
6.91E-02	BMT	FDDDBCBBDEBB
1.61E-01	NCF	GDDDBCBBDGBB
2.31E-01	NCF	GDCDBCDBDGBB
7.06E-03	ECF-A	DAFDDCBBDBBB
3.75E-04	LCF	EDDDBCABDCBB
1.66E-01	BMT	FDDDBCABDEBB
2.50E-01	NCF	GDDDBCABDGBB
4.33E-02	NCF	GDCDBCDBDGBB
4.54E-05	ECF-A	DAADDCBBDBBB
5.06E-06	LCF	EDADBCABDCBB
2.25E-03	BMT	FDADBCABDEBB
3.37E-03	NCF	GDADBCABDGBB
1.49E-05	NCF	GDCAFCDBDGBB
2.05E-06	NCF	GDCAFCDBDGBB

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Table 3.1. Conditional containment failure probabilities for the LOCA PDS

Containment Failure Mode	Conditional Probability (SCET)	Conditional Probability (Reference 4)
No containment failure	7.43E–01	7.37E–01
DCH	1.43E–03	1.71E–03
α mode	7.15E–03	8.15E–03
Bypass[a]	4.97E–03	5.00E–03
Late overpressure	6.13E–04	8.78E–04
BMT	2.43E–01	2.46E–01

---

[a] Bypass failures involve pre–existing leakage.

Table 3.2. Conditional consequences for the LOCA accident progression bins

Accident Progression Bin	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
CDADBCABDCBB	1.1E+00	6.0E+02	1.7E+06	3.51E+06	6.3E+08
CDCAFCDBDCBB	6.3E–01	1.2E+02	3.9E+05	6.63E+05	6.2E+07
CDCCACDBACBB	7.3E–01	4.0E+02	1.1E+06	2.31E+06	3.1E+08
CDCDBCDBDCBB	1.1E+00	6.0E+02	1.7E+06	3.51E+06	6.3E+08
CDDCACABACBB	7.3E–01	4.0E+02	1.1E+06	2.31E+06	3.1E+08
CDDDBCABDCBB	1.1E+00	6.0E+02	1.7E+06	3.51E+06	6.3E+08
CDDDBCBBDCBB	1.1E+00	6.0E+02	1.7E+06	3.51E+06	6.3E+08
DAADDCBBDBBB	1.4E+00	1.4E+03	3.6E+06	9.09E+06	3.2E+09
DAFDDCBBDBBB	1.4E+00	1.5E+03	3.7E+06	9.28E+06	3.1E+09
DDCCACDBACBB	6.2E–01	1.4E+02	4.3E+05	7.77E+05	8.0E+07
DDDCACABACBB	6.2E–01	1.4E+02	4.3E+05	7.77E+05	8.0E+07
EDADBCABDCBB	0.0E+00	3.1E+00	1.0E+04	1.91E+04	2.9E+05
EDDCACABACBB	0.0E+00	3.1E+00	1.0E+04	1.91E+04	2.9E+05
EDDDBCABDCBB	0.0E+00	3.1E+00	1.0E+04	1.91E+04	2.9E+05
EDDDBCBBDCBB	0.0E+00	3.1E+00	1.0E+04	1.91E+04	2.9E+05
FDADBCABDEBB	0.0E+00	8.6E–03	2.3E+01	5.17E+01	0.0E+00
FDDCACABAEBB	0.0E+00	8.6E–03	2.3E+01	5.17E+01	0.0E+00
FDDDBCABDEBB	0.0E+00	8.6E–03	2.3E+01	5.17E+01	0.0E+00
FDDDBCBBDEBB	0.0E+00	8.6E–03	2.3E+01	5.17E+01	0.0E+00
GDADBCABDGBB	0.0E+00	2.6E–02	9.7E+01	1.38E+02	0.0E+00
GDCAFCDBDGBB	0.0E+00	2.6E–02	9.7E+01	1.38E+02	0.0E+00
GDCCACDBAGBB	0.0E+00	2.6E–02	9.7E+01	1.38E+02	0.0E+00
GDCDBCDBDGBB	0.0E+00	2.6E–02	9.7E+01	1.38E+02	0.0E+00
GDDCACABAGBB	0.0E+00	2.6E–02	9.7E+01	1.38E+02	0.0E+00
GDDDBCABDGBB	0.0E+00	2.6E–02	9.7E+01	1.38E+02	0.0E+00
GDDDBCBBDGBB	0.0E+00	2.6E–02	9.7E+01	1.38E+02	0.0E+00

Table 3.3. Annual base case LOCA risk

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50-Mile Dose (person-rem)	Mean 1000-Mile Dose (person-rem)	Mean Offsite Costs ($)
SCET	4E-06	4E-03	9	22	6.48E+03
Reference 4	9E-05	2E-02	41	98	1.31E+05
Relative change	22.5	5	4.6	4.5	20.2

are in many cases one or more orders of magnitude less than the mean source terms calculated in Reference 4. However, there is also the possibility that errors could exist in the version of ZISOR used for the SCET analysis in this report. To check this possibility, ZISOR was run on the four sequences for which Reference 4 provides source term distributions. The results matched the point estimate ZISOR source terms shown in Reference 4. Thus, the version of ZISOR used for this report was considered to be working correctly.

The final possibility for the risk discrepancy is that the version of MACCS used for this analysis gives significantly different results than the version used for Reference 4. MACCS 1.5.11 was used for this analysis, whereas Reference 4 used MACCS 1.5.5. This possibility was discussed with an individual involved with verification of the MACCS code. This individual, who was familiar with the changes made to the code in progressing from version 1.5.5 to version 1.5.11, thought that the results between the two versions might differ by 5-10%, but was not certain how the magnitude of the results would change.

Based on these findings, the authors' conclusion is that the majority of the difference in magnitude between the SCET risk results and those published in Reference 4 is due to the limitations of using a point estimate source term rather than a mean value calculated from a distribution.

The contribution of each containment failure mode to the offsite population dose is listed in Table 3.4. As this table shows, α mode failure and bypass are the largest contributors to offsite dose for the LOCA PDS. DCH and late failures are insignificant in comparison.

3.4 Risk Benefit of Potential Improvements

Reference 2 identified several improvements that have the potential to enhance the performance of the large dry PWR containment during a severe accident. These improvements are as follows: (1) enhanced reactor vessel depressurization capability, (2) cavity flooding, (3) prevention of hydrogen burns in containment, (4) containment venting, and (5) modifications to reduce the frequency of the interfacing systems LOCA (V sequence). The risk benefit of the first four of these improvements is evaluated in this section for the LOCA PDS. The fifth improvement is not evaluated, as it affects only the V sequence, not the conventional LOCA. No effort was made to evaluate the feasibility of any of the potential improvements, because this was beyond the scope of the project.

3.4.1 Enhanced Reactor Vessel Depressurization Capability. The ability to depressurize the reactor vessel during a severe core damage accident is desirous from the standpoint of reducing the threat to containment integrity presented by DCH at the time of vessel failure. Intentional depressurization was modeled in the LOCA SCET by eliminating event HPME from consideration; all sequences in which core damage is not arrested involve vessel failure at low pressure (<200 psig) only. In the Zion APET, vessel failure at low pressure does not present a DCH challenge to the containment. Figure 3.2 shows the SCET that models intentional depressurization.

Table 3.5 shows the change in the conditional containment failure probabilities effected by intentional depressurization.

Table 3.4. Containment failure mode contribution to offsite dose for the LOCA PDS (from SCET)

Containment Failure Mode	Contribution to 50-Mile Dose (%)	Contribution to 1000-Mile Dose (%)
DCH	1.7	1.3
α	74.5	78.3
Bypass[a]	23.6	20.2
Late overpressure	ε	ε
BMT	ε	ε

---

a. Bypass failures involve pre-existing containment leakage.

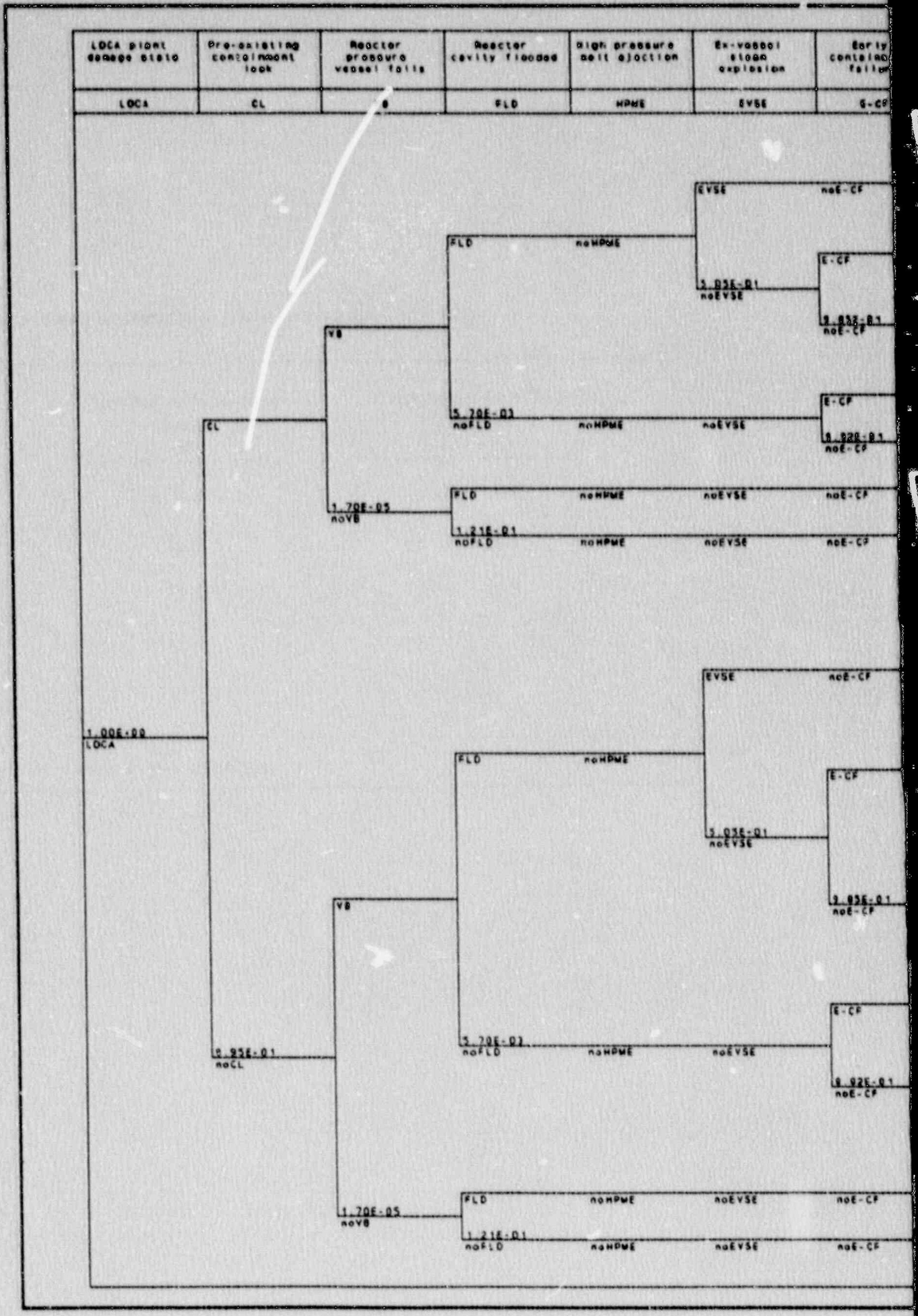
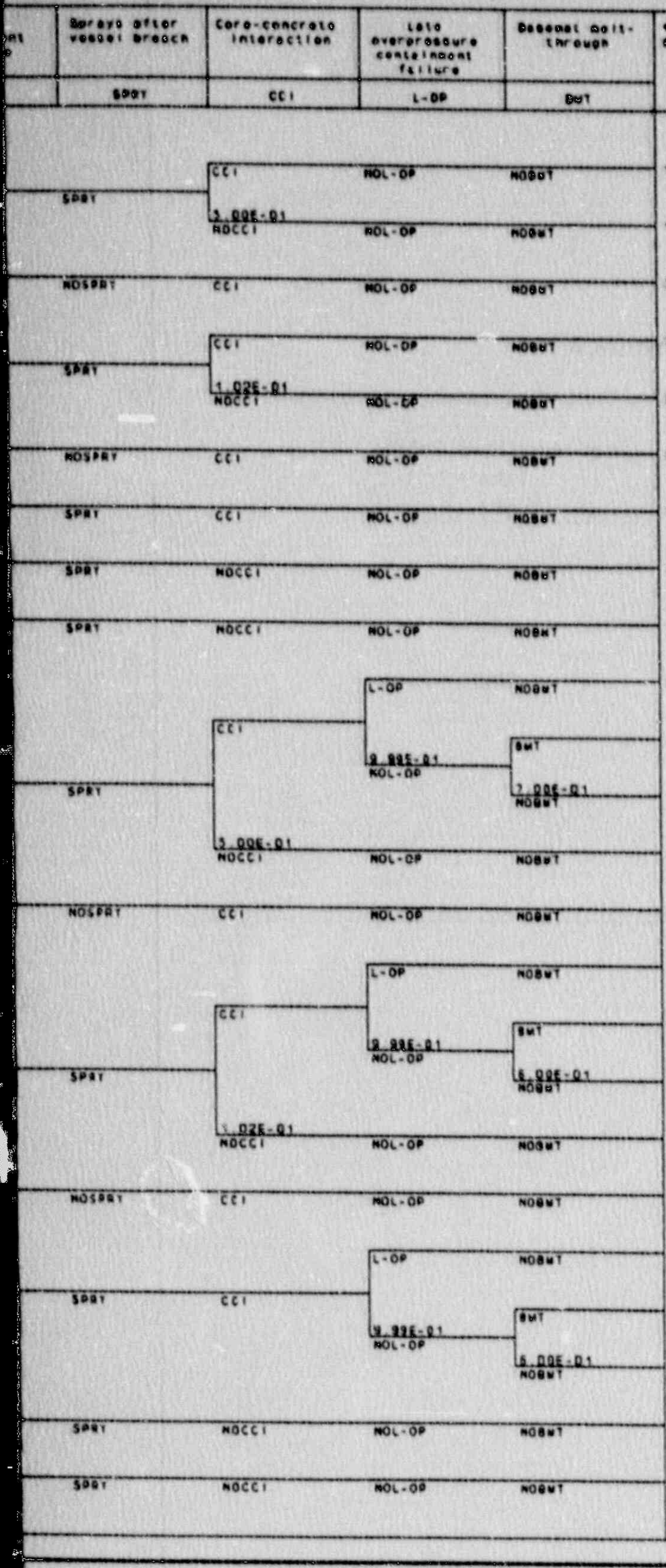


Figure 3.2. LOCA SCET for intentional depressurization.



SEQUENCE PROB.	SEQUENCE CLASS	SEQUENCE DESCRIPTION
1.23E-03	ECF-CL	CDDDBCBDDCBB
1.23E-03	ECF-CL	CDCDBCDBDCBB
3.77E-05	ECF-CL-A	DAFDDCBBDBBB
2.22E-03	ECF-CL	CDDDBCABDCBB
2.52E-04	ECF-CL	CDCDBCDBDCBB
2.78E-07	ECF-CL-A	DAADDCBBDBBB
2.83E-05	ECF-CL	CDADBCABDCBB
7.47E-08	ECF-CL	CDCAFCDBDCBB
1.03E-08	ECF-CL	CDCAFCDBDCBB
2.20E-04	LCF	EDDDBCBBDCBB
7.34E-02	BMT	FDDDBCBBDEBB
1.71E-01	NCF	GDDDBCBBDGBB
2.43E-01	NCF	GDCDBCDBDGBB
7.49E-03	ECF-A	DAFDDCBBDBBB
3.98E-04	LCF	EDDDBCABDCBB
1.77E-01	BMT	FDDDBCABDEBB
2.63E-01	NCF	GDDDBCABDGBB
3.02E-02	NCF	GDCDBCDBDGBB
4.54E-05	ECF-A	DAADDCBBDBBB
5.06E-06	LCF	EDADBCABDCBB
2.25E-03	BMT	FDADBCABDEBB
3.37E-03	NCF	GDADBCABDGBB
1.49E-05	NCF	GDCAFCDBDGBB
2.05E-06	NCF	GDCAFCDBDGBB

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As shown in Table 3.5, depressurization eliminates DCH failures, but leads to a slight increase in the conditional probability of α mode failure. This occurs because the mean probability of α mode failure used in the Zion APET is a factor of ten higher at low vessel pressure (8 x 10^{-3}) than it is at intermediate or higher pressures (8 x 10^{-4}). The effect of this change in containment failure probability on risk is shown in Table 3.6.

Because of the increase in the conditional probability of α mode containment failure brought about by depressurization, there is a small increase in all risk measures apart from the mean number of early fatalities, which decrease very slightly. To reiterate, this result hinges upon the pressure-dependent probabilities assigned to α mode failure in the Zion APET (Question 34). These probabilities are highly uncertain; therefore, the effect of this dependence on vessel pressure was examined in a sensitivity case in which the conditional probability of α mode containment failure, given vessel breach, was taken to be 8.0 x 10^{-4} (the mean value with the RCS at high pressure), regardless of vessel pressure at the time of vessel failure. This revised APET was evaluated with no sampling on Question 34 (α mode containment failure) and the split fractions in the LOCA SCET with depressurization were adjusted to fit the results of the frequency output file generated by EVNTRE. This revised SCET is shown in Figure 3.3.

The revised conditional containment failure probabilities from this SCET are shown in Table 3.7.

As expected, the conditional probability of α mode failure is significantly reduced (by one order of magnitude) from the base case probability. The calculated risk for this case is shown in Table 3.8.

Table 3.5. Conditional containment failure probabilities for the LOCA PDS with operator depressurization

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
No containment failure	7.35E-01	7.43E-01
DCH	0.00	1.43E-03
α mode	7.58E-03	7.15E-03
Bypass[a]	4.96E-03	4.97E-03
Late overpressure	6.23E-04	6.13E-04
BMT	2.53E-01	2.43E-01

a. Bypass failures involve pre-existing containment leakage.

Table 3.6. Annual LOCA risk with operator depressurization

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50-Mile Dose (person-rem)	Mean 1000-Mile Dose (person-rem)	Mean Offsite Costs ($)
Base case	4.11E-06	3.47E-03	9.22	21.74	6.48E+03
SCET	4.06E-06	3.59E-03	9.52	22.58	6.82E+03
% change	-1.22	3.46	3.25	3.86	5.25

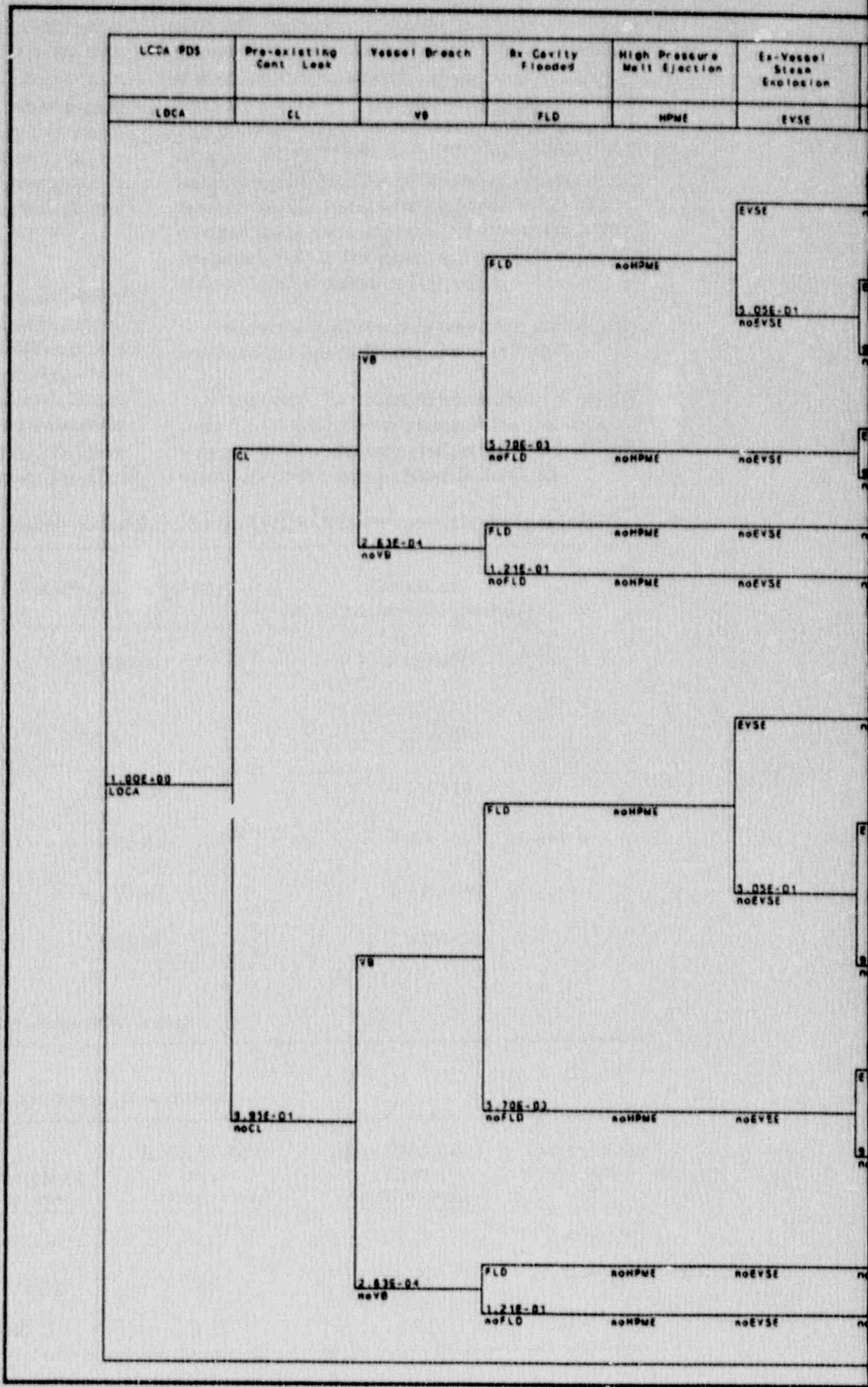
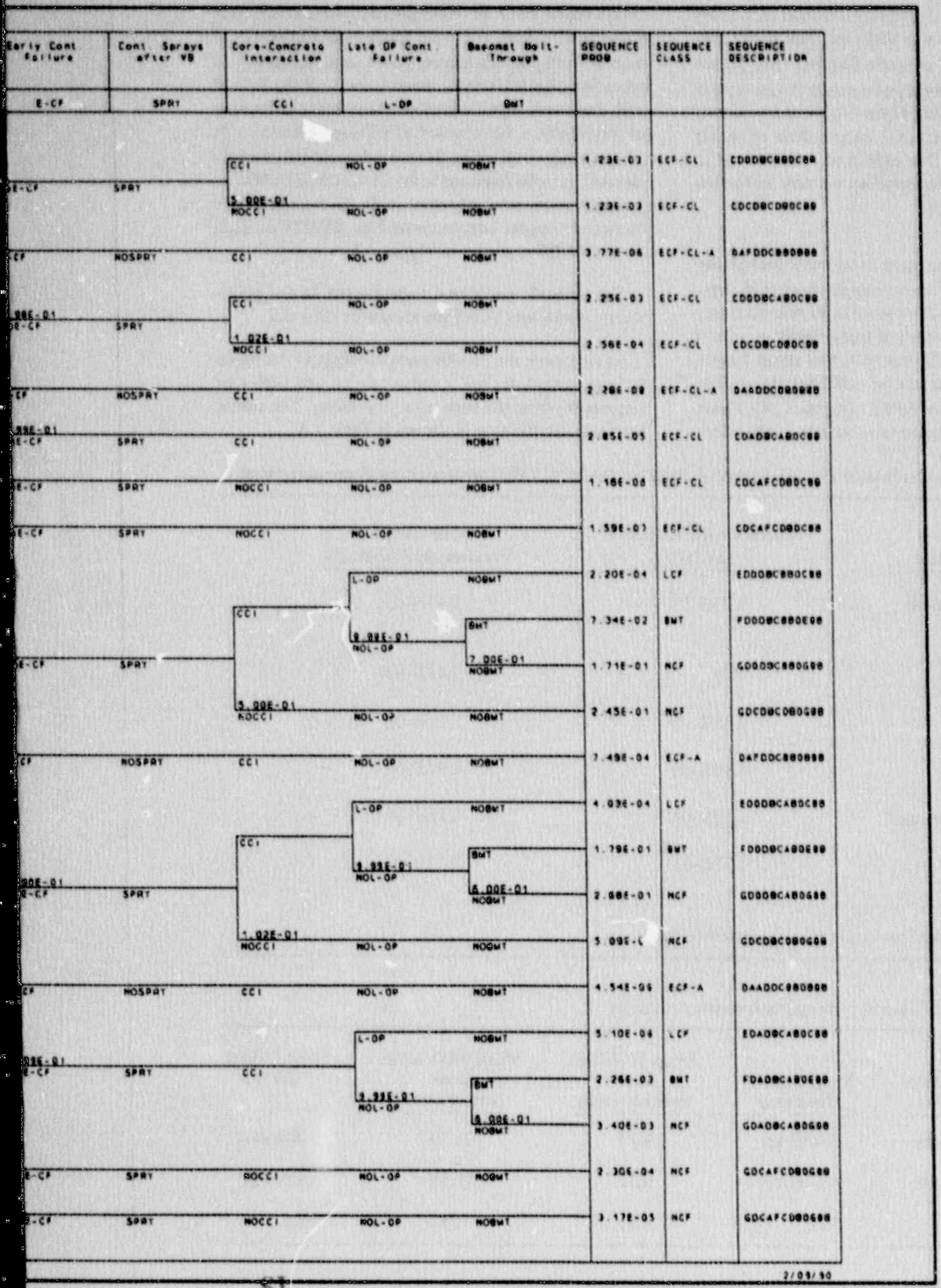


Figure 3.3. LOCA SCET with depressurization and no increase in α mode failure.



SEQUENCE PROB	SEQUENCE CLASS	SEQUENCE DESCRIPTION
1.23E-03	ECF-CL	CDDDBCBBDCBB
1.23E-03	ECF-CL	CDCDBCDBDCBB
3.77E-06	ECF-CL-A	DAFDDCBBDBBB
2.25E-03	ECF-CL	CDDDBCABDCBB
2.56E-04	ECF-CL	CDCDBCDBDCBB
2.28E-08	ECF-CL-A	DAADDCBBDBBB
2.85E-05	ECF-CL	CDADBCABDCBB
1.18E-08	ECF-CL	CDCAFCDBDCBB
1.59E-07	ECF-CL	CDCAFCDBDCBB
2.20E-04	LCF	EDDDBCBBDCBB
7.34E-02	BMT	FDDDBCBBDEBB
1.71E-01	NCF	GDDDBCBBDGBB
2.45E-01	NCF	GDCDBCDBDGBB
7.49E-04	ECF-A	DAFDDCBBDBBB
4.03E-04	LCF	EDDDBCABDCBB
1.79E-01	BMT	FDDDBCABDEBB
2.88E-01	NCF	GDDDBCABDGBB
5.09E-[illegible]	NCF	GDCDBCDBDGBB
4.54E-06	ECF-A	DAADDCBBDBBB
5.10E-06	LCF	EDADBCABDCBB
2.26E-03	BMT	FDADBCABDEBB
3.40E-03	NCF	GDADBCABDGBB
2.30E-04	NCF	GDCAFCDBDGBB
3.17E-05	NCF	GDCAFCDBDGBB

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Table 3.7. Conditional containment failure probabilities for the LOCA PDS with operator depressurization and pressure–independent point estimate probability of α mode containment failure

Containment Failure Mode	Revised Conditional Probability	Base Case Conditional Probability
No containment failure	7.47E–01	7.43E–01
DCH	1.43E–03	1.43E–03
α mode	7.15E–04	7.15E–03
Bypass[a]	5.00E–03	4.97E–03
Late overpressure	6.18E–04	6.13E–04
BMT	2.46E–01	2.43E–01

---

[a] Bypass failures involve pre–existing containment leakage.

Table 3.8. Annual LOCA risk with depressurization and pressure–independent point estimate probability of α mode failure

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	4.11E–06	3.47E–03	9.22	21.74	6.48E+03
SCET	1.70E–06	1.06E–03	2.98	6.35	1.41E+03
% change	–58.6	–69.6	–67.6	–70.8	–78.2

The risk reduction associated with the decreased probability of α mode failure is significant. Because α mode failure is so dominant in the base case, this issue was investigated in a sensitivity case, where the effects of depressurization were isolated from the uncertainty in the α mode failure probability. This investigation was conducted by rerunning the base case with the conditional probability of α mode failure in the APET set at the point estimate value of 8.0×10^{-4}, with no sampling on Question 34. (It is possible, of course, that the probabilities of α mode failure in NUREG–1150 are too low, in which case α mode failure would be an even larger contributor to offsite risk.) The conditional containment failure probabilities for this sensitivity are shown in Table 3.9.

The annual offsite risk for this sensitivity case is shown in Table 3.10.

3.4.2 Cavity Flooding. The purpose of a reactor cavity flooding system would be to provide a flow of water to core debris released into the cavity at the time of vessel failure. This water could quench the debris and maintain a coolable configuration, reducing CCI and mitigating any gradual overpressurization of containment caused by the production of noncondensible gases during CCI. The flooded cavity could cause an initial steam spike at the time of vessel failure, but would not be expected to threaten containment integrity.[2] In analyzing the cavity flooding improvement, the base case probabilities of having a coolable debris geometry were retained. These probabilities are listed here for reference: (1) given α mode or rocket failure of the containment, the probability is 0.7 that the debris is coolable, (2) given HPME or EVSE, there is a 50% chance that the debris is coolable, (3) if there is a gravity pour with no EVSE, there is only a 10% chance of having a coolable debris bed.

The revised SCET used to analyze the addition of a cavity flooding system is shown in Figure [illegible]. Table 3.11 shows the conditional containment failure probabilities calculated from this tree.

As Table 3.11 shows, the addition of a cavity flooding system does not significantly affect the conditional probabilities of containment failure. The reason for this is that most of the base case LOCA sequences already have a wet cavity at the time of vessel breach; therefore, there is little effect from the addition of the flooding system. The effects on risk are shown in Table 3.12.

Table 3.9. Conditional containment failure probabilities for the base case LOCA PDS with pressure–independent point estimate probability of α mode containment failure

Containment Failure Mode	Revised Conditional Probability	Base Case Conditional Probability
No containment failure	7.39E–01	7.35E–01
DCH	0.00	0.00
α mode	7.58E–04	7.58E–03
Bypass[a]	5.00E–03	4.96E–03
Late overpressure	6.28E–04	6.23E–04
BMT	2.55E–01	2.53E–01

a. Bypass failures involve pre–existing containment leakage.

Table 3.10. Annual base case LOCA risk with pressure–independent point estimate probability of α mode failure

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	4.11E–06	3.47E–03	9.22	21.74	6.48E+03
SCET	1.88E–06	1.08E–03	3.05	6.44	1.38E+03
% change	–54.3	–68.9	–66.9	–70.4	–78.7

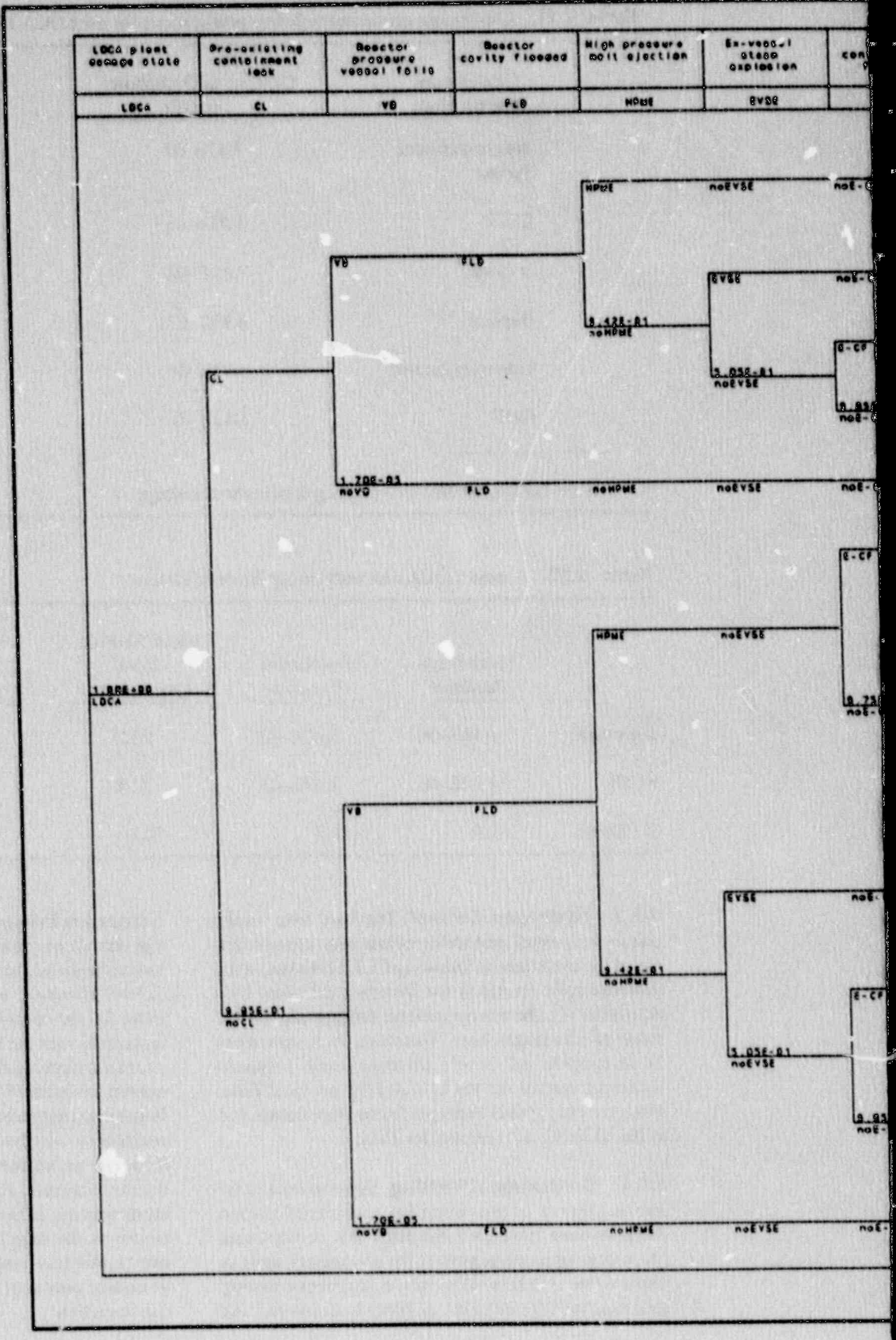

Figure 3.4. LOCA SCET with addition of cavity flooding system.

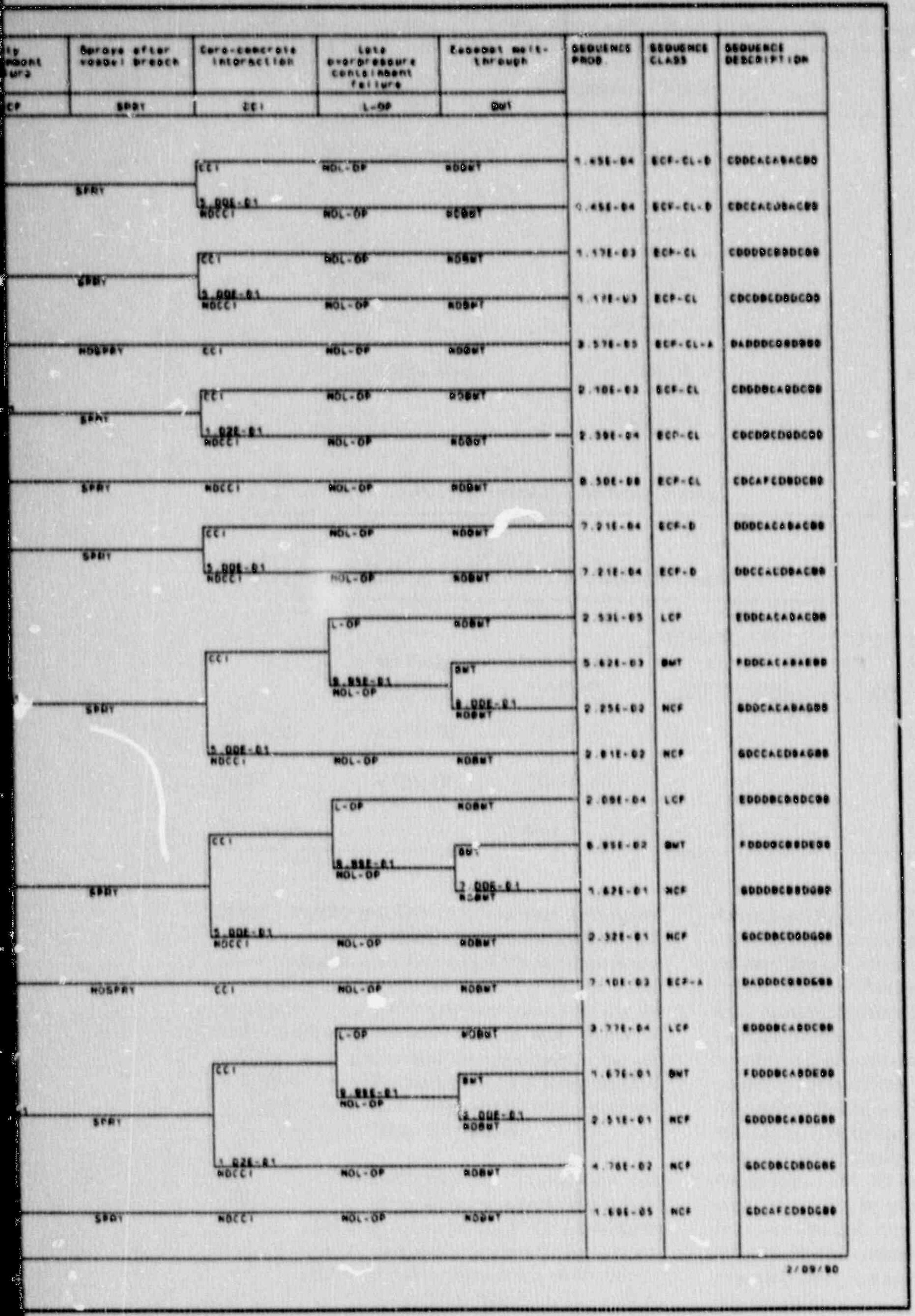

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Table 3.11. Conditional containment failure probabilities for the LOCA PDS with cavity flooding system

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
No containment failure	7.43E–01	7.43E–01
DCH	1.43E–03	1.44E–03
α mode	7.15E–04	7.14E–03
Bypass[a]	4.97E–03	4.97E–03
Late overpressure	6.13E–04	6.11E–04
BMT	2.43E–01	2.42E–01

---

a. Bypass failures involve pre–existing containment leakage.

Table 3.12. Annual LOCA risk with cavity flooding system

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	4.11E–06	3.47E–03	9.22	21.74	6.48E+03
SCET	4.03E–06	2.47E–03	7.18	14.56	2.92E+03
% change	–1.9	–28.7	–22.0	–33.0	–55.0

3.4.3 Hydrogen Control. The base case results show a very small probability of late overpressure failure of the containment following CCI. However, as the realized split fractions for Question 62 show (see Appendix B), these overpressure failures are not the result of a hydrogen burn. Therefore, there appears to be no tangible risk benefit associated with enhanced hydrogen control for the LOCA PDS group at Zion. Note that only global hydrogen burns were considered in the NUREG–1150 model for Zion.

3.4.4 Containment Venting. Because there is no internal means of providing for a scrubbed release when venting from the large dry PWR containment (such as a suppression pool or ice condenser), there is probably no risk benefit to early containment venting unless some type of external filter is employed. As discussed in Reference 2, late venting may have potential benefit in preventing an uncontrolled release of radioactivity as a result of gross containment structural failure. However, because late overpressure containment failure contributes only marginally to the risk associated with the LOCA PDS, there is essentially no benefit to late unfiltered venting. In addition, the current revision of the Westinghouse Owners Group Emergency Procedure Guidelines does not direct the operator to vent the containment, because of the concern over an unfiltered release of fission products to the environment. An evaluation of filtered containment venting is beyond the scope of this analysis. However, the high cost associated with installing an external filtered containment venting system is likely to greatly outweigh any potential benefit in terms of risk reduction.

4. TRANSIENTS AND ANTICIPATED TRANSIENTS WITHOUT SCRAM (ATWS)

The transient + ATWS PDS group at Zion is made up of sequences in which the RCS is intact at the time of core uncovery and AC power is available.

4.1 Transient + ATWS Core Damage Frequency

The transient + ATWS PDS group is composed of 11 individual plant damage states, with a combined frequency of 1.18×10^{-5} per reactor–year, as reported in Table 2.2–3 of Reference 4.

4.2 Transient + ATWS SCET Results

The base case transient + ATWS SCET is shown in Figure 4.1. This SCET, like the LOCA SCET, was constructed using the methodology outlined in Section 2. Table 4.1 shows the containment failure probabilities, conditional on the occurrence of the transient + ATWS PDS, calculated from this SCET and compares them with the probabilities from Reference 4.

The conditional containment failure probabilities calculated from the SCET agree well with those published in Reference 4. As in the LOCA PDS, early containment failure is not likely; however, in the transient + ATWS PDS, DCH is slightly more dominant than α mode failure. Late overpressure failures as a result of hydrogen burns are not likely and the probability of eventual overpressure failure from the buildup of steam and noncondensible gases is vanishingly small, as it was for LOCAs. Again, there is a significant chance of basemat melt–through. But as for LOCAs, the most probable end states involve a containment that is structurally intact.

4.3 Base Case Transient + ATWS Consequences

The SCET end states were binned into accident progression bins and the ZISOR code was again used to generate source terms for these bins (see description in Section 2). Conditional consequences were then calculated for each accident progression bin with the MACCS code. As for LOCAs, the Zion site data and meteorological files were used for these calculations. The conditional consequences for each accident progression bin are shown in Table 4.2.

These conditional consequences are used in Equation 1.1 to obtain the annual transient + ATWS risk for Zion. Table 4.3 compares the calculated annual risk from the SCETs with the published values in Reference 4.

As in the LOCA PDS, the risk calculated with the SCET is lower than the published values in Reference 4, although the differences are less in the transient + ATWS case. Again, this is to be expected when calculating risk based on point estimate source terms generated by ZISOR.

Table 4.4 lists the contribution of each containment failure mode to the offsite dose. DCH failures are slightly more significant than in the LOCA PDS. However, the largest contributor to offsite dose is now containment bypass instead of α mode failure, although the contribution from the latter is still significant. The contribution of α mode failure is down because the RCS is more likely to be at high pressure at the time of vessel breach than in the LOCA PDS group. Late containment failures are again an insignificant contributor to offsite dose.

4.4 Risk Benefit of Potential Improvements

The risk benefit of the potential containment performance improvements identified in Reference 2 is calculated in this section.

4.4.1 Enhanced Reactor Vessel Depressurization Capability. With no accompanying break equivalent in size to an S2 LOCA, opening the pressurizer PORVs at Zion has not been shown to reduce RCS pressure below the DCH cutoff used in Reference 4. However, if intentionally opening the PORVs induces a failure of the pressurizer surge line, then RCS pressure will be reduced to <200 psig at the time of vessel failure and DCH will not be a threat to containment integrity. To model intentional depressurization via the PORVs, an additional event to represent intentional opening of the PORVs could be added to the base case SCET and the conditional probability for the lower branch of this event could be changed to 0.0 to represent opening of the PORVs 100% of the time. Tests indicated that this approach was too simplistic because it did not model the dependencies between depressurization and vessel breach that exist in the APET. A number of attempts were made to

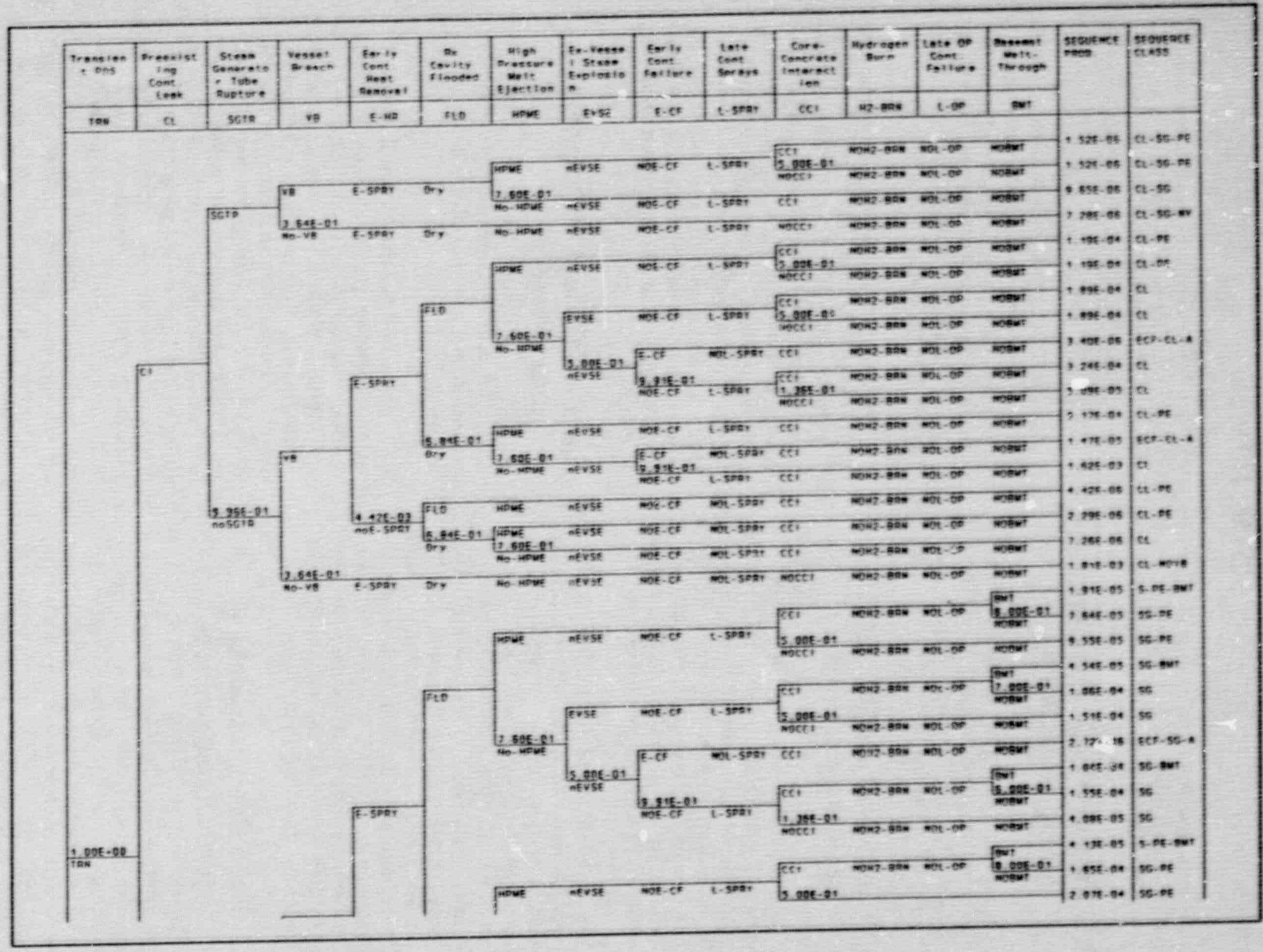

Figure 4.1. Base case transient + ATWS SCET.

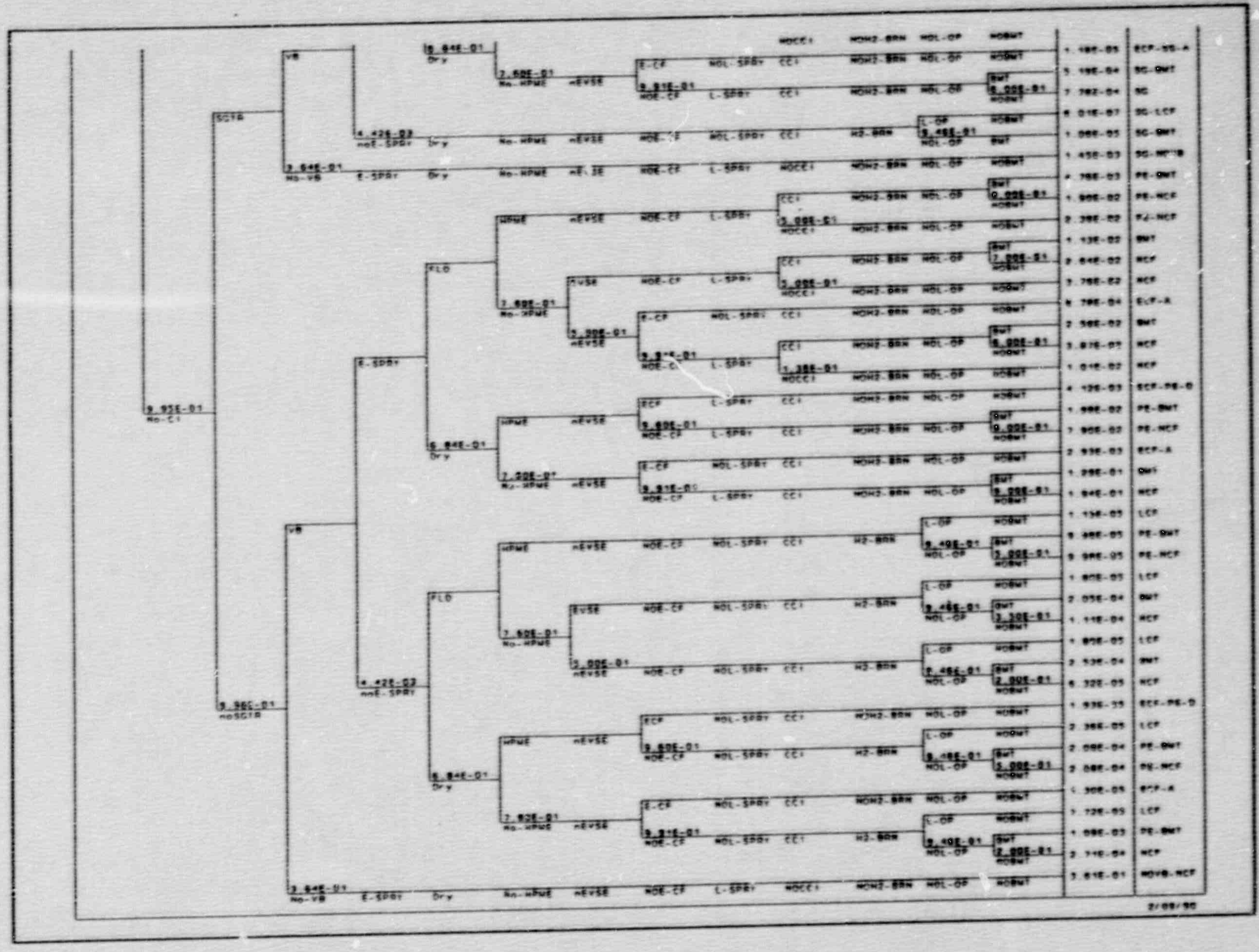

Figure 4.1. (continued).

Table 4.1. Conditional containment failure probabilities for the transient + ATWS PDS

Containment Failure Mode	Conditional Probability (SCET)	Conditional Probability (Reference 4)
No containment failure	7.90E–01	7.90E–01
DCH	4.14E–03	5.19E–03
α mode	3.66E–03	3.51E–03
Bypass[a]	8.94E–03	9.15E–03
Late overpressure	1.49E–04	1.48E–04
BMT	1.93E–01	1.93E–01

---

a. Bypass failures include pre–existing leakage and induced SGTR.

Table 4.2. Conditional consequences for the transient + ATWS accident progression bins

Accident Progression Bin	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
CDACAAABACBB	9.55E+00	4.24E+03	8.21E+06	2.49E+07	1.51E+10
CDACACABACBB	7.30E-01	3.98E+02	1.13E+06	2.31E+06	3.08E+08
CDADBAABDCBB	9.55E+00	4.24E+03	8.21E+06	2.49E+07	1.51E+10
CDADBCABDCBB	1.12E+00	5.98E+02	1.74E+06	3.51E+06	6.30E+08
CDCCAADBACBB	9.55E+00	4.24E+03	8.21E+06	2.49E+07	1.51E+10
CDCCACDBACBB	7.30E-01	3.98E+02	1.13E+06	2.31E+06	3.08E+08
CDCDBCDBDCBB	1.12E+00	5.98E+02	1.74E+06	3.51E+06	6.30E+08
CDCDFADBDCBB	9.54E+00	4.23E+03	8.18E+06	2.48E+07	1.51E+10
CDCDFCDBDCBB	7.30E-01	3.98E+02	1.13E+06	2.31E+06	3.08E+08
CDDCACABACBB	7.30E-01	3.98E+02	1.13E+06	2.31E+06	3.08E+08
CDDDBCABDCBB	1.12E+00	5.98E+02	1.74E+06	3.51E+06	6.30E+08
CHACACABACBB	1.47E+01	4.41E+03	8.06E+06	2.65E+07	1.90E+10
CHADBCABDCBB	1.26E+02	7.04E+03	1.35E+07	4.12E+07	2.79E+10
CHFCACABACBB	1.47E+01	4.41E+03	8.06E+06	2.65E+07	1.90E+10
DAADDABBDBBB	1.01E+01	4.50E+03	8.91E+06	2.71E+07	1.70E+10
DAADDCBBDBBB	1.45E+00	1.42E+03	3.64E+06	9.09E+06	3.20E+09
DAFDDABBDBBB	1.01E+01	4.50E+03	8.91E+06	2.71E+07	1.70E+10
DAFDDCBBDBBB	1.35E+00	1.45E+03	3.73E+06	9.28E+06	3.09E+09
DDACACABACBB	6.17E-01	1.38E+02	4.32E+05	7.77E+05	7.97E+07
DHACACABACBB	6.43E-01	2.11E+03	4.55E+06	1.28E+07	5.95E+09
DHADDCBBDBBB	4.37E+02	9.56E+03	1.94E+07	5.67E+07	4.41E+10
EHACACABACBB	0.00E+00	1.46E+02	4.75E+05	8.75E+05	1.01E+08
EHADBCABDCBB	8.38E-06	2.39E+02	7.51E+05	1.44E+06	1.78E+08
EHFCACABACBB	8.38E-06	2.39E+02	7.51E+05	1.44E+06	1.78E+08
EHFDBCABDCBB	8.82E-04	5.99E+02	1.54E+06	4.06E+06	8.59E+08
FDACACABAEBB	0.00E+00	8.63E–03	2.28E+01	5.17E+01	0.00E+00

Table 4.2. (continued)

Accident Progression Bin	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
FDADBCABDEBB	0.00E+00	8.63E–03	2.28E+01	5.17E+01	0.00E+00
FDDCACABAEBB	0.00E+00	8.63E–03	2.28E+01	5.17E+01	0.00E+00
FDDDBCABDEBB	0.00E+00	8.63E–03	2.28E+01	5.17E+01	0.00E+00
FHACACABAEBB	0.00E+00	7.84E–02	3.18E+02	4.61E+02	1.10E+03
FHADBCABDEBB	0.00E+00	1.31E–01	5.38E+02	7.72E+02	3.42E+03
FHFCACABAEBB	0.00E+00	7.84E–02	3.18E+02	4.61E+02	1.10E+03
FHFDBCABDEBB	0.00E+00	1.31E–01	5.38E+02	7.72E+02	3.42E+03
GDACAAABAEBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDACAAABAFBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDACACABAGBB	0.00E+00	2.63E–02	9.67E+01	1.38E+02	0.00E+00
GDADBAABDEBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDADBAABDFBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDADBCABDGBB	0.00E+00	2.63E–02	9.67E+01	1.38E+02	0.00E+00
GDCCAADBAFBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDCCACDBAGBB	0.00E+00	2.63E–02	9.67E+01	1.38E+02	0.00E+00
GDCDBADBDFBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDCDBCDBDGBB	0.00E+00	2.63E–02	9.67E+01	1.38E+02	0.00E+00
GDCDFADBDFBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDCDFCDBDGBB	0.00E+00	2.63E–02	9.67E+01	1.38E+02	0.00E+00
GDDCAAABAEBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDDCAAABAFBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDDCACABAGBB	0.00E+00	2.63E–02	9.67E+01	1.38E+02	0.00E+00
GDDDBAABDEBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDDDBAABDFBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDDDBCABDGBB	0.00E+00	2.63E–02	9.67E+01	1.38E+02	0.00E+00
GHACACABAGBB	0.00E+00	1.52E–01	6.17E+02	8.77E+02	3.80E+03
GHADBAABDCBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GHADBAABDEBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GHADBCABDGBB	0.00E+00	1.52E–01	6.17E+02	8.77E+02	3.80E+03
GHFCACABAGBB	0.00E+00	1.52E–01	6.17E+02	8.77E+02	3.80E+03
GHFDBCABDGBB	0.00E+00	1.52E–01	6.17E+02	8.77E+02	3.80E+03

Table 4.3. Annual base case transient + ATWS risk

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
SCET	6E–07	3E–04	0.7	1.8	9E+02
Reference 4	4E–06	5E–04	1.2	2.7	3E+03
Relative change	6.7	1.7	1.7	1.5	3.3

Table 4.4. Containment failure mode contribution to offsite dose for the transient + ATWS PDS (from SCET)

Containment Failure Mode	Contribution to 50-Mile Dose (%)	Contribution to 1000-Mile Dose (%)
DCH	3.4	2.3
α	24.6	22.6
Bypass[a]	71.8	74.9
Late overpressure	ϵ	ϵ
BMT	ϵ	ϵ

a. Bypass failures include pre-existing containment leaks and induced SGTR.

approximate this dependency by including more top events in the SCET. However, none of these attempts proved successful; the SCET results still did not agree very well with those predicted by the APET.

This modeling problem appears to be a limitation of the SCET methodology. Vessel breach is a critical top event in the SCET and its complicated dependencies on earlier events in the APET cannot be completely modeled without making the SCET excessively large and complicated. At this point, a choice had to be made between simplicity and accuracy. The decision was made to give up some of the simplicity of analyzing depressurization on the SCET in order to accurately model the dependencies in the APET. SCETs were still produced to show the revised pathways through the APET, but depressurization itself was modeled by adjusting split fractions in the APET.

This decision was influenced by the fortuitous availability of the PSTEVNT post-processor code at this point in the project.[8] PSTEVNT allowed processing of output from EVNTRE runs made in the sampling mode (mode 3), as was done for draft NUREG-1150. Use of PSTEVNT also automated the binning of SCET end states into the ZISOR accident progression bins. The steps in the revised process are as follows:

1. Run EVNTRE in the sampling mode (mode 3) to analyze improvements modeled in the full 72-question APET.
2. Use the binning output file from EVNTRE as input to PSTEVNT.
3. Run PSTEVNT to generate composite sorted output from which the revised SCET is constructed.
4. Run PSTEVNT again to generate the ZISOR accident progression bins and their conditional probabilities of occurrence.

The remaining steps in the risk calculation are the same as were described in Section 2.

Intentional opening of the PORVs was modeled in the APET by adjusting the split fraction for Question 16 to 0.0/1.0 and turning off sampling for this question. The resulting SCET is shown in Figure 4.2. The revised conditional containment failure probabilities are shown in Table 4.5.

As Table 4.5 shows, opening the PORVs significantly reduces the probability of DCH-induced early containment failure. Also, the probability of bypass failure is reduced by the elimination of temperature-induced SGTR. However, there is a slight increase in the probability of late failure. The increase in late overpressure failure is probably attributable to a larger amount of hydrogen being generated in the case where the PORVs are intentionally opened during core degradation. The reason for the slight increase in the probability of BMT is not known. The effects of intentional RCS depressurization on offsite risk are shown in Table 4.6.

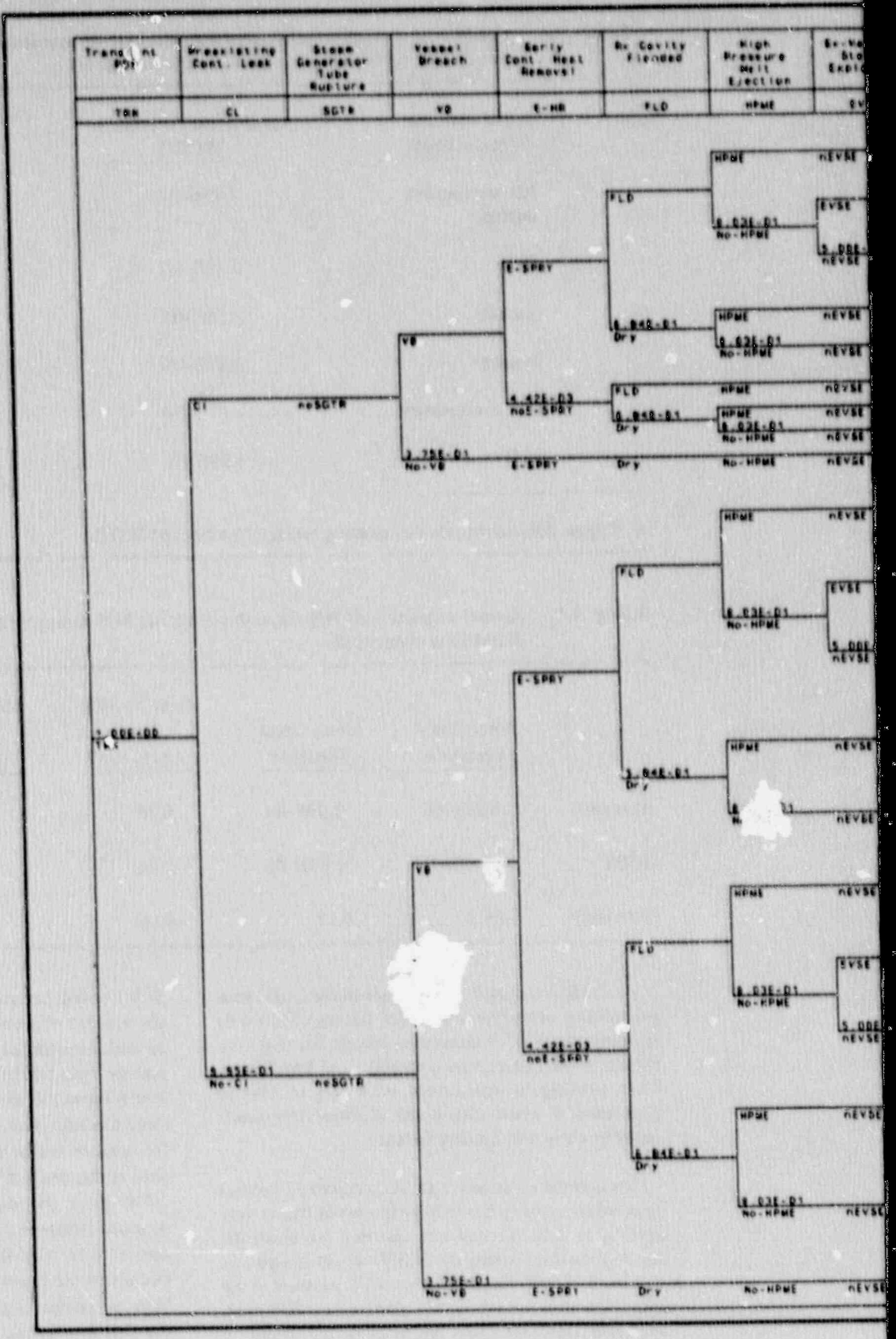

Figure 4.2. Transient + ATWS SCET with intentional depressurization.

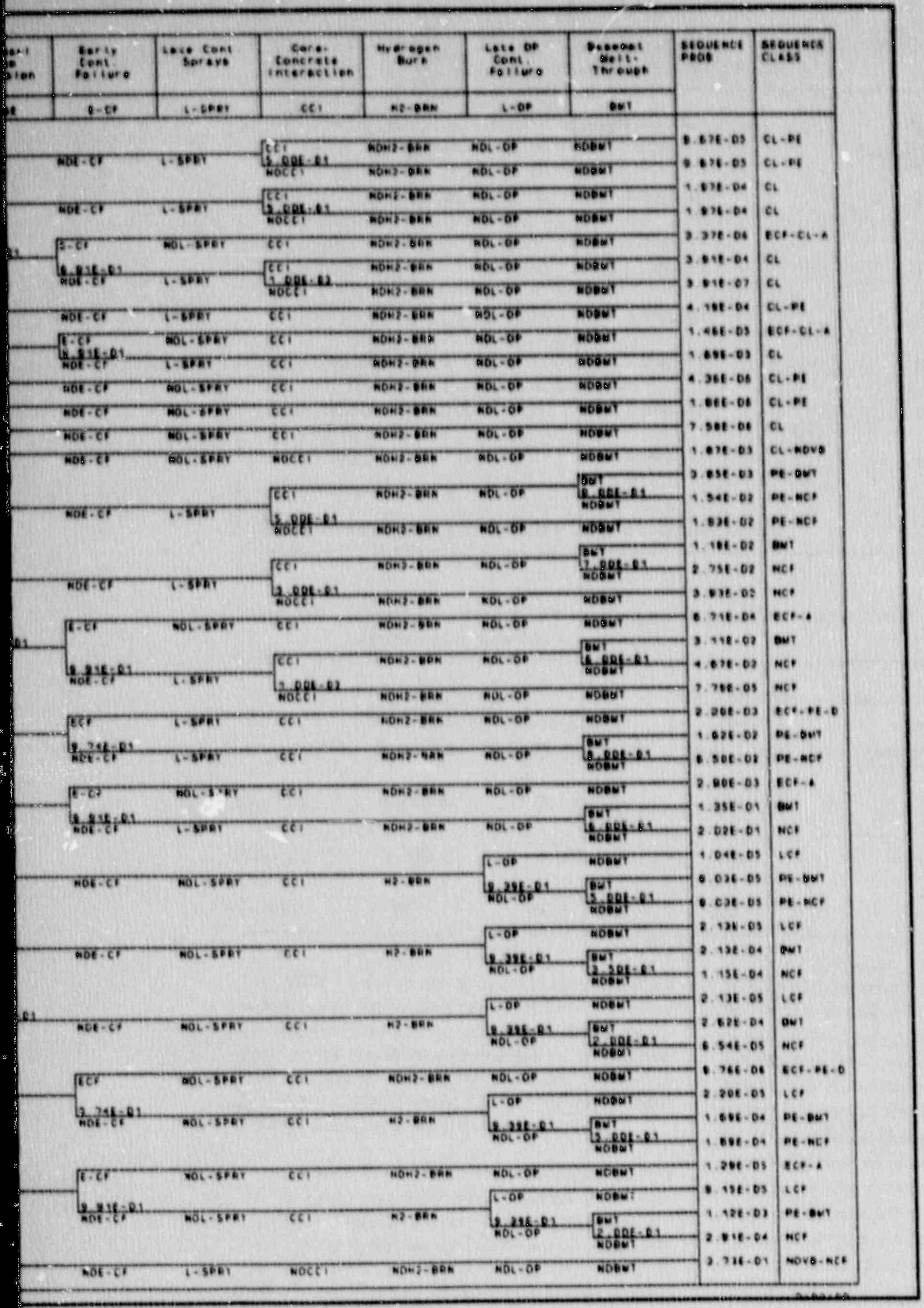
Early Cont. Failure
Late Cont Sprays
Core-Concrete Interaction
Hydrogen Burn
Late DP Cont. Failure
Basemat Melt-Through
SEQUENCE PROB
SEQUENCE CLASS
E-CF
L-SPRY
CCI
H2-BRN
L-DP
BMT
NOE-CF
NOL-SPRY
NOCCI
NOH2-BRN
NOL-DP
NOBMT
ECF
5.00E-01
9.91E-01
9.74E-01
9.39E-01
8.67E-05 CL-PE
9.67E-05 CL-PE
1.97E-04 CL
1.97E-04 CL
3.37E-06 ECF-CL-A
3.91E-04 CL
3.91E-07 CL
4.19E-04 CL-PE
1.46E-05 ECF-CL-A
1.69E-03 CL
4.36E-06 CL-PE
1.86E-06 CL-PE
7.58E-06 CL
1.87E-03 CL-NOVB
3.85E-03 PE-BMT
1.54E-02 PE-NCF
1.83E-02 PE-NCF
1.18E-02 BMT
2.75E-02 NCF
3.93E-02 NCF
6.71E-04 ECF-A
3.11E-02 BMT
4.67E-02 NCF
7.79E-05 NCF
2.20E-03 ECF-PE-D
1.62E-02 PE-BMT
6.50E-02 PE-NCF
2.90E-03 ECF-A
1.35E-01 BMT
2.02E-01 NCF
1.04E-05 LCF
6.03E-05 PE-BMT
6.03E-05 PE-NCF
2.13E-05 LCF
2.13E-04 BMT
1.15E-04 NCF
2.13E-05 LCF
2.62E-04 BMT
6.54E-05 NCF
9.76E-06 ECF-PE-D
2.20E-05 LCF
1.69E-04 PE-BMT
1.69E-04 PE-NCF
1.29E-05 ECF-A
9.15E-05 LCF
1.12E-03 PE-BMT
2.81E-04 NCF
3.73E-01 NOVB-NCF

Table 4.5. Conditional containment failure probabilities for the transient + ATWS PDS with intentional depressurization (HPME not eliminated)

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
No containment failure	7.89E–01	7.90E–01
DCH	2.21E–03	4.14E–03
α mode	3.58E–03	3.66E–03
Bypass[a]	4.97E–03	8.94E–03
Late overpressure	1.67E–04	1.49E–04
BMT	1.99E–01	1.93E–01

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a. Bypass failures include pre–existing leakage and induced SGTR.

Table 4.6. Annual transient + ATWS risk with intentional RCS depressurization (HPME not eliminated)

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	6.22E–07	3.00E–04	0.66	1.79	892
SCET	2.10E–07	9.67E–05	0.26	0.60	176
% change	–66.3	–67.8	–60.6	–66.6	–80.3

As Table 4.6 shows, the decrease in the conditional probability of early containment failure effected by opening the PORVs more than offsets the slight increase in the conditional probability of late failure. This finding is consistent with the results in Reference 4, where offsite risk is completely dominated by early containment failure.

Because the reduction in DCH containment failures effected by opening the PORVs is a result that is very specific to Zion, a sensitivity case was run under the assumption that opening the PORVs would completely eliminate HPME, that is, that the RCS pressure at the time of vessel breach would always be <200 psig. However, this case could not be modeled simply by [illegible] the probability of event HPME in the base case SCET to 0.0, because reducing vessel pressure affects the conditional probability of vessel breach (event VB) as well. Accordingly, a modified APET was evaluated and the split fractions in the SCET were adjusted to match those calculated with the APET. Also, as discussed in Section 3, the Zion APET uses a probability for α mode failure that is dependent upon RCS pressure at the time of vessel breach. If the pressure is >200 psig, the mean conditional probability of α mode failure is 8.0 x 10^{-4}. However, if RCS pressure is <200 psig, the mean probability is 8.0 x 10^{-3}. Because some experts may question the use of such a high probability of α mode failure, a sensitivity case for full depressurization to <200 psig was also run with a pressure–independent α mode failure probability of 8.0×10^{-4}, with no sampling of Question 34 in the APET. The revised SCETs for these cases are shown in Figures 4.3 and 4.4. The containment failure probabilities calculated for these cases are shown in Tables 4.7 and 4.8.

Eliminating HPME eliminates DCH failures, as expected. The conditional probability of α mode failure increases if the pressure-dependent probability distribution from draft NUREG-1150 is used but is decreased significantly if a pressure-independent point estimate is used. Table 4.9 shows the annual offsite risk for the fully depressurized case with the α mode probabilities from draft NUREG-1150 and Table 4.10 shows the risk for the fully depressurized case with the pressure-independent point estimate probability of α mode failure.

Note that the risk reduction for both of the fully depressurized cases is quite large, although it is less where a pressure-dependent α mode probability is used. This is attributable to several factors. First, depressurizing allows injection from low pressure systems, because AC power is available. This reduces the conditional probability of vessel breach. Secondly, depressurization eliminates temperature-induced SGTR, which is a significant contributor to the base case transient + ATWS risk, as shown in Table 4.4. Thirdly, the use of a point estimate probability of α mode failure that is independent of the RCS pressure at the time of vessel breach eliminates failures produced by sampling from the "tail" of the α mode failure distribution. In summary, the primary benefits of depressurization for the transient + ATWS PDS group are the elimination of temperature-induced SGTR and the increased probability of recovering the sequence in-vessel. These benefits are diminished somewhat by the use of the pressure-dependent probability distribution for α mode failure developed for draft NUREG-1150.

4.4.2 Cavity Flooding. The addition of a cavity flooding system was analyzed by appropriately modifying the split fraction of Question 31 in the Zion APET, turning off sampling for this question, and running EVNTRE and PSTEVNT to generate the revised SCET and ZISOR accident progression bins. Figure 4.5 shows the revised SCET for transient + ATWS with the addition of a cavity flooding system. Table 4.11 shows the revised conditional containment failure probabilities.

Cavity flooding leads to an increase in the probability of DCH failure. There is an expected reduction in the probability of BMT. Table 4.12 shows the effect of cavity flooding on offsite risk. For further details, see Section 5.4.2

4.4.3 Hydrogen Control. Improved hydrogen control was modeled in the SCET by eliminating late overpressure containment failure, that is, by setting the probability of the lower branch of event L-OP to 1.0 for all sequences. The new conditional containment failure probabilities are shown in Table 4.13.

Elimination of hydrogen burns produced no reduction in any of the risk measures used in this report. This finding is consistent with Reference 4, where late overpressure containment failure was a negligible contributor to risk.

4.4.4 Containment Venting. As in the LOCA PDS, containment venting is not evaluated for transient + ATWS. See the discussion of containment venting in Section 3.4.4.

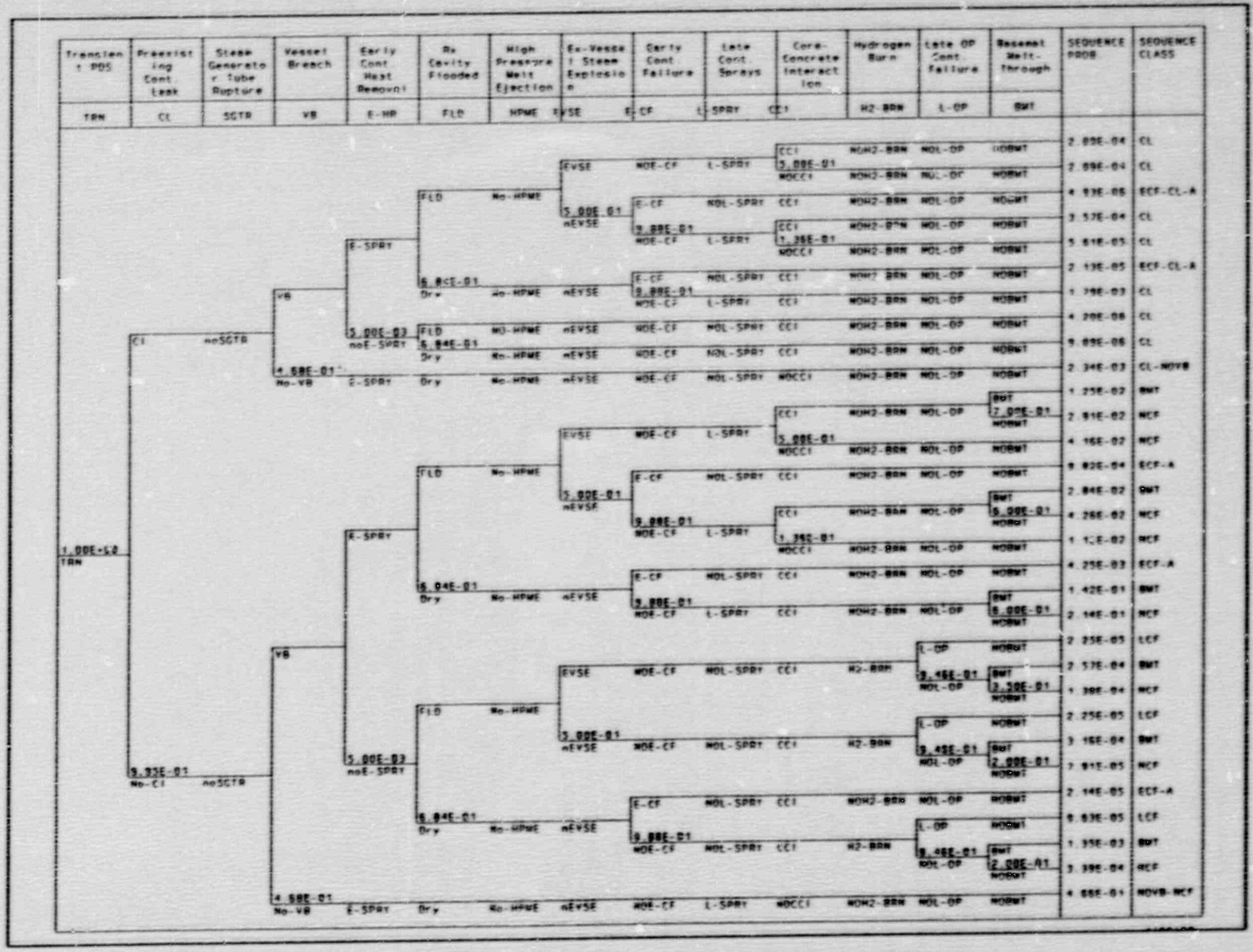

Figure 4.3 Transient + ATWS SCET with full depressurization (no HPME) and pressure-dependent α mode probability.

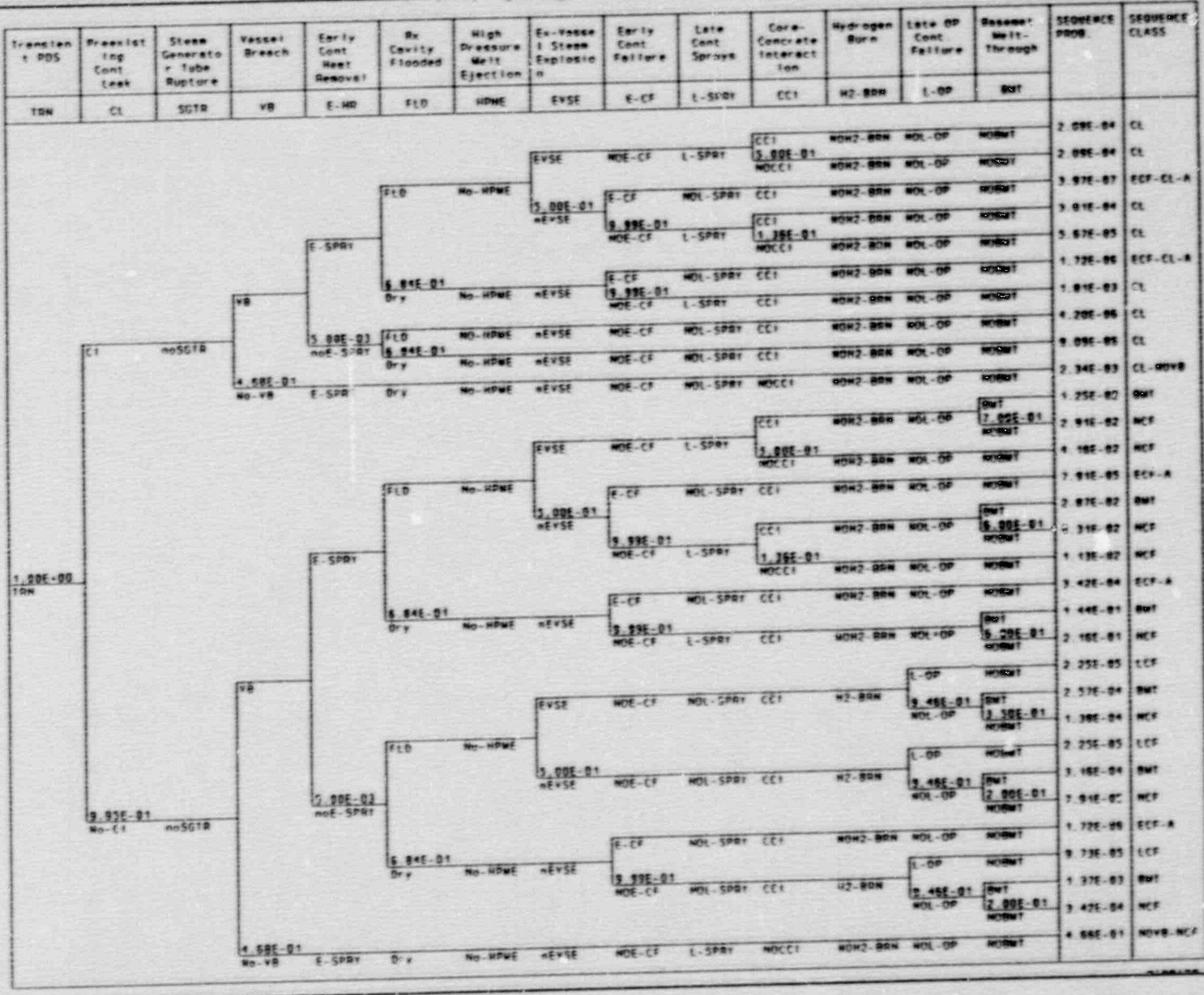

Figure 4.4. Transient + ATWS SCET with intentional depressurization to <200 psig (no HPME) and pressure-independent point estimate α mode probability.

Table 4.7. Conditional containment failure probabilities for the transient + ATWS PDS with operator depressurization and pressure–dependent α mode probability (no HPME)

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
No containment failure	8.05E–01	7.90E–01
DCH	0.00	4.14E–03
α mode	5.28E–03	3.66E–03
Bypass[a]	4.97E–03	8.94E–03
Late overpressure	1.41E–04	1.49E–04
BMT	1.85E–01	1.93E–01

---

[a] Bypass failures involve pre–existing containment leakage.

Table 4.8. Conditional containment failure probabilities for the transient + ATWS PDS with operator depressurization and pressure–independent point estimate α mode probability (no HPME)

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
No containment failure	8.08E–01	7.90E–01
DCH	0.00	4.14E–03
α mode	4.25E–04	3.66E–03
Bypass[a]	5.00E–03	8.94E–03
Late overpressure	1.42E–04	1.49E–04
BMT	1.87E–01	1.93E–01

---

[a] Bypass failures involve pre–existing containment leakage.

Table 4.9. Annual transient + ATWS risk with full RCS depressurization and pressure–dependent α mode probability (No HPME)

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (Person–rem)	Mean 1000–Mile Dose (Person–rem)	Mean Offsite Costs ($)
Base case	6.22E–07	3.00E–04	0.66	1.79	892
SCET	2.67E–07	1.22E–04	0.32	0.76	240
% change	-57.1	–59.4	–51.1	–57.4	–73.1

Table 4.10. Annual transient + ATWS risk with full RCS depressurization and pressure–independent point estimate α mode probability (no HPME)

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (Person–rem)	Mean 1000–Mile Dose (Person–rem)	Mean Offsite Costs ($)
Base case	6.22E–07	3.00E–04	0.66	1.79	892
SCET	8.44E–08	3.85E–05	0.11	0.23	48.0
% change	–86.4	–87.2	–83.5	–87.2	–94.6

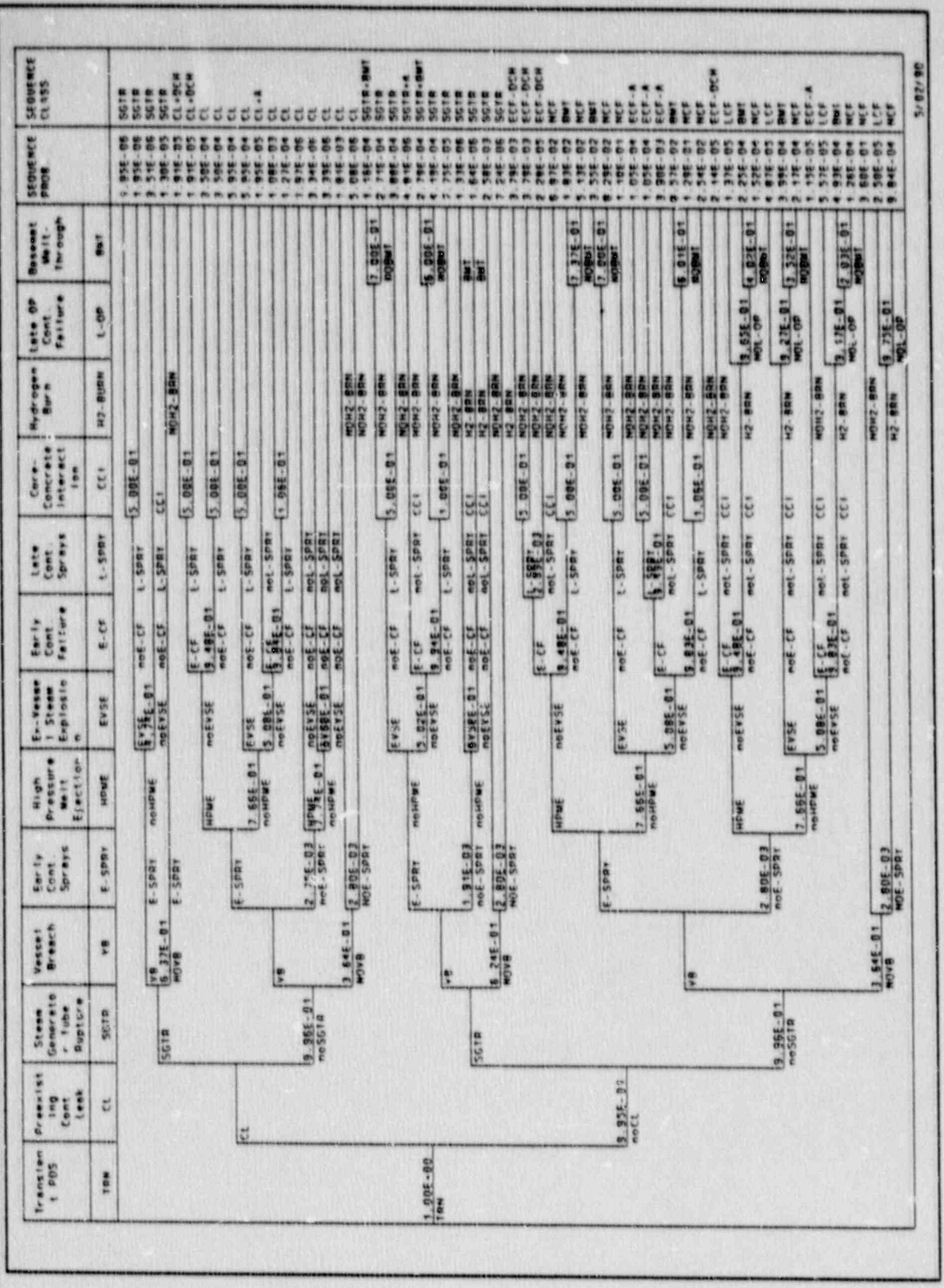

Figure 4.5. Transient + ATWS SCET with cavity flooding system.

Table 4.11. Conditional containment failure probabilities for the transient + ATWS PDS with cavity flooding system

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
No containment failure	8.38E–01	7.90E–01
DCH	7.62E–03	4.14E–03
α mode	4.14E–03	3.66E–03
Bypass[a]	9.12E–03	8.94E–03
Late overpressure	1.43E–04	1.49E–04
BMT	1.41E–01	1.93E–01

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a. Bypass failures involve pre–existing containment leakage.

Table 4.12. Annual transient + ATWS risk with addition of cavity flooding system

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (Person–rem)	Mean 1000–Mile Dose (Person–rem)	Mean Offsite Costs ($)
Base case	6.22E–07	3.00E–04	0.66	1.79	892
SCET	6.58E–07	2.97E–04	0.66	1.74	844
% change	5.8	-1.1	0.0	-2.9	-5.4

Table 4.13. Conditional containment failure probabilities for the transient + ATWS PDS with improved hydrogen control

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
No containment failure	7.90E–01	7.90E–01
DCH	4.14E–03	4.14E–03
α mode	3.66E–03	3.66E–03
Bypass[a]	8.94E–03	8.94E–03
Late overpressure	0.00	1.48E–04
BMT	1.93E–01	1.93E–01

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a. Bypass failures include pre–existing leakage and induced SGTR.

5. STATION BLACKOUT

Plant damage states in the SBO group involve a loss of offsite power followed by failure of the emergency diesel generators (EDGs) to start and run. The turbine-driven auxiliary feedwater system (AFWS) operates until the station batteries are depleted after an assumed interval of four hours. The RCS is intact at the time of core uncovery in one of the SBO PDSs. In the other two, failure of the RCP seals results in an RCS break equivalent in size to a medium LOCA (S2 break) at the time of core uncovery.

5.1 Station Blackout Core Damage Frequency

The SBO group is composed of three PDSs with a total mean frequency of 5.21×10^{-6} per reactor-year from Table 2.2-3 in Reference 4.

5.2 Station Blackout SCET Results

The base case SBO SCET is shown in Figure 5.1. This SCET, like those for the previous PDS groups, was constructed using the methodology outlined in Section 2. Note its similarity to the SCET constructed for the transient + ATWS PDS group in Section 4. Table 5.1 shows the containment failure probabilities, conditional on the occurrence of the SBO PDS, calculated from this SCET and compares them to the probabilities from Reference 4.

The conditional containment failure probabilities calculated from the SCET agree well with those published in Reference 4. Again, the most likely end state is one in which the containment maintains its structural integrity. The most likely mode of early containment failure is DCH. This differs from the LOCA PDS, where α mode failure was more likely than DCH.

5.3 Base Case SBO Consequences

The SCET end states were binned into accident progression bins and the ZISOR code was again used to generate source terms for these bins as described in Section 2. Because of the large number of accident progression bins, the source terms were manually combined into groups in order to reduce the required number of MACCS calculations. Conditional consequences were then calculated for each accident progression bin group with the MACCS code. As for the previous PDS groups, the Zion site data and meteorological files were used for these calculations. The conditional consequences for each accident progression bin are shown in Table 5.2.

Table 5.3 shows the annual risk for the SBO PDS group calculated from Equation 1.1.

Table 5.4 lists the contribution of each containment failure mode to the offsite population dose.

Again, the only significant contributors to offsite dose are early containment failures, with α mode failure being the most dominant. DCH contributes a larger fraction than it did in either the LOCA or transient + ATWS PDS groups. The contribution from containment bypass is also significant.

5.4 Risk Benefit of Potential Improvements

The risk benefit of the potential containment performance improvements identified in Reference 2 is calculated in this section.

5.4.1 Enhanced Reactor Vessel Depressurization Capability. Similar to the transient + ATWS PDS group, intentional depressurization via the pressurizer PORVs could not be accurately modeled with an SCET. Therefore, depressurization was modeled in the APET using the revised methodology discussed in Section 4.4.1. The revised SCET is shown in Figure 5.2 The new conditional probabilities of containment failure thus obtained are shown in Table 5.5.

As Table 5.5 shows, opening the PORVs during SBO does not significantly affect the threat of DCH. Because the APET upon which the model of depressurization is based is specific to the Zion plant, and PORV capacity is a plant-specific parameter,[12] two sensitivity cases were run in which opening the PORVs was assumed to eliminate HPME by reducing vessel pressure below the DCH cutoff of 200 psig. However, just as for the analogous case in the transient + ATWS PDS, this case could not be modeled by simply setting the probability of event HPME in the base case SCET to 0.0, because reducing vessel pressure affects the conditional probability of vessel breach (event VB) as well. Accordingly, a modified APET was evaluated and the split fractions in the SCET were adjusted to match those calculated with the APET. Similar to the transient + ATWS PDS, the

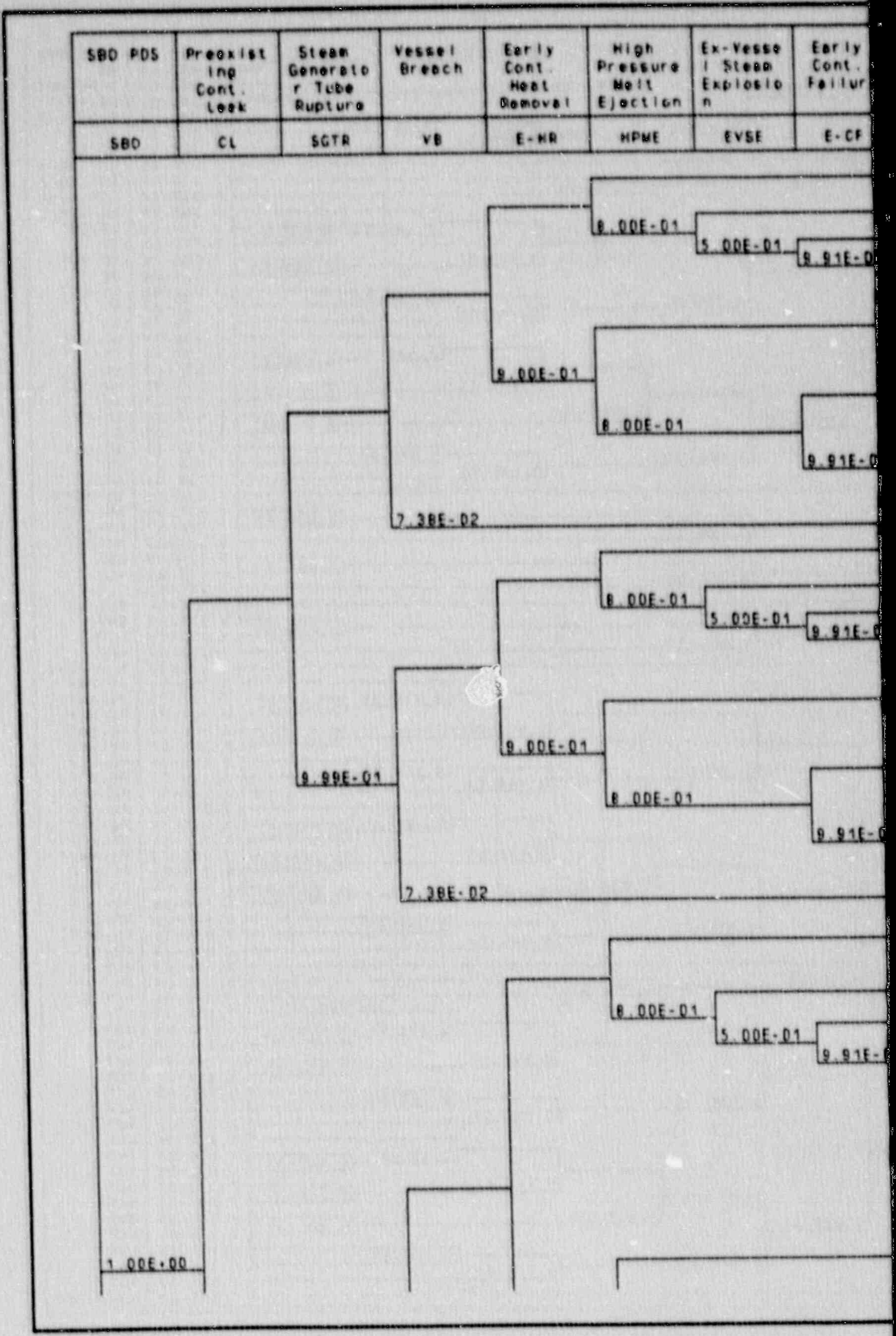
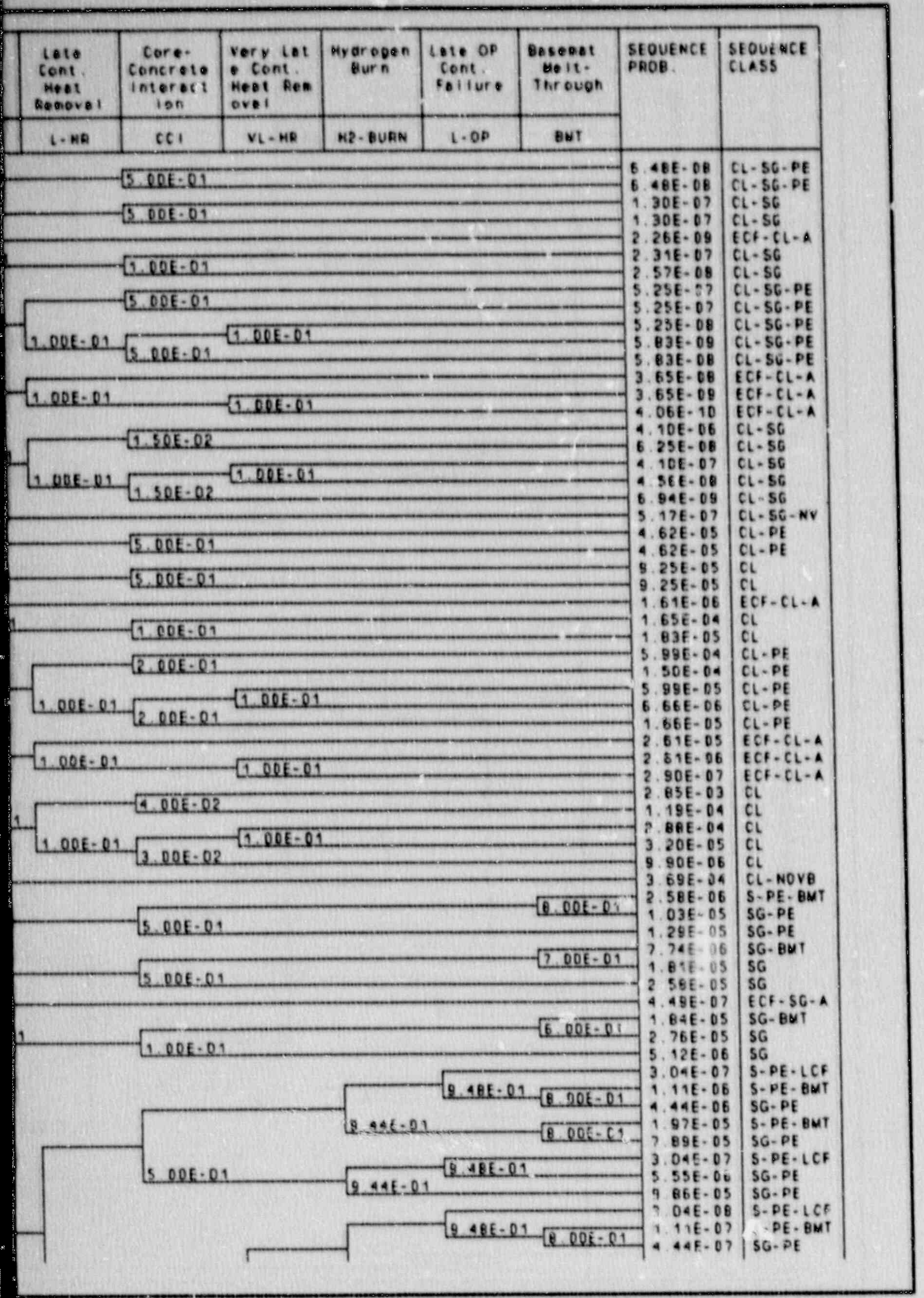


Figure 5.1. Base case SBO SCET.



SEQUENCE PROB.	SEQUENCE CLASS
6.48E-08	CL-SG-PE
6.48E-08	CL-SG-PE
1.30E-07	CL-SG
1.30E-07	CL-SG
2.26E-09	ECF-CL-A
2.31E-07	CL-SG
2.57E-08	CL-SG
5.25E-07	CL-SG-PE
5.25E-07	CL-SG-PE
5.25E-08	CL-SG-PE
5.83E-09	CL-SG-PE
5.83E-08	CL-SG-PE
3.65E-08	ECF-CL-A
3.65E-09	ECF-CL-A
4.06E-10	ECF-CL-A
4.10E-06	CL-SG
6.25E-08	CL-SG
4.10E-07	CL-SG
4.56E-08	CL-SG
6.94E-09	CL-SG
5.17E-07	CL-SG-NV
4.62E-05	CL-PE
4.62E-05	CL-PE
9.25E-05	CL
9.25E-05	CL
1.61E-06	ECF-CL-A
1.65E-04	CL
1.83E-05	CL
5.99E-04	CL-PE
1.50E-04	CL-PE
5.99E-05	CL-PE
6.66E-06	CL-PE
1.66E-05	CL-PE
2.61E-05	ECF-CL-A
2.61E-06	ECF-CL-A
2.90E-07	ECF-CL-A
2.85E-03	CL
1.19E-04	CL
2.88E-04	CL
3.20E-05	CL
9.90E-06	CL
3.69E-04	CL-NOVB
2.58E-06	S-PE-BMT
1.03E-05	SG-PE
1.29E-05	SG-PE
7.74E-06	SG-BMT
1.81E-05	SG
2.58E-05	SG
4.49E-07	ECF-SG-A
1.84E-05	SG-BMT
2.76E-05	SG
5.12E-06	SG
3.04E-07	S-PE-LCF
1.11E-06	S-PE-BMT
4.44E-06	SG-PE
1.97E-05	S-PE-BMT
7.89E-05	SG-PE
3.04E-07	S-PE-LCF
5.55E-06	SG-PE
9.86E-05	SG-PE
7.04E-08	S-PE-LCF
1.11E-07	S-PE-BMT
4.44E-07	SG-PE

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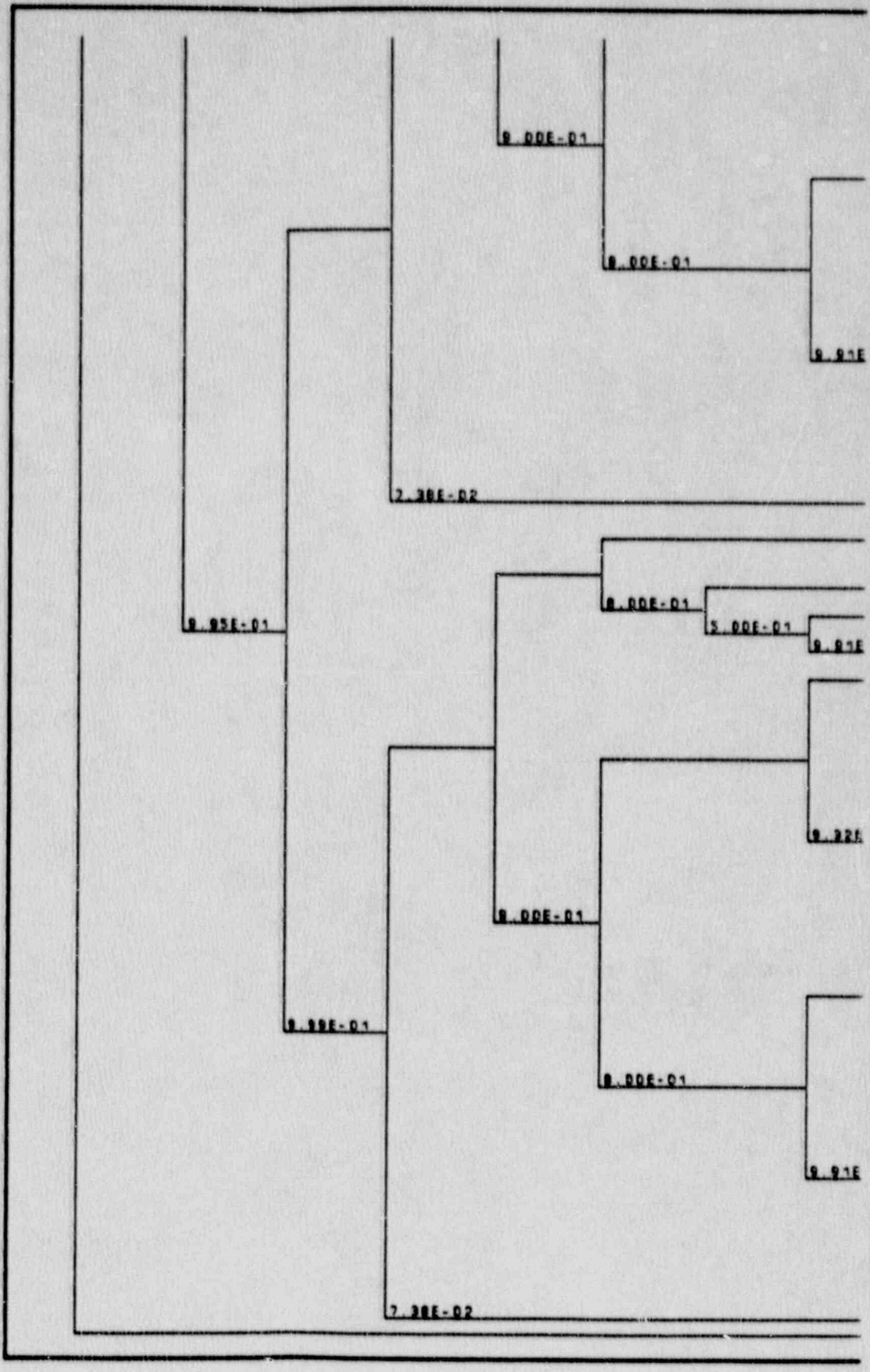
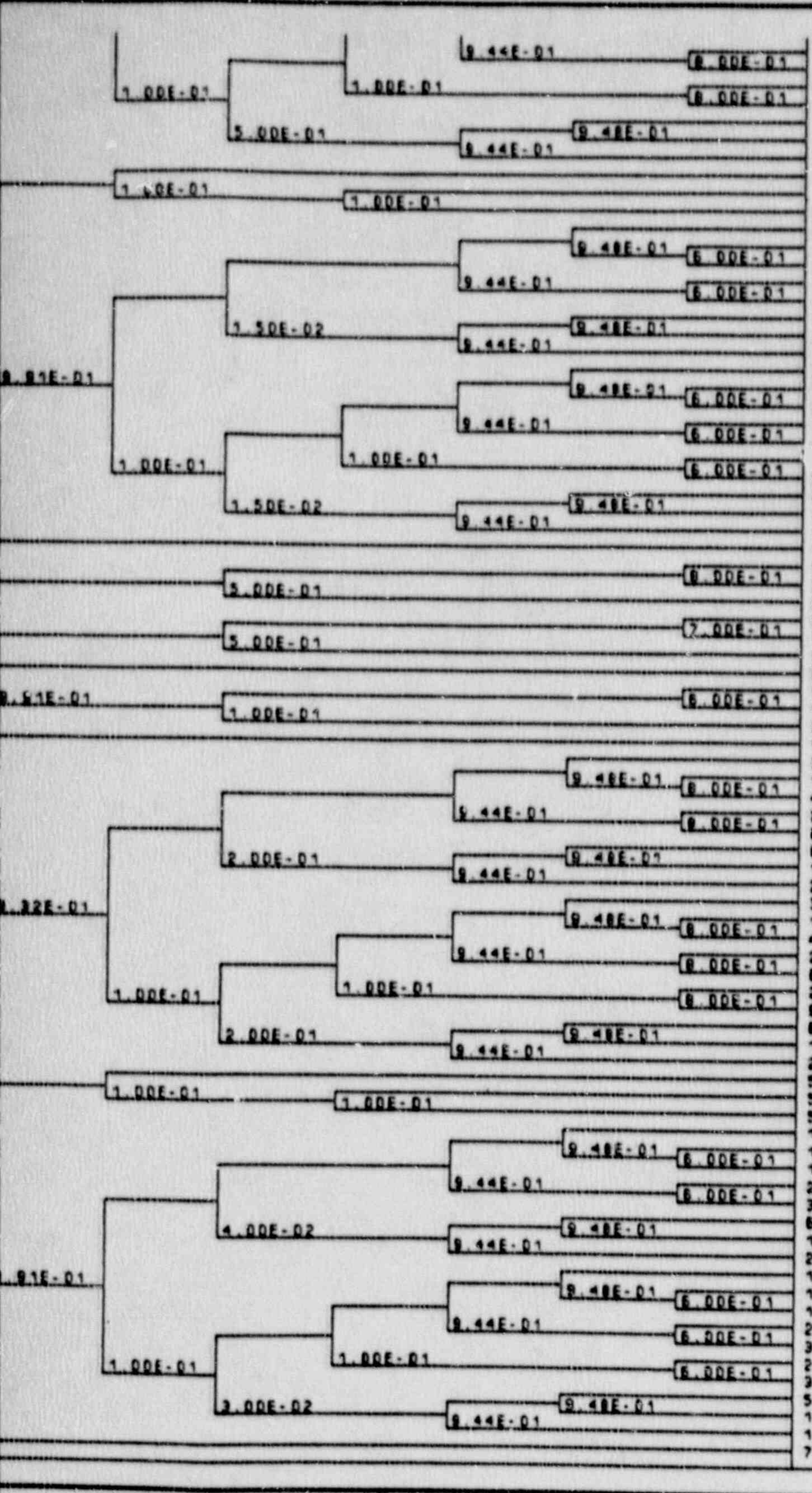


Figure 5.1. (continued).



1.97E-06	S-PE-BMT
7.89E-06	SG
2.32E-07	S-PE-BMT
9.29E-07	SG-PE
3.38E-08	S-PE-LCF
6.16E-07	SG-PE
1.10E-05	SG-PE
7.27E-06	ECF-SG-A
7.27E-07	ECF-SG-A
8.08E-08	ECF-SG-A
2.38E-06	SG-LCF
1.73E-05	SG-BMT
2.60E-05	SG
3.08E-04	SG-BMT
4.62E-04	SG
3.62E-08	SG-LCF
6.60E-07	SG
1.17E-05	SG
2.38E-07	SG-LCF
1.73E-06	SG-BMT
2.60E-06	SG
3.08E-05	SG-BMT
4.62E-05	SG
[illegible].63E-06	SG-BMT
5.44E-06	SG
4.02E-09	SG-LCF
7.33E-08	SG
1.30E-06	SG
1.03E-04	SG-NOVB
1.84E-03	PE-BMT
7.36E-03	PE-NCF
9.20E-03	PE-NCF
5.52E-03	BMT
1.29E-02	NCF
1.84E-02	NCF
3.20E-04	ECF-A
1.31E-02	BMT
1.97E-02	NCF
3.65E-03	NCF
1.13E-02	ECF-PE-D
3.24E-04	PE-LCF
1.18E-03	PE-BMT
4.72E-03	PE-NCF
2.10E-02	PE-BMT
8.39E-02	PE-NCF
8.09E-05	PE-LCF
1.48E-03	PE-NCF
2.62E-02	PE-NCF
3.24E-05	PE-LCF
1.18E-04	PE-BMT
4.72E-04	PE-NCF
2.10E-03	PE-BMT
8.39E-03	PE-NCF
2.47E-04	PE-BMT
9.88E-04	PE-NCF
8.99E-06	PE-LCF
1.64E-04	PE-NCF
2.91E-03	PE-NCF
5.19E-03	ECF-A
5.19E-04	ECF-A
5.76E-05	ECF-A
1.65E-[illegible]	LCF
1.21E-02	BMT
1.81E-02	NCF
2.14E-01	BMT
3.21E-01	NCF
6.89E-05	LCF
1.26E-03	NCF
2.23E-02	NCF
1.67E-04	LCF
1.22E-03	BMT
1.83E-03	NCF
2.17E-02	BMT
3.25E-02	NCF
2.55E-03	BMT
3.82E-03	NCF
5.74E-06	LCF
1.05E-04	NCF
1.86E-03	NCF
7.34E-02	NOVB-NCF

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Table 5.1. Conditional containment failure probabilities for the SBO PDS

Containment Failure Mode	Conditional Probability (SCET)	Conditional Probability (Reference 4)
No containment failure	6.76E-01	6.57E-01
DCH	1.13E-02	1.66E-02
α mode	6.13E-03	6.15E-03
Bypass[a]	6.35E-03	6.42E-03
Late overpressure	2.34E-03	2.58E-03
BMT	2.97E-01	3.11E-01

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[a] Bypass failures include pre-existing leakage and induced SGTR.

Table 5.2. Conditional consequences for the SBO accident progression bins

Accident Progression Bin	Mean Early Fatalities	Mean Latent Fatalities	Mean 50-Mile Dose (person-rem)	Mean 1000-Mile Dose (person-rem)	Mean Offsite Costs ($)
CDCCAADBACBB	9.55E+00	4.24E+03	8.21E+06	2.49E+07	1.51E+10
CDCCACDBACBB	7.30E-01	3.98E+02	1.13E+06	2.31E+06	3.08E+08
CDCDBADBDCBB	9.55E+00	4.24E+03	8.21E+06	2.49E+07	1.51E+10
CDCDBCDBDCBB	1.12E+00	5.98E+02	1.74E+06	3.51E+06	6.30E+08
CDCDFADBDCBB	9.54E+00	4.23E+03	8.18E+06	2.48E+07	1.51E+10
CDCDFCDBDCBB	7.30E-01	3.98E+02	1.13E+06	2.31E+06	3.08E+08
CDDCAAABACBB	9.55E+00	4.24E+03	8.21E+06	2.49E+07	1.51E+10
CDDCACABACBB	7.30E-01	3.98E+02	1.13E+06	2.31E+06	3.08E+08
CDDDBAABDCBB	9.55E+00	4.24E+03	8.21E+06	2.49E+07	1.51E+10
CDDDBCABDCBB	1.12E+00	5.98E+02	1.74E+06	3.51E+06	6.30E+08
CFACAAABACBA	1.67E+01	5.18E+03	9.65E+06	3.07E+07	1.99E+10
CFACACABACBA	2.96E+01	4.45E+03	8.23E+06	2.67E+07	1.90E+10
CFADBAABDCBA	1.67E+01	5.18E+03	9.65E+06	3.07E+07	1.99E+10
CFADBCABDCBA	1.72E+02	6.86E+03	1.33E+07	3.98E+07	2.69E+10
CFCCAADBACBA	1.67E+01	5.18E+03	9.65E+06	3.07E+07	1.99E+10
CFCCACDBACBA	2.96E+01	4.45E+03	8.23E+06	2.67E+07	1.90E+10
CFCDBADBDCBA	1.67E+01	5.18E+03	9.65E+06	3.07E+07	1.99E+10
CFCDBCDBDCBA	1.72E+02	6.86E+03	1.33E+07	3.98E+07	2.69E+10
CGACAAABACBA	1.67E+01	5.18E+03	9.65E+06	3.07E+07	1.99E+10
CGACACABACBA	2.96E+01	4.45E+03	8.23E+06	2.67E+07	1.90E+10
CGADBAABDCBA	1.67E+01	5.18E+03	9.65E+06	3.07E+07	1.99E+10
CGADBCABDCBA	1.72E+02	6.86E+03	1.33E+07	3.98E+07	2.69E+10
CGCCAADBACBA	1.67E+01	5.18E+03	9.65E+06	3.07E+07	1.99E+10
CGCCACDBACBA	2.96E+01	4.45E+03	8.23E+06	2.67E+07	1.90E+10
CGCDBADBDCBA	1.67E+01	5.18E+03	9.65E+06	3.07E+07	1.99E+10
CGCDBCDBDCBA	1.72E+02	6.86E+03	1.33E+07	3.98E+07	2.69E+10
CHACAAABACBA	1.67E+01	5.18E+03	9.65E+06	3.07E+07	1.99E+10
CHACACABACBA	2.96E+01	4.45E+03	8.23E+06	2.67E+07	1.90E+10

Table 5.2. (continued)

Accident Progression Bin	Mean Early Fatalities	Mean Latent Fatalities	Mean 50-Mile Dose (person-rem)	Mean 1000-Mile Dose (person-rem)	Mean Offsite Costs ($)
CHADBAABDCBA	1.67E+01	5.18E+03	9.65E+06	3.07E+07	1.99E+10
CHADBCABDCBA	1.72E+02	7.09E+03	1.38E+07	4.15E+07	2.79E+10
DADDDABBDBBB	1.01E+01	4.50E+03	8.91E+06	2.71E+07	1.70E+10
DADDDCBBDBBB	1.35E+00	1.45E+03	3.73E+06	9.28E+06	3.09E+09
DHACACABACBA	3.09E+00	2.14E+03	4.63E+06	1.29E+07	5.95E+09
DHADDABBDBBA	2.28E+01	5.80E+03	1.07E+07	3.45E+07	2.27E+10
DHADDCBBDBBA	5.47E+02	9.58E+03	1.98E+07	5.72E+07	4.41E+10
EFACACABACBA	0.00E+00	3.33E+00	1.10E+04	2.00E+04	2.86E+05
EFADBCABDCBA	0.00E+00	3.33E+00	1.10E+04	2.00E+04	2.86E+05
EFCCACDBACBA	0.00E+00	3.33E+00	1.10E+04	2.00E+04	2.86E+05
EFCDBCDBDCBA	0.00E+00	3.33E+00	1.10E+04	2.00E+04	2.86E+05
EGACACABACBA	4.67E-07	1.46E+02	4.75E+05	8.77E+05	1.01E+08
EGADBCABDCBA	1.60E-05	2.39E+02	7.53E+05	1.44E+06	1.79E+08
EGCCACDBACBA	4.67E-07	1.46E+02	4.75E+05	8.77E+05	1.01E+08
EGCDBCDBDCBA	1.60E-05	2.39E+02	7.53E+05	1.44E+06	1.79E+08
FDDCACABAEBB	0.00E+00	8.63E-03	2.28E+01	5.17E+01	0.00E+00
FDDDBCABDEBB	0.00E+00	8.63E-03	2.28E+01	5.17E+01	0.00E+00
FFACACABAEBA	0.00E+00	8.63E-03	2.28E+01	5.17E+01	0.00E+00
FFADBCABDEBA	0.00E+00	8.41E-03	2.18E+01	5.04E+01	0.00E+00
FGACACABAEBA	0.00E+00	8.63E-03	2.28E+01	5.17E+01	0.00E+00
FGADBCABDEBA	0.00E+00	8.41E-03	2.18E+01	5.04E+01	0.00E+00
FHACACABAEBA	0.00E+00	3.67E-02	1.43E+02	2.15E+02	1.32E+02
FHADBCABDEBA	0.00E+00	3.67E-02	1.43E+02	2.15E+02	1.32E+02
GDCCAADBAFBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDCCACDBAGBB	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00
GDCDBADBDFBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDCDBCDBDGBB	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00
GDCDFADBDFBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDCDFCDBDGBB	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00
GDDCAAABAEBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDDCAAABAFBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDDCACABAGBB	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00
GDDDBAABDEBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDDDBAABDFBB	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GDDDBCABDGBB	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00
GFACAAABACBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GFACAAABAEBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GFACAAABAFBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GFACACABAGBA	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00
GFADBAABDCBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GFADBAABDEBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GFADBAABDFBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GFADBCABDGBA	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00
GFCCAADBACBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GFCCAADBAFBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GFCCACDBAGBA	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00
GFCDBADBDCBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GFCDBADBDFBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GFCDBCDBDGBA	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00
GGACAAABACBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GGACAAABAEBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GGACAAABAFBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GGACACABAGBA	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00

Table 5.2. (continued)

Accident Progression Bin	Mean Early Fatalities	Mean Latent Fatalities	Mean 50-Mile Dose (person-rem)	Mean 1000-Mile Dose (person-rem)	Mean Offsite Costs ($)
GGADBAABDCBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GGADBAABDEBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GGADBAABDFBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GGADBCABDGBA	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00
GGCCAADBACBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GGCCAADBAFBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GGCCACDBAGBA	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00
GGCDBADBDCBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GGCDBADBDFBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GGCDBCDBDGBA	0.00E+00	2.63E-02	9.67E+01	1.38E+02	0.00E+00
GHACAAABAEBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GHACAAABAFBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GHACACABAGBA	0.00E+00	1.52E-01	6.17E+02	8.77E+02	3.80E+03
GHADBAABDEBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GHADBAABDFBA	8.42E+00	4.23E+03	8.19E+06	2.48E+07	1.51E+10
GHADBCABDGBA	0.00E+00	1.52E-01	6.17E+02	8.77E+02	3.80E+03

Table 5.3. Annual base case SBO risk

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50-Mile Dose (person-rem)	Mean 1000-Mile Dose (person-rem)	Mean Offsite Costs ($)
Reference 4	1E-05	9E-04	2.1	4.8	6E+03
SCET	2E-05	6E-04	1.2	3.5	2E+03
Relative change	0.5	1.5	1.8	1.4	3.0

Table 5.4. Containment failure mode contribution to offsite dose for the SBO PDS (from SCET)

Containment Failure Mode	Contribution to 50-Mile Dose (%)	Contribution to 1000-Mile Dose (%)
DCH	22.5	21.7
α mode	49.8	49.9
Bypass[a]	27.3	28.5
Late overpressure	ε	ε
BMT	ε	ε

---

[a] Bypass failures include pre-existing leakage and induced SGTR.

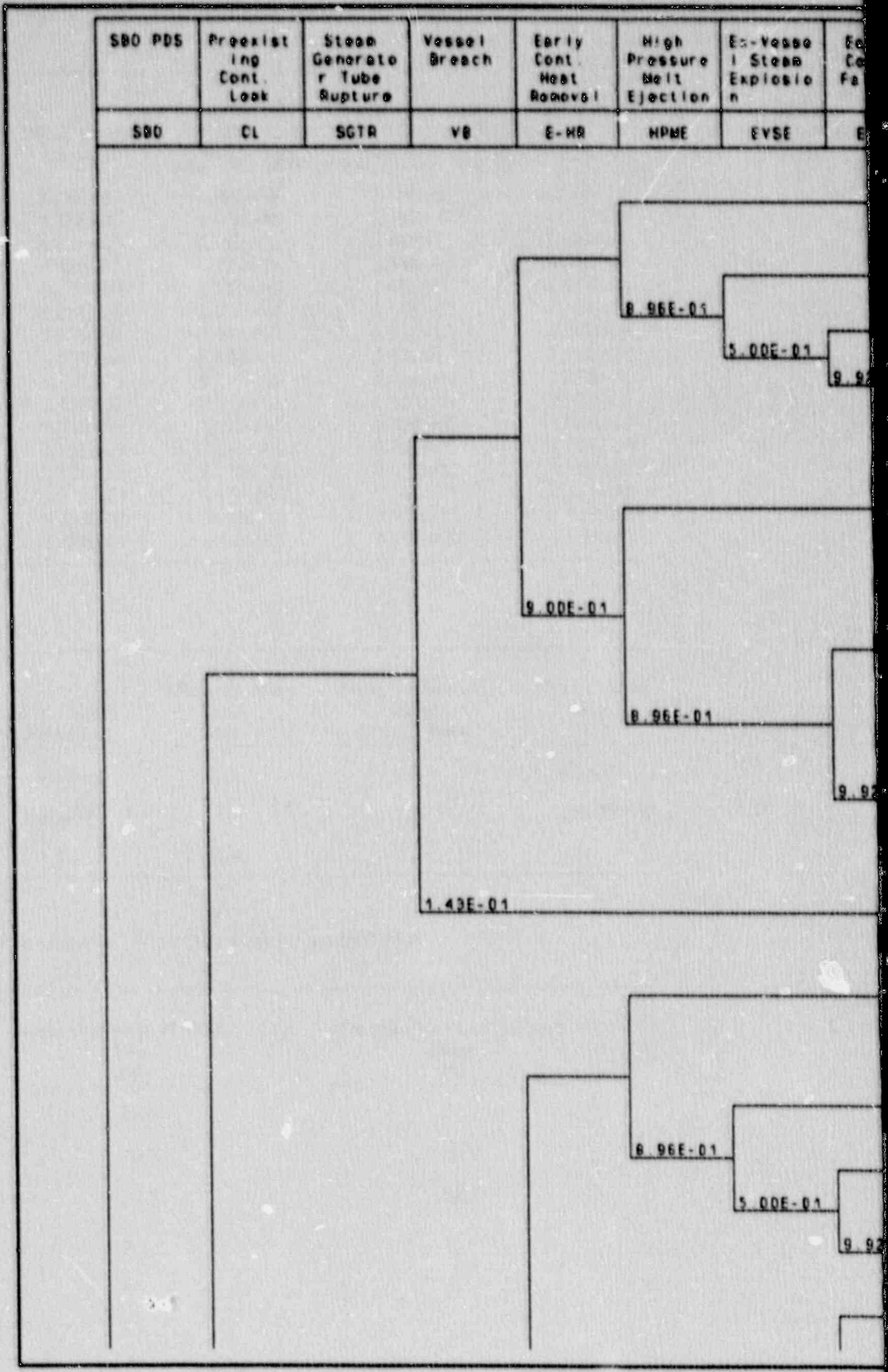
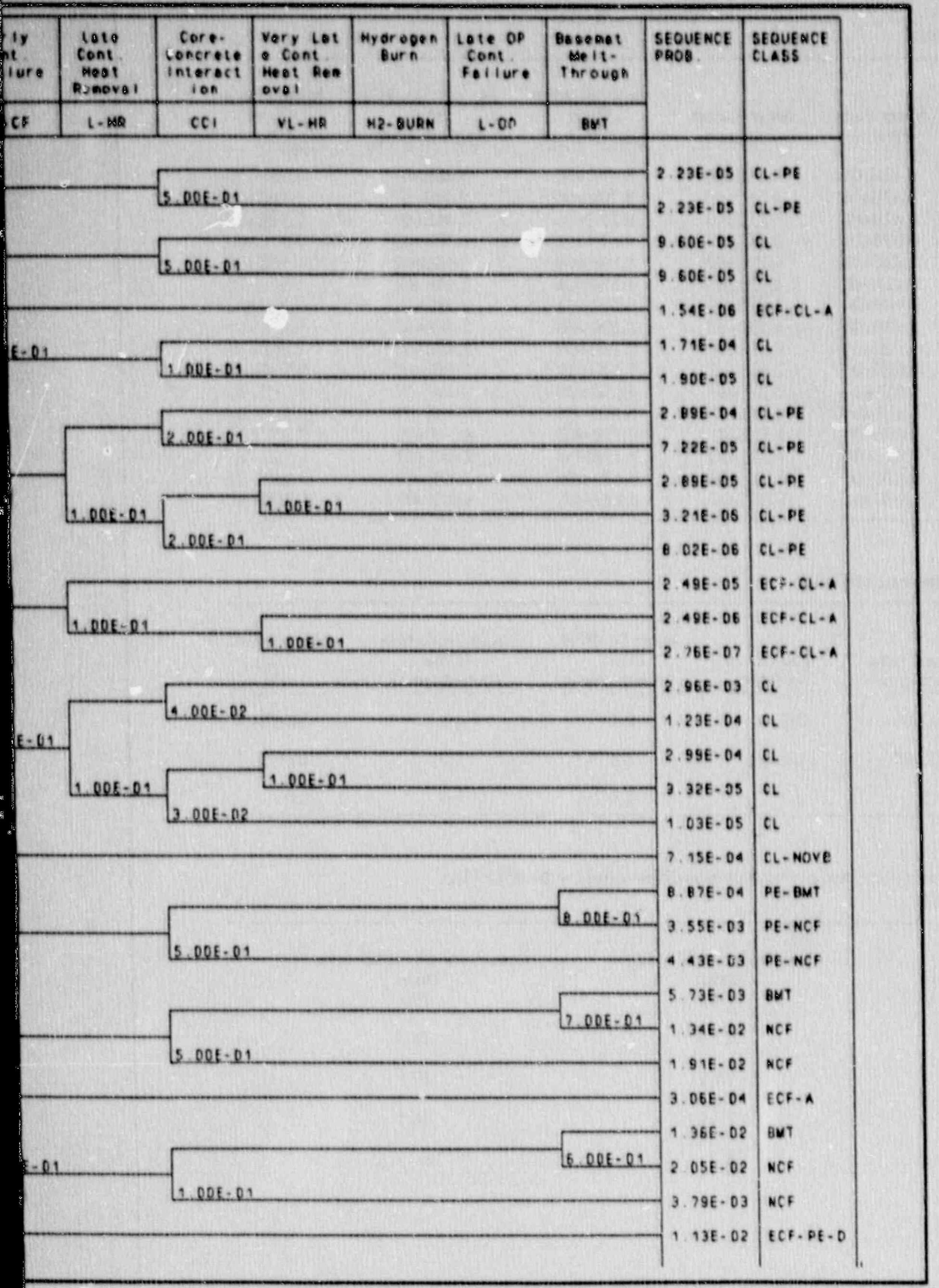


Figure 5.2. SBO SCET with intentional depressurization via the PORVs.



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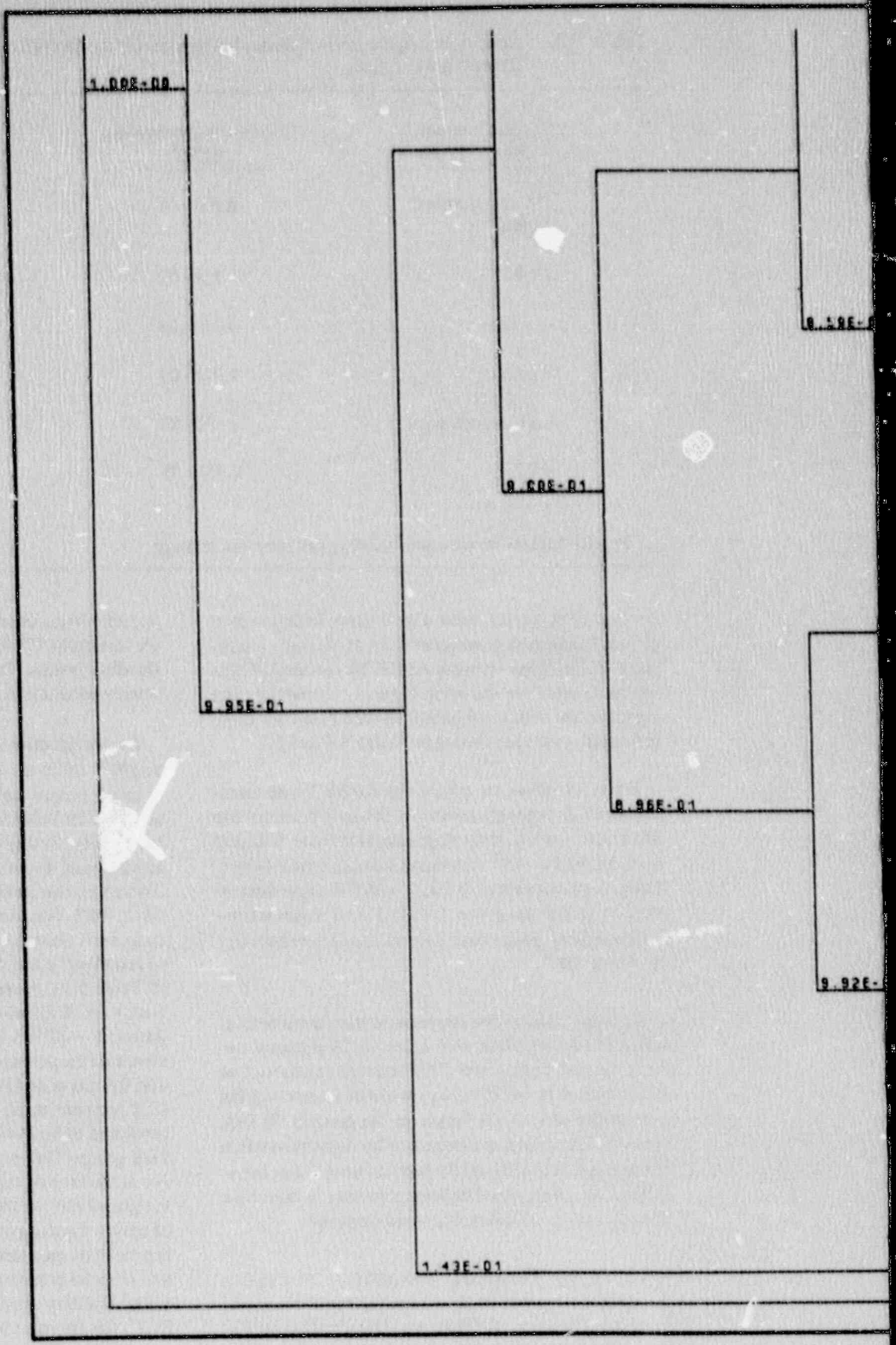

Figure 5.2. (continued).

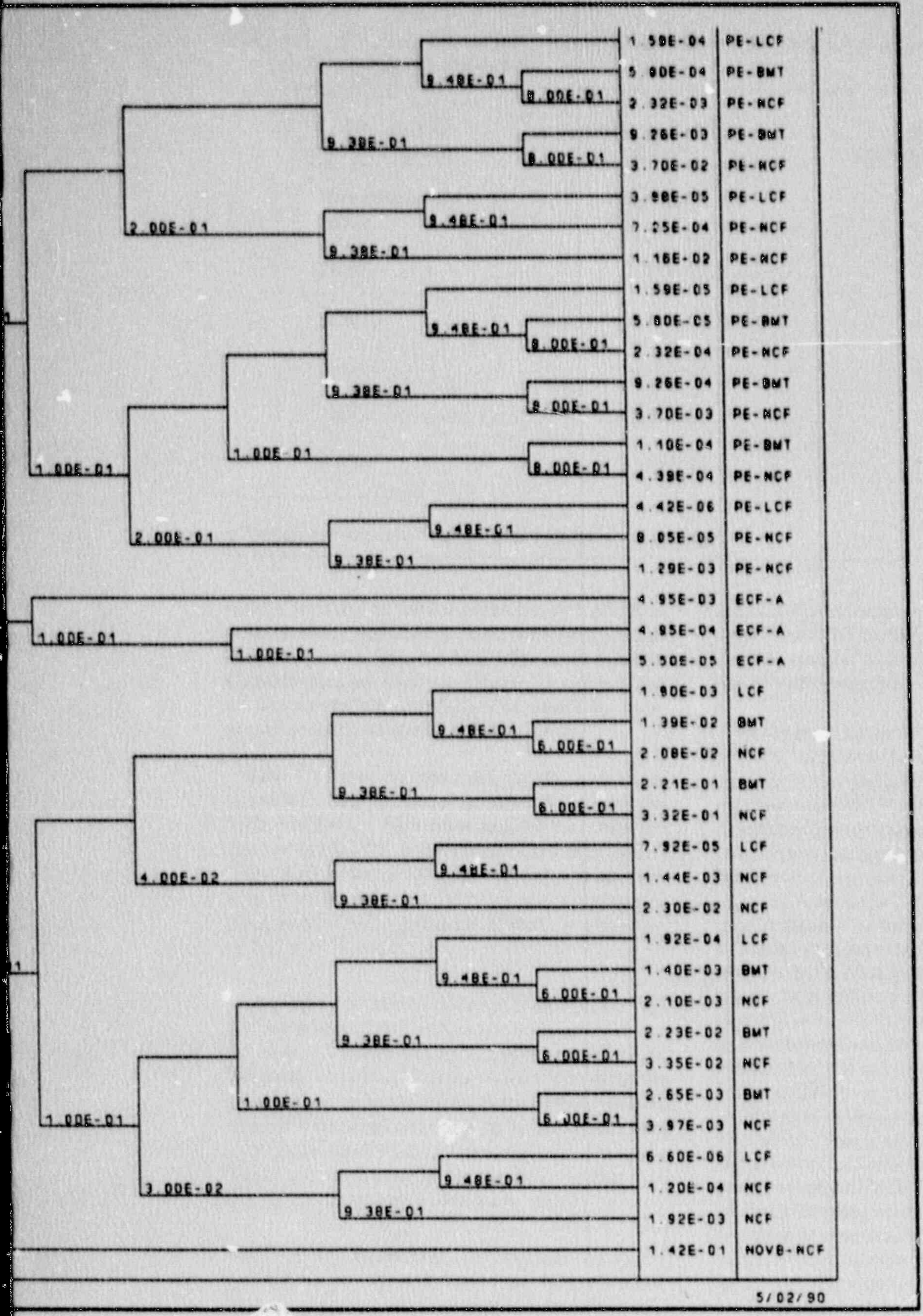
1.59E-04 PE-LCF
9.48E-01
5.90E-04 PE-BMT
8.00E-01
2.32E-03 PE-NCF
9.38E-01
9.26E-03 PE-BMT
8.00E-01
3.70E-02 PE-NCF
3.98E-05 PE-LCF
9.48E-01
2.00E-01
7.25E-04 PE-NCF
9.38E-01
1.16E-02 PE-NCF
1.59E-05 PE-LCF
5.80E-05 PE-BMT
9.48E-01
8.00E-01
2.32E-04 PE-NCF
9.26E-04 PE-BMT
9.38E-01
8.00E-01
3.70E-03 PE-NCF
1.10E-04 PE-BMT
1.00E-01
1.00E-01
8.00E-01
4.39E-04 PE-NCF
4.42E-06 PE-LCF
9.48E-01
2.00E-01
8.05E-05 PE-NCF
9.38E-01
1.29E-03 PE-NCF
4.95E-03 ECF-A
1.00E-01
4.95E-04 ECF-A
1.00E-01
5.50E-05 ECF-A
1.90E-03 LCF
1.39E-02 BMT
9.48E-01
6.00E-01
2.08E-02 NCF
2.21E-01 BMT
9.38E-01
6.00E-01
3.32E-01 NCF
7.92E-05 LCF
9.48E-01
1.44E-03 NCF
4.00E-02
9.38E-01
2.30E-02 NCF
1.92E-04 LCF
1.40E-03 BMT
9.48E-01
6.00E-01
2.10E-03 NCF
2.23E-02 BMT
9.38E-01
6.00E-01
3.35E-02 NCF
2.65E-03 BMT
1.00E-01
6.00E-01
3.97E-03 NCF
1.00E-01
6.60E-06 LCF
9.48E-01
1.20E-04 NCF
3.00E-02
9.38E-01
1.92E-03 NCF
1.42E-01 NOVB-NCF
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Table 5.5. Conditional containment failure probabilities for the SBO PDS with operator depressurization (HPME not eliminated)

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
No containment failure	6.83E–01	6.76E–01
DCH	1.13E–02	1.13E–02
α mode	5.84E–03	6.13E–03
Bypass[a]	4.97E–03	6.35E–03
Late overpressure	2.40E–03	2.34E–03
BMT	2.93E–01	2.97E–01

---

a. Bypass failures involve pre–existing containment leakage.

second sensitivity used a pressure–independent α mode failure probability of 8.0×10^{-4}, with no sampling on Question 34 in the APET. The revised SCETs for these cases are shown in Figures 5.3 and 5.4. The containment failure probabilities calculated for these sensitivity cases are shown in Tables 5.6 and 5.7.

Table 5.8 shows the offsite risk for SBO with intentional RCS depressurization. Table 5.9 shows the SBO risk for the fully depressurized case with the draft NUREG–1150 distribution for α mode failure. Table 5.10 shows the SBO risk with full depressurization to <200 psig (no HPME) and a pressure–independent point estimate α mode probability of 8.0×10^{-4}.

As these tables show, depressurization does not significantly lower SBO risk unless RCS pressure can be reduced below the DCH cutoff (assumed in Reference 4 to be 200 psig) without increasing the probability of α mode failure in the process. In fact, some risk measures are increased by depressurization if the draft NUREG–1150 probabilities of α mode failure are used, since depressurization in this case increases the probability of an early release.

5.4.2 Cavity Flooding. The addition of a cavity flooding system was analyzed by approximately modifying the split fraction of Question 31 in the Zion APET, turning off sampling for this question, and running EVNTRE and PSTEVNT to generate the revised SCET and ZISOR accident progression bins. Figure 5.5 shows the revised SCET for SBO with the addition of a cavity flooding system. Table 5.11 shows the revised conditional containment failure probabilities.

Cavity flooding for SBO reduced DCH failures, but slightly increased the conditional probability of α mode failure and late overpressurization. The output from the PSTEVNT runs also showed a very slight probability of early containment failure as the result of an ex–vessel steam explosion following vessel breach. However, the probability of this event was only ~4×10^{-6}. Because EVNTRE is a single–precision code, such a low probability could simply be the result of round–off error; therefore, it has not been included in Table 5.11. Note that the decrease in the conditional DCH failure probability is in contrast to the transient + ATWS PDS group, where cavity flooding increased the probability of DCH failure. The explanation for this is as follows. In the SBO PDS group, the RCS pressure at the time of vessel breach is generally predicted to be lower than in the transient + ATWS PDS group. This leads to a lower predicted pressure rise at the time of vessel breach, which in turn reduces the probability of DCH failure. Therefore, the effects of cavity flooding on the probability of DCH failure appear to be pressure–dependent; if the RCS is at system set point pressure at the time of vessel breach, then cavity flooding appears to exacerbate the threat from DCH. On the other hand, if RCS pressure is less than system set point pressure, then cavity flooding may offer some benefit in mitigating DCH.

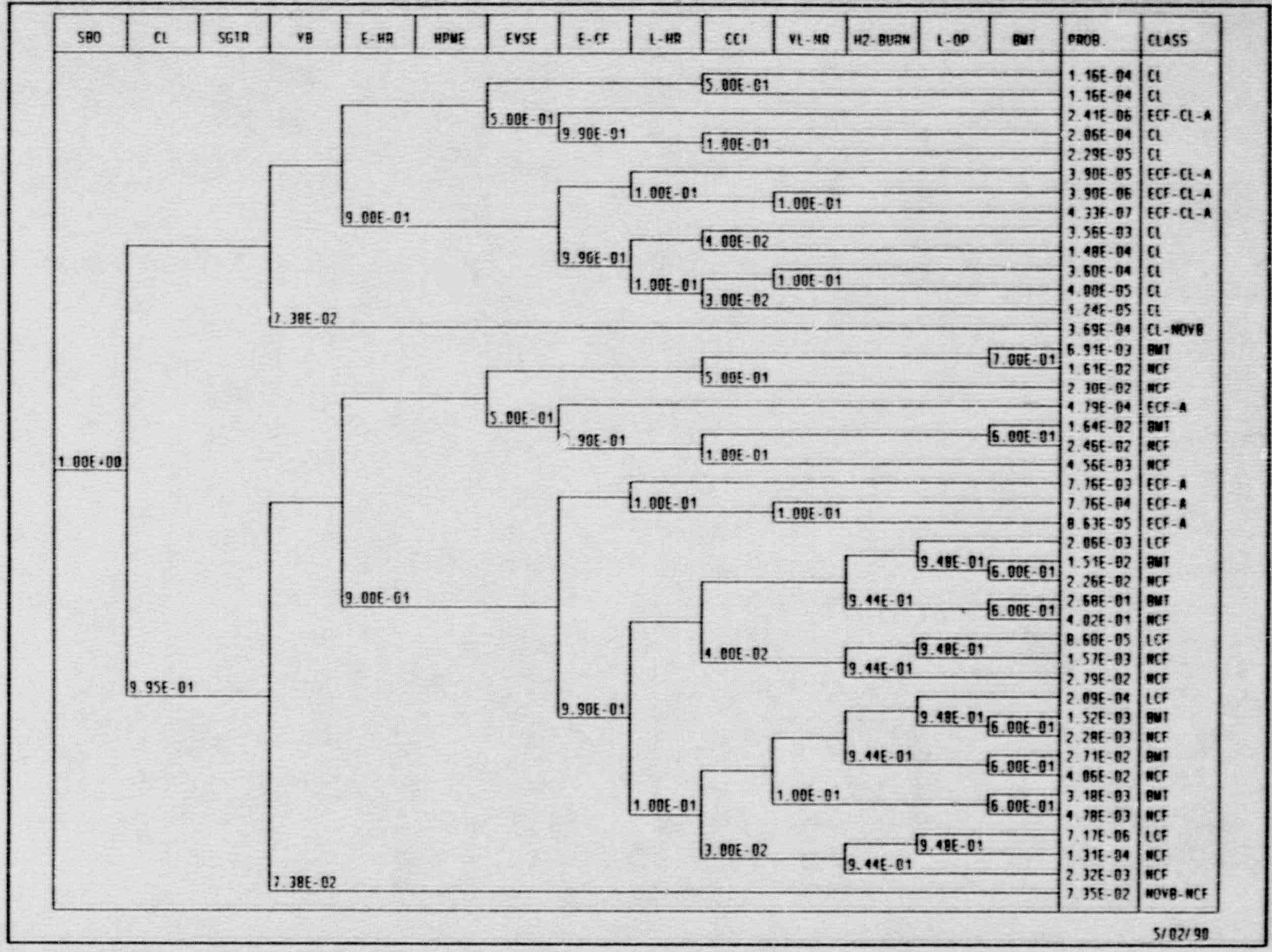


Figure 5.3. SBO SCET with depressurization to <200 psig (no HPME) and pressure-dependent α mode probability.

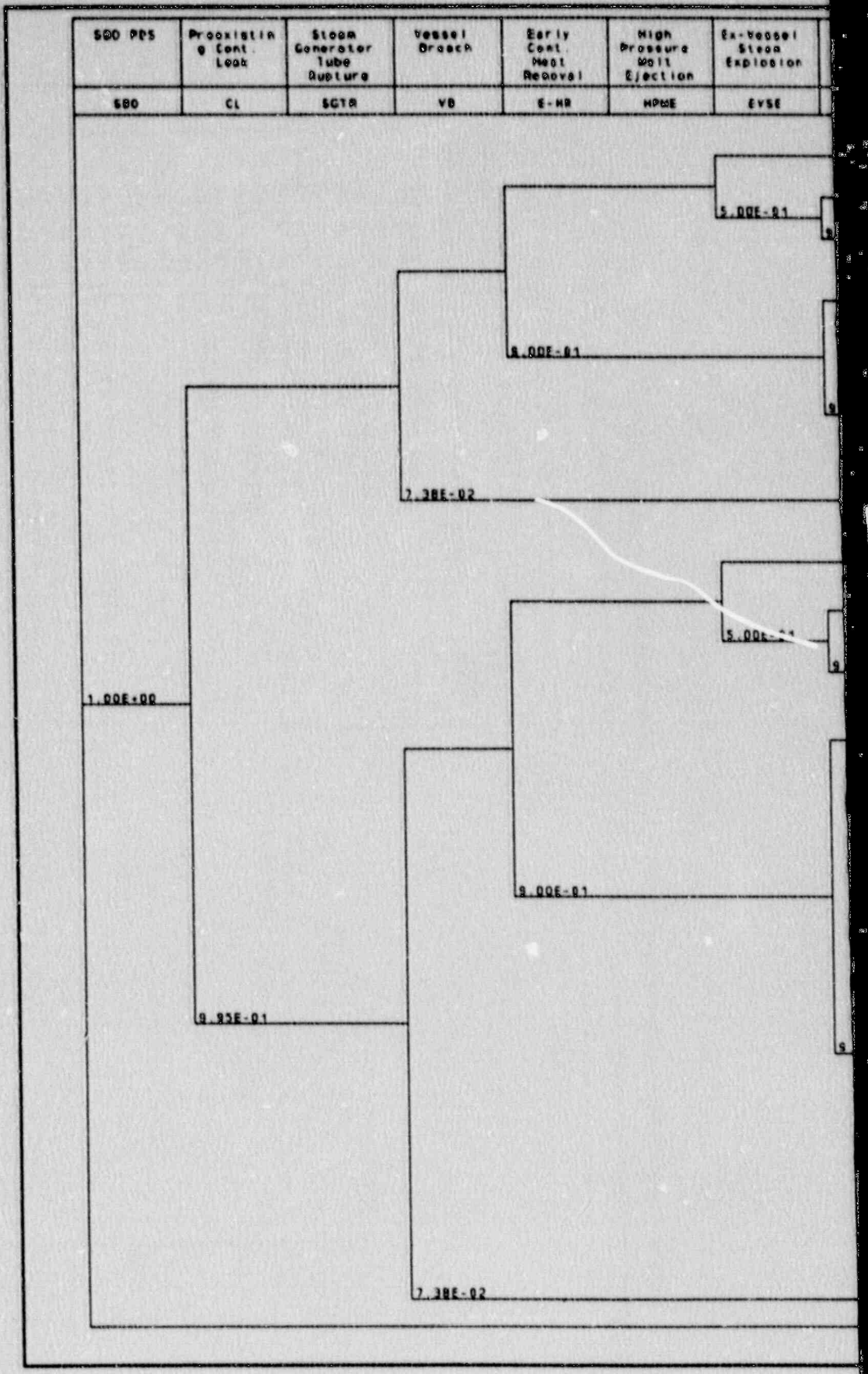
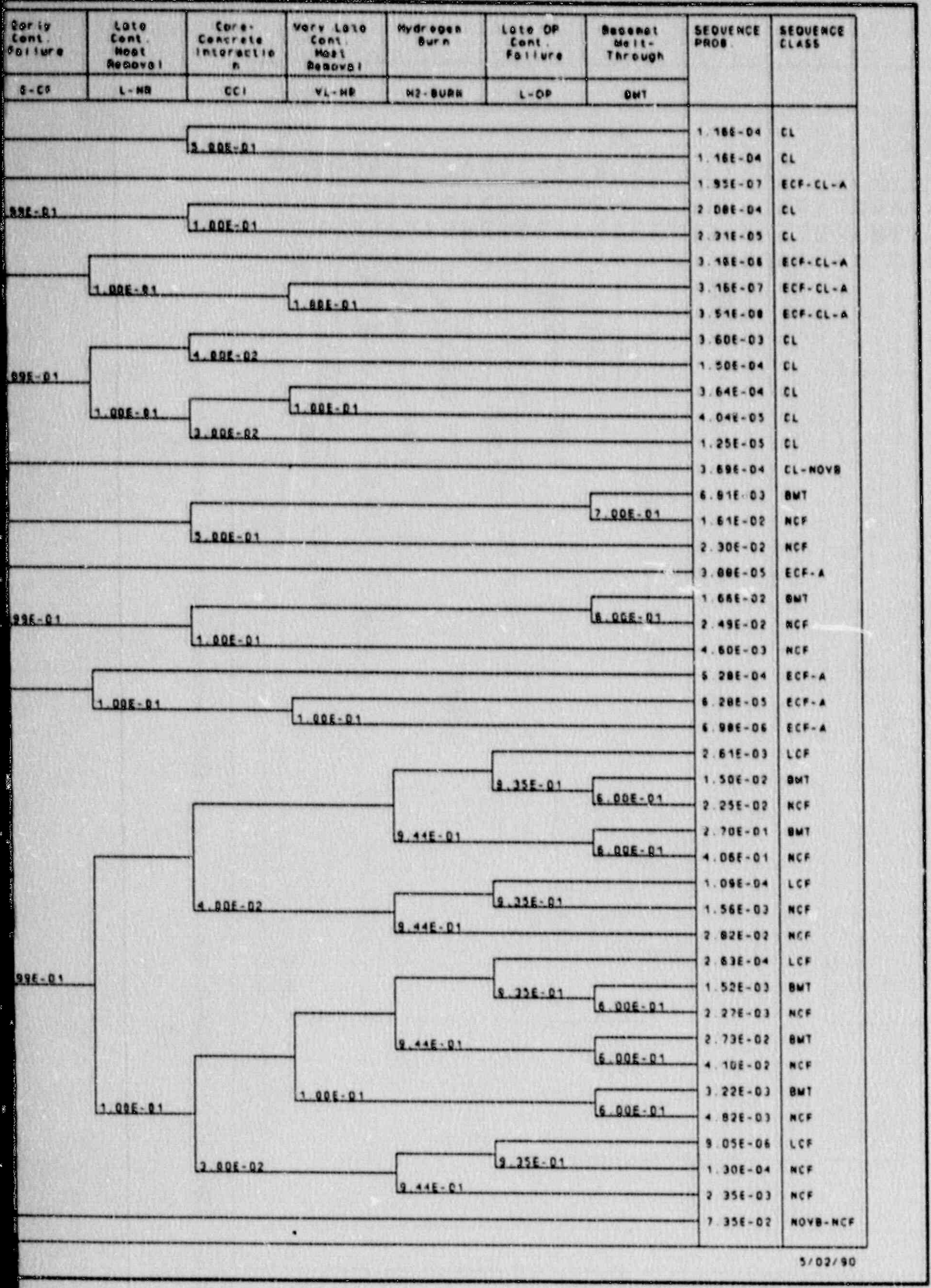


Figure 5.4. SBO SCET with despressurization to <200 psig (no HPME) and pressure-independent point estimate α mo



SEQUENCE PROB.	SEQUENCE CLASS
1.16E-04	CL
1.16E-04	CL
1.95E-07	ECF-CL-A
2.08E-04	CL
2.31E-05	CL
3.16E-06	ECF-CL-A
3.16E-07	ECF-CL-A
3.51E-08	ECF-CL-A
3.60E-03	CL
1.50E-04	CL
3.64E-04	CL
4.04E-05	CL
1.25E-05	CL
3.89E-04	CL-NOVB
6.91E-03	BMT
1.61E-02	NCF
2.30E-02	NCF
3.08E-05	ECF-A
1.66E-02	BMT
2.49E-02	NCF
4.60E-03	NCF
5.28E-04	ECF-A
6.28E-05	ECF-A
6.98E-06	ECF-A
2.61E-03	LCF
1.50E-02	BMT
2.25E-02	NCF
2.70E-01	BMT
4.06E-01	NCF
1.09E-04	LCF
1.56E-03	NCF
2.82E-02	NCF
2.63E-04	LCF
1.52E-03	BMT
2.27E-03	NCF
2.73E-02	BMT
4.10E-02	NCF
3.22E-03	BMT
4.82E-03	NCF
9.05E-06	LCF
1.30E-04	NCF
2.35E-03	NCF
7.35E-02	NOVB-NCF

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e probability.

Table 5.6. Conditional containment failure probabilities for the SBO PDS with operator depressurization and pressure–dependent α mode probability
(no HPME)

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
No containment failure	6.46E–01	6.76E–01
DCH	0.00	1.13E–02
α mode	9.15E–03	6.13E–03
Bypass[a]	4.95E–03	6.35E–03
Late overpressure	2.36E–03	2.34E–03
BMT	3.38E–01	2.97E–01

---

a. Bypass failures involve pre–existing containment leakage.

Table 5.7. Conditional containment failure probabilities for the SBO PDS with operator depressurization and pressure–independent point estimate α mode probability
(no HPME)

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
No containment failure	6.51E–01	6.76E–01
DCH	0.00	1.13E–02
α mode	7.41E–04	6.13E–03
Bypass[a]	5.00E–03	6.35E–03
Late overpressure	2.99E–03	2.34E–03
BMT	3.41E–01	2.97E–01

---

a. Bypass failures involve pre–existing containment leakage.

Table 5.8. Annual SBO risk with intentional RCS depressurization (HPME not eliminated)

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	1.99E–05	5.87E–04	1.21	3.49	2.34E+03
SCET	1.91E–05	5.38E–04	1.11	3.20	2.15E+03
% change	–4.1	–8.5	–8.2	–8.6	–8.5

Table 5.9. Annual SBO risk with RCS depressurization <200 psig and pressure–dependent α mode probability (no HPME)

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	1.99E–05	5.87E–04	1.21	3.49	2.34E+03
SCET	2.84E–05	5.85E–04	1.20	3.47	2.58E+03
% change	43.2	–0.3	–0.9	–0.6	–10.1

Table 5.10. Annual SBO risk with RCS depressurization <200 psig and pressure–independent point estimate α mode probability (no HPME)

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	1.99E–05	5.87E–04	1.21	3.49	2.34E+03
SCET	5.74E–06	1.87E–04	3.70E–01	1.09	7.48E+02
% change	–71.2	–68.2	–69.4	–68.8	– 68.1

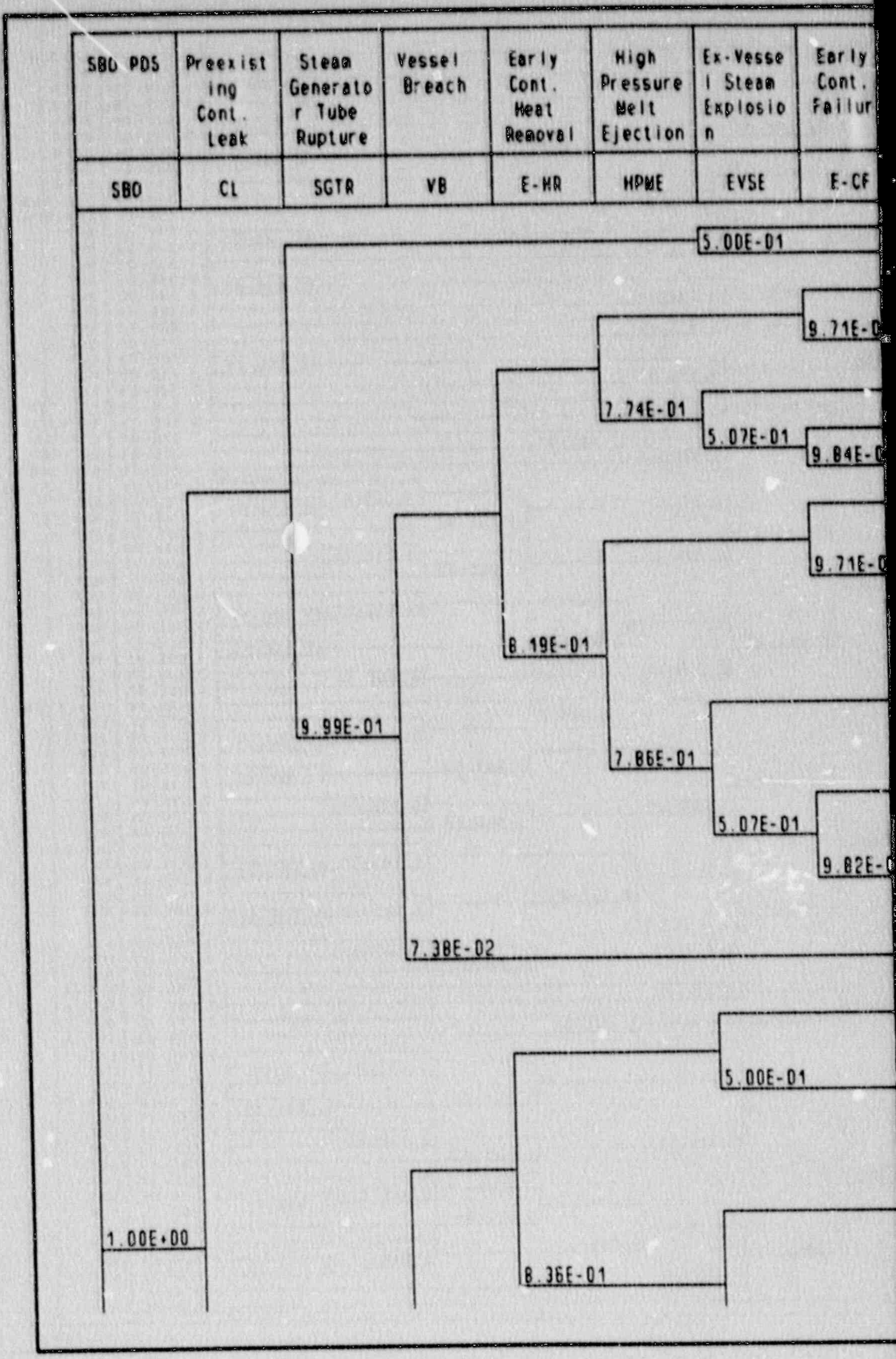
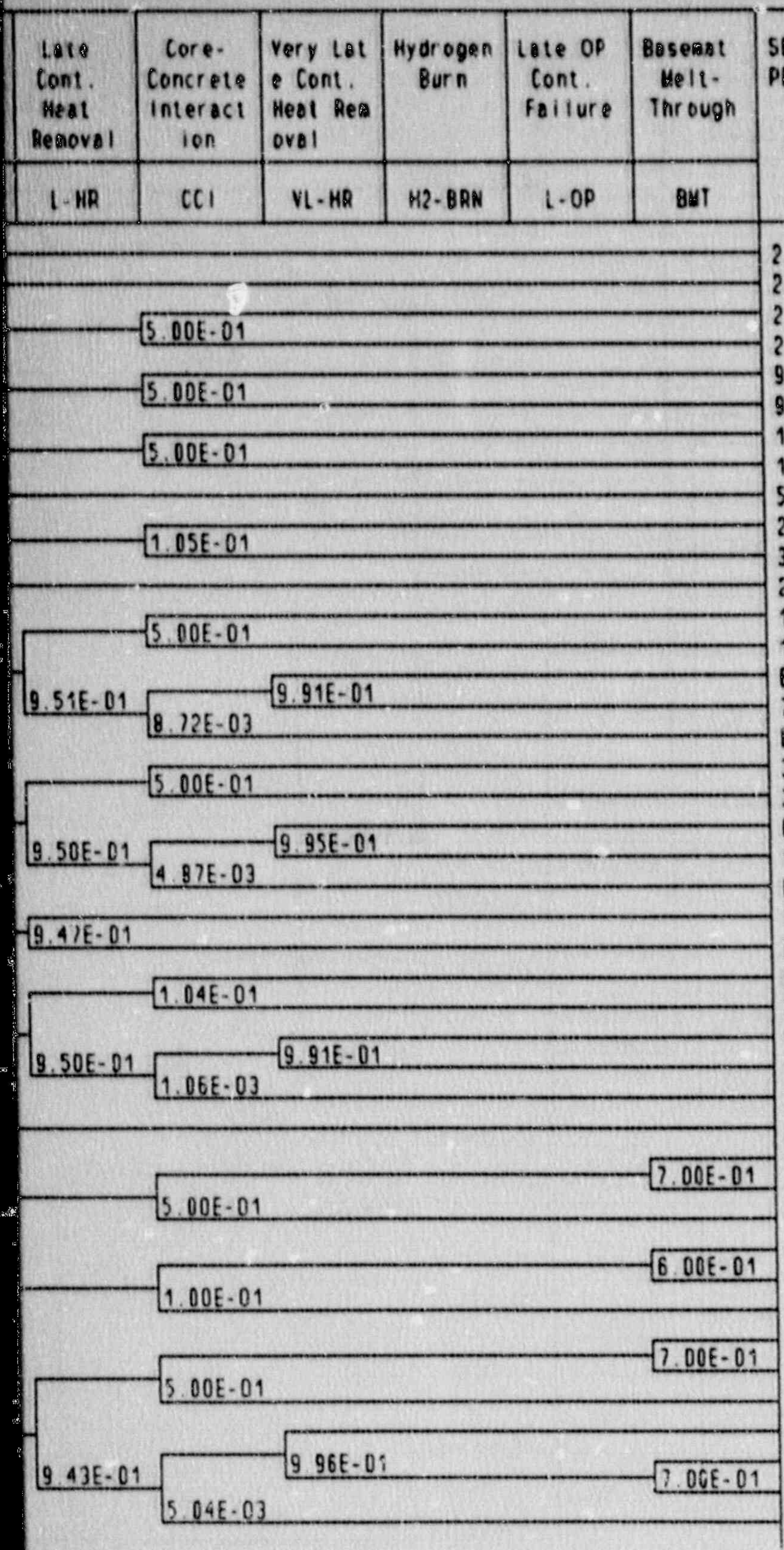


Figure 5.5. SBO SCET with cavity flooding system.



SEQUENCE PROB.	SEQUENCE CLASS
2.49E-06	SGTR
2.49E-06	SGTR
2.77E-06	CL-DCH
2.77E-06	CL-DCH
9.19E-05	CL
9.19E-05	CL
1.60E-04	CL
1.60E-04	CL
5.30E-06	CL-A
2.89E-04	CL
3.38E-05	CL
2.35E-05	CL-DCH
1.95E-05	CL
1.95E-05	CL
6.53E-06	CL
7.36E-04	CL
6.53E-06	CL
3.68E-05	CL
3.68E-05	CL
6.79E-06	CL
1.38E-03	CL
6.79E-06	CL
1.40E-06	CL-A
2.49E-05	CL-A
6.66E-05	CL
7.75E-06	CL
1.23E-05	CL
1.39E-03	CL
1.49E-06	CL
3.69E-04	CL-NOVB
1.57E-05	SG-BMT
3.67E-05	SGTR
5.24E-05	SGTR
3.77E-05	SGTR
5.66E-05	SGTR
1.05E-05	SGTR
4.55E-06	SGTR
1.06E-05	SGTR
1.52E-05	SGTR
1.77E-06	SGTR
1.49E-04	SGTR
3.47E-04	SGTR
2.52E-06	SGTR

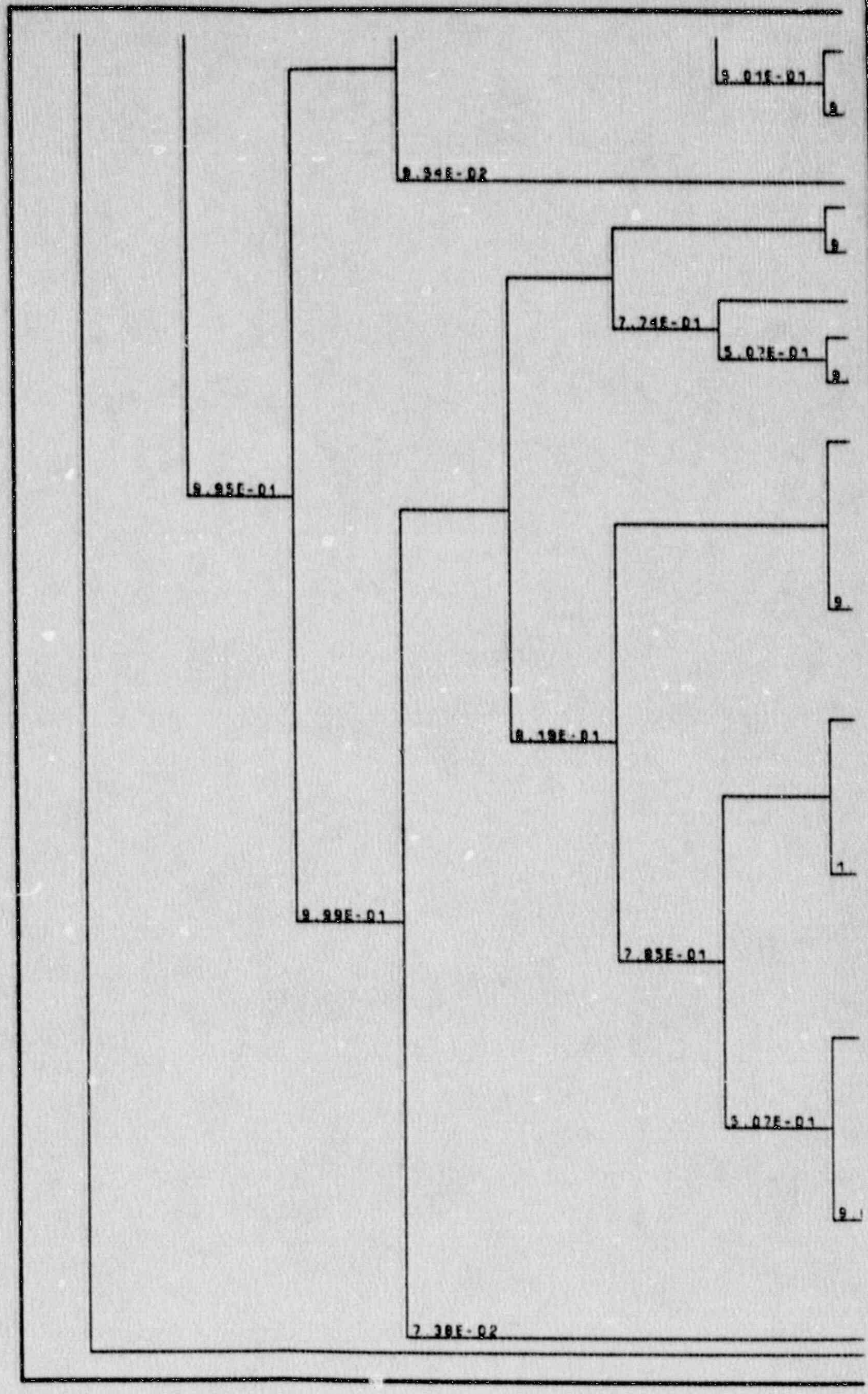


Figure 5.5. (continued).

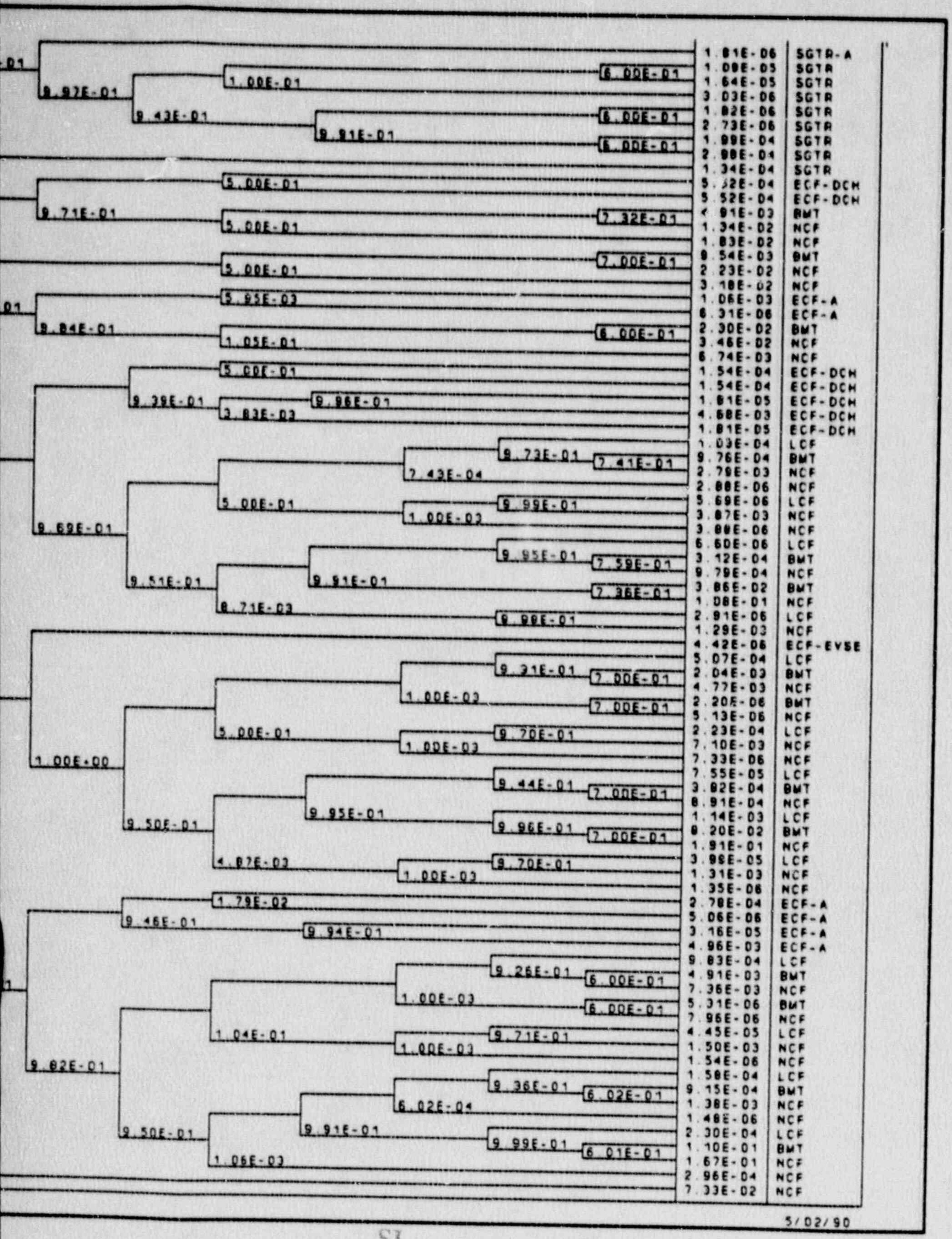


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Table 5.12 shows the SBO risk with the addition of the cavity flooding system.

5.4.3 Hydrogen Control. Improved hydrogen control was modeled in the SCET by eliminating late overpressure containment failure by setting the probability for the lower branch of event L–OP to 1.0 for all sequences. The new conditional containment failure probabilities are shown in Table 5.13.

Elimination of hydrogen–induced overpressure failures provided no reduction in any of the risk measures used in this report. This finding is consistent with Reference 4, where late overpressure failure was a negligible contributor to risk.

5.4.4 Containment Venting. As in the LOCA PDS, containment venting is not evaluated for SBO. See the discussion of containment venting in Section 3.4.4.

Table 5.11. Conditional containment failure probabilities for the SBO PDS with cavity flooding system

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
No containment failure	7.00E–01	6.76E–01
DCH	6.13E–03	1.13E–02
α mode	6.37E–03	6.13E–03
Bypass[a]	6.37E–03	6.35E–03
Late overpressure	3.52E–03	2.34E–03
BMT	2.78E–01	2.97E–01

---

[a] Bypass failures include pre–existing leakage and induced SGTR.

Table 5.12. Annual SBO risk with cavity flooding system

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	1.99E–05	5.87E–04	1.21	3.49	2.34E+03
SCET	1.81E–05	4.88E–04	1.00	2.89	1.99E+03
% change	– 9.2	–17.8	–17.1	–17.3	–15.1

Table 5.13. Conditional containment failure probabilities for the SBO PDS with improved hydrogen control

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
No containment failure	6.78E–01	6.76E–01
DCH	1.13E–02	1.13E–02
α mode	6.13E–03	6.13E–03
Bypass[a]	6.35E–03	6.35E–03
Late overpressure	0.00	2.34E–03
BMT	2.98E–01	2.97E–01

---

a. Bypass failures include pre–existing leakage and induced SGTR.

6. CONTAINMENT BYPASS SEQUENCES

Reference 4 splits sequences that involve containment bypass into two PDS groups. The first group, group 4, is made up of four PDSs in which the initiating event is SGTR. In one of these PDSs, the secondary relief valves stick open, resulting in a release that bypasses both primary containment and the secondary systems. In the other three PDSs, the secondary relief valves do not stick open. The second group, group 5, is made up of a single PDS, initiated by an interfacing systems LOCA (V sequence). This is assumed to be a large break in the low pressure RCS piping outside primary containment in the auxiliary building.

6.1 Bypass Core Damage Frequency

For the purposes of the accident progression analysis in this report, the convention adopted in Reference 4 of grouping together the V sequence and the three group 4 PDSs involving SGTR with no stuck–open secondary relief valves is followed. This grouping will be referred to as the V + SGTR PDS in this report. The remaining bypass sequence, which involves an initial SGTR with the secondary relief valves stuck open, will be referred to as the SGTR PDS. The annual frequencies of these two PDSs are taken from Table 2.2–3 in Reference 4 and are listed here for convenience.

V + SGTR: 1.69×10^{-7} per reactor–year

SGTR: 1.30×10^{-6} per reactor–year

6.2 Bypass SCET Results

One base case SCET was developed for each of the two bypass PDSs. Figure 6.1 shows the base case SCET for the V + SGTR PDS, Figure 6.2 the SGTR PDS alone.

Table 6.1 shows the conditional containment failure probabilities for the V + SGTR PDS.

Table 6.2 shows the analogous results for the SGTR PDS.

6.3 Base Case Bypass Consequences

The SCET end states were binned into accident progression bins and the ZISOR code was again used to generate source terms for these bins as described in Section 2. Conditional consequences were then calculated for each accident progression bin group with the MACCS code. As for the previous PDS groups, the Zion site data and meteorological files were used for these calculations. The conditional consequences for each accident progression bin are shown in Tables 6.3 and 6.4 for the V + SGTR and SGTR PDSs, respectively.

Tables 6.5 and 6.6 show the annual risk calculated for the V + SGTR and SGTR PDSs. The risk from Reference 4 is a combination of the risk from the V + SGTR and the SGTR PDS groups.

Calculations for this report slightly overestimate all risk measures for the SGTR PDS, except early fatalities, which are slightly underestimated. The higher values are very likely attributable to the use of point estimate source terms from ZISOR and the use of a later version of MACCS than was used for Reference 4. Most of the risk for the bypass sequences comes from the SGTR PDS. This result cannot be ascertained from Reference 4 but is plausible for two reasons. First, as Table 6.4 shows, the conditional consequences are generally higher than for the V + SGTR PDS group. Secondly, the core damage frequency of the SGTR PDS is significantly greater than that of the V + SGTR group. Recall that the SGTR PDS involves an initiating SGTR with the secondary relief valves stuck open. This provides a direct release path to the environment. Sequences in the V + SGTR group involve a V break or SGTR with no stuck–open secondary relief valves. Therefore, the release path is through the auxiliary building, providing some decontamination of the release.

6.4 Risk Benefits of Potential Improvements

The risk benefit of the potential containment performance improvements identified in Reference 2 is calculated in this section.

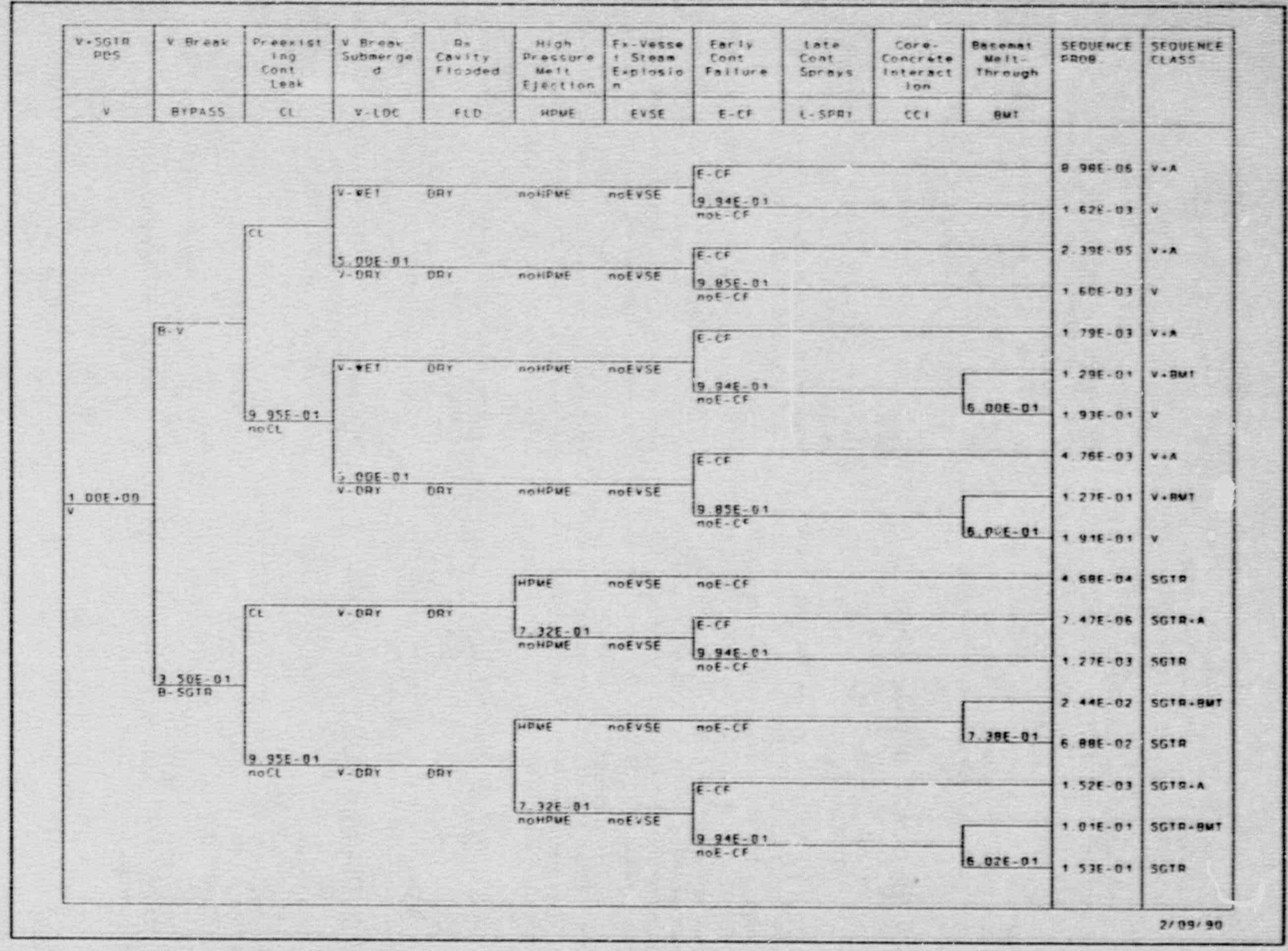

Figure 6.1. Base case SCET for the V + SGTR PDS.

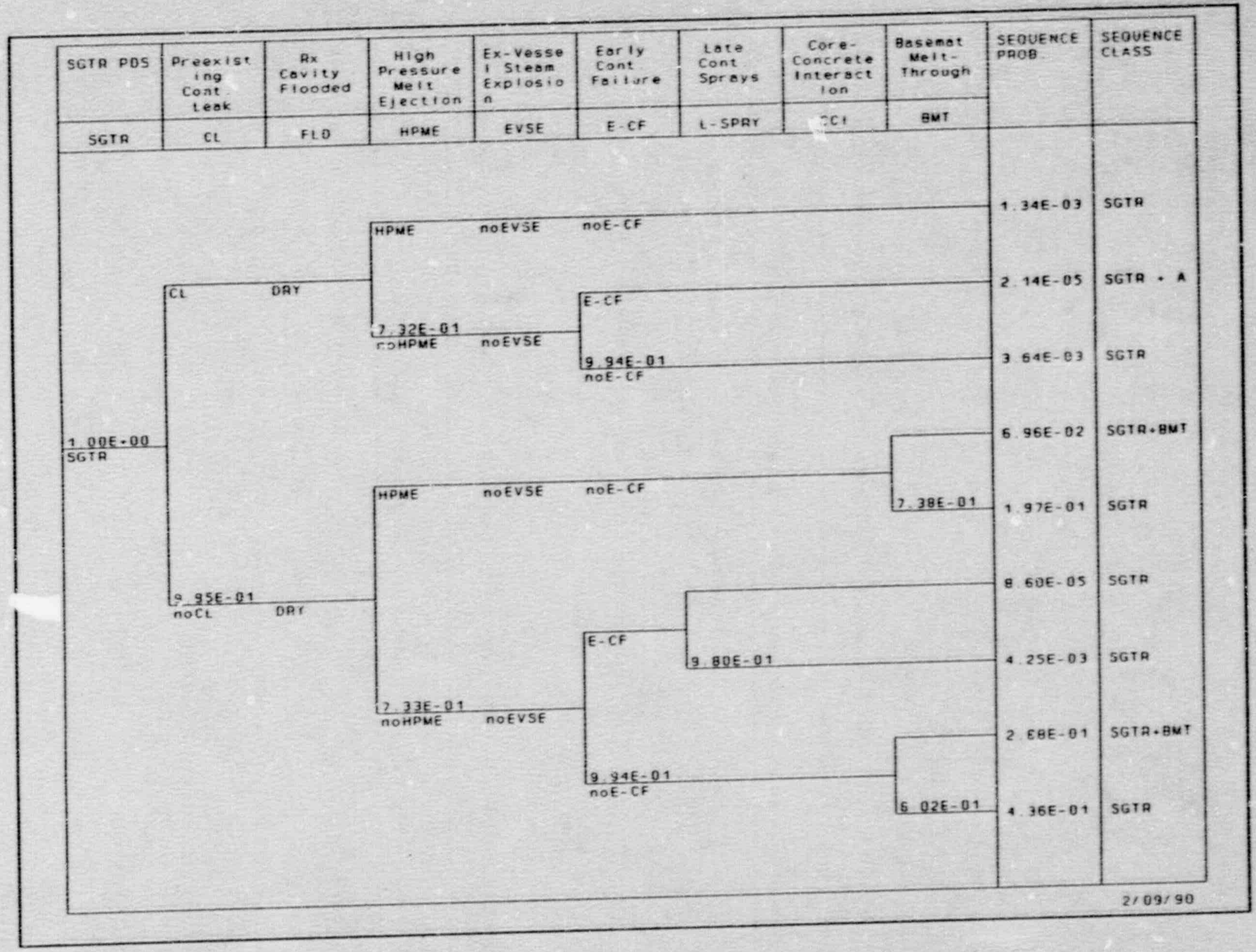

Figure 6.2. Base case SCET for the SGTR PDS.

Table 6.1. Conditional containment failure probabilities for the V + SGTR PDS

Containment Failure Mode	Conditional Probability (SCET)	Conditional Probability (Reference 4)
Event V only	3.87E–01	1.00[a]
Event V + α	6.58E–03	0.00[a]
Event V + BMT	2.56E–01	0.00[a]
SGTR only	2.24E–01	0.00[a]
SGTR + α	1.53E–03	0.00[a]
SGTR + BMT	1.25E–01	0.00[a]

---

a. Reference 4 does not subdivide the containment failure modes for the bypass sequences; all end states are grouped into the bypass category.

Table 6.2. Conditional containment failure probabilities for the SGTR PDS

Containment Failure Mode	Conditional Probability (SCET)	Conditional Probability (Reference 4)
SGTR only	6.42E–01	1.00[a]
SGTR + α	2.14E–05	0.00[a]
SGTR + BMT	3.58E–01	0.00[a]

---

a. Reference 4 does not subdivide the containment failure modes for the bypass sequences; all end states are grouped into the bypass category.

Table 6.3. Conditional consequences for the V + SGTR accident progression bins

Accident Progression Bin	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
AAADDCBADBBB	2.94E+01	3.83E+03	7.33E+06	2.30E+07	1.54E+10
ADADBCAADCBB	2.94E+01	3.83E+03	7.33E+06	2.30E+07	1.54E+10
ADADBCAADFBB	3.01E+01	4.24E+03	8.23E+06	2.58E+07	1.71E+10
BAADDCBADBBB	1.69E+01	1.43E+03	3.63E+06	8.44E+06	3.42E+09
BDADBCAADCBB	1.69E+01	1.43E+03	3.63E+06	8.44E+06	3.42E+09
BDADBCAADFBB	1.70E+01	1.56E+03	3.91E+06	9.39E+06	3.67E+09
CDACAAAABCBB	2.95E+00	3.94E+03	7.30E+06	2.35E+07	1.51E+10
CDADBAAADCBB	2.95E+00	3.94E+03	7.30E+06	2.35E+07	1.51E+10
DAADDABADBBB	3.53E+00	4.25E+03	8.18E+06	2.59E+07	1.70E+10
DDADDABADBBB	2.95E+00	3.94E+03	7.30E+06	2.35E+07	1.51E+10
GDACAAAABFBB	2.45E+00	3.91E+03	7.23E+06	2.34E+07	1.50E+10
GDADBAAADFBB	2.45E+00	3.91E+03	7.23E+06	2.34E+07	1.50E+10

Table 6.4. Conditional consequences for the SGTR accident progression bins

Accident Progression Bin	Mean Early Fatalities	Mean Latent Fatalities	Mean 50-Mile Dose (person-rem)	Mean 1000-Mile Dose (person-rem)	Mean Offsite Costs ($)
CDACABBABCBB	4.40E+00	6.95E+03	1.10E+07	4.18E+07	3.70E+10
CDADBBAADCBB	4.41E+00	6.97E+03	1.10E+07	4.19E+07	3.70E+10
DAADDBBADBBB	4.82E+00	7.34E+03	1.16E+07	4.45E+07	3.91E+10
DDADDBBADBBB	4.41E+00	6.97E+03	1.10E+07	4.19E+07	3.70E+10
GDACABBABFBB	4.40E+00	6.95E+03	1.09E+07	4.17E+07	3.70E+10
GDADBBAADFBB	4.40E+00	6.95E+03	1.09E+07	4.17E+07	3.70E+10

Table 6.5. Annual base case V + SGTR risk

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50-Mile Dose (person-rem)	Mean 1000-Mile Dose (person-rem)	Mean Offsite Costs ($)
Reference 4	6E-06	5E-03	10.4	30.1	3.7E+04
SCET	3E-06	6E-04	1.1	3.3	2E+03
Relative change	2.0	8.3	9.5	9.1	18.5

Table 6.6. Annual base case SGTR risk

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50-Mile Dose (person-rem)	Mean 1000-Mile Dose (person-rem)	Mean Offsite Costs ($)
Reference 4	6E-06	5E-03	10.4	30.1	4E+04
SCET	6E-06	9E-03	14.2	54.2	5E+04
Relative change	0.0	0.6	0.7	0.6	0.8

6.4.1 Enhanced Reactor Vessel Depressurization Capability. As was the case for the transient + ATWS and SBO PDS groups, intentional depressurization via the pressurizer PORVs could not be accurately modeled with an SCET. Therefore, depressurization was modeled in the APET using the revised methodology discussed in Section 4.4.1. The revised SCETs are shown in Figures 6.3 and 6.4. The new conditional probabilities of containment failure are shown in Tables 6.7 and 6.8.

Intentionally opening the PORVs does not change the overall probability of containment bypass, as the containment was bypassed by the initiating event. It can, however, alter the conditional probabilities of other accompanying modes of containment failure. The most significant of these is the conditional probability of α mode failure given reactor vessel breach, which increases in the depressurized case. The effects of this change on risk are shown in Tables 6.9 and 6.10.

Not surprisingly, depressurization has no effect on risk resulting from bypass sequences, even though the conditional probability of α mode failure is higher in the depressurized case. The fact that the release bypasses containment is more important in terms of offsite risk than the additional containment breach that results from α mode failure. In other words, α mode failure is a higher order contributor to risk in the bypass PDS group.

6.4.2 Cavity Flooding. As for the case of SBO, the addition of a cavity flooding system was analyzed by appropriately modifying the split fraction of Question 1 in the Zion APET, turning off sampling for this question, and running EVNTRE and PSTEVNT to generate the revised SCET and ZISOR accident progression bins. Figures 6.5 and 6.6 show the revised SCETs for the bypass PDS groups with the addition of a cavity flooding system.

Tables 6.11 and 6.12 show the conditional containment failure probabilities with the addition of the cavity flooding system.

The preceding two tables show an interesting result, namely the occurrence of DCH failures as a result of having a flooded cavity at the time of vessel breach. This is a result that is very specific to the modeling assumptions in the Zion APET. Reference 2 discusses the effects on DCH of having a flooded reactor cavity but no firm conclusions were drawn, because some calculations showed a beneficial effect, while others showed detrimental effects. The effects on risk are shown in Tables 6.13 and 6.14.

As was the case for depressurization, the addition of a cavity flooding system has an insignificant effect on bypass risk. The slight reduction in risk for the V + SGTR group is probably attributable to scrubbing of releases from containment after vessel breach by the water assumed to be present in the reactor cavity.

6.4.3 Hydrogen Control and Containment Venting. Improvements in the hydrogen control system and containment venting were not analyzed for bypass sequences. An improved hydrogen control system was not evaluated as no hydrogen burns were predicted in the base case APET run. Containment venting was not analyzed because the release bypasses containment, rendering containment venting ineffective as a mitigation strategy.

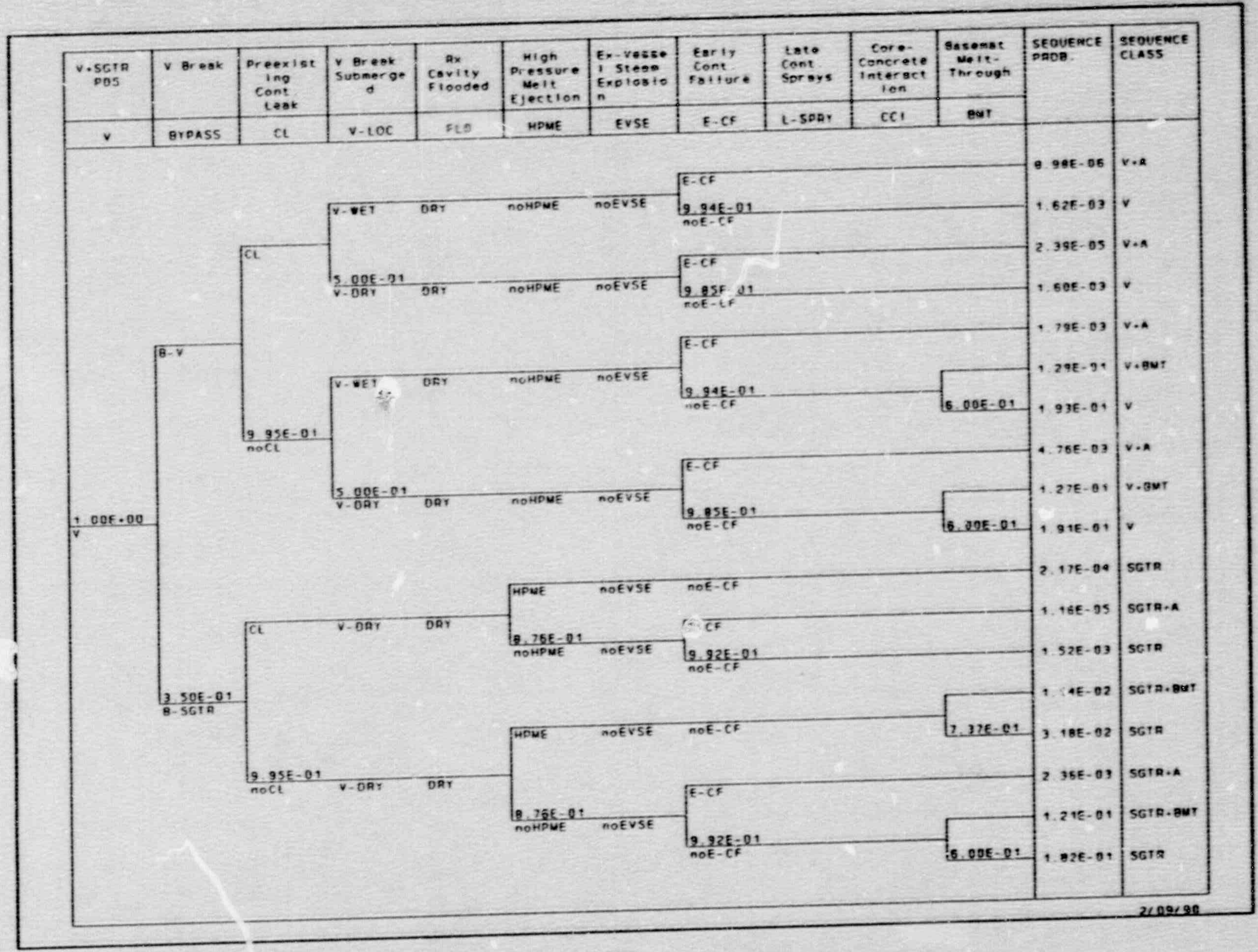

Figure 6.3. V + SGTR SCET with intentional depressurization via the PORVs.

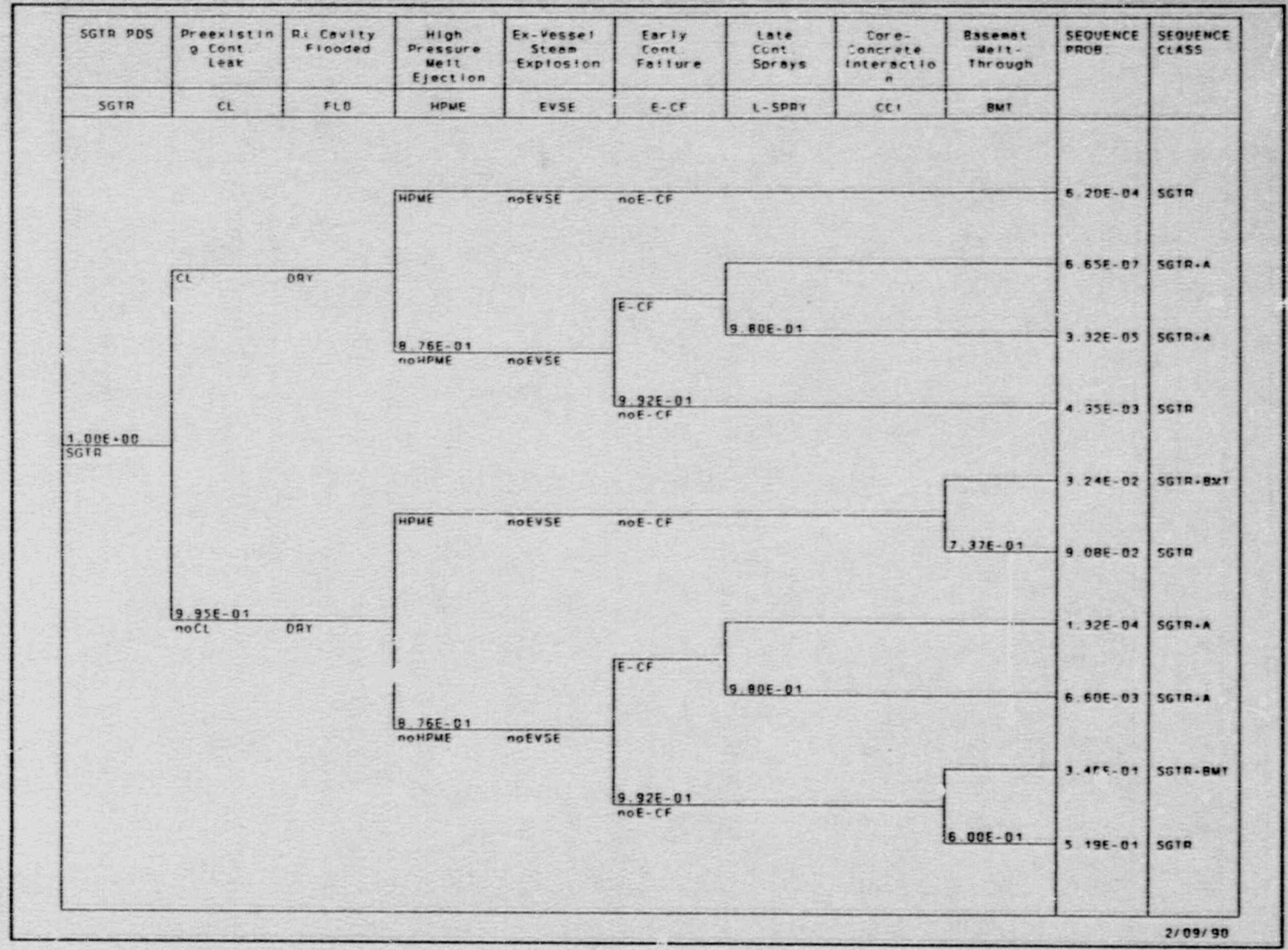

Figure 6.4. SGTR SCET with intentional depressurization via the PORVs.

Table 6.7. Conditional containment failure probabilities for the V + SGTR PDS with intentional depressurization via the PORVs

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
Event V only	3.87E–01	3.87E–01
Event V + α	6.58E–03	6.58E–03
Event V + BMT	2.56E–01	2.56E–01
SGTR only	2.16E–01	2.24E–01
SGTR + α	2.37E–03	1.53E–03
SGTR + BMT	1.32E–01	1.25E–01

Table 6.8. Conditional containment failure probabilities for the SGTR PDS with intentional depressurization via the PORVs

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
SGTR only	6.15E–01	6.42E–01
SGTR + α	6.77E–03	2.14E–05
SGTR + BMT	3.78E–01	3.58E–01

Table 6.9 Annual V + SGTR risk with intentional depressurization via the PORVs

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	2.74E–06	5.50E–04	1.10	3.32	2.03E+03
SCET	2.74E–06	5.50E–04	1.10	3.32	2.03E+03
% change	0.00	0.00	0.00	0.00	0.00

Table 6.10. Annual SGTR risk with intentional depressurization via the PORVs

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	5.72E–06	9.04E–03	14.17	54.23	4.81E+04
SCET	5.72E–06	9.04E–03	14.18	54.24	4.81E+04
% change	0.00	0.00	0.00	0.00	0.00

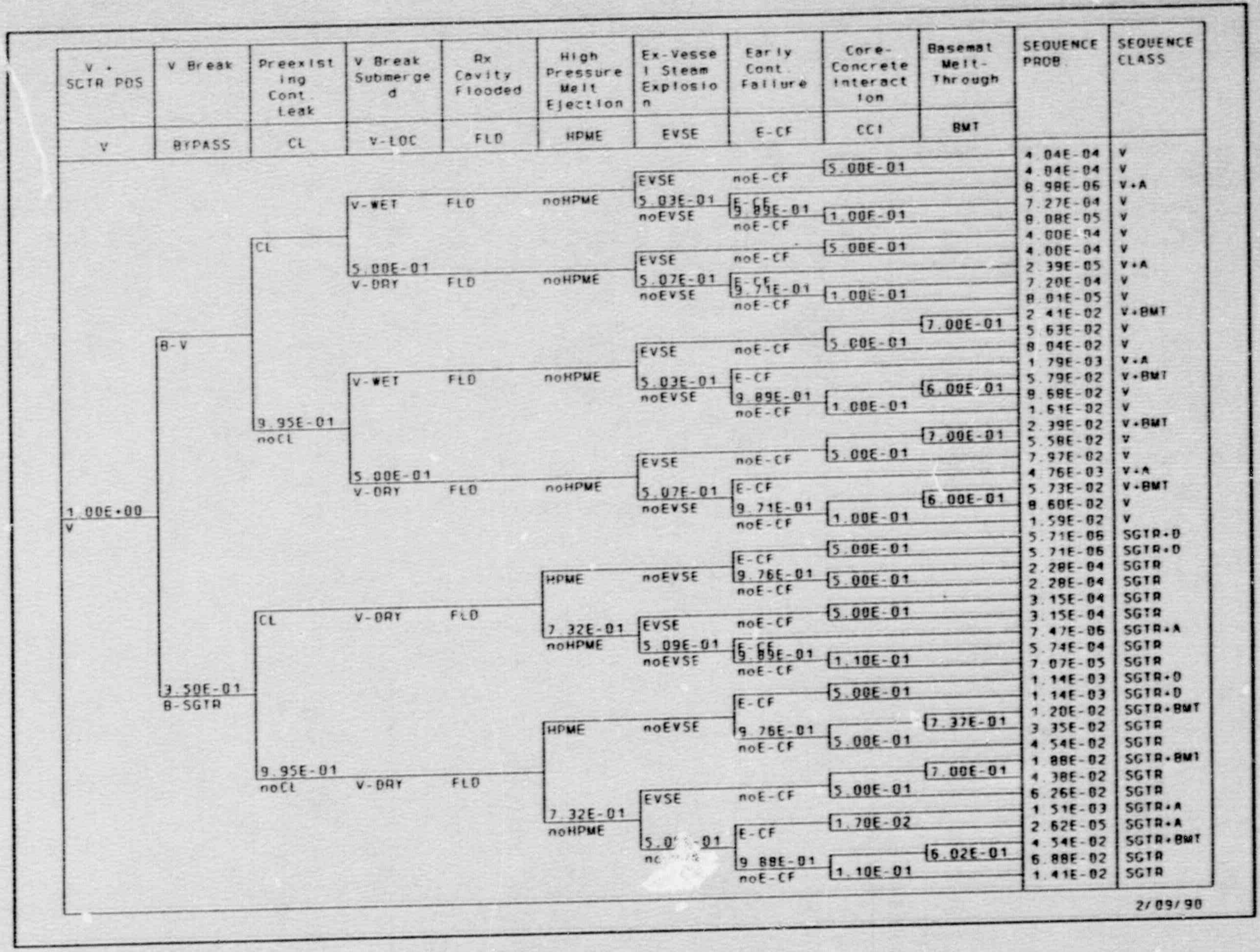

Figure 6.5. V + SGTR SCET with addition of cavity flooding system.

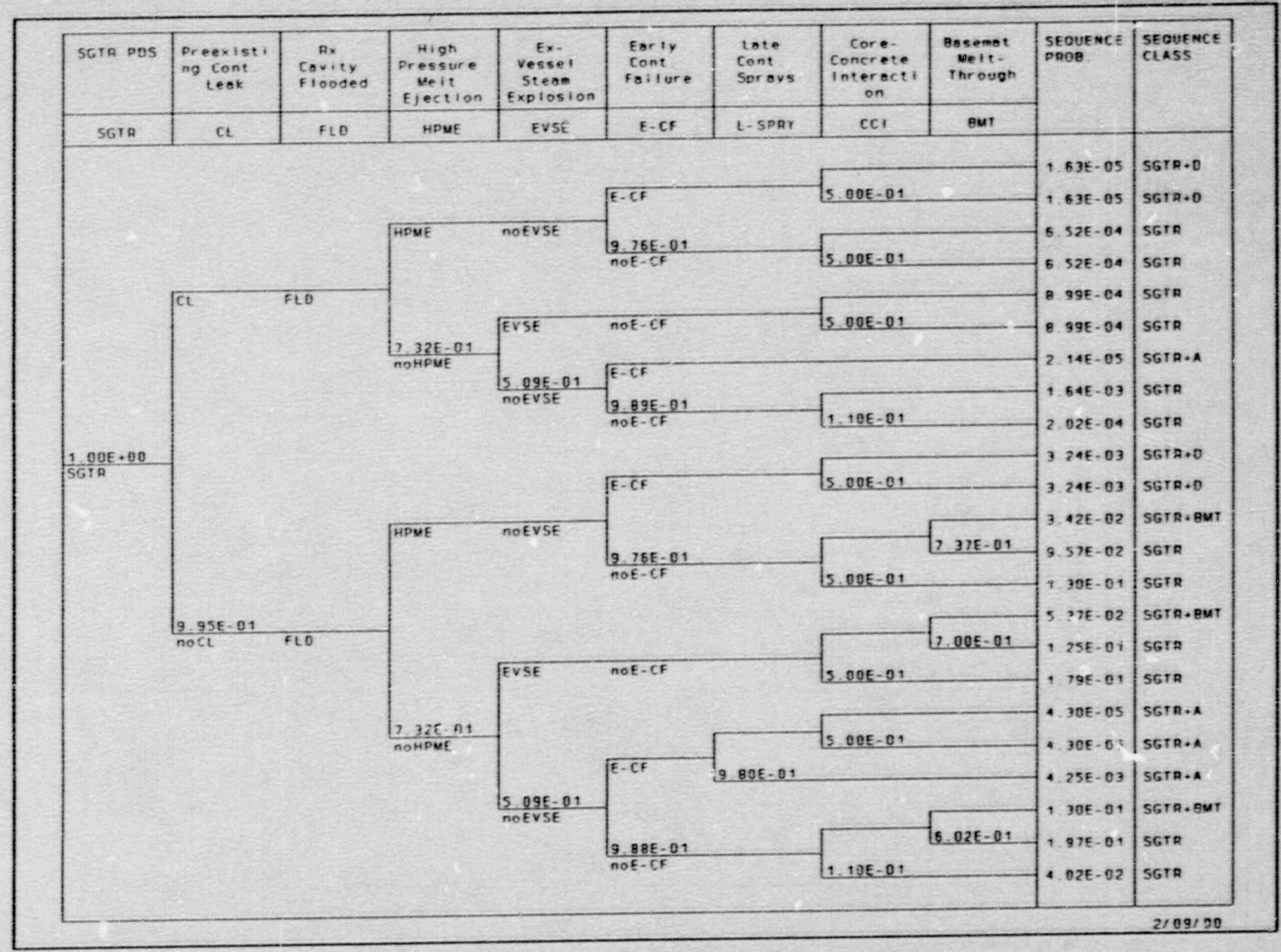

Figure 6.6. SGTR SCET with addition of cavity flooding system.

Table 6.11. Conditional containment failure probabilities for the V + SGTR PDS with addition of cavity flooding system

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
Event V only	4.80E–01	3.87E–01
Event V + α	6.58E–03	6.58E–03
Event V + BMT	1.63E–01	2.56E–01
SGTR only	2.70E–01	2.24E–01
SGTR + α	1.54E–03	1.53E–03
SGTR + BMT	7.62E–02	1.25E–01
SGTR + DCH	2.29E–03	0.00

Table 6.12. Conditional containment failure probabilities for the SGTR PDS with addition of cavity flooding system

Containment Failure Mode	Conditional Probability (SCET)	Base Case Conditional Probability
SGTR only	7.72E–01	6.42E–01
SGTR + α	4.36E–03	2.14E–05
SGTR + BMT	2.18E–01	3.58E–01
SGTR + DCH	6.51E–03	0.00

Table 6.13. Annual V + SGTR risk with addition of cavity flooding system

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	2.74E–06	5.50E–04	1.10	3.32	2.03E+03
SCET	2.69E–06	5.16E–04	1.02	3.08	1.90E+03
% change	–1.7	–6.3	–7.0	–7.3	–6.2

Table 6.14. Annual SGTR risk with addition of cavity flooding system

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	5.72E–06	9.04E–03	14.17	54.23	4.81E+04
SCET	5.72E–06	9.04E–03	14.17	54.21	4.81E+04
% change	0.00	0.00	0.00	0.00	0.00

7. SUMMARY OF TECHNICAL FINDINGS

This section begins with a summation of the results from the previous sections. Table 7.1 presents the composite risk results for the base case and the improvements and sensitivities, summed over all plant damage state groups.

Several conclusions can be drawn concerning the benefits of the potential improvements that have been examined in this report. However, the authors must preface these conclusions with a very important caveat, one that was stated earlier but bears repeating: *the analysis of improvements performed for this report is both plant–specific and site–specific to Zion.* These results should not be applied to other large dry PWR containments without further analysis, with due consideration given to plant–specific and site–specific features that can affect the results. This having been said, we present the following conclusions.

The benefits to risk of intentional operator depressurization cannot be judged conclusively. There appear to be both positive and negative effects to vessel depressurization. First, vessel breach may be prevented in some sequences by intentional depressurization, since depressurization may allow injection from available low pressure systems. This is the case, for example, in the transient + ATWS PDS group. Depressurization also eliminates temperature–induced SGTR, which bypasses the containment. However, depressurization reduces but does not eliminate DCH failures for Zion, because the capacity of the pressurizer PORVs has not been shown to be sufficient to fully depressurize the RCS. Finally, if the conditional probabilities of α mode failure developed for draft NUREG–1150 are used, then the benefits of depressurization may be offset by an increased probability of early containment failure, because draft NUREG–1150 has judged α mode failure to be more likely at low RCS pressures.

The addition of a cavity flooding system yields a slight reduction in risk but may increase the probability of DCH failure in some sequences. The effect of a flooded cavity on the threat from DCH is not conclusively known. The discussion in Reference 2 appears to indicate that the effect may be plant–specific, enhancing the threat at some plants while mitigating it at others. At any rate, the risk reduction is not significant *for Zion.* The benefit in reducing DCH was also found to be at least somewhat pressure–dependent. In those sequences where the RCS is likely to be at system set point pressure at the time of vessel breach, cavity flooding was found to exacerbate the threat from DCH. On the other hand, in sequences such as SBO, where the RCS pressure at the time of vessel breach was likely to be less than system set point pressure, cavity

Table 7.1. Composite annual risk results

	Mean Early Fatalities	Mean Latent Fatalities	Mean 50–Mile Dose (person–rem)	Mean 1000–Mile Dose (person–rem)	Mean Offsite Costs ($)
Base case	3.31E–05	1.39E–02	26.3	84.6	5.99E+04
Depressurization via PORVs	3.18E–05	1.38E–02	26.2	83.9	5.93E+04
Full depressurization #1 (no HPME)	4.12E–05	1.39E–02	26.3	84.4	5.98E+04
Full depressurization #2 (no HPME)[a]	1.60E–05	1.09E–02	18.7	65.2	5.23E+04
Cavity flooding	3.12E–05	1.28E–02	24.0	76.5	5.58E+04
H_2 control	3.31E–05	1.39E–02	26.3	84.6	5.99E+04

a. This case includes the use of a point estimate α mode failure probability of 8.0×10^{-4}.

flooding was found to be of some benefit in mitigating DCH. Flooding the cavity does increase the conditional probability of an ex-vessel steam explosion; however, because ex-vessel steam explosions are an insignificant threat to containment integrity at Zion, this effect does not increase offsite risk.

Improvements in the hydrogen control systems are of no benefit in terms of risk. This result is very Zion-specific. Other plants, particularly those with smaller subatmospheric containments, might realize a more significant risk reduction from hydrogen control improvements.

Improvements to reduce the frequency of containment bypass sequences would provide the greatest tangible risk reduction benefit. For Zion, containment bypass sequences, both the interfacing systems LOCA and SGTR, contribute very significantly to the annual offsite risk. "Front-end" improvements to reduce the incidence of bypass initiators were not analyzed. However, any reductions in bypass frequency would provide a corresponding reduction in all risk measures. Based on a plant visit to Surry, D. C. Williams[a] mentions two possible mitigative strategies. The first of these is to attempt to ensure that the break location in the V sequence is submerged. The second is a suggestion to reflood the steam generators in the case of SGTR, in order to ensure that the release from the RCS is scrubbed through a volume of water. Neither of these suggestions has been evaluated in this report, because the means to do so were unavailable. The improvements for Surry were evaluated and a significant reduction was found in the early and latent fatality risk (no doses or offsite costs were calculated).[b] Both may have the potential to generically reduce the bypass sequence risk. However, the efficacy and cost-effectiveness of these strategies would best be determined on a plant-specific basis.

Gradual overpressurization by noncondensible gases (including steam) is not a threat to containment integrity for Zion. Containment failure by eventual overpressurization (time scale of one or more days) was predicted only in the APET runs made for the LOCA plant damage state group. Even in these cases, the conditional probability of eventual overpressurization was very small. Again, this result is Zion-specific. The conditional probability of late containment failure as the result of BMT was considerable; however, these failures are negligible contributors to offsite risk.

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[a] D. C. Williams, "PWR Dry Containment Parametrics: CONTAIN Calculations," draft letter report dated November 27, 1989.

[b] J. J. Gregory, "PWR Dry Containment Parametrics: NUREG-1150 Sensitivity Studies for the Surry Plant," draft letter report dated December 14, 1989.

8. REFERENCES

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4. C. K. Park et al., *Evaluation of Severe Accident Risks: Zion Unit 1*, draft NUREG/CR-4551, Volume 7, Revision 1, dated July 1989.

5. J. M. Griesmeyer, and L. N. Smith, *A Reference Manual for the Event Progression Analysis Code (EVNTRE)*, NUREG/CR-5174, September 1989.

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7. *ETA-II, Version 1.2*, Los Altos, California, Science Applications International Corporation, 1989.

8. S. J. Higgins, *A User's Manual for the Postprocessing Program PSTEVNT*, NUREG/CR-5380, November 1989.

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10. D. I. Chanin et al., *MELCOR Accident Consequence Code System*, draft NUREG/CR-4691 dated September 21, 1988.

11. *Lotus 1-2-3, Release 2.01*, Cambridge, Massachusetts: Lotus Development Corporation, 1987.

12. P. D. Wheatley et al., *Evaluation of Operational Safety at Babcock and Wilcox Plants, 2 - Thermal-Hydraulic Results*, NUREG/CR-4966, Volume 2, November 1987.

APPENDIX A

ZION ACCIDENT PROGRESSION EVENT TREE

APPENDIX A

Zion Accident Progression Event Tree

The listing of the full 72-question APET for the Zion plant is provided here for reference. This is the APET used in the NUREG-1150 analysis of the LOCA PDS group for Zion. The APETs for the other PDS groups are similar.

Zion LOCA Accident Progression Event Tree

```
  ZION APET, Rev 6, 6 MAR 89 - 72 Questions - PDS-2,  LOCAS
   72
  NQuest
    1               1.000
  'PDS-2, LHS'      PInit                                                  $ PDS - 1st Letter    ( T = PORV )
1 Size and Location of RCS Break when the Core Uncovers?                   $      RIQ       7       8       9
    6    Brk-A      Brk-S2      Brk-S3      Brk-V      B-SGTR     B-PORV   $      10       13      17      18
    1        1           2           3          4           5          6   $      19       21      22      23
         0.046       0.954       0.000      0.000       0.000      0.000   $      44       51      58      71
2 For SGTR, are the Secondary System SRVs Stuck Open?                      $ PDS - 1st Letter
    2  SSRV-StO    SSRVnStO                                                $      RIQ       7       8
    1        1           2
         0.000       1.000                                                 $ PDS - 2nd Letter
3 Status of ECCS?                                                         $      RIQ      16      20      23
    5   B-ECCS      BaECCS      BfECCS      B-LPIS    BiECCS
    2        1           2           3           4     5
    3 Cases
    1        1                                    $ Case 1: Large Break in the RCS
             1                                    $     Used for PDS Group 3
          Brk-A
          0.000     0.0004      0.1266      0.000   0.873
    2        1                                    $ Case 2: Small or Very Small Break in the RCS
             2                                   $     Used for PDS Groups 3 & 6
         Brk-S2
          0.000      0.000      0.9643      0.0003  0.0354
        Otherwise                                 $ Case 3: S3 breaks etc.           RCS
          0.000      0.000      0.997       0.000   0.003
 4 Status of Sprays?                                                        $ PDS - 3rd Letter
     6    B-Sp        BaSp        BfSp    noB-SWHX     BASp       BCSp      $      RIQ      24      27
     2       1           2           3           4        5          6
     2   Cases
     1      1
            1
           Brk-A
          1.000      0.000       0.000       0.000     0.000      0.000
          Otherwise
          1.000      0.000       0.000       0.000     0.000      0.000     $ PDS - Not used for Surry
 5 Status of Fan Coolers?
     3    B-FC       BaFC        BfFC         $      RIQ      25
     2       1           2           3
     3   Cases
     1       1                   $ Case 1: S3 Breaks
             3
            B-S3
             .5   .005   .495
```

```
    1        1               $ Case 2: S2
             2
             B-S2
             .5343    .0036    .4621
    Otherwise                $ case 3 : A/S1
          0.9961     0.0004      0.0035
6 Status of AC Power?                                                   $ PDS - 4th Letter
    3   B-ACP       BaACP       BfACP                                   $     RIQ      16       19       20
    1        1          2           3
          1.000      0.000       0.000
7 RWST Injected into Containment?                                       $ PDS - 5th Letter
    3   RWST-In     RWSTaIn     RWSTfIn            $ RWST Injected implies that the cont.      $ RIQ      31
    2        1          2           3              $ sprays operated in the injection mode,
    3 Cases                                        $ or a break or leak into the containment.
    1        1                            $ Case 1: A size breaks
             1
        B-A
          0.877      0.000       0.123
   1         1
             2
             B-S2                            $ Case 2: S2 size break
          1.000      0.000       0.000
        Otherwise                           $ Case 3: S3 breaks
          0.005      0.000       0.995
8 Heat Removal from the Steam Generators?                               $ PDS - 6th Letter   $ RIQ       9
    4    SG-HR       SGaHR       SGfHR        SGdHR $ SG-HR = operating when core uncovers.         10       13
    2        1          2           3             4 $ SGdHR = operated until batteries              17       28
    2 Cases                                         $     depleted but not operating when           19       51
    1        1                                      $     core uncovers                             44
             6                                    $ Case 1: B-PORV
        B-PORV                                      $     in PDS Group 1
          0.000      0.000       1.000       0.000
        Otherwise                                   $ Case 2: All other breaks
          1.000      0.000       0.000       0.000 $
9 Did the Operators Depressurize the Secondary before the Core Uncovers?  $ PDS - 6th Letter
    2  SecDePr     noScDePr                                                       $ RIQ      13       19
    2        1          2                                                 $          28       44       51
    3 Cases
    1        1                             $ Case 1: B-PORV
             6                             $     in PDS Group 1
        B-PORV
          0.000      1.000
    1        1                             $ Case 2:  S2-size break
             2                             $
        Brk-S2
          1.000      0.000
        Otherwise                          $ Case 3: All other break sizes
          1.000      0.000                 $     and PDSs not in Group 1
10 Cooling for RCP Seals?                                                $ PDS - 7th Letter
    3    B-PSC       BaPSC       BfPSC                                            $ RIQ      15
    2        1          2           3
    3 Cases
    1        1                             $ Case 1: A Breaks
             1
        B-A
          0.993      0.000       0.007
    1        1                             $ Case 2 : S2 Breaks
             2
             B-S2
             .033   .000   .967
        Otherwise                          $ Case 3: S3 Breaks
          0.000      0.000       1.000
```

```
                                                                           $ PDS - 7th Letter
11 Initial Containment Leak or Isolation Failure?
     2   B-Leak     noB-Leak                         $ Leak = 0.1 sq.ft.               $ RIQ     56       61
     1      1          2                             $  Seabrook data                   68       69       71
       0.00500    0.99500
12 Event V - Break Location under Water?
     2    V-Wet        V-Dry                $ Zion FSAR calculation
     1      1            2
        0.500        0.500
13 RCS Pressure at the Start of Core Degradation?                            $     RIQ      14       15       17
     4   E-SSPr       E-HiPr       E-ImPr       E-LoPr                       $              23       28       29
     2      1            2            3            4
     4 Cases
     2      1            1                            $ Case 1: Large Break
            1     +      4                            $      - Low Pressure - 200 psia or less.
         Brk-A    or   Brk-V                          $      [ Following cases cannot have A-size breaks ]
          0.000        0.000        0.000        1.000
     1      1                                         $ Case 2: No Break in the RCS
            6                                         $      - System Setpoint Pressure - around 2500 psia.
         B-PORV                                       $      [ Following cases must have S2 or S3 or SGTR ]
          1.000        0.000        0.000        0.000
     1      9                                         $ Case 3: Sec. DePr. & ( S3 or S2 or SGTR )
            1                                         $      - IM Pressure - 200 to 600 psia.
        SecDePr
          0.000        0.000        1.000        0.000
        Otherwise                                     $ Case 4: S2 or S3 with AFW but noDePr or with no AFW
          0.000        1.000        0.000        0.000 ) $      - High Pressure - 1000 to 1400 psia.
 14 Do the PORVs or SRVs Stick Open?
      2  PORV-StO     PORVnStO                                                $     RIQ      15       17       18
      2      1            2                                                   $              21       22
      2 Cases
      1       13                          $ Case 1: RCS at setpoint pressure, no breaks -
               1                          $      All the water loss is thru the PORVs.
        E-SSPr
      0.500   0.500
        Otherwise                         $ Case 2: RCS not at setpoint pressure -
        0.000   1.000
  15 Temperature-Induced RCP Seal Failure?  (After core uncovering)
       2  EB-PSS3      noEB-PSF                                          $ RIQ     17       18       21
       2      1            2              $ No S2 Seal Breaks -          $         22
       4 Cases                            $      only 0.4% were S2 in ASEP.
       1      10                          $ Case 1: Have seal cooling.
               1
           B-PSC
           0.000        1.000
       2      13           14             $ Case 2: RCS at Setpoint Pressure.
               1     *      2
          E-SSPr    & PORVnStO            $ Distribution from ASEP special panel.
           0.707        0.293
       1      13                          $ Case 3: RCS at High Pressure.
               2
          E-HiPr
           0.650        0.350
         Otherwise                        $ Case 4: RCS at IM or low pressure.
           0.600        0.400
   16 Is the RCS Depressurized before Breach by Opening the PZR PORVs?
        2  PrmDePr      noPrDePr                                          $     RIQ      15       17       18
        2      1            2                                             $              21       22
        2 Cases
        3      6            3           3  $ Case 1: Have AC Power, and Operators
               1     *     -4     *    -1  $      have not already failed to DePressurize.
           B-ACP    & noB-LPIS  & noB-ECCS
           0.900        0.100              $ Case 2: No AC Power.
         Otherwise                         $      Opening the PORVs is prohibited
           0.000        1.000              $      by procedures .
```

```
17 Temperature-Induced Hot Leg or Surge Line Break?
     2   EB-HLA     noEB-HLA                                $ Distribution from                 RIQ      18      21
     2        1           2                                 $ In-Vessel Issue 1.
     3 Cases
     4       13     *      16          14          15  $ Case 1: No breaks & no AFW -
              1    *       2    *      2   *       2  $     RCS around 2500 psia.
         E-SSPr   & noPrDePr   & PORVnStO  & noEB-PSF  $     Hot leg break likely.
          0.722       0.278
     6        1           1           8           8          16         14         $ Case 2: S3 break & no Ar
       (      3    +      5 ) *(      2    +      4 ) *      2   *      2         $   - RCS around 2000 psia
       ( Brk-S3   or B-SGTR ) &(  SGaHR   or  SGdHR ) & noPrDePr & PORVnStO        $   Hot leg break unlikely
          0.357       0.643
        Otherwise -- noSSPr                                 $ Case 3: RCS not at 2000-2500 psia.
          0.001       0.999
18 Temperature-Induced SGTR?
     2  E-SGTRS3    noE-SGTR                                $ Distribution from                 RIQ      22      58
     2        1           2                                 $ In-Vessel Issue 2. Freq is conditional to q 17
     2 Cases
     4       13          16          14          15             $ Case 1: No breaks & no AFW -
              1    *      2    *      2   *       2            $ RCS at setpoint pressure.
         E-SSPr   & noPrDePr   & PORVnStO  & noEB-PSF          $ SGTR very unlikely.
          0.018       0.982
        Otherwise                                                   $ Case 2: RCS not at Setpoint Pressure
          0.000       1.000                                         $ - SGTR not credible
19 Is AC Power Available Early (Between Uncovering TAF & VB-30 min)?
     3   E-ACP       EaACP       EfACP                                                       $ RIQ     20      24
     2        1           2           3                                                      $         25      44
     7 Cases
     1        6                            $ Case 1: Had power initially
              1                            $     - have power now.
          B-ACP                            $     B-ACP implies SG-HR.
          1.000       0.000       0.000
     1        6                            $ Case 2: Power failed initially
              3                            $     - not recoverable.
          BfACP                            $     Remaining cases have recoverable power.
          0.000       0.000       1.000
     2        8           8                $ Case 3: No initial AFW.  (Fast TMLB')
              2    +      3                $     Recovery period = 0.5 to 2 hours.
          SGaHR   or  SGfHR                $     Remaining cases have SGdHR - AFW initially available.
          0.564       0.436       0.000
     1        1                            $ Case 4: Initial AFW & S2 Break - S2RRR-RDYR & S2RRR-RCYR
              2                            $     Recovery Period = 1 to 4 hours.
         Brk-S2                            $     BaACP & SGdHR implied by previous questions.
          0.736       0.264       0.000
     2        1           9                $ Case 5: Initial AFW & S3 Break - S3RRR-RCYR
              3    *      2                $     No Depressurization of the Secondary
         Brk-S3   &  noScDePr              $     Recovery Period = 4 to 5.5 hours
          0.393       0.607       0.000
     2        1           9                $ Case 6: Initial AFW & S3 Break - S3RRR-RDYR
              3    *      1                $     Secondary Depressurized
         Brk-S3   &  SecDePr               $     Recovery Period = 4 to 10 hours
          0.801       0.199       0.000
        Otherwise - B-PORV                 $ Case 7: Initial AFW & no Break, SecDePr - TRRR-RDYR & TRRR-RDYY
          0.675       0.325       0.000    $     Recovery Period = 7 to 12 hours
20 After Power Recovery, Is Coolant Injection Re-Established Promptly?
     2   E-RECC     noE-RECC                                                                 $ RIQ     23
     2        1           2
     3 Cases
     1        3            $ Case 0: automatic inj. ECCS operating!
              1
              B-ECCS
              1.000     0.000
```

```
     3        6          19           3   $ Case 1: If electric power is
              2   *       1   *       2   $     restored core cooling should
         BaACP  &     E-ACP  &   BaECCS   $     be re-established promptly.
          0.950       0.050
        Otherwise                         $ Case 2: Power not restored, or ECCS failed,
          0.000       1.000               $     or LPIS has been available all along.
21 Rate of Blowdown to Containment?    [ This is blowdown before vessel breach. ]
     4    EBD-A      EBD-S2      EBD-S3       noEBD                               $ RIQ     27       22
     2        1           2           3           4
     4 Cases
     2        1          17                             $ Case 1: Large break -
              1   +       1                             $   initial or induced.
         Brk-A or    EB-HLA
          1.000       0.000       0.000       0.000
     1        1                                         $ Case 2 : V no blowdown
              4
            Brk-V
            0.000  0.000   0.000  1.000
     3        1          14          16                 $ Case 3: S2 break - initial,
              2   +       1   +       1                 $   induced, or deliberate.
        Brk-S2 or  PORV-StD or PrmDePr                  $   Includes stuck-open PORV.
          0.000       1.000       0.000       0.000
        Otherwise                                       $ Case 4: S3 and some SGTR -
          0.000       0.000       1.000       0.000
22 Vessel Pressure just before Breach?
     4   I-SSPr      I-HiPr      I-ImPr      I-LoPr                         $    RIQ      23       28       35
     2        1           2           3           4                         $             38       39       42
     4 Cases                                                                $             48       49       58
     5       21           1           1          16          14           $ Case 1: Large Break or
              1   +       4   + (     2 * (       1   +       1 ) )       $ S2 with PORVs open.
          EBD-A or    Brk-V or ( Brk-S2 & ( PrmDePr or  PORV-StD) )       $ Low Pressure - < 200 psia.
          0.000       0.000       0.000       1.000
     1       21                                         $ Case 2: S2 Break
              2                                         $ Intermediate Pessure - 200-600 psia.
         EBD-S2                                         $   [No A breaks by Case 1]
       0.000   0.000   1.000   0.000
     4       15          18           1           1   $ Case 3: S3 Break
              1   +       1   +       3   +       5   $ High Pressure - 1000-2000 psia.
        EB-PSS3   orE-SGTRS3  or Brk-S3   or B-SGTR   $   [EBD-S3 includes B-PORV - can't use here]
        0.000   1.000  0.00     0.000
        Otherwise - B-PORV                              $ Case 4: RCS Pressure Boundary Intact -
          1.000       0.000       0.000       0.000   $ System Setpoint Pressure - 2300 to 2500 psia.
23 Is Core Damage Arrested?   No Vessel Breach?                        $     RIQ      28       35       36
     2      noVB         VB                                            $      39      40       51       56
     2        1           2                                            $      57      69       70
     9 Cases
     2       19           3                 $ Case 1: No power or no injection
             -1   +       3                 $     assures vessel breach.
        noE-ACP or   BfECCS                 $     Rest of cases have electric power before VB.
          0.000       1.000
     2        1           3                 $ Case 2: Large Initial Break with LPIS available all along.
              1   *       4                 $     RCS will depressurize before core damage
          Brk-A   &  B-LPIS                 $     has gone very far.
          0.950       0.050
     4       22           3          22           3   $ Case 3: Depressurization was either later or
      (       4   *       4 )+ (     -1    *      1 ) $   slower than in Case 2.  Chances of
      ( I-LoPr   &   B-LPIS )or(noI-SSPr   & B-ECCS ) $   avoiding VB are less than in Case 2.
          0.900       0.100
     1        3                             $ Case 4: The remaining cases must have recoverable ECCS.
             -2                             $     They have electric power by case 1.
        noBaECCS                            $     E.G., B-LPIS & Hi-Pr goes to VB at this case.
          0.000       1.000
```

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     2       8          8             $ Case 5: No initial AFW - TRRR-RSR.
       (     2   +      3 )           $     Recovery period = 0.5 to 2 hours.
      ( SGaHR  or  SGfHR )           $    Remaining cases have SGdHR - AFW initially available.
          0.900      0.100
     1       1                        $ Case 6: Initial AFW & S2 Break - S2RRR-RDR & S2RRR-RCR.
             2                        $     Recovery Period = 1 to 4 hours.
         Brk-S2                       $     BaACP & SGdHR implied by previous questions.
          0.700      0.300
     2       1          9             $ Case 7: Initial AFW & S3 Break - S3RRR-RCR.
             3   *      2             $     No Depressurization of the Secondary.
         Brk-S3  &  noScDePr          $     Recovery Period = 4 to 5.5 hours.
          0.500      0.500
     2       1          9             $ Case 8: Initial AFW & S3 Break - S3RRR-RDR.
             3   *      1             $     Secondary Depressurized.
         Brk-S3  &  SecDePr           $     Recovery Period = 4 to 10 hours.
        !23,5,1     !23,5,2
        Otherwise - B-PORV            $ Case 9: Initial AFW & no Break, SecDePr - TRRR-RDR & TRRR-RDY.
        !23,5,1     !23,5,2           $     Recovery Period = 7 to 12 hours.
24 Early Sprays?
     3     E-Sp       EaSp        EfSp                                          $ RIQ     26       31
     2       1          2           3                                           $         43       58
     4 Cases
     3       4     4    4             $ Case 1: Had sprays on or
             1  +  5  + 6             $         operating on ps demand
         B-Sp  or BASp or BCSp
          1.000      0.000       0.000
     1       4                        $ Case 2: Sprays were failed
             3                        $         - stay failed.
          BfSp
          0.000      0.000       1.000
     2       4          19            $ Case 3: Sprays were available and have power now
             2   *      1             $         - sprays operate. Even if containment pressure
          BaSp   &   E-ACP            $         never gets high enough for auto actuation, assume
          1.000      0.000       0.000$         operator will turn on sprays to cool sump water.
        Otherwise                     $ Case 4: No power
          0.000      1.000       0.000$         - sprays remain available.
25 Early Fan Coolers?
     3     E-FC       EaFC        EfFC                                          $ RIQ     26       46
     2       1          2           3
     4 Cases
     1       5                        $ Case 1: Had fan coolers at start
             1                        $         - have fan coolers now.
          B-FC
          1.000      0.000       0.000
     1       5                        $ Case 2: Fan coolers were failed
             3                        $         - stay failed.
          EfFC
          0.000      0.000       1.000
     2       5          19            $ Case 3: Fan Coolers were available and have power now
             2   *      1             $         - fan coolers operate. Even if containment
          BaFC   &   E-ACP            $         pressure never gets high enough for auto
          1.000      0.000       0.000$         actuation, assume operator will turn on.
        Otherwise                     $ Case 4: No power - fan
          0.000      1.000       0.000$         coolers remain available.
26 Early Containment Heat Removal?
     2     E-CHR      EfCHR                                                     $ RIQ     27
     2       1          2
     3 Cases
     1      25                        $ Case 1: Have Fans - Have CHR
             1
            E-FC
            1.000    0.000
```

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     2       24          20               $ Case 2: Have Sprays and ECCS
              1    *      1               $         - Have CHR
           E-Sp   and  E-RECC
          1.000      0.000
         Otherwise                        $ Case 2: No Sprays, No Fan Coolers
          0.000      1.000                $         - No CHR
27 Baseline Containment Pressure just before VB?
                                                                          $ PUIQ     42
     1   IPBase
     4       1                            $  IPBase - Parameter  1
     4 Cases
     2       21          23               $ Case 1: No blowdown to containment, or
              4    +      1               $     no vessel breach.  Containment will be
          noEBD   or   noVB               $     near normal operating pressure.
          1.000
     1                                    $         pressure in psia
     1   15.00
     2       26           4               $ Case 2: Have Sprays or Fan Coolers and
              1    *     -4               $     Service Water.  Containment
          E-CHR   &   B-SWHX              $     will be near Ambient Pressure.
          1.000                           $     See S2D run in BMI-2139
     1
     1   19.00
     2       26          21               $ Case 3: No CHR and blowdown to
              2    *      1               $     containment from a large break.
          EfCHR   &   EBD-A               $     Pressure around 44 Psia, S2DCirFir BMI-2139
          1.000
     1
     1   44.00
        Otherwise                         $ Case 4: No sprays and no large break.
          1.000                           $     Pressure around 24-26 psia.
     1                                    $     See TMLBn BMI-2139
     1   26.00
 28 Time of Accumulator Discharge?
      3   AcDbCM       AcDdCM       AcDaVB                          $     RIQ        29        50        56
      2       1            2            3
      3 Cases
      4      13           13            8           9  $ Case 1: Accumulators Discharge
              3    +       4 + (        4    *       1 ) $ before Core Degradation starts
          E-ImPr   or E-LoPr or(    SGdHR   &   SecDePr )
          1.000       0.000        0.000
      2      22           22                   $ Case 2: Accumulators Discharge
              3    +       4                   $ during Core Degradation
          I-ImPr   or I-LoPr
          0.000       1.000        0.000
        Otherwise                              $ Case 3: Accumulators Discharge
          0.000       0.000        1.000       $ at Vessel Breach
 29 Fraction of Zr Oxidized In-Vessel during Core Degradation?
      1  ZrOx-InV                                                     $ PUIQ     30        59
      4       1                                $ ZrOx-InV- Parameter  2
      7 Cases
      2      13           28    $ Case 1: RCS at System Setpoint Pressure (2500 psia)
              1    *      -2    $     Accm. dump before or after core melt
          E-SSPr   &   AcDnCM   $     In-Vessel #5 - Case 1a/1c
          1.000
      1
      2     0.44
      2      13           28    $ Case 2: RCS at System Setpoint Pressure (2500 psia)
              1    *       2    $     Accumulator dump during core melt
          E-SSPr   &   AcDdCM   $     In-Vessel #5 - Case 1b
          1.000
      1
      2     0.50
```

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   2        13           28   $ Case 3: RCS at High Pressure (1000-1400 psia)
             2   *       -2   $      Accm. dump before or after core melt
        E-HiPr   &   AcDnCM   $      In-Vessel #5 - Case 2a/2c/5
         1.000
   1
   2     0.32
   2        13           28   $ Case 4: RCS at High Pressure (1000-1400 psia)
             2   *        2   $      Accumulator dump during core melt
        E-HiPr   &   AcDdCM   $      In-Vessel #5 - Case 2b
         1.000
   1
   2     0.38
   2        13           28   $ Case 5: Intermediate Pressure (200-600 psia)
             3   *       -2   $      Accm. dump before or after core melt
        E-ImPr   &   AcDnCM   $      In-Vessel #5 - Case 3a
         1.000
   1
   2     0.[illegible]
   2        13           28   $ Case 6: Intermediate Pressure (200-600 psia)
             3   *        2   $      Accumulator dump during core melt
        E-ImPr   &   AcDdCM   $      In-Vessel #5 - Case 3b
         1.000
   1
   2     0.52
        Otherwise - E-LoPr    $ Case 7: Low RCS Pressure (<200 psia)
         1.000                $      In-Vessel #5 - Case 4
   1
   2     0.45
30 Amount of Zr Oxidized In-Vessel during Core Degradation?
    2   Hi-ZrOx     Lo-ZrOx
    5         1           2                 $ Put fraction Zr oxidized
    1         2                             $ into 2 categories -- need
       ZrOx-InV                             $ this information for SURSOR
          AND
       GETHRESH  1     0.4
              Fraction of Zr Oxidized In-Vessel
31 Amount of Water in the Reactor Cavity at Vessel Breach?
    2   RC-Wet      RC-Dry                                                     $      RIQ       38        39        40
    2        1           2                                                     $                50        56        69
    2 Cases
    3         7          7     19           $ Case 1: RWST not injected only
              3    + (  2  *    -1)         $         criterion for dry cav.
       RWSTf     or (RWSla & NoEACP)        $     Time of Accm. Dump irrelevant for DCH & EVSE,
         0.000        1.000                 $     If Dump at VB, it will be after DCH or EVSE.
       Otherwise                            $ Case 2: RWST injected or sprays operating -
         1.000        0.000                 $     The Cavity is Full (12,000 ft3 = 340 m3).
32 Fraction of Core Released from Vessel at Breach?
    1   FCorRel                                                              $ PUIQ     33
    3         1                             $  FCorRel- Parameter  3
         1.000                              $ Fraction Released or Expelled Promptly at Breach
    1                                       $ Distribution from In-Vessel Issue 6
    3     0.30
33 Amount of Core Released from Vessel at Breach?
    3   Hi-FCoR     Md-FCoR      Lo-FCoR             $ This question puts the fractions        $ RIQ      38
    5         1           2            3             $ obtained in the previous question          39      48
    1         3                                      $ into a small number of categories.
       FCorRel
          AND
       GETHRESH  2     0.4          0.2
              Fraction of Core Participating in HPME
```

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34 Does an Alpha Mode Event Fail both the Vessel and the Containment?
     2    Alpha      noAlpha                                               $    RIQ      35      38      39
     2        1            2                                               $     42      43      48      49
     3 Cases
     2       23           22    $ Case 1: Core Damage Not Arrested and
              2  *         4    $      Low Pressure in the RCS
             VB  &    1-LoPr
        0.0080        0.9920
     2       23           22    $ Case 2: Core Damage Not Arrested and
              2  *        -4    $      IM, High, or SS Pressure in the RCS
             VB  &   noI-LoPr
        0.0008        0.9992
       Otherwise                $ Case 3: Core Damage Arrested, no VB
        0.0000        1.0000
35 Type of Vessel Breach?                                                  $    RIQ      36      37      38
     4     PrEj         Pour        BtmHd       noVBoA                     $             40      42      48
     2        1            2           3            4                      $             49      58
     5 Cases
     2       23           34                             $ Case 1: No Vessel Breach
              1  +         1                             $      or Alpha Failure
           noVB   or   Alpha
          0.000        0.000       0.000        1.000
      1       22                                         $ Case 2: RCS at System Setpoint Pressure.
               1                                         $      In-Vessel Issue 6
         1-SSPr                                          $      Case 1
         0.7900       0.1900      0.0200       0.0000
      1       22                                         $ Case 3: RCS at High Pressure.
               2                                         $      In-V #6 - Case 2
         1-HiPr
         0.6000       0.3800      0.0200        0.0000
      1       22                                         $ Case 4: RCS at Intermediate Pressure.
               3                                         $      In-V #6 - Case 3
         1-ImPr
         0.6000       0.3800      0.0200       0.0000
         Otherwise - 1-LoPr                              $ Case 5: RCS at Low Pressure.
         0.0000       1.0000      0.0000       0.0000
36 Does the Vessel become a "Rocket" and Fail the Containment?
      2   Rocket     noRocket                                              $    RIQ      38      39      42
      2        1            2                                              $             43      48      49
      2 Cases
      2       35           22    $ Case 1: Gross Bottom Head Failure - Rocket
               3    *        1    $      is possible only for this mode of VB
           BtmHd    &   1-SSPr    $      and at maximum pressure in the vessel.
           0.001        0.999
         Otherwise                $ Case 2: Not BtmHd & SSPr - Rocket Not Credible.
           0.000        1.000
 37 Size of Hole in Vessel (after Ablation)?
      2   LrgHole     SmlHole                                                          $ RIQ     38      39
      2        1            2
      2 Cases
      1       35                  $ Case 1: HPME - Distribution for Hole Size
               1
            PrEj
           0.100        0.900
         Otherwise                $ Case 2: Not HPME - Large Hole or Irrelevant
           1.000        0.000
 38 Pressure Rise at Vessel Breach?     Large Hole Cases
      1    DP-VB                                                                       $ PUIQ    42
      4        1                            $  dp1-VB - Parameter  4
     16 Cases
```

```
1      23                          $ Case 1: No Vessel Breach
        1
     noVB
    1.000
1                                  $ Pressure rise in psi
4    0.00
2      34         36               $ Case 2: Alpha Mode or Rocket -
        1  +       1               $     Very Large Dummy Value used to
    Alpha or  Rocket               $     Assure Containment Failure.
    1.000
1
4  777.00
2      22         35               $ Case 3: Low Pressure in RCS, or Pour.
        4    +     2               $     Loads Issue 9, Case 4
   I-LoPr   or  Pour
    1.000
1
4   24.90
1      37                          $ Case 4: Small Hole Cases -
        2                          $     Treated in next question
  SmlHole
    1.000                          $     The following questions are
1                                  $     thus all large hole cases.
4    0.00
3     22         31          33  $ Case 5: IM Pressure in RCS.                          506
       3   *      1    *      1  $     Cavity Full or Part Full.                        507
  I-ImPr   &  RC-Wet   &  Hi-FCoR  $     High Fraction Ejected                          508
   1.000                         $     Loads Issue 9, Case 3  curve 9
1                                                                                       510
4  75.70                                                                                511
3     22         31          33  $ Case 6: IM Pressure in RCS.                          512
       3   *      1    *      2  $     Cavity Full or Part Full.                        513
  I-ImPr   &  RC-Wet   &  Md-FCor $  Medium Fraction Ejected
   1.000                         $     Loads Issue 9, Case 3   curve 11
1                                                                                       516
4  51.90                                                                                517
3     22         31          33  $ Case 7: IM Pressure in RCS.                          512
       3   *      1    *      3  $     Cavity Full or Part Full.                        513
  I-ImPr   &  RC-Wet   &  Lo-FCor $  Low Fraction Ejected
   1.000                         $     Loads Issue 9, Case 3   curve 11
1                                                                                       516
4  51.90                                                                                517
3     22         24          33  $ Case 8: IM Pressure in RCS.                          518
       3   *     -1    *      1  $     no sprays                                        519
  I-ImPr   &  No-Esp   &  Hi-FCoR  $    High Fraction Ejected                           520
   1.000                         $     Loads Issue 9, Case 3A    curve 13
1                                                                                       522
4  85.20                                                                                523
3     22         24          33  $ Case 9: IM Pressure.
       3   *     -1    *      2  $         no sprays
  I-ImPr   &  No-Esp   &  Md-Fcor $       int ejection
   1.000                         $         Case 3A  curve 15
1
4   57.2
3     22         24          33  $ Case 10: IM Pressure.
       3   *     -1    *      3  $         no sprays
  I-ImPr   &  No-Esp   &  Lo-Fcor $       low ejection
   1.000                         $         Case 3A  curve 15
1
4   57.2
```

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                                                                                          524
4      22          22          31          33   $ Case 11: SS or Hi Pressure in RCS.      525
  (     1  +        2  ) *      2     *     1   $     Cavity Dry.                         526
  ( 1-SSPr or   1-HiPr  ) & RC-Dry     & Hi-FCoR $     High Fraction Ejected
    1.000                                       $     Loads Issue 9, Case 1B/1C    curve 5
                                                                                          528
1                                                                                         529
4    105.00
4      22          22          31          33   $ Case 12: SS or Hi Pressure in RCS.
  (     1  +        2  ) *      2     *     2   $     Cavity Dry.                         531
  ( 1-SSPr or   1-HiPr  ) & RC-Dry     &  Md-FCor  $ Medium Fraction Ejected            532
1.000                                       $     Loads Issue 9, Case 1B/1C   curve 7     534
1                                                                                         535
4    70.70
4      22          22          31          33   $ Case 13: SS or Hi Pressure in RCS.
  (     1  +        2  ) *      2     *     3   $     Cavity Dry.                         531
  ( 1-SSPr or   I-HiPr  ) & RC-Dry     &  Lo-FCor  $ Low Fraction Ejected            532
1.000                                       $     Loads Issue 9, Case 1B/1C   curve 7
                                                                                          534
1                                                                                         535
4    70.70                                                                                542
4      22     22     31     33      $ Case 14: SS or Hi Pr & Cavity Wet
       ( 1  +   2) *   1  *   1
       (1-SSPr or 1-HiPr)andRC-WetandHi-FCor   $   High Fraction Ejected
544
       1.000                        $     Loads Issue 9, Cases 1    curve 1           545
                                                                                          546
1                                                                                         547
4    95.00                                                                                542
4      22     22     31     33      $ Case 15: SS or Hi Pr & Cavity Wet
       ( 1  +   2) *   1  *   2
       (1-SSPr or 1-HiPr)andRC-WetandMd-FCor   $   Medium Fraction Ejacted
544
       1.000                        $     Loads Issue 9, Cases 1    curve 1           545
                                                                                          546
1                                                                                         547
4    95.00                                                                                554
   Otherwise                        $ Case 16: SS or Hi Pressure & Cavity Wet
     1.000                                                                                556
1                                   $     Low Fraction Ejected
4    64.70                          $     Loads Issue 9, Cases 1    curve 3
                                                                                          558
39 Pressure Rise at Vessel Breach?     Small Hole Cases
                                                                      $ PUIQ     42       559
 1    DP-VB                                                                               560
 4       1                          $  dp2-VB - Parameter  5                              561
 13  Cases                                                                                562
 5       37          23          34          22          36  $ Case 1: Large Hole, or no VB, or Alpha,     563
          1   +       1   +       1   +       4   +       1  $      or Rocket, or Low Pressure -           564
     LrgHole  or   noVB    or  Alpha   or 1-LoPr   or Rocket $      Treated in previous question.          565
      1.000                                                  $      The following questions are            566
                                                             $      thus all small hole cases.
1                                                                                         567
5     0.00                                                                                568
3        22          31          33   $ Case 2: IM Pressure in RCS.                       569
          3   *       1   *       1   $     Cavity Full or Part Full.                     570
     1-ImPr  &   RC-Wet  &   Hi-FCoR  $     High Fraction Ejected
      1.000                           $     Loads Issue 9, Case 3   curve 10
                                                                                          572
1                                                                                         573
5     63.70                                                                               574
3        22          31          33   $ Case 3: IM Pressure in RCS.                       575
          3   *       1   *       2   $     Cavity Full or Part Full.                     576
     1-ImPr  &   RC-Wet  &   Md-FCor  $     Medium Fraction Ejected
      1.000                           $     Loads Issue 9, Case 3    curve 12
                                                                                          578
1                                                                                         579
5     44.50
```

```
   3      22         31         33  $ Case 4: IM Pressure in RCS.                                         574
           3 *        1 *        3  $     Cavity Full or Part Full.                                       575
    1-ImPr  &  RC-Wet  &  Lo-FCor   $     Low Fraction Ejected                                       576
     1.000                          $     Loads Issue 9, Case 3    curve 12
   1                                                                                                  578
   5   44.50                                                                                          579
   3      22         24         33  $ Case 5: IM Pressure in RCS.                                     580
           3 *       -1 *        1  $      no sprays                                                  581
    1-ImPr  &  No-Esp  and Hi-FCoR  $    High Fraction Ejected                                        582
     1.000                          $     Loads Issue 9, Case 3   curve 14
   1                                                                                                  584
   5   71.40                                                                                          585
   3      22         24         33  $ Case 6: Same as 5 but int ejected
           3  *      -1  *       2  $      Loads Issue 9 Case 3    cu    39 Pressure Rise at Vessel Breach?     Small
Hole Cases
        1-ImPr and No_esp and  Md-FCor
      1.000
   1
   5    49.50
   3      22         24         33  $ Case 7: Same as 5 but low ejected
           3  *      -1  *       3  $      Loads Issue 9 Case 3    cu    39 Pressure Rise at Vessel Breach?     Small
Hole Cases
        1-ImPr and No_esp and  Lo-FCor
      1.000
   1
   5    49.50
   4      22         22          31          33  $ Case 8: SS or Hi Pressure in RCS.                  586
    (      1 +        2  ) *      2   *       1  $     Cavity Dry.                                    587
    ( 1-SSPr or   1-HiPr  ) & RC-Dry    & Hi-FCoR  $     High Fraction Ejected                        588
      1.000                                      $     Loads Issue 9, Case 1B/1C   curve 6
   1                                                                                                  590
   5    95.60                                                                                         591
   4      22         22          31          33  $ Case 9: SS or Hi Pressure in RCS.                  592
    (      1 +        2  ) *      2   *       2  $     Cavity Dry.                                    593
    ( 1-SSPr or   1-HiPr  ) & RC-Dry    &  Lo-FCor   $   Medium Fraction Ejected
      1.000                                      $     Loads Issue 9, Case 1B/1C   curve 8
   1                                                                                                  596
   5    64.20                                                                                         597
   4      22         22          31          33  $ Case 10: SS or Hi Pressure in RCS.                  592
    (      1 +        2  ) *      2   *       3  $     Cavity Dry.                                    593
    ( 1-SSPr or   1-HiPr  ) & RC-Dry    &  Md-FCor   $   Low Fraction Ejected
      1.000                                      $     Loads Issue 9, Case 1B/1C   curve 8
   1                                                                                                  596
   5    64.20                                                                                         597
   4      22         22        31        33      $ Case 11: SS or Hi Pr & Cavity Wet
         (1 +        2)  *     1   *     1
      (1-SSPr or 1-HiPr)&RC-Wet  &  Hi-FCor      $     High Fraction Ejected                          606
      1.000                                      $     Loads Issue 9, Case 1    curve 2
   1                                                                                                  608
   5    85.80                                                                                         609
   4      22         22        31        33      $ Case 12: SS or Hi Pr & Cavity Wet
         (1 +        2)  *     1   *     2
      (1-SSPr or 1-HiPr)&RC-Wet  &  Md-FCor      $     Med Fraction Ejected                           606
      1.000                                      $     Loads Issue 9, Case 1    curve 2
   1                                                                                                  608
   5    85.80                                                                                         609
     Otherwise                                   $ Case 13 : SS or Hi Pressure & Cavity Wet            616
      1.000
   1                                             $     Low Fraction Ejected                           618
   5    57.60                                    $     Loads Issue 9, Case 1     curve 4
```

```
40 Does a Significant Ex-Vessel Steam Explosion Occur?                                        $ RIQ     47      48
     2     EVSE       noEVSE                                                                           49
     2        1            2
     2 Cases
     2       3[illegible]          35                    $ Case 1: Gravity Pour into Pool in Cavity
             1             2                    $     is the only case where EVSE is possible.
        RC-Wet  &      Pour
         0.500      0.500
       Otherwise -- No EVSE                     $ Case 2: Alpha Mode, or Rocket, or
         0.000      1.000                       $     no VB, or HPME, or cavity dry.
41 Containment Failure Pressure?
     1     CF-Pr                                $ Read Failure Pressure and Random Number for Failure Mode
     3        1                                 $   CF-Pr - Parameter  6                 $ Both PUIO     42       64
          1.000                                 $  RndNum - Parameter  7
     2                                          $ Failure Pressure in psig
     6   128.20                                 $ Distribution from Structural Issue 2
     7     0.50
42 Containment Failure, and Type of Containment Failure?
     5  ICF-CtRp     ICF-Rupt     ICF-Leak     no-ICF      ICF-Shear        $     RIQ      43       56       58
     6        1            2            3          4          5              $              61       64       68
     2 Cases                                                                 $              69       71
     2       34           36                              $ Case 1: Alpha or Rocket -
             1  +          1                              $     Rupture Assured
         Alpha or    Rocket
     2        1            4
        IPBase       dp1-VB
           AND
        GETHRESH  4     999   3       2          1
        Dummy Values to Assure Rupture
     Otherwise                                            $ Case 2:
     5        1            4            5          6          7
         IPBase      dp1-VB       dp2-VB       CF-Pr      RndNum
        FUN-ICFFst
        GETHRESH  4   4   3   2   1
        User Function for Fast Pressure Rise
 43 Sprays after Vessel Breach?                           $ ( The 5 to 30 minutes after VB are crucial
      3    12-Sp        12aSp        12fSp                $ for spray removal of the RCS releases
      2        1            2            3                $ for SSPr and HiPr cases. )
      5 Cases                                                                               $ RIQ     45
      3       24           34           36    $ Case 1: Sprays failed - remain failed.
              3   +        1    +        1    $     Alpha or Rocket always fail sprays.
           EfSp   or   Alpha    or Rocket
          0.000        0.000        1.000
      2       24           42                 $ Case 2: Sprays available & no Cat. Rupture -
              2   *        -1                 $     Sprays stay available. ( Have not asked
           EaSp   & noICFCRp                  $     power recovery since last spray question. )
          0.000        1.000        0.000
      2       24           42                 $ Case 3: Sprays operating & no Cat. Rupture
              1   *        -1                 $     - Sprays stay operating.
           E-Sp   & noICFCRp
          1.000        0.000        0.000
      2       24           42                 $ Case 4: Cat. Rupture at Vessel Breach -
              1   *         1                 $     Sprays Operating
           E-Sp   & ICF-CtRp
          0.900        0.000        0.100
        Otherwise -- EaSp & ICF-CtRp          $ Case 5: CR at VB, sprays only available.
          0.000      !43,4,1      !43,4,3
```

```
44 Is AC Power Available Late (during CCI)?
    3    L-ACP       LaACP        LfACP                                  $ RIQ     45      46      51
    2        1           2            3
    7  Cases
    1       19                              $ Case 1: Had power initially or
             1                              $     recovered it already - have power now.
         E-ACP
         1.000       0.000        0.000
    1       19                              $ Case 2: Power failed initially
             3                              $     - not recoverable.
         EfACP                              $     Remaining cases have recoverable power.
         0.000       0.000        1.000
    2        8           8                  $ Case 3: No initial AFW.  (Fast TMLB')
             2   +       3                  $     Uncov. at 100; VB at 160 min.
         SGaHR   or  SGfHR                  $     Recovery period = 2 to 9 hours.
         0.888       0.112        0.000     $     Remaining cases have SGdHR - AFW initially available.
    1        1                              $ Case 4: Initial AFW & S2 Break - S2RRR-RDYR & S2RRR-RCYR
             2                              $     Recovery Period = 4 to 9 hours.
        Brk-S2                              $     BaACP & SGdHR implied by previous questions.
         0.754       0.246        0.000
    2        1           9                  $ Case 5: Initial AFW & S3 Break - S3RRR-RCYR
             3   *       2                  $     No Depressurization of the Secondary
        Brk-S3   &  noScDePr                $     Recovery Period = 5.5 to 9 hours
         0.601       0.399        0.000
    2        1           9                  $ Case 6: Initial AFW & S3 Break - S3RRR-RDYR
             3   *       1                  $     Secondary Depressurized
        Brk-S3   &  SecDePr                 $     Recovery Period = 10 to 17 hours
         0.731       0.269        0.000
      Otherwise - B-PORV                    $ Case 7: Initial AFW & no Break, SecDePr - TRRR-RDYR & TRRR-RDYY
         0.604       0.396        0.000     $     Recovery Period = 12 to 17 hours
45 Late Sprays?     (during CCI)
    3     L-Sp        LaSp         LfSp                                  $ RIQ     47      50      52
    2        1           2            3
    4 Cases
    1       43                              $ Case 1: Had sprays after VB - have sprays now.
             1
         I2-Sp
         1.000       0.000        0.000
    1       43                              $ Case 2: Sprays failed earlier - stay failed.
             3
         I2fSp
         0.000       0.000        1.000
    2       43          44                  $ Case 3: Sprays were available and power has been
             2   *       1                  $         recovered, so sprays operate.
         I2aSp   &  L-ACP
         1.000       0.000        0.000
      Otherwise                             $ Case 4: AC power not recovered, so
         0.000       1.000        0.000     $         sprays remain available.
46 Late Fan Coolers?
    3     L-FC        LaFC         LfFC                                  $ RIQ     47      53
    2        1           2            3
    4 Cases
    1       25                              $ Case 1: Had fan coolers before
             1                              $         - have fan coolers now.
          E-FC
         1.000       0.000        0.000
    1       25                              $ Case 2: Fan coolers were failed
             3                              $         - stay failed.
          EfFC
         0.000       0.000        1.000
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```
  2       25         44               $ Case 3: Fan coolers were available and have power now
           2    *     1               $           - fan coolers operate.
        EaFC    &  L-ACP
       1.000      0.000       0.000
      Otherwise                       $ Case 4: No power - fan
       0.000      1.000       0.000   $           coolers remain available.
47 Late Containment Heat Removal?
    2    L-CHR       LfCHR
    2        1           2
    2 Cases
    1       46                        $ Case 1 : have fan coolers
             1
           L-FC
       1.000      0.000
      Otherwise                       $ Case 2: No Sprays, No Fan Coolers
       0.000      1.000               $           - No CHR
48 Amount of Core Available for CCI?
    3   Lrg-CCI     Med-CCI     Sml-CCI           $ Large means > 70%             $ RIQ      57
    2       1           2           3             $ Medium means > 30% and < 70%
    6 Cases                                       $ Small means < 30%
    2       34         36                                     $ Case 1: Alpha Mode or Rocket
             1    +     1
        Alpha    or Rocket
        0.000      1.000        0.000
    1       35                                                $ Case 2: No Vessel Breach
             4
       noVBoA
        0.000       0.000        1.000
    4       35          35          22          33    $ Case 3: HPME and Fr. Ejected Not Small
      (      1 +  (      3   *       -4 ))*      -3
      (   PrEj or (   BtmHd  &  noI-LoPr))&     NoLoFCor
        0.000       1.000       0.000
    4       35          35          22          33                $ Case 4: HPME and Fraction Ejected Small
      (      1 +  (      3   *       -4 )) *      3
      (   PrEj or (   BtmHd  &  noI-LoPr)) & Lo-FCoR
        1.000       0.000       0.000
    4       35          35          22          40                $ Case 5: Gravity Pour and EVSE
      (      2 +  (      3   *        4 )) *      1
      (   Pour or (   BtmHd  &   I-LoPr )) &   EVSE
        0.500       0.500       0.000
      Otherwise                                                   $ Case 6: Gravity Pour, no EVSE
        1.000       0.000       0.000
 49 Is the Debris Bed in a Coolable Configuration?
     2      CDB        noCDB                                                  $ RIQ     50
     2        1            2
     5 Cases
     2       34           36                 $ Case 1: Alpha or Rocket -
              1    +       1                 $     At least some of the Core Debris will
          Alpha    or Rocket                 $     be widely scattered throughout containment.
          0.700        0.300
     1       35                              $ Case 2: No VB.
              4
         noVBoA
          1.000        0.000
     3       35           35          22   $ Case 3: High Pressure Melt Ejection.
              1 +  (       3   *      -4 ) $     At least some of the Core Debris will
           PrEj or (   BtmHd   &  noI-LoPr) $     be widely scattered throughout containme it.
          0.500        0.500
```

```
     1       40                        $ Case 4: Gravity Pour with EVSE.
              1                        $     EVSE likely to distribute some debris outside containment.
           EVSE                        $     But fine particles may make debris in the cavity noncoolable.
          0.500       0.500
        Otherwsie                      $ Case 5: Gravity Pour with no EVSE.
          0.100       0.900            $     Debris bed is not likely to be coolable.
 50 Does Prompt CCI Occur?
     2  PrmptCCI    noPrmCCI                                               $ RIQ     55      56
     2        1           2                                                $         57      68
     2 Cases
     4       49          31          28          23   $ Case 1: Coolable Debris with Water, or no VB - no
       (      1 * (       1    +      3 ))+       1   $     prompt CCI.  Late sprays are not considered
       (    CDB & (  RC-Wet    or AcDaVB ))or  noVB   $     because they may start at any time during CCI
          0.000       1.000                           $     and water is needed from the start.
        Otherwise -- Not coolable or no water         $ Case 2: No water in the Reactor Cavity
          1.000       0.000                           $     or debris not coolable - prompt CCI.
 51 Is AC Power Available Very Late (after CCI)?
     3   L2-ACP      L2aACP      L2fACP                             $ RIQ     52      53
     2        1           2           3                             $         58      65      66
     4  Cases
     1       44                        $ Case 1: Had power initially or
              1                        $     recovered it already - have power now.
          L-ACP
          1.000       0.000       0.000
     1       44                        $ Case 2: Power failed initially
              3                        $     - not recoverable.
          LfACP                        $     Remaining case have power recoverable.
          0.000       0.000       1.000
     4        8           1           1          9   $ Case 3: Initial AFW & ( no Break or S3 with SecDePr )
              4  * (      6 +  (      3   *      1 )) $     TRRR-RDYR, TRRR-RDYY, or S3RRR-RDYR
          SGdHR  & ( B-PORV or ( Brk-S3  &  SecDePr )) $     Recovery Period = 17 to 24 hours
          0.679       0.321       0.000
        Otherwise                      $ Case 4: All other blackout cases - TRRR-RSYR, S3RRR-RCYR,
          0.916       0.084       0.000 $     & S2RRR-RaYR - Recovery Period = 9 to 24 hours
 52 Very Late Sprays?
     3    L2-Sp       L2aSp       L2fSp                             $ RIQ     54      55      65
     2        1           2           3
     4 Cases
     1       45                        $ Case 1: Had sprays after VB - have sprays now.
              1
           L-Sp
          1.000       0.000       0.000
     1       45                        $ Case 2: Sprays failed earlier - stay failed.
              3
           LfSp
          0.000       0.000       1.000
     2       45          51            $ Case 3: Sprays were available and power has been
              2   *       1            $         recovered, so sprays operate.
           LaSp    & L2-ACP
          1.000       0.000       0.000
        Otherwise                      $ Case 4: AC power not recovered, so
          0.000       1.000       0.000 $         sprays remain available.
 53 Very Late Fan Coolers?
     3    L2-FC       L2aFC       L2fFC                                  $ RIQ     54      66
     2        1           2           3
     4 Cases
     1       46                        $ Case 1: Had fan coolers before
              1                        $         - have fan coolers now.
           L-FC
          1.000       0.000       0.000
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   1       46                          $ Case 2: Fan coolers were failed
            3                          $         - stay failed.
          LfFC
         0.000       0.000       1.000
   2       46           51             $ Case 3: Fan coolers were available
            2    *       1             $         and have power now
          LaFC    & L2-ACP             $         - fan coolers operate.
         1.000       0.000       0.000
        Otherwise                      $ Case 4: No power - fan
         0.000       1.000       0.000 $         coolers remain available.
54 Very Late Containment Heat Removal?                                          $ RIQ     56      60
    2   L2-CHR      L2fCHR
    2        1           2
    2 Cases
    1            53              $ Case 1: Have Fan Coolers
                  1              $         - Have CHR
                L2-FC
          1.000       0.000
        Otherwise                       $ Case 2: No Sprays, No Fan Coolers
          0.000       1.000             $         - No CHR
55 Does Delayed CCI Occur?                                                      $ RIQ     56      57
    2  DelydCCI    noDldCCI                                                     $         68      69
    2        1           2
    2 Cases
    4       50          52          50          23   $ Case 1: Did not have CCI promptly (so debris
      (      2   *       1 ) +       1   +       1   $     is coolable), and have water now, or had
      (noPrmCCI  &   L2-Sp ) orPrmptCCI  or   noVB   $     prompt CCI, or no VB - can't have CCI now.
          0.000       1.000
        Otherwise                                    $ Case 2: Water boiled off and there are no
          1.000       0.000                          $     sprays now - delayed CCI occurs.
56 Baseline Containment Pressure Very Late?                                     $ PUIQ    63      64
    1  L2PBase
    4       1                           $ L2PBase - Parameter  B
    6 Cases
    4       42          42   42      23   $ Case 1: Containment already
             1 +         2   +5 +     1   $     ruptured or no vessel breach.
      ICF-CtRp or ICF-Rupt or ICF-SH or   noVB
          1.000
    1
    8    15.00
    3       54          11          42  $ Case 2: Have CHR or a leak.
             1   +       1   +       3  $     No rupture by case 1.
        L2-CHR   or B-Leak  or ICF-Leak
          1.000
    1
    8    16.00
    3       50          31          28  $ Case 3: Prompt CCI with Cavity Dry after VB
             1   *       2   *      -3  $     - Generate only the non-cond. gases from C[illegible].
      PrmptCCI   &  RC-Dry   & noAcDaVB $     By cases 1 & 2 have no CF & no CHR.
          1.000                         $     35 psia from STCP, Letter Rept., TB & S3B.
    1
    8    35.00
    3       50          31          28  $ Case 4: Prompt CCI Under Water, Debris Bed is Not Coolable
             1 * (       1   +       3 ) $     - Generate the non-cond. gases from CCI and some steam.
      PrmptCCI & ( RC-Wet    or AcDaVB ) $     By cases 1 & 2 have no CF & no CHR.
          1.000
    1
    8    47.00
    3       55          31          28  $ Case 5: Debris is Coolable, but the Cavity is only 1/4 Full.
             1   *       2   *       3  $     The Accumulator Water (1.7E5 lbm) Boils Off in about an
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        DelydCCl &   RC-Dry  &   AcDaVB   $     Hour, and then CCl Starts.  Have Steam and Non-Cond. Gases.
          1.000
     1
     8    53.00
        Otherwise -- DelydCCl & RC-Full   $ Case 6: Debris bed is Coolable and the Cavity is Full (7.2E5 lbm)
          1.000                           $     It takes Many Hours to Boil Off the Water before CCl starts.
     1                                    $     Intact Cont. & No CHR.  This Case is Not Realizable at Surry.
     8    70.00
57 How much H2 and CO2 is Produced during CCl?
     2      CCl       noCCl               $  H2-CCl - Parameter  9                $ Both PUIQ     59
     4       1          2                 $ CO2-CCl - Parameter 10
     4  Cases
     2        50          55              $ Case 1: No CCl.
              2  *        2
        noPrmCCl &  noDldCCl              $  H2-CCl = Hydrogen produced by CCl (Kg-moles) in additon to
          0.000       1.000               $           that produced by oxidizing the rest of the Zr.
     2                                    $           It includes any CO produced.
     9     0.00        0.00               $ CO2-CCl = Carbon Dioxide produced by CCl (Kg-moles)
    10     0.00        0.00
     1        48                          $ Case 2: A large amount (> 70%) of
               1                          $ the core is involved in CCl.
         Lrg-CCl
          1.000       0.000
     2
     9   220.00        0.00
    10    35.00        0.00
     1        48                          $ Case 3: A moderate amount (30-70%) of
               2                          $ the core is involved in CCl.
         Med-CCl
          1.000       0.000
     2
     9   130.00        0.00
    10    22.00        0.00
         Otherwise -- Sml-CCl             $ Case 4: A small amount (< 30%) of
          1.000       0.000               $ the core is involved in CCl.
     2
     9    37.00        0.00
    10     7.00        0.00
   How much Hydrogen Burns or Leaks Out of Containment?
     1  FrH2-Rem                          $ FrH2-Brn- Parameter 11                $ Both PUIQ     59
     4         1                          $ FrH2-Lk - Parameter 12
     5 Cases
     2         1          42              $ Case 1: Containment has failed -
               4   +     -4               $     Most of the Hydrogen has leaked out.  Since the
           Brk-V   or    ICF              $     containament is already failed, the fractions
           1.000                          $     burned and leaked do not matter much.
     2                                    $ FrH2-Brn = Fraction of H2 from before VB burned at VB.
    11      0.00                          $ FrH2-Lk  = Fraction of H2 leaked out of containment.
    12      0.80
     4        35          35 .       22          24   $ Case 2: HPME occured at VB, and the containment was
        (      1 + (       3  *       -4 )) *      1  $     not steam-inert. Most of the hydrogen from before
        (   PrEj or     BtmHd  &  notLoPr )) &   E-Sp $     VB burned.
           1.000
     2                                                $     None of these cases apply when AC power is con-
    11      0.90                                      $     tinuously available.  See Flammability Question.
    12      0.00
     4        35          35         22          24   $ Case 3: HPME occured at VB, and the cont. could have
        (      1 + (       3  *       -4 )) *     -1  $     been steam-inert.  Some hydrogen from before VB
        (   PrEj or (  BtmHd  &  notLoPr )) & noE-Sp  $     could have burned, but the hydrogen produced at
           1.000                                      $     VB is not likely to have burned.
     2
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```
   11      0.30
   12      0.00
    3        1           18          35   $ Case 4: SGTR and Pour - Most of the H2 from before VB will have
      (      5    +       1   ) *     2   $     leaked out thru the SGTR, but a good portion of the H2
      ( B-SGTR   orE-SGTRS3 ) &   Pour    $     from CCI will remain in the containment.
          1.000
    2
   11      0.00
   12      0.50
        Otherwise                         $ Case 5: Intact Containment and no burn -
          1.000                           $     All the Hydrogen generated
    2                                     $     remains in Containment.
   11      0.00
   12      0.00
59 Add H2 produced by CCI to H2 already in Containment
                                                                      $  P13 UIQ     61      63
    2      L2-H2      L2nH2
    5        1          2                 $ L2H2-Cnt- Parameter 13 is defined in the User Function
    6        2          9         10           11          12          13
       ZrOx-InV     H2-CCI     CO2-CCI     FrH2-Brn     FrH2-Lk     L2H2-Cnt
       FUN-H2CCI
       'THRESH'         1        0.001                  $ Function also adds CO2 to inert gas
              L2H2-Cnt defined in User Function
60 Amount of Steam in Containment after CCI?
                                                                         $ PUIQ      61      63
    1  L2StmCnt
    4       1                             $ L2StmCnt- Parameter 14
    2 Cases
    1       54                            $ Case 1: CHR Operating
             1                            $     300 kg-moles - calculated from
        L2-CHR                            $     S2D-Epsilon in BMI-2104
          1.000                           $     T = 132F, p= 14.2 psia
    1                                     $     assuming saturation
   14   340.00
        Otherwise                         $ Case 2: Sprays Not Operating
          1.000                           $     3000 kg-moles - calculated from
    1                                     $     TMLB'-Epsilon in BMI-2104
   14  3350.00                            $     T = 249F, p= 53.7 psia
61 Is the H2 Concentration Flammable?
                                                                          $ RIQ      62
    2   L2-H2F     noL2-H2F
    6       1          2
    2 Cases
    4      11         42         19         24   $ Case 1: Isolation Failure or Cont. Failed at VB -
            1    +    -4 +  (     1    *     1 ) $     Combustion Not of Interest; or, Had AC Power &
      B-Leak    or   I-CF or (  E-ACP   &    E-Sp ) $  Sprays All Along - H2 will Burn whenever the Cont
    1      13                                    $     Atmosphere becomes Flammable - these Small Burns
        L2H2-Cnt                                 $     will Not Fail the Surry Containment.
          'AND'
        'THRESH'        1     999.000
              High Dummy Value
        Otherwise                         $ Case 2: Containment Intact
    2      13          14                 $     Compare H2 concentration to limits
        L2H2-Cnt    L2StmCnt
        FUN-FLMBL
        'GETHRESH'       1       2.000
              BRNTYP returns 2 for Deflagration, 3 for Detonation
62 Does Ignition Occur?                 Conversion Ratio?
                                                                          $ RIQ      63      64
    2     L2-HB      noL2-HB                                               $ Both PUIQ      63
    4        1          2                 $ L2-ConvR- Parameter 15
    3 Cases                               $ dp-Scale- Parameter 16
    2       61         51
             1    *     1                 $ Case 1: H2 Concentration is Flammable and
```

```
        L2-H2F    &  L2-ACP              $     AC Power is Available -
         0.999       0.001               $     Ignition is Highly Likely.
     2
    15     0.95        0.00
    16     0.90        0.00
     2      61          51               $ Case 2: H2 Concentration is Flammable and
             1    *     -1               $     AC Power is Not Available -
        L2-H2F    & noL2-ACP             $     Ignition is Indeterminate.
         0.300       0.700
     2
    15     0.95        0.00
    16     0.90        0.00
        Otherwise                        $ Case 3: Concentration not flammable or steam-inert.
         0.000       1.000
     2                                   $ L2-ConvR = Conversion Ratio = Combustion Efficiency
    15     0.00        0.00              $ dp-Scale = Scale factor on pressure rise
    16     0.00        0.00
63 Resulting Pressure Rise?
     2  L2-H2Rrn    L2nH2Brn                                           $       P17 UIQ     64
     6        1           2              $ dp-L2HB - Parameter 17
     2 Cases                                                 $ P19 Defined Here in User Function
     1       62                          $ Case 1: No Ignition
              2
        noL2-HB
     1       17                          $ L2H2-Cnt= H2 in Containment (Kg-moles)
        dp-L2HB                          $ L2StmCnt = Steam in Containment (Kg-moles)
        FUN-NOBURN
        'THRESH'         1      999.000
                Set DP-L2HB to zero.
        Otherwise                        $ Case 2: Ignition
     6       13          14          15          8          16          17
        L2H2-Cnt    L2StmCnt    L2-ConvR    L2PBase     dp-Scale    dp-L2HB
        FUN-LH2BRN
        'THRESH'         1        1.000
                Calculate pressure rise from combustion
64 Containment Failure, and Type of Containment Failure?
     5  L2CF-CRp    L2CF-Rp     L2CF-Lk    L2CF-SHEAR  no-L2CF                              $ RIQ     65       68
     6        1          2           3           4       5                                $          69      71
     2 Cases
     1       42                                      $ Case 1: Containment already failed -
             -4                                      $     Can't fail now.
            ICF
     1        8
        L2PBase
            AND
        GETHRESH 4   999   888   777   666
        Dummy Values to Assure No Failure
     Otherwise                                      $ Case 2:
     4        8          17          6           7
        L2PBase     dp-L2HB       CF-Pr       RndNum
        FUN-LCFFst
        GETHRESH  4   4  3  2  1
        User Function for Fast Pressure Rise
65 Sprays after Very Late CF?
     2     F-Sp      noF-Sp                                                      $ RIQ     67      68
     2        1           2
     3 Cases
     2       52          51                 $ Case 1: Sprays failed or power not recoverable.
              3  +        3                 $         Assume AC power always recovered by this time,
         L2fSp or    L2fACP                 $         so sprays operate unless damaged by CF
          0.000       1.000                 $         in the remaining cases.
```

```
     1        64                          $ Case 2: Catastrophic rupture of containment -
               1                          $         spray failure unlikely.
        L2CF-CRp                          $     Use the same values as in question 42.
        !43,4,1     !43,4,3
        Otherwise                         $ Case 3: No catastrophic rupture -
          1.000       0.000               $         sprays operate.
66 Fan Coolers after Very Late CF?
     2    F-FC        FfFC                                                     $ RIQ     67
     2       1           2
     2 Cases
     2      53          51                $ Case 1: Fan coolers failed or power not recoverable
             3 +         3                $         Fan coolers do not operate.
        L2fFC or    L2fACP
          0.000       1.000               $ Case 2: Fan coolers either were operating, or
        Otherwise                         $         were available and we assume that we
          1.000       0.000               $         have power now - fan coolers operate.
67 Containment Heat Removal after Very Late CF?
     2    F-CHR       FfCHR                                                    $ RIQ     69
     2       1           2
     2 Cases
     2      65          66                $ Case 1: Have Sprays or Fan Coolers
             1 +         1                $ - Have CHR
          F-Sp   or   F-FC
          1.000       0.000
        Otherwise                         $ Case 2: No Sprays, No Fan Coolers
          0.000       1.000               $ - No CHR
68 Eventual Basemat Melt-through?
     3  MTnDePr     MTwDePr        noMT                                        $ RIQ     70
     2       1           2           3
     7 Cases
     4      11          23          42          64  $ Case 1: Containment failed already,
             1 +         1 +        -4 +        -5  $     or no VB - BMT is not of interest.
         B-Leak or     noVB or     ICF or     L2CF
          0.000       0.000       1.000
     3      50          55          65              $ Case 2: Coolable debris bed and sprays operating
             2    *      2    *      1              $     - no basemat melt-thru.  If FCs drained to the
        noPrmCCI  & noDldCCI  &    F-Sp             $     cavity, could use F-CHR instead of F-Sp.
          0.000       0.000       1.000
     2      48          65                          $ Case 3: Large fraction of core in CCI, water covered.
             1    *      1                          $     This and the following cases must
         Lrg-CCI  &   F-Sp                          $     have CCI by case 2.
          0.300       0.100       0.600
     2      48          65                          $ Case 4: Large fraction of core in CCI, dry cavity.
             1    *      2
         Lrg-CCI  &  noF-Sp
          0.400       0.400       0.200
     2      48          65                          $ Case 5: Medium fraction of core in CCI, water covered
             2    *      1
         Med-CCI  &   F-Sp
          0.150       0.050       0.800
     2      48          65                          $ Case 6: Medium fraction of core in CCI, dry cavity.
             2    *      2
         Med-CCI  &  noF-Sp
          0.250       0.250       0.500
        Otherwise - Sml-CCI                         $ Case 7: Small fraction of core in CCI, wet or dry.
          0.025       0.025       0.950
69 Eventual Overpressure Failure of Containment?
     2  F-CF-OP     noFCFOP                                                    $ RIQ     70
     2       1           2
     3 Cases
```

```
     5        11          23          42          64          67 $ Case 1: Containment is already
               1 +         1    +     -4    +     -5    +      1 $ failed, or have CHR, or have
          B-Leak or     noVB    or   ICF    or  L2CF    or F-CHR $ no VB - OP now not credible.
           0.000       1.000
     2        55          31                     $ Case 2: CDB boiled off a full cavity
               1    *      1                     $     of water - OP now is at least possible.
        DelydCCl    &  RC-Wet
           0.050       0.950
       Otherwise                                 $ Case 3: Did not boil off full cavity - noncondensibles alone
           0.001       0.999                     $     or with boiloff of accumulator water won't result in OP.
70 Basemat Melt-through before Overpressure Failure?
     3   F-BMT      FCF-Lk      Neither                                                          $ RIQ    71
     2       1           2            3          $ Very Late OP Failure is always leak
     5 Cases
     2        68          69                     $ Case 1: Have eventual BMT, but
              -3    *      2                     $     do not have eventual OP.
             BMT    &  noFCFOP
           1.000       0.000        0.000
     2        68          69                     $ Case 2: Have eventual OP, but
               3    *      1                     $     do not have eventual BMT.
            noMT    &  F-CF-OP
           0.000       1.000        0.000
     2        68          69                     $ Case 3: Have eventual OP and have
               1    *      1                     $     BMT which does not depressurize
        MTnDePr     &  F-CF-OP                   $     containment in two hours or less.
           0.250       0.750        0.000
     2        68          69                     $ Case 4: Have eventual OP and have
               2    *      1                     $     BMT which does depressurize
         MTwDePr    &  F-CF-OP                         containment in two hours or less.
           0.500       0.500        0.000
       Otherwise                                 $ Case 5: Have neither BMT nor
           0.000       0.000        1.000        $     OP, or already have CF.
 71 Final Containment Condition?
     6  F-Ruptr      F-Leak         F-MT       Bypass        noCF  Shear
     2        1           2            3            4           5     6
     6 Cases
     4       42          42           64           64               $ Case 1: Containment ruptured.
              1  +        2  +         1  +         2
       ICF-CtRp or ICF-Rupt or L2CF-CRp or L2CF-Rp
          1.000       0.000        0.000        0.000       0.000  0.000
     4       11          42           64           70               $ Case 2: Containment leaks.
              1  +        3  +         3  +         2
         B-Leak  or ICF-Leak or L2CF-Lk  or  FCF-Lk
          0.000       1.000        0.000        0.000       0.000  0.000
     2       42          64
              5  +        4
         ICF-Shear or L2CF-Shear
          0.000   0.000   0.000   0.000   0.000   1.000
     3        1           1           18                            $ Case 3: Containment bypassed.
              4 +         5  +         1
         Brk-V or    B-SGTR or   E-SGTRS3
          0.000       0.000        0.000        1.000       0.000  0.000
     1       70                                                     $ Case 4: Basemat Melt-Thru.
              1
          F-BMT
          0.000       0.000        1.000        0.000       0.000  0.000
      Otherwise                                                     $ Case 6: No Containment Failure.
          0.000       0.000        0.000        0.000       1.000   0.000
    72    Time of core damage
     2       ECorD          LCorD
     2         1              2
```

```
 2    Cases
 4      3    8       5     19
         5  + 1  +(  2  *   1)
      BiECCS or SG-HR or(BaECCS and E-ACP)
        0.000         1.000
Otherwise
        1.000         0.000
```

APPENDIX B

REALIZED APET SPLIT FRACTIONS FOR THE ZION LOCA PDS GROUP

APPENDIX B

Realized APET Split Fractions
for the Zion LOCA PDS Group

This Appendix lists the realized split fractions from a sampling evaluation of the Zion LOCA APET. The evaluation consisted of 150 Latin Hypercube Samples, with the questions sampled according to the input sampling files obtained from BNL.

```
Realized LOCA split fractions, 150 LHS, base case, no truncation

           TREE ID:        ZION APET, Rev 6, 8 MAR 89 - 72 Questions - PDS-2,  LOCAS
    # OF QUESTIONS:   72
      OBSERVATIONS:   150
        FOR SERI[illegible] CET FINAL SAMP
       SEQUENCE [illegible]        PDS-2, LHS

 ********  QUESTION:    1  Size and Location of RCS Break when the Core Uncovers?           $
Q-TYPE/TIMES ASKED:        INDEP. INPUT PROB.                         300
          BRANCHES:           Brk-A     Brk-S2    Brk-S3    Brk-V     B-SGTR    B-PORV
                                1         2         3         4         5         6
    REALIZED SPLIT:        4.600E-02 9.540E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00

 ********  QUESTION:    2  For SGTR, are the Secondary System SRVs Stuck Open?              $
Q-TYPE/TIMES ASKED:        INDEP. INPUT PROB.                         300
          BRANCHES:          SSRV-StO  SSRVnStO
                                1         2
    REALIZED SPLIT:        0.000E+00 1.000E+00

 ********  QUESTION:    3  Status of ECCS?                                                  $
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                           900
          BRANCHES:           B-ECCS    BaECCS    BfECCS    B-LPIS    BiECCS
                                1         2         3         4         5
    REALIZED SPLIT:        0.000E+00 1.840E-05 9.258E-01 2.862E-04 7.393E-02

                   SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     4.600E-02
      DEPENDENCIES:     1
     REQ. BRANCHES:     1
       DESCRIPTION:  Brk-A
  CASE/BRANCH SPLIT:           0.000E+00 1.840E-05 5.824E-03 0.000E+00 4.016E-02

  CASE NUMBER/SPLIT:    2     9.540E-01
      DEPENDENCIES:     1
     REQ. BRANCHES:     2
       DESCRIPTION:  Brk-S2
  CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 9.199E-01 2.862E-04 3.377E-02

 ********  QUESTION:    4  Status of Sprays?                                                $
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                           900
```

```
         BRANCHES:            B-Sp       BaSp      BfSp      noB-SWHX  BASp      BCSp
                               1          2         3          4        5         6
    REALIZED SPLIT:          1.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

                    SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     4.600E-02
       DEPENDENCIES:    1
      REQ. BRANCHES:    1
        DESCRIPTION:  Brk-A
  CASE/BRANCH SPLIT:          4.600E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:    2     9.540E-01
        DESCRIPTION:              Otherwise
  CASE/BRANCH SPLIT:          9.540E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00


******** QUESTION:    5  Status of Fan Coolers?                                      $
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                        2700
         BRANCHES:            B-FC      BaFC      BfFC
                               1         2         3
    REALIZED SPLIT:          5.555E-01 3.453E-03 4.410E-01

                    SUMMARY BY CASE

  CASE NUMBER/SPLIT:    2     9.540E-01
       DEPENDENCIES:    1
      REQ. BRANCHES:    2
        DESCRIPTION:  Brk-S2
  CASE/BRANCH SPLIT:          5.097E-01 3.434E-03 4.408E-01

  CASE NUMBER/SPLIT:    3     4.600E-02
        DESCRIPTION:          Otherwise             $ case 3 : A/S1
  CASE/BRANCH SPLIT:          4.582E-02 1.840E-05 1.610E-04


******** QUESTION:    6  Status of AC Power?                                         $
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                      2700
         BRANCHES:            B-ACP     BaACP     BfACP
                               1         2         3
    REALIZED SPLIT:          1.000E+00 0.000E+00 0.000E+00


******** QUESTION:    7  RWST Injected into Containment?                             $
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                        4050
         BRANCHES:            RWST-In   RWSTaIn   RWSTfIn
                               1         2         3
    REALIZED SPLIT:          9.943E-01 0.000E+00 5.658E-03

                    SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     4.600E-02
       DEPENDENCIES:    1
      REQ. BRANCHES:    1
        DESCRIPTION:  Brk-A
  CASE/BRANCH SPLIT:          4.034E-02 0.000E+00 5.658E-03

  CASE NUMBER/SPLIT:    2     9.540E-01
       DEPENDENCIES:    1
      REQ. BRANCHES:    2
        DESCRIPTION:  Brk-S2
  CASE/BRANCH SPLIT:          9.540E-01 0.000E+00 0.000E+00


******** QUESTION:    8  Heat Removal from the Steam Generators?                     $
```

```
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                           4050
          BRANCHES:          SG-HR     SGaHR      SGfHR      SGdHR
                               1          2          3          4
    REALIZED SPLIT:          1.000E+00 0.000E+00 0.000E+00 0.000E+00

                       SUMMARY BY CASE

 CASE NUMBER/SPLIT:    2      1.000E+00
       DESCRIPTION:              Otherwise                                   $ Case 2: All other brea
 CASE/BRANCH SPLIT:           1.000E+00 0.000E+00 0.000E+00 0.000E+00


********  QUESTION:    9  Did the Operators Depressurize the Secondary before the Core Uncovers?  $
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                           4050
          BRANCHES:          SecDePr   noScDePr
                               1          2
    REALIZED SPLIT:          1.000E+00 0.000E+00

                       SUMMARY BY CASE

 CASE NUMBER/SPLIT:    2      9.540E-01
      DEPENDENCIES:    1
     REQ. BRANCHES:    2
       DESCRIPTION:  Brk-S2
 CASE/BRANCH SPLIT:           9.540E-01 0.000E+00

 CASE NUMBER/SPLIT:    3      4.600E-02
       DESCRIPTION:              Otherwise                          $ Case 3: All other break sizes
 CASE/BRANCH SPLIT:           4.600E-02 0.000E+00


********  QUESTION:   10  Cooling for RCP Seals?                                                 $
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                           8100
          BRANCHES:          B-PSC     BaPSC      BfPSC
                               1          2          3
    REALIZED SPLIT:          7.716E-02 0.000E+00 9.228E-01

                       SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      4.600E-02
      DEPENDENCIES:    1
     REQ. BRANCHES:    1
       DESCRIPTION:  Brk-A
 CASE/BRANCH SPLIT:           4.568E-02 0.000E+00 3.220E-04

 CASE NUMBER/SPLIT:    2      9.540E-01
      DEPENDENCIES:    1
     REQ. BRANCHES:    2
       DESCRIPTION:  Brk-S2
 CASE/BRANCH SPLIT:           3.148E-02 0.000E+00 9.225E-01

********  QUESTION:   11  Initial Containment Leak or Isolation Failure?                         $
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                         16200
          BRANCHES:          B-Leak    noB-Leak
                               1          2
    REALIZED SPLIT:          5.000E-03 9.950E-01


********  QUESTION:   12  Event V - Break Location under Water?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                         16200
          BRANCHES:          V-Wet     V-Dry
                               1          2
    REALIZED SPLIT:          5.000E-01 5.000E-01
```

```
********  QUESTION:   13  RCS Pressure at the Start of Core Degradation?                      $
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                           16200
        BRANCHES:            E-SSPr    E-HiPr    E-ImPr    E-LoPr
                               1         2         3         4
   REALIZED SPLIT:          0.000E+00 0.000E+00 9.540E-01 4.600E-02

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     4.600E-02
      DEPENDENCIES:    1         1
     REQ. BRANCHES:    1    +    4
       DESCRIPTION:  Brk-A     Brk-V
 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 4.600E-02

 CASE NUMBER/SPLIT:    3     9.540E-01
      DEPENDENCIES:    9
     REQ. BRANCHES:    1
       DESCRIPTION:  SecDePr
 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 9.540E-01 0.000E+00


********  QUESTION:   14  Do the PORVs or SRVs Stick Open?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                           16200
        BRANCHES:            PORV-StO  PORVnStO
                               1         2
   REALIZED SPLIT:          0.000E+00 1.000E+00

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    2     1.000E+00
       DESCRIPTION:             Otherwise                       $ Case 2: RCS not at setpoint pres
 CASE/BRANCH SPLIT:          0.000E+00 1.000E+00


*******  QUESTION:   15  Temperature-Induced RCP Seal Failure?  (After core uncovering)
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                           16200
        BRANCHES:            EB-PSS3   noEB-PSF
                               1         2
   REALIZED SPLIT:          5.537E-01 4.463E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     7.716E-02
      DEPENDENCIES:   10
     REQ. BRANCHES:    1
       DESCRIPTION:  B-PSC
 CASE/BRANCH SPLIT:          0.000E+00 7.716E-02

 CASE NUMBER/SPLIT:    4     9.228E-01
       DESCRIPTION:             Otherwise                       $ Case 4: RCS at IM or low pressur
 CASE/BRANCH SPLIT:          5.537E-01 3.691E-01

********  QUESTION:   16  Is the RCS Depressurized before Breach by Opening the PZR PORVs?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                           30600
        BRANCHES:            PrmDePr  [illegible]rDePr
                               1         2
   REALIZED SPLIT:          5.000E-01 5.000E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     9.997E-01
      DEPENDENCIES:    6         3          3
     REQ. BRANCHES:    1    *   /4    *    /1
```

```
      DESCRIPTION:  B-ACP    /B-LPIS   /B-ECCS
CASE/BRANCH SPLIT:           5.000E-01 4.997E-01

CASE NUMBER/SPLIT:    2      2.862E-04
      DESCRIPTION:             Otherwise                      $     Opening the PORVs is prohibi
CASE/BRANCH SPLIT:           0.000E+00 2.862E-04


******** QUESTION:    17  Temperature-Induced Hot Leg or Surge Line Break?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                                61200
          BRANCHES:             EB-HLA    noEB-HLA
                                  1          2
    REALIZED SPLIT:            1.000E-03 9.990E-01

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    3      1.000E+00
      DESCRIPTION:              Otherwise -- noSSPr                       $ Case 3: RCS not at 2
CASE/BRANCH SPLIT:           1.000E-03 9.990E-01


******** QUESTION:    18  Temperature-Induced SGTR?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                                61200
          BRANCHES:             E-SGTRS3  noE-SGTR
                                  1          2
    REALIZED SPLIT:            0.000E+00 1.000E+00

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    2      1.000E+00
      DESCRIPTION:              Otherwise                                       $ Case 2: R
CASE/BRANCH SPLIT:           0.000E+00 1.000E+00


******** QUESTION:    19  Is AC Power Available Early (Between Uncovering TAF & VB-30 min)?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                                61200
          BRANCHES:             E-ACP      EaACP      EfACP
                                  1          2          3
    REALIZED SPLIT:            1.000E+00 0.000E+00 0.000E+00

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    1      1.000E+00
     DEPENDENCIES:    6
    REQ. BRANCHES:    1
      DESCRIPTION:  B-ACP
CASE/BRANCH SPLIT:           1.000E+00 0.000E+00 0.000E+00


******** QUESTION:    20  After Power Recovery, Is Coolant Injection Re-Established Promptly?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                                61200
          BRANCHES:             E-RECC    noE-RECC
                                  1          2
    REALIZED SPLIT:            0.000E+00 1.000E+00

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    3      1.000E+00
      DESCRIPTION:              Otherwise                         $ Case 2: Power not restored, or E
CASE/BRANCH SPLIT:           0.000E+00 1.000E+00


******** QUESTION:    21  Rate of Blowdown to Containment?     [ This is blowdown before vessel bre
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                                61200
          BRANCHES:             EBD-A     EBD-S2     EBD-S3     noEBD
```

```
                              1          2          3          4
   REALIZED SPLIT:          4.695E-02 9.531E-01 0.000E+00 0.000E+00

                   SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     4.695E-02
       DEPENDENCIES:    1        17
      REQ. BRANCHES:    1   +    1
        DESCRIPTION:  Brk-A     EB-HLA
  CASE/BRANCH SPLIT:          4.695E-02 0.000E+00 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:    3     9.531E-01
       DEPENDENCIES:    1        14         16
      REQ. BRANCHES:    2   +    1    +     1
        DESCRIPTION:  Brk-S2    PORV-StO  PrmDePr
  CASE/BRANCH SPLIT:          0.000E+00 9.531E-01 0.000E+00 0.000E+00


******** QUESTION:   22  Vessel Pressure just before Breach?
Q-TYPE/TIMES ASKED:       DEP  INPUT PROB.                              61200
          BRANCHES:             I-SSPr     I-HiPr     I-ImPr     I-LoPr
                                  1          2          3          4
   REALIZED SPLIT:          0.000E+00 0.000E+00 9.612E-02 9.039E-01

                   SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     5.235E-01
       DEPENDENCIES:   21          1          1         16         14
      REQ. BRANCHES:    1   +      4    +(    2     *(    1    +     1))
        DESCRIPTION:  EBD-A     Brk-V      Brk-S2     PrmDePr    PORV-StO
  CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 5.235E-01

  CASE NUMBER/SPLIT:    2     4.765E-01
       DEPENDENCIES:   21
      REQ. BRANCHES:    2
        DESCRIPTION:  EBD-S2
  CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 9.612E-02 3.804E-01


******** QUESTION:   23  Is Core Damage Arrested?   No Vessel Breach?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                              78840
          BRANCHES:             noVB       VB
                                  1          2
   REALIZED SPLIT:          2.227E-04 9.998E-01

                   SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     9.258E-01
       DEPENDENCIES:   19          3
      REQ. BRANCHES:   /1   +      3
        DESCRIPTION:  /E-ACP      BfECCS
  CASE/BRANCH SPLIT:          0.000E+00 9.258E-01

  CASE NUMBER/SPLIT:    3     2.290E-04
       DEPENDENCIES:   22          3         22          3
      REQ. BRANCHES: (  4    *     4)   +(  /1     *     1)
        DESCRIPTION:  I-LoPr    B-LPIS    /I-SSPr     B-ECCS
  CASE/BRANCH SPLIT.          2.061E-04 2.290E-05

  CASE NUMBER/SPLIT.    4     7.399E-02
       DEPENDENCIES:    3
      REQ. BRANCHES:   /2
        DESCRIPTION:  /BaECCS
  CASE/BRANCH SPLIT:          0.000E+00 7.399E-02
```

```
CASE NUMBER/SPLIT:    9     1.840E-05
     DESCRIPTION:              Otherwise - B-PORV            $ Case 9: Initial AFW & no Break.
CASE/BRANCH SPLIT:          1.656E-05 1.840E-06


******** QUESTION:   24  Early Sprays?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                             78840
         BRANCHES:              E-Sp      EaSp      EfSp
                                 1         2         3
   REALIZED SPLIT:          1.000E+00 0.000E+00 0.000E+00

                   SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     1.000E+00
      DEPENDENCIES:    4         4         4
     REQ. BRANCHES:    1    +    5    +    6
       DESCRIPTION:  B-Sp      BASp      BCSp
 CASE/BRANCH SPLIT:          1.000E+00 0.000E+00 0.000E+00


******** QUESTION:   25  Early Fan Coolers?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                             78840
         BRANCHES:              E-FC      EaFC      EfFC
                                 1         2         3
   REALIZED SPLIT:          5.590E-01 0.000E+00 4.410E-01

                   SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     5.556E-01
      DEPENDENCIES:    5
     REQ. BRANCHES:    1
       DESCRIPTION:  B-FC
 CASE/BRANCH SPLIT:          5.556E-01 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2     4.410E-01
      DEPENDENCIES:    5
     REQ. BRANCHES:    3
       DESCRIPTION:  BfFC
 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 4.410E-01

 CASE NUMBER/SPLIT:    3     3.453E-03
      DEPENDENCIES:    5        19
     REQ. BRANCHES:    2    *    1
       DESCRIPTION:  BaFC      E-ACP
 CASE/BRANCH SPLIT:          3.453E-03 0.000E+00 0.000E+00


******** QUESTION:   26  Early Containment Heat Removal?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                             78840
         BRANCHES:              E-CHR     EfCHR
                                 1         2
   REALIZED SPLIT:          5.590E-01 4.410E-01

                   SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     5.590E-01
      DEPENDENCIES:   25
     REQ. BRANCHES:    1
       DESCRIPTION:  E-FC
 CASE/BRANCH SPLIT:          5.590E-01 0.000E+00

 CASE NUMBER/SPLIT:    3     4.410E-01
       DESCRIPTION:              Otherwise                   $ Case 2: No Sprays, No Fan Cooler
 CASE/BRANCH SPLIT:          0.000E+00 4.410E-01
```

```
******** QUESTION:   27  Baseline Containment Pressure just before VB?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB. INPUT PARM.              78840
          BRANCHES:            IPBase
                                 1
    REALIZED SPLIT:            1.000E+00

                     SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1      2.227E-04
       DEPENDENCIES:   21         23
      REQ. BRANCHES:    4    +     1
        DESCRIPTION:  noEBD      noVB
 CASE/BRANCH SPLIT:            2.227E-04

  CASE NUMBER/SPLIT:    2      5.589E-01
       DEPENDENCIES:   26          4
      REQ. BRANCHES:    1    *    /4
        DESCRIPTION:  E-CHR     /noB-SWHX
 CASE/BRANCH SPLIT:            5.589E-01

  CASE NUMBER/SPLIT:    3      6.017E-04
       DEPENDENCIES:   26         21
      REQ. BRANCHES:    2    *     1
        DESCRIPTION:  EfCHR      EBD-A
 CASE/BRANCH SPLIT:            6.017E-04

  CASE NUMBER/SPLIT:    4      4.403E-01
        DESCRIPTION:               Otherwise                      $ Case 4: No sprays and no large b
 CASE/BRANCH SPLIT:            4.403E-01


******** QUESTION:   28  Time of Accumulator Discharge?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                          78840
          BRANCHES:            AcDbCM    AcDdCM    AcDaVB
                                 1         2         3
    REALIZED SPLIT:            1.000E+00 0.000E+00 0.000E+00

                     SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1      1.000E+00
       DEPENDENCIES:   13        13        8         9
      REQ. BRANCHES:    3    +    4    +(  4    *    1)
        DESCRIPTION:  E-ImPr    E-LoPr    SGdHR     SecDePr
 CASE/BRANCH SPLIT:            1.000E+00 0.000E+00 0.000E+00


******** QUESTION:   29  Fraction of Zr Oxidized In-Vessel during Core Degradation?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB. INPUT PARM.              78840
          BRANCHES:            ZrOx-InV
                                 1
    REALIZED SPLIT:            1.000E+00

                     SUMMARY BY CASE

  CASE NUMBER/SPLIT:    5      9.540E-01
       DEPENDENCIES:   13         28
      REQ. BRANCHES:    3    *    /2
        DESCRIPTION:  E-ImPr    /AcDdCM
 CASE/BRANCH SPLIT:            9.540E-01

  CASE NUMBER/SPLIT:    7      4.600E-02
        DESCRIPTION:               Otherwise - E-LoPr    $ Case 7: Low RCS Pressure (<200 psia)
 CASE/BRANCH SPLIT:            4.600E-02
```

```
******** QUESTION:   30  Amount of Zr Oxidized In-Vessel during Core Degradation?
Q-TYPE/TIMES ASKED:       INDEP. CALC. PROB.                          78840
          BRANCHES:           Hi-ZrOx   Lo-ZrOx
                                 1         2
    REALIZED SPLIT:          4.976E-01 5.025E-01

******** QUESTION:   31  Amount of Water in the Reactor Cavity at Vessel Breach?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                            78840
          BRANCHES:           RC-Wet    RC-Dry
                                 1         2
    REALIZED SPLIT:          9.944E-01 5.658E-03

                    SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     5.658E-03
       DEPENDENCIES:    7         7         19
      REQ. BRANCHES:    3    +(   2    *    /1)
        DESCRIPTION:  RWSTfIn   RWSTaIn   /E-ACP
  CASE/BRANCH SPLIT:          0.000E+00 5.658E-03

  CASE NUMBER/SPLIT:    2     9.944E-01
        DESCRIPTION:             Otherwise                    $ Case 2: RWST injected or sprays
  CASE/BRANCH SPLIT:          9.944E-01 0.000E+00

******** QUESTION:   32  Fraction of Core Released from Vessel at Breach?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB. INPUT PARM.              78840
          BRANCHES:           FCorRel
                                 1
    REALIZED SPLIT:          1.000E+00

******** QUESTION:   33  Amount of Core Released from Vessel at Breach?
Q-TYPE/TIMES ASKED:       INDEP. CALC. PROB.                          78840
          BRANCHES:           Hi-FCoR   Md-FCoR   Lo-FCoR
                                 1         2         3
    REALIZED SPLIT:          2.667E-01 4.467E-01 2.867E-01

******** QUESTION:   34  Does an Alpha Mode Event Fail both the Vessel and the Containment?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                            105636
          BRANCHES:           Alpha     noAlpha
                                 1         2
    REALIZED SPLIT:          8.146E-03 9.919E-01

                    SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     9.037E-01
       DEPENDENCIES:   23         22
      REQ. BRANCHES:    2    *     4
        DESCRIPTION:  VB          I-LoPr
  CASE/BRANCH SPLIT:          8.070E-03 8.956E-01

  CASE NUMBER/SPLIT:    2     9.612E-02
       DEPENDENCIES:   23         22
      REQ. BRANCHES:    2    *    /4
        DESCRIPTION:  VB         /I-LoPr
  CASE/BRANCH SPLIT:          7.689E-05 9.604E-02

  CASE NUMBER/SPLIT:    3     2.227E-04
        DESCRIPTION:             Otherwise           $ Case 3: Core Damage Arrested, no VB
  CASE/BRANCH SPLIT:          0.000E+00 2.227E-04
```

```
******** QUESTION:   35  Type of Vessel Breach?                                                  $
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                               106320
         BRANCHES:            PrEj      Pour      BtmHd     noVBoA
                               1         2         3          4
   REALIZED SPLIT:            5.153E-02 9.391E-01 1.052E-03 8.369E-03

                  SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      8.369E-03
      DEPENDENCIES:   23        34
      REQ. BRANCHES:   1    +    1
        DESCRIPTION:  noVB      Alpha
 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 8.369E-03

 CASE NUMBER/SPLIT:    4      9.604E-02
      DEPENDENCIES:   22
      REQ. BRANCHES:   3
        DESCRIPTION:  I-ImPr
 CASE/BRANCH SPLIT:           5.153E-02 4.346E-02 1.052E-03 0.000E+00

 CASE NUMBER/SPLIT:    5      8.956E-01
        DESCRIPTION:             Otherwise - I-LoPr                          $ Case 5: RCS at Low P
 CASE/BRANCH SPLIT:           0.000E+00 8.956E-01 0.000E+00 0.000E+00


******** QUESTION:   36  Does the Vessel become a "Rocket" and Fail the Containment?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                               106320
         BRANCHES:             Rocket    noRocket
                               1         2
   REALIZED SPLIT:            0.000E+00 1.000E+00

                  SUMMARY BY CASE

 CASE NUMBER/SPLIT:    2      1.000E+00
        DESCRIPTION:             Otherwise           $ Case 2: Not BtmHd & SSPr - Rocket Not Credib
 CASE/BRANCH SPLIT:           0.000E+00 1.000E+00


******** QUESTION:   37  Size of Hole in Vessel (after Ablation)?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                               106320
         BRANCHES:             LrgHole   SmlHole
                               1         2
   REALIZED SPLIT:            9.485E-01 5.153E-02

                  SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      5.153E-02
      DEPENDENCIES:   35
      REQ. BRANCHES:   1
        DESCRIPTION:  PrEj
 CASE/BRANCH SPLIT:           0.000E+00 5.153E-02

 CASE NUMBER/SPLIT:    2      9.485E-01
        DESCRIPTION:             Otherwise           $ Case 2: Not HPME - Large Hole or Irrelevant
 CASE/BRANCH SPLIT:           9.485E-01 0.000E+00


******** QUESTION:   38  Pressure Rise at Vessel Breach?    Large Hole Cases
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB. INPUT PARM.                   106320
         BRANCHES:             DP-VB
                               1
   REALIZED SPLIT:            1.000E+00

                  SUMMARY BY CASE
```

```
CASE NUMBER/SPLIT:     1      2.227E-04
     DEPENDENCIES:    23
    REQ. BRANCHES:     1
      DESCRIPTION:   noVB
CASE/BRANCH SPLIT:            2.227E-04

CASE NUMBER/SPLIT:     2      8.146E-03
     DEPENDENCIES:    34        36
    REQ. BRANCHES:     1    +    1
      DESCRIPTION:   Alpha     Rocket
CASE/BRANCH SPLIT:            8.146E-03

CASE NUMBER/SPLIT:     3      9.391E-01
     DEPENDENCIES:    22        35
    REQ. BRANCHES:     4    +    2
      DESCRIPTION:   I-LoPr    Pour
CASE/BRANCH SPLIT:            9.391E-01

CASE NUMBER/SPLIT:     4      5.153E-02
     DEPENDENCIES:    37
    REQ. BRANCHES:     2
      DESCRIPTION:   SmlHole
CASE/BRANCH SPLIT:            5.153E-02

CASE NUMBER/SPLIT:     5      3.689E-04
     DEPENDENCIES:    22        31        33
    REQ. BRANCHES:     3    *    1    *    1
      DESCRIPTION:   I-ImPr    RC-Wet    Hi-FCoR
CASE/BRANCH SPLIT:            3.689E-04

CASE NUMBER/SPLIT:     6      2.977E-04
     DEPENDENCIES:    22        31        33
    REQ. BRANCHES:     3    *    1    *    2
      DESCRIPTION:   I-ImPr    RC-Wet    Md-FCoR
CASE/BRANCH SPLIT:            2.977E-04

CASE NUMBER/SPLIT:     7      3.850E-04
     DEPENDENCIES:    22        31        33
    REQ. BRANCHES:     3    *    1    *    3
      DESCRIPTION:   I-ImPr    RC-Wet    Lo-FCoR
CASE/BRANCH SPLIT:            3.850E-04


********  QUESTION:   39  Pressure Rise at Vessel Breach?     Small Hole Cases
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB. INPUT PARM.              106320
          BRANCHES:           DP-VB
                                1
    REALIZED SPLIT:           1.000E+00

                   SUMMARY BY CASE

CASE NUMBER/SPLIT:     1      9.485E-01
     DEPENDENCIES:    37        23        34        22        36
    REQ. BRANCHES:     1    +    1    +    1    +    4    +    1
      DESCRIPTION:   LrgHole   noVB      Alpha     I-LoPr    Rocket
CASE/BRANCH SPLIT:            9.485E-01

CASE NUMBER/SPLIT:     2      1.808E-02
     DEPENDENCIES:    22        31        33
    REQ. BRANCHES:     3    *    1    *    1
      DESCRIPTION:   I-ImPr    RC-Wet    Hi-FCoR
CASE/BRANCH SPLIT:            1.808E-02

CASE NUMBER/SPLIT:     3      1.459E-02
```

```
       DEPENDENCIES:  22        31        33
      REQ. BRANCHES:   3    *    1    *    2
        DESCRIPTION:  I-ImPr    RC-Wet    Md-FCoR
  CASE/BRANCH SPLIT:           1.459E-02

  CASE NUMBER/SPLIT:   4      1.886E-02
       DEPENDENCIES:  22        31        33
      REQ. BRANCHES:   3    *    1    *    3
        DESCRIPTION:  I-ImPr    RC-Wet    Lo-FCoR
  CASE/BRANCH SPLIT:           1.886E-02


********  QUESTION:   40  Does a Significant Ex-Vessel Steam Explosion Occur?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                          145236
          BRANCHES:           EVSE      noEVSE
                               1          2
    REALIZED SPLIT:           4.667E-01 5.333E-01

                  SUMMARY BY CASE

  CASE NUMBER/SPLIT:   1      9.335E-01
       DEPENDENCIES:  31        35
      REQ. BRANCHES:   1    *    2
        DESCRIPTION:  RC-Wet    Pour
  CASE/BRANCH SPLIT:          4.667E-01 4.667E-01

  CASE NUMBER/SPLIT:   2      6.655E-02
        DESCRIPTION:            Otherwise -- No EVSE            $ Case 2: Alpha Mode, or Rocket, o
  CASE/BRANCH SPLIT:          0.000E+00 6.655E-02


********  QUESTION:   41  Containment Failure Pressure?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB. INPUT PARM.            145236
          BRANCHES:           CF-Pr
                               1
    REALIZED SPLIT:           1.000E+00


********  QUESTION:   42  Containment Failure, and Type of Containment Failure?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                          145236
          BRANCHES:           ICF-CtRp  ICF-Rupt  ICF-Leak  no-ICF    ICF-Shear
                               1         2         3         4         5
    REALIZED SPLIT:           0.000E+00 8.147E-03 1.436E-03 9.904E-01 4.691E-05

                  SUMMARY BY CASE

  CASE NUMBER/SPLIT:   1      8.147E-03
       DEPENDENCIES:  34        36
      REQ. BRANCHES:   1    +    1
        DESCRIPTION:  Alpha     Rocket
  CASE/BRANCH SPLIT:          0.000E+00 8.147E-03 0.000E+00 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:   2      9.919E-01
        DESCRIPTION:          Otherwise                                     $ Case 2:
  CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 1.436E-03 9.904E-01 4.691E-05


********  QUESTION:   43  Sprays after Vessel Breach?                       $ ( The 5 to 30 minute
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                          145236
          BRANCHES:           I2-Sp     I2aSp     I2fSp
                               1         2         3
    REALIZED SPLIT:           9.919E-01 0.000E+00 8.147E-03

                  SUMMARY BY CASE
```

```
 CASE NUMBER/SPLIT:    1     8.147E-03
      DEPENDENCIES:   24       34        36
     REQ. BRANCHES:    3   +    1    +    1
       DESCRIPTION:  EfSp     Alpha     Rocket
 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 8.147E-03

 CASE NUMBER/SPLIT:    3     9.919E-01
      DEPENDENCIES:   24       42
     REQ. BRANCHES:    1   *   /1
       DESCRIPTION:  E-Sp     /ICF-CtRp
 CASE/BRANCH SPLIT:          9.919E-01 0.000E+00 0.000E+00


******** QUESTION:   44  Is AC Power Available Late (during CCI)?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                               145236
          BRANCHES:           L-ACP     LaACP     LfACP
                                1         2         3
    REALIZED SPLIT:          1.000E+00 0.000E+00 0.000E+00

                     SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     1.000E+00
      DEPENDENCIES:   19
     REQ. BRANCHES:    1
       DESCRIPTION:  E-ACP
 CASE/BRANCH SPLIT:          1.000E+00 0.000E+00 0.000E+00


******** QUESTION:   45  Late Sprays?     (during CCI)
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                               145236
          BRANCHES:           L-Sp      LaSp      LfSp
                                1         2         3
    REALIZED SPLIT:          9.919E-01 0.000E+00 8.147E-03

                     SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     9.919E-01
      DEPENDENCIES:   43
     REQ. BRANCHES:    1
       DESCRIPTION:  I2-Sp
 CASE/BRANCH SPLIT:          9.919E-01 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2     8.147E-03
      DEPENDENCIES:   43
     REQ. BRANCHES:    3
       DESCRIPTION:  I2fSp
 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 8.147E-03


******** QUESTION:   46  Late Fan Coolers?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                               145236
          BRANCHES:           L-FC      LaFC      LfFC
                                1         2         3
    REALIZED SPLIT:          5.590E-01 0.000E+00 4.410E-01

                     SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     5.590E-01
      DEPENDENCIES:   25
     REQ. BRANCHES:    1
       DESCRIPTION:  E-FC
 CASE/BRANCH SPLIT:          5.590E-01 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2     4.410E-01
      DEPENDENCIES:   25
```

```
     REQ. BRANCHES:    3
       DESCRIPTION:  EfFC
  CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 4.410E-01


 ********  QUESTION:   47  Late Containment Heat Removal?
 Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                        145236
           BRANCHES:           L-CHR     LfCHR
                                 1         2
     REALIZED SPLIT:           5.590E-01 4.410E-01

                     SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     5.590E-01
       DEPENDENCIES:   46
      REQ. BRANCHES:    1
        DESCRIPTION:  L-FC
  CASE/BRANCH SPLIT:          5.590E-01 0.000E+00

  CASE NUMBER/SPLIT:    2     4.410E-01
        DESCRIPTION:              Otherwise                       $ Case 2: No Sprays, No Fan Cooler
  CASE/BRANCH SPLIT:          0.000E+00 4.410E-01


 ********  QUESTION:   48  Amount of Core Available for CCI?
 Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                        184152
           BRANCHES:           Lrg-CCI   Med-CCI   Sml-CCI
                                 1         2         3
     REALIZED SPLIT:           7.250E-01 2.749E-01 2.227E-04

                     SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     8.147E-03
       DEPENDENCIES:   34        36
      REQ. BRANCHES:    1    +    1
        DESCRIPTION:  Alpha     Rocket
  CASE/BRANCH SPLIT:          0.000E+00 8.147E-03 0.000E+00

  CASE NUMBER/SPLIT:    2     2.227E-04
       DEPENDENCIES:   35
      REQ. BRANCHES:    4
        DESCRIPTION.  noVBoA
  CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 2.227E-04

  CASE NUMBER/SPLIT:    3     3.334E-02
       DEPENDENCIES:   35        35        22        33
      REQ. BRANCHES: (  1    +(   3    *   /4))  *   /3
        DESCRIPTION:  PrEj      BtmHd    /I-LoPr   /Lo-FCoR
  CASE/BRANCH SPLIT:          0.000E+00 3.334E-02 0.000E+00

  CASE NUMBER/SPLIT:    4     1.925E-02
       DEPENDENCIES:   35        35        22        33
      REQ. BRANCHES: (  1    +(   3    *   /4))  *    3
        DESCRIPTION:  PrEj      BtmHd    /I-LoPr    Lo-FCoR
  CASE/BRANCH SPLIT:          1.925E-02 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:    5     4.668E-01
       DEPENDENCIES:   35        35        22        40
      REQ. BRANCHES: (  2    +(   3    *    4))  *    1
        DESCRIPTION:  Pour      BtmHd     I-LoPr    EVSE
  CASE/BRANCH SPLIT:          2.334E-01 2.334E-01 0.000E+00

  CASE NUMBER/SPLIT:    6     4.724E-01
        DESCRIPTION:              Otherwise                                 $ Case 6:
  CASE/BRANCH SPLIT:          4.724E-01 0.000E+00 0.000E+00
```

```
******** QUESTION:   49  Is the Debris Bed in a Coolable Configuration?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                           350664
          BRANCHES:          CDB       noCDB
                              1          2
    REALIZED SPLIT:         3.129E-01 6.873E-01

                  SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1      8.148E-03
       DEPENDENCIES:   34         36
      REQ. BRANCHES:    1    +     1
        DESCRIPTION:  Alpha     Rocket
  CASE/BRANCH SPLIT:           5.703E-03 2.444E-03

  CASE NUMBER/SPLIT:    2      2.227E-04
       DEPENDENCIES:   35
      REQ. BRANCHES:    4
        DESCRIPTION:  noVBoA
  CASE/BRANCH SPLIT:           2.227E-04 0.000E+00

  CASE NUMBER/SPLIT:    3      5.259E-02
       DEPENDENCIES:   35         35         22
      REQ. BRANCHES:    1     +(   3     *   /4)
        DESCRIPTION:  PrEj       BtmHd    /I-LoPr
  CASE/BRANCH SPLIT:           2.630E-02 2.630E-02

  CASE NUMBER/SPLIT:    4      4.668E-01
       DEPENDENCIES:   40
      REQ. BRANCHES:    1
        DESCRIPTION:  EVSE
  CASE/BRANCH SPLIT:           2.334E-01 2.334E-01

  CASE NUMBER/SPLIT:    5      4.724E-01
        DESCRIPTION:              Otherwise                       $ Case 5: Gravity Pour with no EVS
  CASE/BRANCH SPLIT:           4.724E-02 4.252E-01


******** QUESTION:   50  Does Prompt CCI Occur?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                           350664
          BRANCHES:          PrmptCCI  noPrmCCI
                              1          2
    REALIZED SPLIT:         6.879E-01 3.122E-01

                  SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1      3.122E-01
       DEPENDENCIES:   49         31         28         23
      REQ. BRANCHES: (  1     *(   1    +    3))   +    1
        DESCRIPTION:  CDB        RC-Wet    AcDaVB    noVB
  CASE/BRANCH SPLIT:           0.000E+00 3.122E-01

  CASE NUMBER/SPLIT:    2      6.879E-01
        DESCRIPTION:              Otherwise -- Not coolable or no water        $ Case 2: No water in
  CASE/BRANCH SPLIT:           6.879E-01 0.000E+00


******** QUESTION:   51  Is AC Power Available Very Late (after CCI)?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                           350664
          BRANCHES:          L2-ACP    L2aACP    L2fACP
                              1          2         3
    REALIZED SPLIT:         1.000E+00 0.000E+00 0.000E+00

                  SUMMARY BY CASE
```

```
 CASE NUMBER/SPLIT:    1     1.000E+00
      DEPENDENCIES:   44
     REQ. BRANCHES:    1
       DESCRIPTION:   L-ACP
 CASE/BRANCH SPLIT:          1.000E+00 0.000E+00 0.000E+00


******** QUESTION:    52  Very Late Sprays?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                          350664
          BRANCHES:              L2-Sp     L2aSp     L2fSp
                                   1         2         3
   REALIZED SPLIT:           9.919E-01 0.000E+00 8.147E-03

                  SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     9.919E-01
      DEPENDENCIES:   45
     REQ. BRANCHES:    1
       DESCRIPTION:   L-Sp
 CASE/BRANCH SPLIT:          9.919E-01 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2     8.147E-03
      DEPENDENCIES:   45
     REQ. BRANCHES:    3
       DESCRIPTION:   LfSp
 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 8.147E-03


******** QUESTION:    53  Very Late Fan Coolers?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                          350664
          BRANCHES:              L2-FC     L2aFC     L2fFC
                                   1         2         3
   REALIZED SPLIT:           5.590E-01 0.000E+00 4.411E-01

                  SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     5.590E-01
      DEPENDENCIES:   46
     REQ. BRANCHES:    1
       DESCRIPTION:   L-FC
 CASE/BRANCH SPLIT:          5.590E-01 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2     4.411E-01
      DEPENDENCIES:   46
     REQ. BRANCHES:    3
       DESCRIPTION:   LfFC
 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 4.411E-01


******** QUESTION:    54  Very Late Containment Heat Removal?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                          350664
          BRANCHES:              L2-CHR    L2fCHR
                                   1         2
   REALIZED SPLIT:           5.590E-01 4.411E-01

                  SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     5.590E-01
      DEPENDENCIES:   53
     REQ. BRANCHES:    1
       DESCRIPTION:   L2-FC
 CASE/BRANCH SPLIT:          5.590E-01 0.000E+00

 CASE NUMBER/SPLIT:    2     4.411E-01
```

```
       DESCRIPTION:             Otherwise                        $ Case 2: No Sprays, No Fan Cooler
 CASE/BRANCH SPLIT:          0.000E+00 4.411E-01


******** QUESTION:    55  Does Delayed CCI Occur?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                  350664
          BRANCHES:            DelydCCI  noDldCCI
                                   1         2
    REALIZED SPLIT:          5.663E-03 9.943E-01

                      SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     9.943E-01
      DEPENDENCIES:   50          52          50         23
     REQ. BRANCHES: (  2     *     1)    +    1     +    1
       DESCRIPTION:  noPrmCCI  L2-Sp      PrmptCCI   noVB
 CASE/BRANCH SPLIT:          0.000E+00 9.943E-01

 CASE NUMBER/SPLIT:    2     5.663E-03
       DESCRIPTION:             Otherwise                                  $ Case 2: Water boiled
 CASE/BRANCH SPLIT:          5.663E-03 0.000E+00


******** QUESTION:    56  Baseline Containment Pressure Very Late?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB. INPUT PARM.          350664
          BRANCHES:             L2PBase
                                   1
    REALIZED SPLIT:          1.000E+00

                      SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     8.417E-03
      DEPENDENCIES:   42          42          42          23
     REQ. BRANCHES:    1     +     2     +     5     +     1
       DESCRIPTION:  ICF-CtRp  ICF-Rupt  ICF-Shear noVB
 CASE/BRANCH SPLIT:          8.417E-03

 CASE NUMBER/SPLIT:    2     5.571E-01
      DEPENDENCIES:   54          11          42
     REQ. BRANCHES:    1     +     1     +     3
       DESCRIPTION:  L2-CHR     B-Leak    ICF-Leak
 CASE/BRANCH SPLIT:          5.571E-01

 CASE NUMBER/SPLIT:    3     1.924E-05
      DEPENDENCIES:   50          31          28
     REQ. BRANCHES:    1     *     2     *    /3
       DESCRIPTION:  PrmptCCI  RC-Dry     /AcDaVB
 CASE/BRANCH SPLIT:          1.924E-05

 CASE NUMBER/SPLIT:    4     2.995E-01
      DEPENDENCIES:   50          31          28
     REQ. BRANCHES:    1     *(    1     +    3)
       DESCRIPTION:  PrmptCCI  RC-Wet      AcDaVB
 CASE/BRANCH SPLIT:          2.995E-01

 CASE NUMBER/SPLIT:    6     1.351E-01
       DESCRIPTION:             Otherwise -- DelydCCI & RC-Full   $ Case 6: Debris bed is Coolable a
 CASE/BRANCH SPLIT:          1.351E-01


******** QUESTION:    57  How much H2 and CO2 is Produced during CCI?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB. INPUT PARM.          350664
          BRANCHES:             CCI       noCCI
                                 1          2
    REALIZED SPLIT:          6.935E 01 3.066E-01
```

```
                  SUMMARY BY CASE

CASE NUMBER/SPLIT:     1      3.066E-01
     DEPENDENCIES:    50         55
    REQ. BRANCHES:     2    *     2
      DESCRIPTION:  noPrmCCI  noDldCCI
CASE/BRANCH SPLIT:            0.000E+00 3.066E-01

CASE NUMBER/SPLIT:     2      5.520E-01
     DEPENDENCIES:    48
    REQ. BRANCHES:     1
      DESCRIPTION:  Lrg-CCI
CASE/BRANCH SPLIT:            5.520E-01 0.000E+00

CASE NUMBER/SPLIT:     3      1.415E-01
     DEPENDENCIES:    48
    REQ. BRANCHES:     2
      DESCRIPTION:  Med-CCI
CASE/BRANCH SPLIT:            1.415E-01 0.000E+00


******** QUESTION:    58  How much Hydrogen Burns or Leaks Out of Containment?
Q-TYPE/TIMES ASKED:         DEP. INPUT PROB. INPUT PARM.              350664
          BRANCHES:             FrH2-Rem
                                   1
    REALIZED SPLIT:             1.000E+00

                  SUMMARY BY CASE

CASE NUMBER/SPLIT:     1      9.631E-03
     DEPENDENCIES:     1         42
    REQ. BRANCHES:     4    +    /4
      DESCRIPTION:  Brk-V      /no-ICF
CASE/BRANCH SPLIT:            9.631E-03

CASE NUMBER/SPLIT:     2      5.112E-02
     DEPENDENCIES:    35         35         22         24
    REQ. BRANCHES: (   1     +(   3    *   /4))   *    1
      DESCRIPTION:  PrEj        BtmHd     /I-LoPr     E-Sp
CASE/BRANCH SPLIT:            5.112E-02

CASE NUMBER/SPLIT:     5      9.393E-01
      DESCRIPTION:                Otherwise                        $ Case 5: Intact Containment and n
CASE/BRANCH SPLIT:            9.393E-01


******** QUESTION:    59  Add H2 produced by CCI to H2 already in Containment
Q-TYPE/TIMES ASKED:         INDEP. CALC. PROB.                        350664
          BRANCHES:             L2-H2     L2nH2
                                  1         2
    REALIZED SPLIT:             6.935E-01 3.066E-01


******** QUESTION:    60  Amount of Steam in Containment after CCI?
Q-TYPE/TIMES ASKED:         DEP. INPUT PROB. INPUT PARM.              350664
          BRANCHES:             L2StmCnt
                                   1
    REALIZED SPLIT:             1.000E+00

                  SUMMARY BY CASE

CASE NUMBER/SPLIT:     1      5.590E-01
     DEPENDENCIES:    54
    REQ. BRANCHES:     1
```

```
      DESCRIPTION:  L2-CHR
 CASE/BRANCH SPLIT:          5.590E-01

 CASE NUMBER/SPLIT:    2     4.411E-01
       DESCRIPTION:             Otherwise                          $ Case 2: Sprays Not Operating
 CASE/BRANCH SPLIT:          4.411E-01


******** QUESTION:   61  Is the H2 Concentration Flammable?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                           350664
          BRANCHES:             L2-H2F    noL2-H2F
                                  1          2
    REALIZED SPLIT:           0.000E+00 1.000E+00

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     1.000E+00
     DEPENDENCIES:    11          42          19          24
     REQ. BRANCHES:    1    +    /4     +(    1     *      1)
       DESCRIPTION:  B-Leak    /no-ICF     E-ACP       E-Sp
 CASE/BRANCH SPLIT:           0.000E+00 1.000E+00


******** QUESTION:   62  Does Ignition Occur?                  Conversion Ratio?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB. INPUT PARM.            350664
          BRANCHES:             L2-HB     noL2-HB
                                  1          2
    REALIZED SPLIT:           0.000E+00 1.000E+00

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    3     1.000E+00
       DESCRIPTION:             Otherwise                          $ Case 3: Concentration not flamma
 CASE/BRANCH SPLIT:           0.000E+00 1.000E+00


******** QUESTION:   63  Resulting Pressure Rise?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                           350664
          BRANCHES:             L2-H2Brn  L2nH2Brn
                                  1          2
    REALIZED SPLIT:           0.000E+00 1.000E+00

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     1.000E+00
      DEPENDENCIES:   62
     REQ. BRANCHES:    2
       DESCRIPTION:  noL2-HB
 CASE/BRANCH SPLIT:           0.000E+00 1.000E+00


******** QUESTION:   64  Containment Failure, and Type of Containment Failure?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                                  350664
          BRANCHES:             L2CF-CRp  L2CF-Rp   L2CF-Lk   L2CF-SHEA no-L2CF
                                  1          2         3          4         5
    REALIZED SPLIT:           0.000E+00 0.000E+00 8.775E-04 0.000E+00 9.991E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     9.631E-03
      DEPENDENCIES:   42
     REQ. BRANCHES:   /4
       DESCRIPTION:  /no-ICF
 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 9.631E-03
```

```
 CASE NUMBER/SPLIT:     2     9.904E-01
       DESCRIPTION:           Otherwise                                       $ Case 2:
 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 8.775E-04 0.000E+00 9.895E-01


********* QUESTION:    65  Sprays after Very Late CF?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB                           350664
          BRANCHES:            F-Sp      noF-Sp
                                 1         2
    REALIZED SPLIT:           9.919E-01 8.147E-03

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:     1     8.147E-03
      DEPENDENCIES:    52        51
     REQ. BRANCHES:     3    +    3
       DESCRIPTION:   L2fSp     L2fACP
 CASE/BRANCH SPLIT:           0.000E+00 8.147E-03

 CASE NUMBER/SPLIT:     3     9.919E-01
       DESCRIPTION:              Otherwise                           $ Case 3: No catastrophic rupture
 CASE/BRANCH SPLIT:           9.919E-01 0.000E+00


********* QUESTION:    66  Fan Coolers after Very Late CF?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                          350664
          BRANCHES:            F-FC      FfFC
                                 1         2
    REALIZED SPLIT:           5.590E-01 4.411E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:     1     4.411E-01
      DEPENDENCIES:    53        51
     REQ. BRANCHES:     3    +    3
       DESCRIPTION:   L2fFC     L2fACP
 CASE/BRANCH SPLIT:           0.000E+00 4.411E-01

 CASE NUMBER/SPLIT:     2     5.590E-01
       DESCRIPTION:              Otherwise                           $        were available and we as
 CASE/BRANCH SPLIT:           5.590E-01 0.000E+00


********* QUESTION:    67  Containment Heat Removal after Very Late CF?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                          350664
          BRANCHES:            F-CHR     FfCHR
                                 1         2
    REALIZED SPLIT:           9.965E-01 3.551E-03

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:     1     9.965E-01
      DEPENDENCIES:    65        66
     REQ. BRANCHES:     1    +    1
       DESCRIPTION:   F-Sp      F-FC
 CASE/BRANCH SPLIT:           9.965E-01 0.000E+00

 CASE NUMBER/SPLIT:     2     3.551E-03
       DESCRIPTION:              Otherwise                           $ Case 2: No Sprays, No Fan Cooler
 CASE/BRANCH SPLIT:           0.000E+00 3.551E-03


********* QUESTION:    68  Eventual Basemat Melt-through?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                          511296
          BRANCHES:            MTnDePr   MTwDePr   noMT
```

```
                              1         2         3
   REALIZED SPLIT:          1.846E-01 6.153E-02 7.541E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:     1     1.568E-02
      DEPENDENCIES:   11        23        42        64
      REQ. BRANCHES:   1   +    1    +   /4    +   /5
        DESCRIPTION:  B-Leak    noVB     /no-ICF   /no-L2CF
 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 1.568E-02

 CASE NUMBER/SPLIT:     2     3.032E-01
      DEPENDENCIES:   50        55        65
      REQ. BRANCHES:   2   *    2    *    1
        DESCRIPTION:  noPrmCCI  noDldCCI  F-Sp
 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 3.032E-01

 CASE NUMBER/SPLIT:     3     5.493E-01
      DEPENDENCIES:   48        65
      REQ. BRANCHES:   1   *    1
        DESCRIPTION:  Lrg-CCI   F-Sp
 CASE/BRANCH SPLIT:           1.648E-01 5.493E-02 3.296E-01

 CASE NUMBER/SPLIT:     5     1.320E-01
      DEPENDENCIES:   48        65
      REQ. BRANCHES:   2   *    1
        DESCRIPTION:  Med-CCI   F-Sp
 CASE/BRANCH SPLIT:           1.980E-02 6.599E-03 1.056E-01


 ********  QUESTION:   69  Eventual Overpressure Failure of Containment?
 Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                       511296
           BRANCHES:          F-CF-OP   noFCFOP
                                 1         2
    REALIZED SPLIT:          0.000E+00 1.000E+00

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:     1     1.000E+00
      DEPENDENCIES:   11        23        42        64        67
      REQ. BRANCHES:   1   +    1    +   /4    +   /5    +    1
        DESCRIPTION:  B-Leak    noVB     /no-ICF   /no-L2CF   F-CHR
 CASE/BRANCH SPLIT:           0.000E+00 1.000E+00


 ********  QUESTION:   70  Basemat Melt-through before Overpressure Failure?
 Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                       511296
           BRANCHES:          F-BMT     FCF-Lk    Neither
                                1         2         3
    REALIZED SPLIT:          2.461E-01 0.000E+00 7.540E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:     1     2.461E-01
      DEPENDENCIES:   68        69
      REQ. BRANCHES:  /3   *    2
        DESCRIPTION: /noMT      noFCFOP
 CASE/BRANCH SPLIT:           2.461E-01 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:     5     7.540E-01
        DESCRIPTION:             Otherwise                 $ Case 5: Have neither BMT nor
 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 7.540E-01


 ********  QUESTION:   71  Final Containment Condition?
```

```
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                           511296
          BRANCHES:             F-Ruptr   F-Leak    F-MT      Bypass    noCF       Shear
                                 1         2         3         4         5         6
    REALIZED SPLIT:             8.148E-03 7.267E-03 2.461E-01 0.000E+00 7.386E-01 4.668E-05

                      SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1       8.148E-03
       DEPENDENCIES:   42         42        64        64
      REQ. BRANCHES:    1    +    2    +    1    +    2
        DESCRIPTION:   ICF-CtRp  ICF-Rupt  L2CF-CRp  L2CF-Rp
  CASE/BRANCH SPLIT:            8.148E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:    2       7.267E-03
       DEPENDENCIES:   11         42        64        70
      REQ. BRANCHES:    1    +    3    +    3    +    2
        DESCRIPTION:   B-Leak    ICF-Leak  L2CF-Lk   FCF-Lk
  CASE/BRANCH SPLIT:            0.000E+00 7.267E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:    3       4.668E-05
       DEPENDENCIES:   42         64
      REQ. BRANCHES:    5    +    4
        DESCRIPTION:   ICF-Shear L2CF-SHEA
  CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.668E-05

  CASE NUMBER/SPLIT:    5       2.461E-01
       DEPENDENCIES:   70
      REQ. BRANCHES:    1
        DESCRIPTION:   F-BMT
  CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 2.461E-01 0.000E+00 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:    6       7.386E-01
        DESCRIPTION:               Otherwise                                        $ Case 6: No C
  CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00 0.000E+00 7.386E-01 0.000E+00

********  QUESTION:   72  Time of core damage
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                           511296
          BRANCHES:             ECorD     LCorD
                                 1         2
    REALIZED SPLIT:             0.000E+00 1.000E+00

                      SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1       1.000E+00
       DEPENDENCIES:    3          8         3        19
      REQ. BRANCHES:    5    +    1    +(   2    *    1)
        DESCRIPTION:   BiECCS     SG-HR     BaECCS    E-ACP
  CASE/BRANCH SPLIT:            0.000E+00 1.000E+00
```

APPENDIX C

ZION ACCIDENT PROGRESSION BINNING FILE FROM DRAFT NUREG/CR–4551

APPENDIX C

Zion Accident Progression Binning File From Draft NUREG/CR-4551

This Appendix lists the EVNTRE input file used to bin the end states of the Zion APET into accident progression bins for the ZISOR source term analysis in draft NUREG/CR-4551 for Zion.

```
Zion Binning - Rev. 5 - 6/2/89 - 12 Characteristics
12 CF-Time  Sprays  CCI  RCS-Pres  VB-Mode  SGTR  Amt-CCI
  Zr-Ox  HPME  CF-Size  RCS-Hole  CD-Time
 7   7  V-Dry  V-Wet  Early-CF  CF-at-VB  Late-CF  VLate-CF  No-CF      $ Char. 1, Containment Failure Time
 4   7       71           1          18          71                   $ Case 1, Attr. 7 (G), No CF or No V
              5  +((      5  +        1 ) *       4  )
           noCF or(( B-SGTR or  E-SGTRS3) & Bypass    )
 2   1        1          12                 $ Case 2, Attr. 1 (A), V-Dry
              4    *      2
           Brk-V   &   V-Dry
 2   2        1          12                 $ Case 3, Attr. 2 (B), V-Wet
              4    *      1
           Brk-V   &   V-Wet
 4   3       11          42      42     42   $ Case 4, Attr. 3 (C), CF before Vessel Breach
              1    *     -1    * -5  *  -2
          B-Leak   & noICF-CR  & noICF-Sh &noICF-Rp
 1   4       42                             $ Case 5, Attr. 4 (D), CF at Vessel Breach
             -4
           I-CF
 1   5       64                             $ Case 6, Attr. 5 (E), Very Late CF (after CCI)
             -5
          L2-CF
 2   6       70          71                 $ Case 7, Attr. 6 (F), Final CF (about 24 hours after VB)
              2    +      3
          FCF-Lk   or    F-MT
 8   8  Sp-Early  Sp-E+I  Sp-E+I+L  SpAlways  Sp-Late  Sp-L+VL
        Sp-VL  Sp-Never  Sp-Final                            $ Characteristic 2, Sprays
 4   1       24          43          45          52  $ Case 1, Attr. 1 (A), Early sprays only
              1    *     -1 *        -1   *      -1
           E-Sp    & noI2-Sp &    noL-Sp  &  noL2-Sp
 4   2       24          43          45          52  $ Case 2, Attr. 2 (B), Early & Im sprays only
              1    *      1 *        -1   *      -1
           E-Sp    &   I2-Sp &    noL-Sp  &  noL2-Sp
 4   3       24          43          45          52  $ Case 3, Attr. 3 (C), Early, Im & Late sprays
              1    *      1 *         1   *      -1
           E-Sp    &   I2-Sp &      L-Sp  &  noL2-Sp
 4   4       24          43          45          52  $ Case 4, Attr. 4 (D), Sprays always
              1    *      1 *         1   *       1  $          ( Always w/r/t releases )
           E-Sp    &   I2-Sp &      L-Sp  &    L2-Sp
 4   5       24          43          45          52  $ Case 5, Attr. 5 (E), Late sprays only
             -1    *     -1 *         1   *      -1
          E-CHR    & noI2-Sp &      L-Sp  &  noL2-Sp
 4   6       24          43          45          52  $ Case 6, Attr.6 (F), Late & VL sprays only
             -1    *     -1 *         1   *       1
          E-CHR    & noI2-Sp &      L-Sp  &    L2-Sp
 4   7       24          43          45          52  $ Case 7, Attr. 7 (G), Very Late sprays only
             -1    *     -1 *        -1   *       1
          E-CHR    & noI2-Sp &    noL-Sp  &    L2-Sp
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5   8        24          43          45          52  65 $ Case 8, Attr. 8 (H), Sprays never
          ( -1   *      -1 *        -1   *       -1)+ 1  $         ( Never w/r/t releases )
         E-CHR   & noI2-Sp &    noL-Sp  &  noL2-Sp or F-Sp
6   6  Promt-Dry  PromtShlw  No-CCI  PromtDeep  SDlyd-Dry  LDlyd-Dry      $ Characteristic 3,
3   1        50          31          28                                   $     Core-Concrete Interaction
              1   *       2   *      -3 $ Case 1, Attr. 1 (A), Prompt CCI - Cavity Dry
       PrmptCCI  &  RC-Dry   & noAcDaVB
3   2        50          31          28 $ Case 2, Attr. 2 (B), Prompt CCI - Shallow Pool Scrubbing
              1   *       2   *       3 $   Cavity contains accumulator water only
       PrmptCCI  &  RC-Dry   &  AcDaVB
2   3        50          55             $ Case 3, Attr. 3 (C), No CCI
              2   *       2             $   Coolable with water, or no VB.
       noPrmCCI  & noDldCCI
2   4        50          31             $ Case 4, Attr. 4 (D), Prompt CCI - Deep Pool Scrubbing
              1   *       1             $   Cavity is full ( 14 feet )
       PrmptCCI  &  RC-Wet
2   5        55          26             $ Case 5, Attr. 5 (E), Delayed CCI - Cavity Dry
              1   *       3             $   Short Delay - Boil off Accumulator water only
       DelydCCI  &  AcDaVB
2   6        55          31             $ Case 6, Attr. 6 (F), Delayed CCI - Cavity Dry
              1   *       1             $   Long Delay - Boil off Full (14 ft) Cavity
       DelydCCI  &  RC-Wet
4   4  SSPr  HiPr  ImPr  LoPr                                   $ Characteristic 4, RCS Pressure before VB
1   1        22                $ Case 1, Attr. 1 (A), System setpoint pressure
              1
        I-SSPr
1   2        22                $ Case 2, Attr. 2 (B), High pressure
              2
        I-HiPr
1   3        22                $ Case 3, Attr. 3 (C), Intermediate pressure
              3
        I-ImPr
1   4        22                $ Case 4, Attr. 4 (D), Low pressure
              4
        I-LoPr
6   6  VB-HPME  VB-Pour  VB-BtmHd  Alpha  Rocket  No-VB        $ Characteristic 5, Mode of Vessel Breach
1   1        35                $ Case 1, Attr. 1 (A), Pressurized Ejection (incl. Direct Heating)
              1                            $ Characteristic 5 is Not Used in SURSOR.
           PrEj                            $ All HPME information is obtained from Char. 9.
1   2        35                $ Case 2, Attr. 2 (B), Gravity Pour
              2
           Pour
1   5        36                $ Case 3, Attr. 5 (E), Rocket
              1                $           Has to come before BtmHd since BtmHd required for Rocket
         Rocket
1   3        35                $ Case 4, Attr. 3 (C), Gross Bottom Head Failure
              3
          BtmHd
1   4        34                $ Case 5, Attr. 4 (D), Alpha Mode
              1
          Alpha
1   6        23                $ Case 6, Attr. 6 (F), No Vessel Breach
              1
           noVB
3   3  SGTR  SGTR-SRVO  No-SGTR                                 $ Char. 6, Steam Generator Tube Rupture
3   1         1           2           18    $ Case 1, Attr. 1 (A), SGTR
      (       5  *        2  ) +       1    $         Secondary system SRVs are not stuck open
      ( B-SGTR  &  SSRVnStO )orE-SGTRS3
2   2         1           2                 $ Case 2, Attr. 2 (B), SGTR with Stuck-Open SRVs
              5  *        1
        B-SGTR  &  SSRV-StO
2   3         1          18                 $ Case 3, Attr. 3 (C), No SGTR
             -5  *        2
       noB-SGTR &  noE-SGTR
4   4  Lrg-CCI  Med-CCI  Sml-CCI  No-CCI                        $ Characteristic 7, Amount of Core in CCI
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2   4      50          55             $ Case 1, Attr. 4 (D), No CCI
           2     *     2
      noPrmCCI  & noDldCCI
1   1      48     35     35   22      $ Case 2, Attr. 1 (A), Large Amount of Core in CCI (70-100%)
           1  +   1  + ( 3 * -4)
      Lrg-CCI
1   2      48                         $ Case 3, Attr. 2 (B), Medium Amount of Core in CCI (30-70%)
           2
      Med-CCI
1   3      48                         $ Case 4, Attr. 3 (C), Small Amount of Core in CCI (0-30%)
           3
      Sml-CCI
2   2  Lo-ZrOx  Hi-ZrOx                            $ Characteristic 8, Zr Oxidation
1   1      30                         $ Case 1, Attr. 1 (A), Lo Zr Oxidation (<40%) In-Vessel
           2
      Lo-ZrOx
1   2      30                         $ Case 2, Attr. 2 (B), Hi Zr Oxidation (>40%) In-Vessel
           1
      Hi-ZrOx
4   4  Hi-HPME  Md-HPME  Lo-HPME  No-HPME              $ Char. 9, High Pressure Melt Ejection
4   1      33         35         35        22   $ Case 1, Attr. 1 (A), High Fraction Ejected (>40%)
           1  * (      1 + (      3   *     -4 ))
      Hi-FCoR & (   PrEj or (  BtmHd  &  noI-LoPr))
4   2      33         35         35        22   $ Case 2, Attr. 2 (B), Medium Fraction Ejected (20-40%)
           2  * (      1 + (      3   *     -4 ))
      Md-FCoR & (   PrEj or (  BtmHd  &  noI-LoPr))
4   3      33         35         35        22   $ Case 3, Attr. 3 (C), Low Fraction Ejected (<20%)
           3  * (      1 + (      3   *     -4 ))
      Lo-FCoR & (   PrEj or (  BtmHd  &  noI-LoPr))
1   4      35                                   $ Case 4, Attr. 4 (D), No HPME
           -1
      noPrEj
7   7  Cat-Rupt  Rupture  Leak  SHEAR  BMT  Bypass  No-CF          $ 10th Char., Type of Cont. Failure
1   6      71                         $ Case 1, Attr. 6 (F), Bypass (V or SGTR)
           4
      Bypass
2   1      42          64             $ Case 2, Attr. 1 (A), Catastrophic Rupture
           1    +      1
      ICF-CtRp  orL2CF-CRp
2   2      42          64             $ Case 3, Attr. 2 (B), Rupture
           2    +      2
      ICF-Rupt  orL2CF-Rp
1   3      71                         $ Case 4, Attr. 3 (C), Leak
           2
      F-Leak
1   4      71                         $ Case 5, Attr. 4 (D), SHEAR
           6
      F-SHEAR
1   5      71                         $ Case 6, Attr. 5 (E), BMT
           3
      F-MT
1   7      71
           5
      NOCF
2   2  1-Hole  2-Holes                             $ Char. 11, Number of Holes in the RCS
4   1      21          21          34          36   $ Case 1, Attr. 1 (A), One Hole
           -1    *     -2    *     2     *     2    $    Event V = 1 hole - path too long
      noEBD-A   & noEBD-S2  &  noAlpha   & noRocket
4   2      21          21          34          36   $ Case 2, Attr. 2 (B), Two Holes
           1     +     2     +     1     +     1    $    S3 Holes are too Small for Natural Circulation
      EBD-A     or EBD-S2   or  Alpha    or Rocket
2   2  E-CD      L-CD
1   1      72
           1
```

```
         ECorD
1   2      72
            2
         LCorD
1
10     1    4   6   8   5   9   3   7    2  10
       CF-Time   CD-Time  RCS-Pres  SGTR    Zr-Ox   VB-Mode   HPME   CCI
       Amt-CCI    RCS-Hole   Sprays   CF-Size
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11. ABSTRACT (200 words or less)

This report calculates the risk benefit associated with potential performance improvements for the large dry pressurized water reactor (PWR) containment. The analysis is based on the June 1989 draft NUREG-1150 results for the Zion commercial nuclear reactor. Simplified containment event trees and the large accident progression event trees from draft NUREG-1150 are used to evaluate the effects of potential improvements on the response of the Zion containment to dominant severe accident sequences. Source terms are generated parametrically using the ZISOR code and offsite consequences are calculated with the MELCOR Accident Consequence Code System (MACCS). These results give point estimates of the risk reduction associated with each containment improvement identified by Brookhaven National Laboratory in their draft Issues Characterization Report.

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