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An Assessment of BWR Mark III Containment Challenges, Failure Modes, and Potential Improvements in Performance

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ABSTRACT

This report describes risk–significant challenges posed to Mark III containment systems by severe accidents as identified for Grand Gulf. Design similarities and differences between the Mark III plants that are important to containment performance are summarized. The accident sequences responsible for the challenges and the postulated containment failure modes associated with each challenge are identified and described. Improvements are discussed that have the potential either to prevent or delay containment failure, or to mitigate the offsite consequences of a fission product release. For each of these potential improvements, a qualitative analysis is provided. A limited quantitative risk analysis is provided for selected potential improvements.

FIN No. A6885—BWR Mark II and Mark III Venting/Enhancements

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FOREWORD

SECY–88–147, 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 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 were needed included the uncertainty in the ability of LWR containments to successfully survive some severe accident challenges, as indicated by 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 boiling water reactor (BWR) Mark III containment owners with information they may find useful in their IPE. No requirements are contained in this report; it is provided for information only. Generic letter 88–20, Supplement 3, dated July 6, 1990 provides specific guidance to the industry on the use of this and similar reports.

ACRONYMS

ac	Alternating current
ADS	Automatic depressurization system
ARI	Alternate rod insertion
ATWS	Anticipated transient without scram
BWR	Boiling water reactor
BWROG	BWR Owners Group
CCI	Core–concrete interaction
CDF	Core damage frequency
CLWG	Containment Loads Working Group
CPI	Containment performance improvement
CRD	Control rod drive
CS	Core spray
CST	Condensate storage tank
DBA	Design basis accident
dc	Direct current
DCH	Direct containment heating
DF	Decontamination factor
ECCS	Emergency core cooling systems
EDG	Emergency diesel generator
EOP	Emergency operating procedures
EPG	Emergency Procedure Guidelines
ESF	Engineered safety feature
FCI	Fuel–coolant interaction
FSAR	Final Safety Analysis Report
HCTL	Heat capacity temperature limit
HEP	Human error probability
HIS	Hydrogen ignition system
HPCS	High–pressure core spray
HVAC	Heating, ventilation, and air conditioning
INEL	Idaho National Engineering Laboratory
IPE	Individual Plant Examination
KWU	Kraftwerk Union
LFL	Lower flammability limit
LOCA	Loss–of–coolant accident
LOSP	Loss of offsite power
LPCI	Low–pressure coolant injection
LPCS	Low–pressure core spray
LTSB	Long–term station blackout
MAAP	Modular Accident Analysis Program
MACCS	MELCOR Accident Consequence Code System
MSCWL	Minimum steam cooling water level
MSIV	Main steam isolation valve
MVSS	Multi–Venturi Scrubber System
NPSH	Net positive suction head
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PCPL	Primary containment pressure limit
PCS	Power conversion system

PDS	Plant damage state
PRA	Probabilistic risk assessment
RCIC	Reactor core isolation cooling
RHR	Residual heat removal
RPS	Reactor protection system
RPT	Recirculation pump trip
RPV	Reactor pressure vessel
SARRP	Severe Accident Risk Reduction Program
SBO	Station blackout
SGTS	Standby gas treatment system
SLCS	Standby liquid control system
SNL	Sandia National Laboratory
SRV	Safety/relief valve
STCP	Source Term Code Package
STSB	Short–term station blackout
TAF	Top of active fuel
TW	Loss of long–term containment heat removal

AN ASSESSMENT OF BWR MARK III CONTAINMENT CHALLENGES, FAILURE MODES, AND POTENTIAL IMPROVEMENTS IN PERFORMANCE

EXECUTIVE SUMMARY

This report concerns boiling water reactor (BWR) plants with a Mark III containment design, of which there are four in the U.S.: Grand Gulf, Clinton, Riverbend, and Perry. This report focuses on the identification of potential challenges to containment integrity that can arise from a severe accident and the potential improvements that could reduce the probability of containment failure or mitigate the offsite consequences in the event that a severe accident should occur. The impact of these improvements upon core damage frequency, containment failure probability, or risk is examined both qualitatively and quantitatively. The quantitative portion of the analysis used models and data specific to the Grand Gulf plant, and may not be generic to the remaining Mark III plants. The estimated costs for selected improvements were taken from previously published information and are not meant to be interpreted as final estimates.

The most recent NUREG–1150 analysis of Grand Gulf (dated June 1989) has identified the dominant containment failure challenges to be the result of station blackout (SBO) accident sequences. The most significant challenges arising from these sequences are due to potential hydrogen deflagrations and detonations, fuel–coolant interactions (FCI), and containment overpressurization by noncondensible gases from core–concrete interactions (CCI).

Potential improvements to reduce the risk from station blackout include enhanced reactor pressure vessel (RPV) depressurization capability, the installation of a backup power supply for the existing hydrogen ignition systems or the installation of powerless ignitors, improvements to the existing fire water system, enhanced operator control over the upper containment pool dump valves, a means of preventing weir wall overflow prior to vessel breach, and a method of venting the containment through a hardened pipe that is independent of normal and emergency ac power sources. The backup power supply for the ignitors could also be sized to provide power for the upper containment pool dump valves. The backup power supply would provide an "uninterruptible" hydrogen ignition system that would burn the hydrogen in a controlled manner before it could reach concentrations capable of threatening containment integrity. Providing enhanced operator control over the upper containment pool dump valves would permit dumping of the water at potentially advantageous times when the normal pool dump initiation signals were not available, and would also provide the operators with the ability to prohibit dumping at other times. Venting the containment at the primary containment pressure limit (PCPL) via "soft" HVAC ductwork can result in a failure of the ductwork and thus raises concerns about the habitability of the auxiliary building and the survivability of the equipment in the affected area. A hardened vent would eliminate these potential concerns. An external filter could reduce the offsite consequences of venting that occur in the Mark III as a result of drywell–to–wetwell leakage and other suppression pool bypass paths.

Table ES–1 summarizes the potential qualitative benefits, as well as any identified negative aspects, of each of the proposed improvements.

A quantitative accident progression analysis was performed for selected potential improvements to estimate the impact of the improvement on containment response. The impact on offsite consequences was evaluated for selected

Table ES–1. Qualitative assessment of benefits and drawbacks of potential Mark III containment improvements

Potential Improvement	Potential Benefits	Potential Drawbacks
Enhanced reactor depressurization system ($0.5M–1.4M)	Reduces frequency of some core damage sequences	Increases likelihood of ex–vessel FCI
	Reduces amount of hydrogen generated in–vessel	
	Reduces likelihood of direct containment heating (DCH)	
	Increases the ability to add water to the RPV	
Post–core damage reactor depressurization system ($0.5M–1.4M)	Reduces likelihood of DCH	Increases likelihood of ex–vessel FCI
	Increases the ability to add water to the RPV	Does not change frequency of core damage
		Increases amount of hydrogen generated in–vessel
Backup water supply system ($0.81M–2.4M)	Reduces frequency of some core damage sequences	New hardware may be expensive
	Increases likelihood of cavity flooding (see below)	
	Relatively low cost if fire protection system is used	
Hydrogen control by improved ignition system—backup power to the ignitors ($300K)	Reduces containment failures due to hydrogen deflagrations and detonations [short–term station blackout (ST–SBO) sequences]	Increases likelihood of containment failure for [long–term station blackout (LT–SBO) sequences]
Prevention of weir wall overflow	Reduces likelihood of ex–vessel FCI	May increase likelihood of suppression pool bypass
		Increases likelihood of dry CCI

Table ES–1. (continued)

Potential Improvement	Potential Benefits	Potential Drawbacks
Cavity flooding via upper pool dump	Reduces likelihood of dry CCI	Increases likelihood of FCI
	Provides scrubbing of fission products should suppression pool bypass occur	Increases likelihood of hydrogen burn if dump occurs after core damage
Containment venting		
Hard–pipe vent system with dedicated power source ($0.69M–6.1M)	Prevents late overpressure failures for transients with scram	High likelihood of suppression pool bypass may lead to increase in risk
	Preemptive venting reduces containment base pressure prior to core damage	Moderately high cost May not prevent thermal failure or FCI
	Reduces probability of ex–vessel steam explosion by reducing weir wall overflow	Can lead to inadvertent release
Filtered containment vent system with dedicated power source ($5M–50M)	See above	See above
	Ensures scrubbing of releases	High cost

improvements. Full use was made of the tools developed for the June 1989 Draft NUREG–1150 analysis of Grand Gulf. Thus, no attempt was made to develop independent or simplified containment event trees for analyzing containment response; the accident progression analysis in this report contains the same level of detail as the Draft NUREG–1150 analysis of Grand Gulf, with the exception that no uncertainty analysis was performed for this report. No analysis was made of front–end risk reductions, that is, improvements that could reduce core damage frequency.

In terms of reducing the probability of containment failure, the only *individual* improvements found to be of benefit were backup power to the hydrogen ignition system and early containment venting. Enhanced depressurization (following core damage) increased the probability of an in–vessel steam explosion as the probability of a steam explosion at low pressure (100–200 psi) is greater than at high pressure (1000 psi). This offset the increased probability of recovering injection in the dominant plant damage state. Preventing water from overflowing the weir wall was found to increase dry CCI that significantly increased the late threat to containment. Enhancements to ensure the availability of upper pool dump during blackout sequences were found to increase the probability of early containment failure with suppression pool bypass, because pool dump results in a higher probability of a flooded or wet cavity at the time of vessel breach. This increases the probability of a large ex–vessel steam explosion at the time of vessel breach, which increases the impulse loads on the drywell. An ex–vessel steam explosion also produces large quantities of hydrogen because debris fragmentation markedly increases the rate of ex–vessel oxidation. The additional hydrogen can ignite, further increasing the probability of containment failure at the time of vessel breach.

Detailed offsite consequence calculations were performed for early containment venting. A significant increase in all consequence measures was seen in comparison with the base case.

Three improvement combinations were evaluated in detail, both in terms of containment response and offsite consequences. The first combination evaluated was an improved hydrogen ignition system with 100% diffusion burn efficiency, enhanced reactor depressurization following core damage prevention of water from flowing over the weir wall, and an increased probability that the operators get the fire water system aligned so that low–pressure injection into the reactor vessel occurs in fast station blackout sequences with the fire water system available, no power recovery, and failure of all other emergency injection systems The second combination was identical to the first except that water was permitted to flow over the weir wall. The third combination was like the first, except that ex–vessel steam explosions were eliminated.

The early containment venting and upper pool dump modifications were not included in any of these combinations because of the detrimental effects that were observed for these modifications in the individual sensitivity analyses. However, the analysis of these improvements did not reflect the findings of deterministic analyses performed since the publication of Draft 1150. These other analyses indicate that containment venting can be very important in prevention of ex–vessel steam explosions.

Both combined improvement cases with no weir wall overflow reduced the early threat to containment integrity (early threats occur prior to or at the time of reactor vessel failure). However, these combinations of improvements significantly increased the late threat (late threats occur a number of hours after vessel failure) to the containment, primarily as a result of the CCI that occurs in the dry cavity. However, recent MELCOR calculations for a depressurized short–term SBO sequence performed at Oak Ridge National Laboratory indicate that the containment threat from CCI may be of less significance than identified in Draft NUREG–1150.

Calculations were performed to determine the effect of the dry cavity combined improvements on offsite consequences. Table ES–2 presents these results along with those of the base case. The table shows that dry cavity combined improvements result in a small reduction in the offsite doses. In general, the conditional probabilities of the releases were reduced, but the severity of the releases was increased from the base case; the dry cavity modifications increase the severity of a given release, because there is little or no scrubbing of the release. As forementioned, the late threat to the containment in a depressurized SBO sequence could be less severe than was modeled in Draft NUREG–1150. Therefore, the risk reduction for a dry cavity may be larger than the results from this analysis would suggest. However, the benefits of scrubbing through an overlying pool of water could be lost if no water injection system to the reactor vessel is ever recovered.

In the case of the combined improvements where water is permitted to overflow the weir wall (i.e., the cavity is wet in some cases and dry in others, rather than always dry), there is a reduction in the probability of late containment failure and an increase in the probability of containment survival as compared to the case with no weir wall overflow. Although the probability of early containment failure is virtually the same in both cases, there is a decrease in the probability of late and no suppression pool bypass, and an increase in the probability of early suppression pool

Table ES-2. Grand Gulf combined improvement risk comparison

	Mean Early Fatalities (per ry[a])	Mean Latent Fatalities (per ry)	Mean 50–Mile Dose (man–rem/ry)	Mean 1000–Mile Dose (man–rem/ry)	Mean Offsite Costs ($/ry)
Base case	6.2E–09	1.7E–03	7.8E–01	10.4	2.2E+03
Combined improvement with no weir wall overflow	6.8E–09	1.7E–03	7.6E–01	10.3	2.7E+03
Combined improvement with weir wall overflow permitted	2.7E–09	1.2E–03	6.2E–01	7.66	1.5E+03
Combined improvement with no weir wall overflow, no EVSE[b]	5.3E–09	1.6E–03	7.4E–01	10.0	2.5E+03

a. Reactor year.

b. Ex–vessel steam explosion.

bypass. When the combined improvements with weir wall overflow are compared to the base case, the net effects are decreases in every early containment failure mode and increases in the conditional probabilities of late containment failure, venting, containment survival, and in–vessel recovery. However, as in the case of the containment venting analysis, this analysis did not reflect the results of deterministic analyses performed since the publication of Draft 1150. Important factors missing from this analysis are deterministic analysis of potential steam explosions effects, suppression pool bypass, or lack of pool bypass.

Table ES–2 presents the results for the base case and the combined improvement cases. As indicated in the table, the risk measures for the combined case with weir wall overflow are all smaller than those for any other case. Compared with the base case values, the mean early fatalities decreased 56%, the mean latent fatalities decreased 29%, the mean 50–mile and 1000–mile doses decreased 21% and 23%, respectively, and the mean offsite costs decreased 30%. However, for Grand Gulf, the base case is already very small and includes a wide uncertainty range. Other plants may observe more significant changes in risk.

These results indicate that the modification to prevent weir wall overflow may reduce the overall benefits of the other combined improvements, because the reduced probability of flooding in the cavity increases the probability that dry CCI will occur. A comparison of the two combined improvements indicates that the effects on risk of the increased probability of dry CCI outweigh those brought about by the decrease in the probability of ex–vessel steam explosions.

These results should not be used without careful consideration to the underlying assumptions and implications in the suite of NUREG–1150 analysis codes. For example, when corium enters the in–pedestal area and no water is initially present, there is an 80% chance that no CCI will occur if vessel breach occurs at high pressure and an injection source is present. This probability drops to 16% if vessel breach occurs at low pressure. These probabilities imply that vessel breach at low pressure is not as likely to result in a coolable debris bed geometry as a high–pressure breach. Another implication is that a low–pressure injection source is not likely to prevent CCI (although it will cause scrubbing of the resulting release); CCI will initiate under water and become as vigorous as if no water had been present, only delayed. Other possible implications are that the water overlying the corium will never touch the corium and thereby will not provide any significant cooling, or that an insulating crust will develop and separate the corium from the water. The final result, that there is only a 16% chance that injection will prevent CCI after a low–pressure vessel breach, results from consideration of research completed at the time the study was performed.

This suite of codes does not always permit easy transfer of new results from other analyses, experiments, or experiences into the current research. As a minimum, these results should be compared against experiments and analyses completed after the June 1989 NUREG–1150 effort. For example, the recent Oak Ridge MELCOR calculations indicate that in at least one depressurized ST–SBO sequence, the late threat to containment from CCI may be less severe than was modeled in Draft NUREG–1150.

Each of the potential improvements can have an impact on the others and thus the potential benefits of the combined improvements can have greater benefit. The combinations of improvements that have been discussed in this report are not necessarily the only or best combinations for Grand Gulf or any other Mark III facility, but were those that seemed to have the greatest potential for reducing containment failure probability or risk. The offsite risk and core damage frequency at Grand Gulf are low and are made up of many small contributors. Therefore, the potential benefits from these improvements are small.

This analysis should not be viewed as a final evaluation of the benefits (reductions in containment challenges and offsite consequences) for any BWR/6 with a Mark III containment. However, it should be considered when preparing or conducting an Individual Plant Examination (IPE).

1. INTRODUCTION

This report discusses dominant severe accident challenges, as identified by current severe accident research, which can threaten the integrity of boiling water reactors (BWRs) with Mark III containments. Potential improvements are identified and evaluated as to their ability to arrest or delay core damage, prevent or delay containment failure, or mitigate the offsite consequences of a fission product release.

The containment challenges identified in this report involve many phenomenological issues that are still the subject of considerable uncertainty. The material in this report relies primarily on the findings of NRC-sponsored research. Controversial and highly uncertain issues are described to provide a reference for further discussion.

The BWR Mark III plants and their important safety design features, along with the differences and similarities among the various plants, are discussed in Section 2. Section 3 discusses the important accident sequences that could challenge containment integrity. Section 4 describes the containment challenges and failure modes resulting from the dominant accident sequences. Section 5 describes improvements that have the potential to prevent core damage or mitigate containment failure and offsite consequences. A qualitative assessment is provided to identify the benefits and drawbacks associated with each potential improvement. Sections 6–13 describe the quantitative assessment performed to estimate the benefit for each potential improvement.

2. MARK III PLANT FEATURES

A general summary of design information for the BWRs with Mark III containments is presented in this section. As indicated in Table 2–1, there are presently four nuclear power plants with Mark III containments, located at four different sites. Different architectural/engineering and construction firms were used to build the four plants. Design similarities and differences are presented in Tables 2–2 and 2–3.

2.1 Reactor Design

BWR plants with Mark III containments feature the General Electric Company (GE) BWR/6 reactor product line. Table 2–2 summarizes some of the important reactor design and emergency core cooling system (ECCS) information.

The ECCS for the BWR/6 reactors includes a high–pressure core spray (HPCS) system, a low–pressure core spray (LPCS) system, the low–pressure coolant injection (LPCI) function of the residual heat removal (RHR) system, and the automatic depressurization system (ADS). These systems are segregated into three divisions to provide separation of redundant functions. Division I comprises one train of LPCI, LPCS, Division I of ADS, an independent standby ac–power source, and an independent dc battery to provide emergency dc power to vital loads. Division II is composed of the remaining two LPCI trains of RHR, Division II of ADS, and independent ac and dc power sources analogous to those in Division I. Division III consists of HPCS, a dedicated diesel generator as an independent standby ac power source, and an independent dc power source.

Table 2–1. United States nuclear power plants with Mark III containments[a]

Utility/Plant Name	Architectural Engineer	Construction Firm	Date of Commercial Operation
Cleveland Electric Illuminating	Gilbert	Utility	11/87
Perry 1			
Gulf States Utilities	Stone & Webster	Stone & Webster	6/86
Riverbend 1			
Illinois Power	Sargent & Lundy	Baldwin	11/87
Clinton 1			
System Energy Resources	Bechtel	Bechtel	7/85
Grand Gulf 1			

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a. "World List of Nuclear Power Plants," *Nuclear News*, February 1989.

Table 2-2. Comparison of BWR Mark III reactor design characteristics

	Plant			
Parameter	Clinton	Grand Gulf	Perry	River Bend
Reactor Design				
Model	BWR/6	BWR/6	BWR/6	BWR/6
Vessel ID (in.)	218	251	238	218
Number of fuel bundles	624	800	748	624
Rated power (MWth)	2894	3833	3579	2894
Power density (kW/L)	52.4	54.1	54.1	52.4
Turbine bypass (%)	35	35	35	10
ECCS				
HPCS				
Flow (gpm)				
at 1147 psid	1400	1650	1550	1400
at 200 psid	5010	7115	6000	5010
Minimum NPSH (ft)	5	4	5	5
Design	ac motor	ac motor	ac motor	ac motor
Injection location	Above core sparger	Above core sparger	Above core sparger	Above core sparger
LPCS				
Flow (gpm)	5010	7115	6000	5010 128 psid
Design	ac motor	ac motor	ac motor	ac motor
Injection location	Above core sparger	Above core sparger	Above core sparger	Above core sparger

Table 2–2. (continued)

Parameter	Clinton	Grand Gulf	Perry	River Bend
LPCI				
Flow (gpm)	5050*3 24 psid	7450*3 24 psid	6500*3 20 psid	5050*3 24 psid
Design	ac motor	ac motor	ac motor	ac motor
Injection location	core shroud	core shroud	core shroud	
ADS–designated SRVs	7	8	8	7
RCIC				
Flow (gpm)	600	800	700	600
Design	Turbine	Turbine	Turbine	Turbine
Injection location	RPV head	Feedwater	RPV head	RPV head

Table 2–3. Comparison of BWR Mark III primary containment design characteristics

Parameter	Clinton	Grand Gulf	Perry	River Bend
Containment Design				
Total free volume (Mft^3)	1.80	1.67	1.42	1.43
Pool volume (Mft^3)	0.136	0.14	0.12	0.13
Containment volume/thermal power rating (ft^3/kW)	0.62	0.44	0.34	0.41

Table 2–3. (continued)

	Plant			
Parameter	Clinton	Grand Gulf	Perry	River Bend
Containment Design				
Containment pool volume/ thermal power rating (ft^3/kW)	0.047	0.037	0.034	0.045
Drywell/wetwell vents				
Number	102	135	120	129
Design pressure (psig)				
Internal	15	15	15	15
External	3		0.8	0.6
Drywell design pressure (psig)				
Internal	30	30	30	25
External	17	21	21	20
Maximum leakage (%vol/day)	0.65	0.35	0.20	0.26
RHR HXs				
Removal rate (MBtu/hr)	37.8*2	50.0*2	46.9*2	37.8*2
% of core thermal power	0.765	0.764	0.768	0.765
Containment spray flow rate (gpm)	3800*2	5650*2	5250*2	N/A
DBA peak response				
Drywell (psig)	18.9	22.0	22.1	19.2
Containment (psig)	8.7	11.5	11.3	7.6

Table 2-3. (continued)

	Plant			
Parameter	Clinton	Grand Gulf	Perry	River Bend
Containment Design				
Combustible gas control				
H_2 mixing drywell to containment (scfm)	800*2	1000*2	500*2	2600*2
Containment purge to SGTS (scfm)	300*2	65*2	50	2500
H_2 recombiner (scfm)	70*2	100*2	100*2	100*2
H_2 ignitors (no.)	115	90		104
Secondary containment	1.71	3.64	0.393	0.357
Volume (Mft^3)				
Annulus	—	—	0.393	0.357
Auxiliary building	—	3.04	—	1.15
Enclosure building	—	0.60	—	—
Fuel building	—	—	—	0.724
Operating pressure (in wg)				
Annulus	—	-0.40	-3.0	—
Auxiliary building	-0.25	-0.125	0.0	0.0
Enclosure building	—	0.0	—	—
Fuel building	—	—	—	-0.55
In-leakage rate (%vol/day)	0.65	—	100	—
Fission product control systems				
Capacity (ft^3/min)	4000*2	12,500*2	700*2	12,500*2

The ECCS systems associated with the BWR/6 plants are designed with sufficient net positive suction head (NPSH) to ensure pumping capability with the suppression pool water at saturated conditions. This feature becomes significant during accident sequences that challenge the heat capacity limits of the suppression pool. It is also important for sequences that involve containment venting or containment failure before vessel failure, conditions that could result in rapid containment depressurization with accompanying flashing of the suppression pool water.

The HPCS system delivers water to the reactor core through a peripheral ring spray sparger mounted inside the core shroud and above the core. The system is capable of supplying coolant over the entire range of reactor system operating pressures. The primary purpose of the system is to maintain reactor water inventory after small breaks that do not depressurize the reactor vessel. It also provides spray cooling heat transfer during sequences involving core uncovery. The HPCS system can draw a suction from either the condensate storage tank (CST) or the suppression pool. The transfer of suction from the CST to the suppression pool is fully automatic; it occurs on either the low CST or high suppression pool level. HPCS is automatically actuated on either lower reactor vessel water level (Level 2, which is well above the top of active fuel) or high drywell pressure (~2 psig).

Other high–pressure injection systems include the condensate/feedwater system, the reactor core isolation cooling (RCIC) system, and the control rod drive (CRD) hydraulic system. The RCIC and CRD systems are not part of the ECCS and have a lower makeup flow rate than the ECCS. However, in postulated high–pressure severe accidents, these systems may be important sources of makeup flow. The RCIC makeup flow rates are included in Table 2–2. The turbine–driven RCIC system delivers approximately 10% of the maximum HPCS flow rate. Although a survey of plant–specific CRD flow rates was not made, it is expected that the CRD injection rate during normal operations would be approximately 65 gpm. With optimum manual valve lineup, each CRD pump could probably deliver more than 100 gpm to the reactor vessel.

All of the Mark III plants include an automatic depressurization system (ADS) as part of the ECCS to depressurize the reactor vessel and allow low–pressure ECCS injection. Upon receipt of an ADS initiation signal, the ADS opens a subset of the safety/relief valves (SRVs). Vessel effluent is piped through the SRVs to spargers located near the bottom of the suppression pool. Discharging effluent into the bottom of the suppression pool maximizes the condensation of steam and the scrubbing of any nonnoble gas fission products in the effluent.

The SRVs are grouped into banks of valves that operate in unison to protect the vessel from overpressurization. Each SRV bank has a successively increasing pressure setpoint to provide graduated pressure relief with increasing reactor system pressure.

Two low–pressure injection systems, LPCS and LPCI, are provided as part of the ECCS. LPCS is an independent loop similar to the HPCS, except that LPCS is a low–pressure system, it does not have a dedicated independent power supply, and no suction path from the CST is available. LPCI is an operational mode of the residual heat removal (RHR) system and is a large capacity, low–pressure system.

RCIC is steam turbine driven and is capable of taking suction from either the CST or the suppression pool to supply high pressure makeup flow. Alternatively, a suction path from the RHR system can be established to support the steam–condensing mode of RHR. Unlike the ECCS, RCIC is only designed to operate with suction temperatures up to 140°F. Automatic actuation of RCIC occurs on a low reactor water level signal (Level 2) to provide makeup flow to the vessel. As with HPCS, suction transfer from the CST to the suppression pool occurs automatically.

The RCIC connection to RHR allows RCIC to pump condensate discharge from the RHR heat exchangers, produced during the RHR steam–condensing mode of operation, back to the vessel.

The steam-condensing mode of RHR, in conjunction with the RCIC return, is designed to condense all of the steam generated 1.5 h following a scram from 100% power. Except at Grand Gulf, the discharge line of RCIC injects into the vessel head spray connection. The head spray injection produces a steam-quenching effect, which depressurizes the reactor vessel. At Grand Gulf, RCIC injects into a feedwater line. A comparison of RCIC systems is provided in Table 2-2.

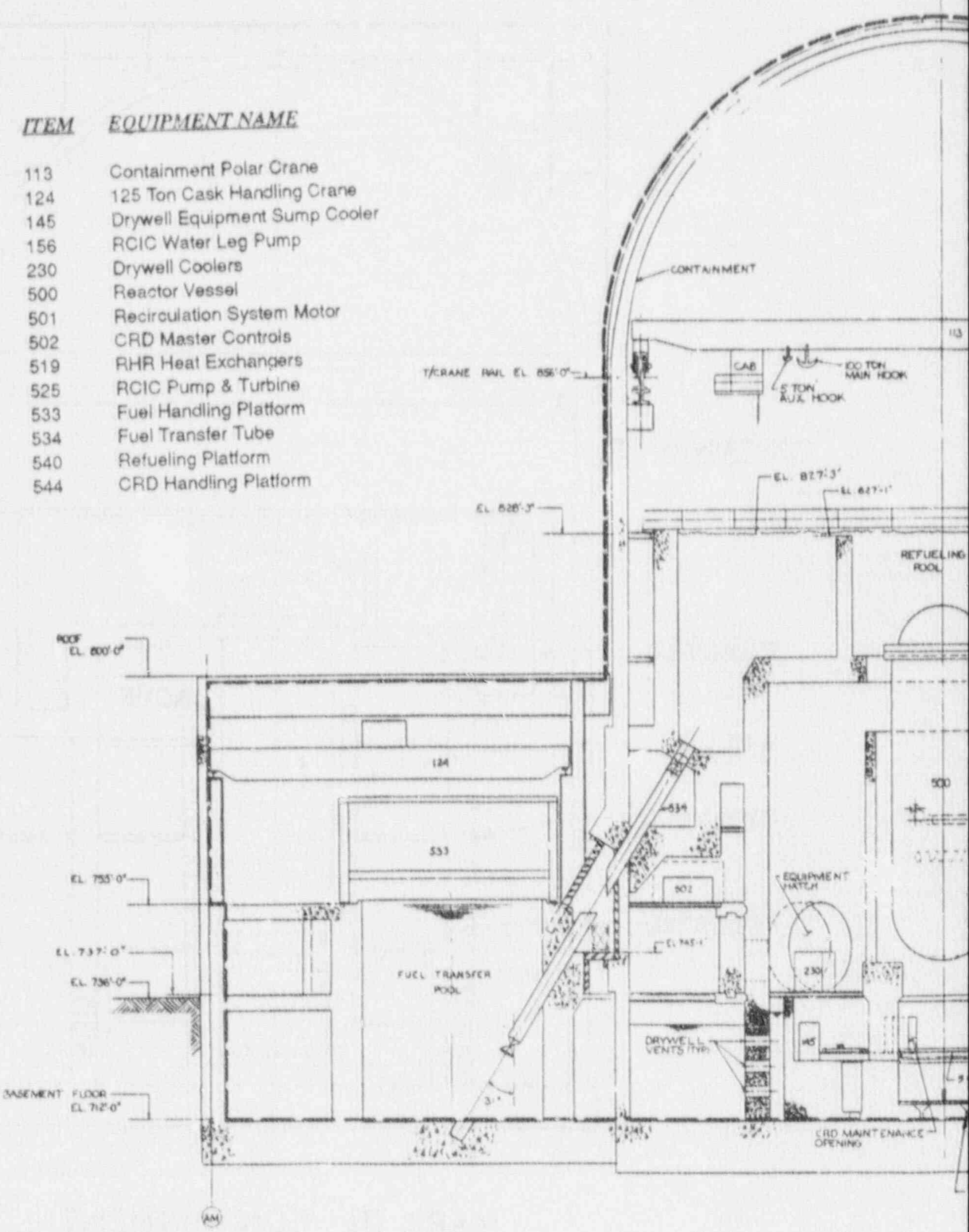
Reactivity control is provided by cruciform-shaped bottom entry control rods. The reactor protection system (RPS) monitors several system parameters and, if necessary, generates a reactor scram signal to rapidly insert the control rods into the core. Anticipated transient without scram (ATWS) protection is provided by the alternate rod insertion (ARI) and recirculation pump trip (RPT) functions. The ARI system provides a backup scram signal should the electrical portion of the RPS fail. The ATWS RPT function trips the field breakers to the recirculation pump motors, rapidly increasing the core void fraction, and thus reducing core thermal power to the natural circulation rod line limits. Redundant reactivity control is provided by the standby liquid control system (SLCS). The SLCS is manually initiated from the control room to pump a sodium pentaborate solution into the reactor if the reactor cannot be shut down, or be kept shut down with the control rods.

2.2 Containment Design

The BWR Mark III containment consists of two regions, the drywell and the wetwell (see Figure 2-1). The wetwell consists of an annular region around the drywell and is separated from the drywell by the drywell and weir walls. The drywell atmosphere is in contact with the suppression pool water surface in the annular region between the weir wall and the drywell wall. When the drywell airspace is pressurized, the suppression pool water is depressed in the drywell and gases from the drywell are forced through submerged holes in the drywell wall into the suppression pool. Because the holes in the drywell wall are below the normal water level of the pool, all effluent entering the wetwell passes through the water in the suppression pool, except for the normal suppression pool bypass leakage. The benefits of the suppression pool include (a) scrubbing of the non-noble gas fission products, (b) a source of water for the ECCS, (c) cooling of the noble gases, and (d) a large heat sink for steam condensation. For example, a 140,000 ft^3 pool is capable of absorbing 100 MW-hr of energy with only a 40°F rise in temperature.

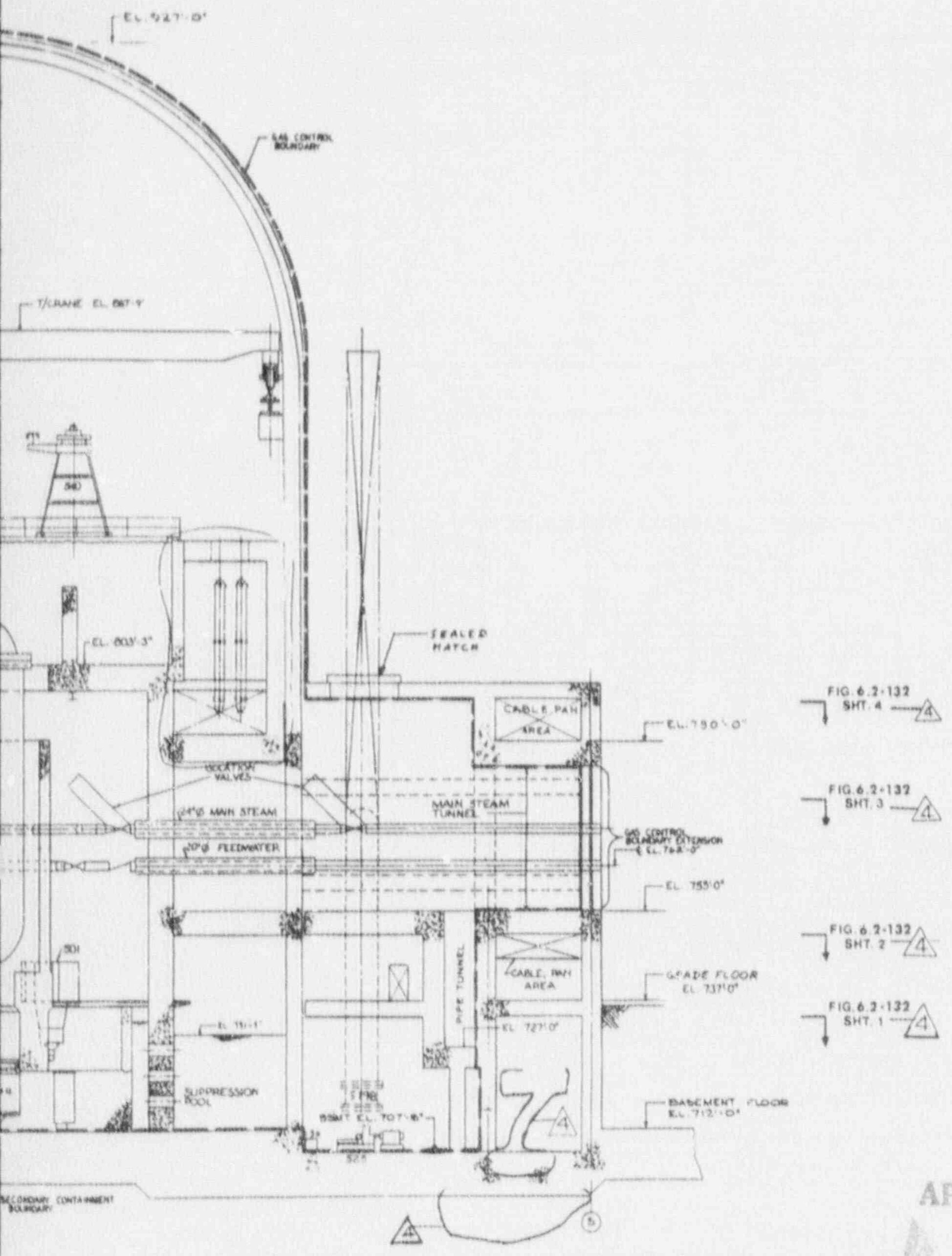
Table 2-3 summarizes the general containment design information for the four Mark III plant sites. The Mark III containment has a much larger free volume (1.8×10^6 ft^3) than previous BWR designs (0.5×10^6 ft^3 for Mark IIs and 0.2×10^6 ft^3 for Marks Is). Because of the larger size of the Mark III containment, containment inerting was not included in its design, and systems are provided for hydrogen control during design basis accidents.

Figures 2-1 through 2-4 show the general containment layout at each of the Mark III units studied. Two basic containment construction types are employed. At Perry and River Bend the containment boundary is a free-standing steel shell that is contained within a concrete reactor building. The Clinton and Grand Gulf containments are both constructed from a steel-lined reinforced concrete shell. Grand Gulf, which was chosen as the Mark III NUREG-1150 study plant, has a concrete containment boundary consisting of the foundation mat, the cylindrical wall, and the reactor building dome. The flat circular foundation mat is 9 ft 6 in. thick and has an outside diameter of 134 ft. The foundation mat supports a right circular cylindrical wall 3 ft 6 in. thick, with an inner radius of 62 ft. and a height of 144 ft 9 in. from the top of the foundation mat to the springline. Located above the cylindrical wall is the hemispherical shell of the containment dome; 2 ft 6 in. thick with an inside radius of 62 ft. The inner surface of the concrete wall and dome is completely lined with welded steel plate to form a gas-tight barrier. The volume within the containment boundary consists of the drywell, the wetwells, and suppression pool. The drywell is connected to the wetwell by 28-in. diameter vents in the cylindrical drywell wall (made of reinforced concret



ITEM	*EQUIPMENT NAME*
113	Containment Polar Crane
124	125 Ton Cask Handling Crane
145	Drywell Equipment Sump Cooler
156	RCIC Water Leg Pump
230	Drywell Coolers
500	Reactor Vessel
501	Recirculation System Motor
502	CRD Master Controls
519	RHR Heat Exchangers
525	RCIC Pump & Turbine
533	Fuel Handling Platform
534	Fuel Transfer Tube
540	Refueling Platform
544	CRD Handling Platform

Figure 2–1. Clinton containment layout.



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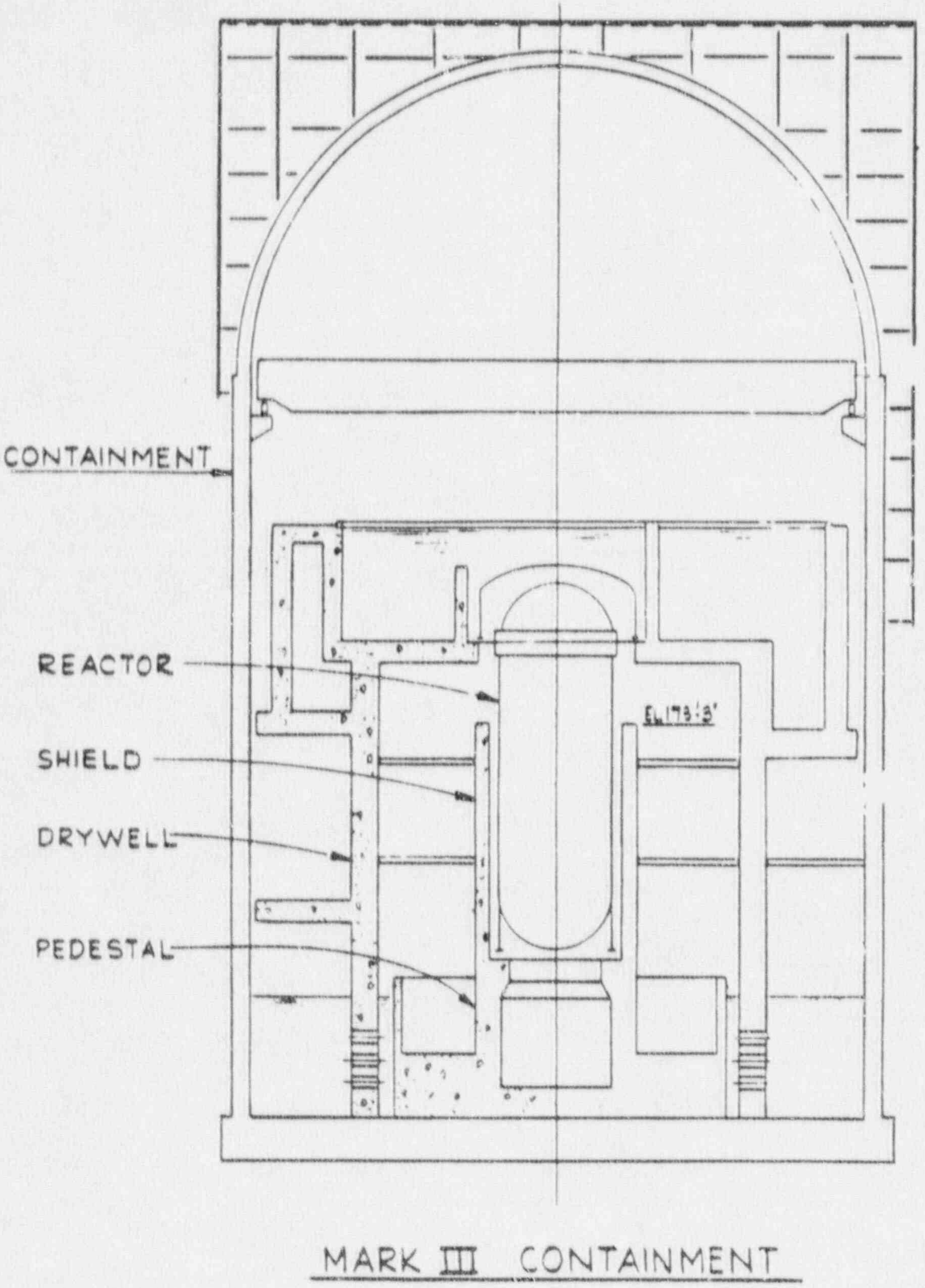


Figure 2–2. Grand Gulf containment layout.

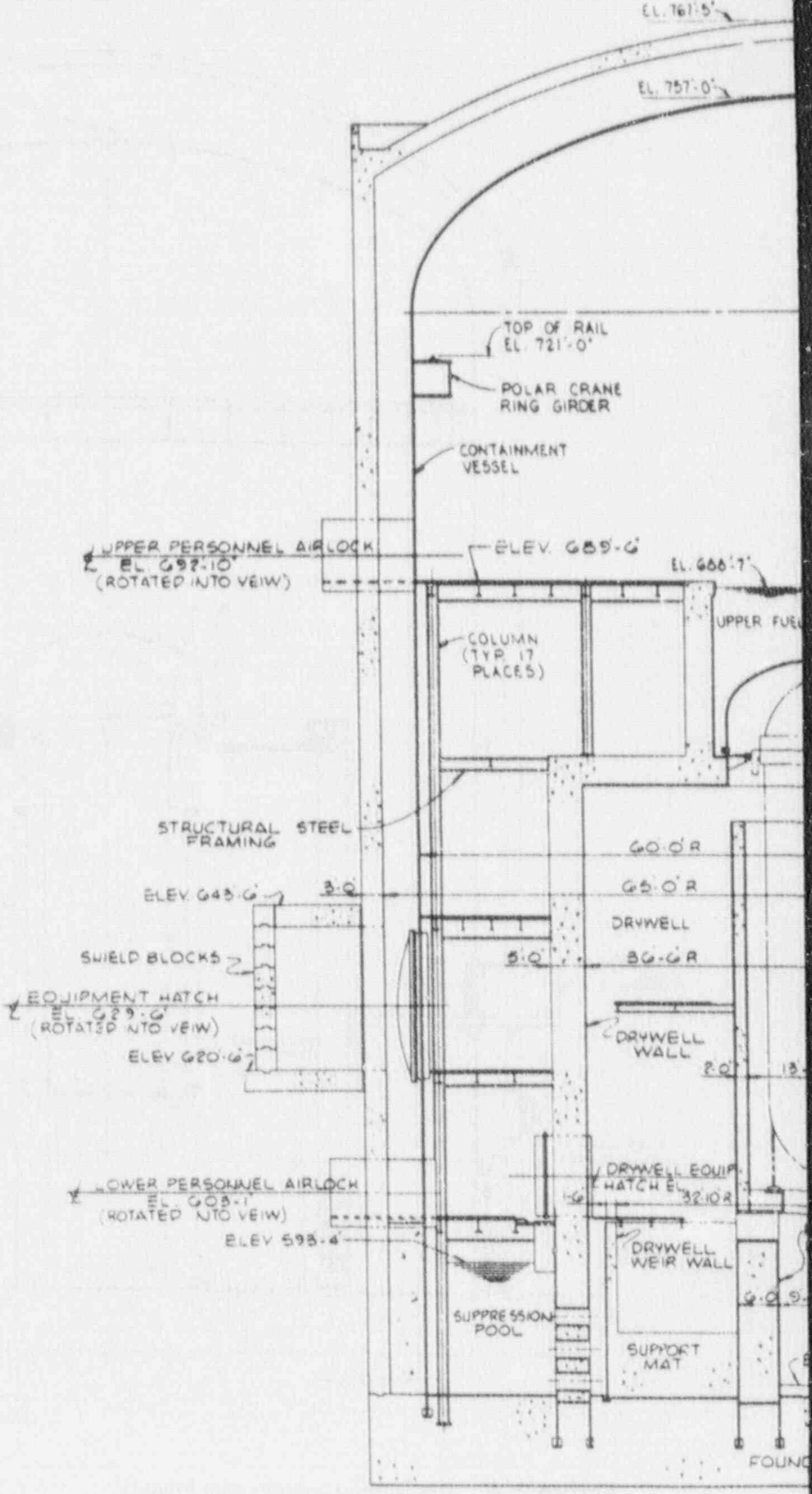
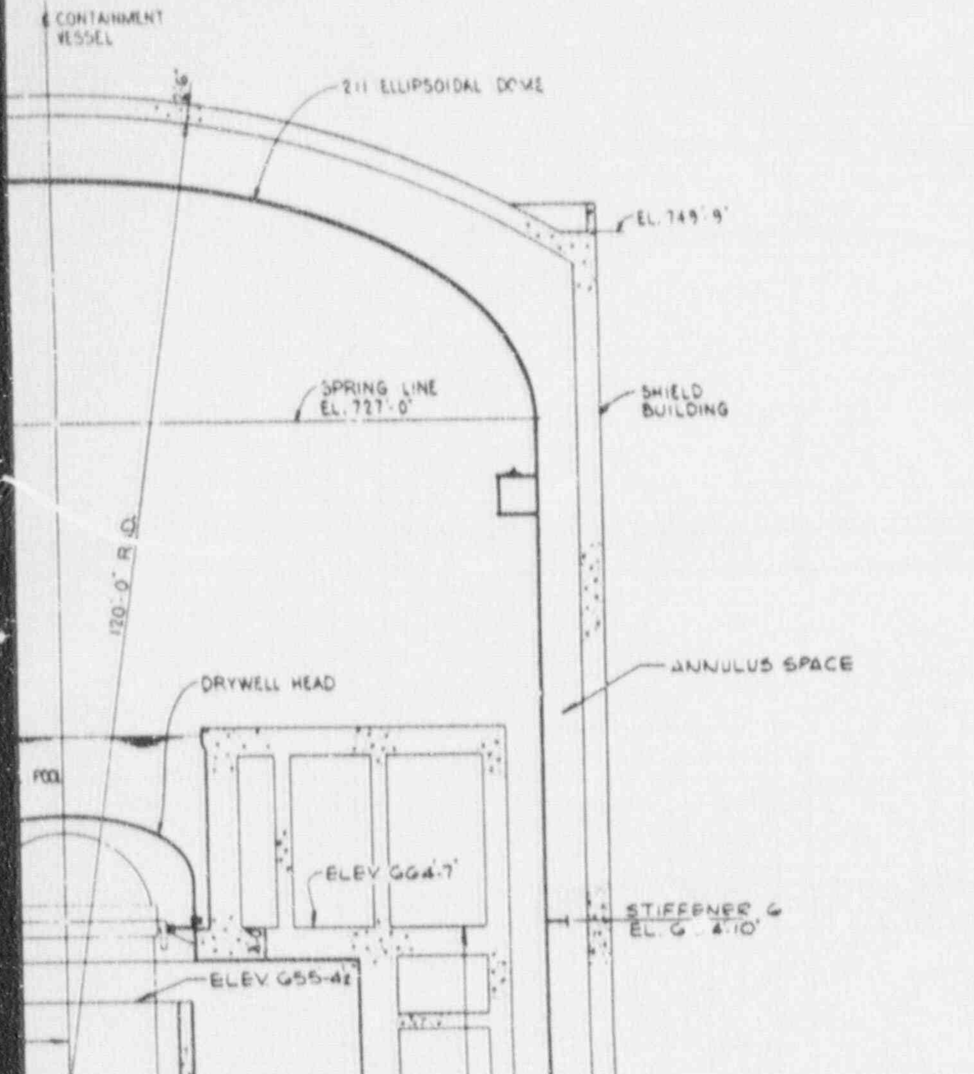


Figure 2–3. Perry containment layout.



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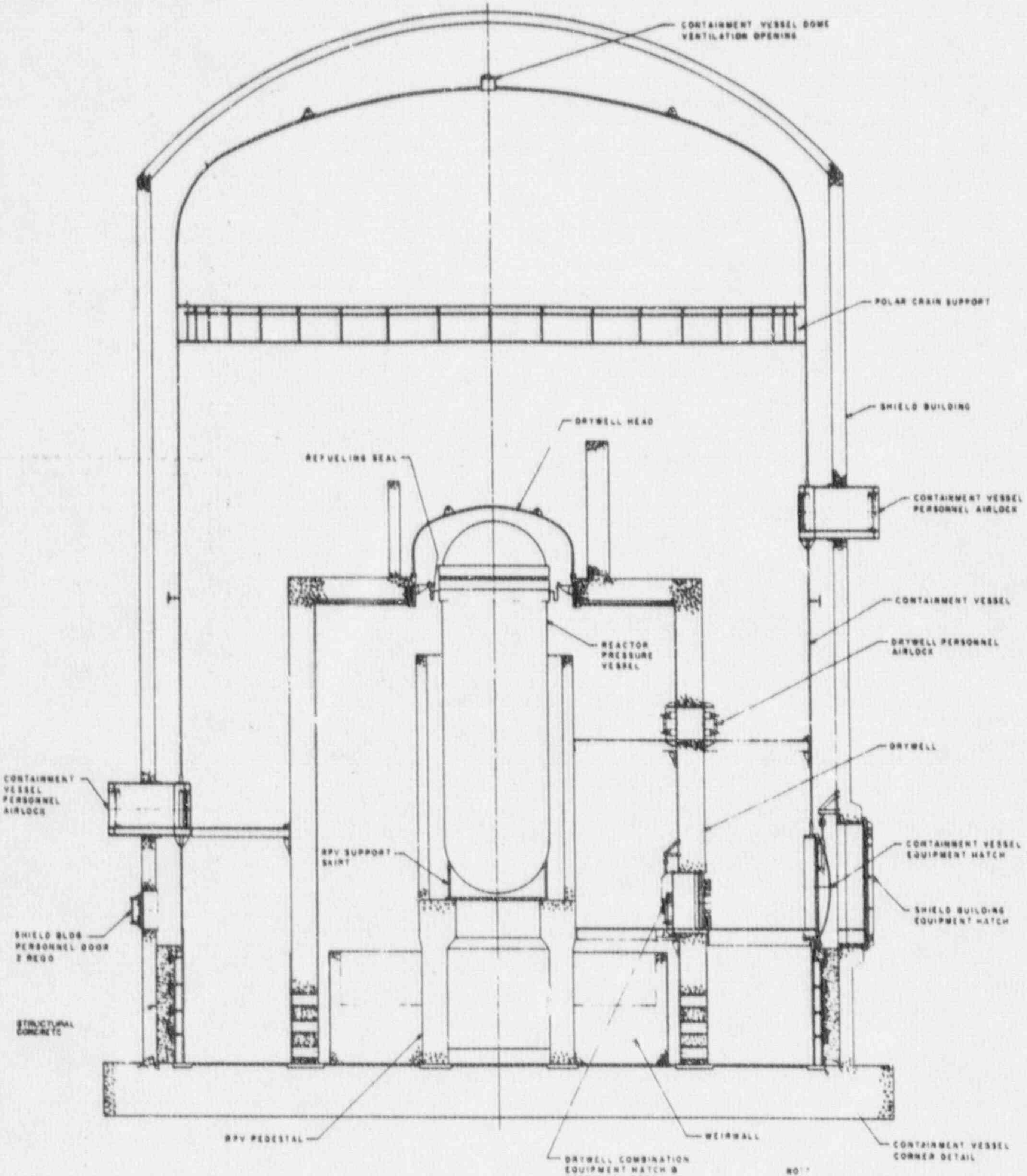

Figure 2–4. River Bend containment layout.

located below the surface of the suppression pool. A water seal is maintained over the vents by a 17-ft weir wall located inside of the drywell wall. Steam released within the drywell boundary is generally relieved through the annulus between the weir wall and drywell wall, out through the submerged vents, and into the wetwell water volume, where the remainder of the steam is condensed.

The SRVs discharge through quenchers located at the bottom of the suppression pool. Vacuum breakers located in the drywell on the SRV tailpipes prevent the tailpipes from drawing water up from the suppression pool as the steam in the lines condenses following SRV closure.

The Grand Gulf reactor vessel is supported by a 5.75-ft thick cylindrical pedestal. Exterior to the pedestal is a 9-ft thick concrete support mat that sits above the foundation mat and extends from the reactor support pedestal to the base of the drywell weir wall. The cavity within the pedestal is 21 ft 2 in. in diameter and 6 ft 3 in. deep from the basemat to the top of the reactor pressure vessel (RPV) pedestal mat. Molten core debris from a postulated failure of the RPV bottom head would likely be contained within the pedestal cavity. Should corium attack cause the pedestal to fail, a resulting vessel movement would likely initiate a suppression pool bypass because of seal failures of attached piping at the drywell and containment boundaries.

During normal plant operations at Grand Gulf, equipment and floor drains in the drywell drain to sumps located in the in-pedestal cavity. There are two 460-gal sumps, each of which is equipped with two 50-gpm ac-powered level control pumps. Each sump has a single 4-in. discharge line common to the two level control pumps. This discharge line is equipped with a pair of normally open, air-operated isolation valves in series. These valves will automatically close during certain conditions, namely, reactor vessel low water level—Level 2, high drywell pressure, loss of control air, or loss of power to the solenoid pilot valve, and can also be closed by remote manual operation from the control room. Fluid from the two active sumps is normally discharged to two 5000-gal auxiliary building drain transfer tanks, and from there to equipment and floor drain collection tanks in the radwaste building. The drywell floor drain collection sump has four floor drain lines from the 100 ft 9 in. level of the drywell. The floor drains are each 4-in. lines that feed two 8-in. drain headers, one of which is reduced to 6 in. before discharging to the floor drain sump. During severe accidents, the sump discharge lines will isolate and the sump pumps may experience loss of power, allowing the sumps to overflow. The drain lines into the sump will provide a flow path for water accumulating on the drywell floor. Because the sumps are equipped with well-fitted, but not water-tight steel plate access covers, flooding of the pedestal will be possible before water levels on the drywell floor reach the pedestal access and CRD removal opening. The rate at which flooding of the pedestal cavity occurs is limited by the rate of leakage from the sump vent (approximately a 1/2-in. line) or from around the sump cover. There should also be a flow path from the pedestal cavity floor into the sump, but it is not shown in the Grand Gulf FSAR. As discussed later in this report, the rate at which the cavity can be filled through the floor drain lines is an important consideration in determining the potential for a steam explosion should a severe accident progress to the point of RPV failure.

The containment internal design pressure is 15 psig for all Mark IIIs. There is a significant margin between the design pressure and the maximum design basis accident (DBA) pressure for both the containment and drywell structures. The peak containment pressures calculated for design basis accidents occur during the long-term phase of a main steamline break when the peak suppression pool temperatures are reached. Several analyses have estimated the Mark III ultimate containment pressures to be significantly higher than the design pressure, with values ranging from 55 to 100 psig.[1] The higher ultimate strengths are associated with the free-standing steel designs of Perry and River Bend.

All of the Mark III plants, with the exception of River Bend, have a containment spray operating mode for their residual heat removal (RHR) systems. In addition to the LPCI mode discussed earlier, RHR can also be used to remove energy from containment when aligned in either the suppression pool cooling mode or the containment spray mode. Two RHR pump trains circulate suppression pool water through two heat exchangers and back to either the suppression pool or the containment spray nozzles. Containment sprays are initiated automatically during a loss-of-coolant accident (LOCA) ten minutes after the containment pressure exceeds the spray initiation setpoint. The containment sprays will condense steam in the containment and scrub non-noble gas fission products. Vacuum breakers are installed in the drywell, which communicate with the suppression pool air space to control rapid weir wall overflow in a large break LOCA. Drywell vacuum relief is not required to assist in hydrogen dilution or to protect the structural integrity of the drywell following a large break LOCA.[2] (River Bend has neither a containment spray system nor drywell vacuum breakers. However, it does have a unique safety-grade fan cooler system.) The Perry FSAR specifies elemental and particulate iodine removal rates of 2.5/h and 0.88/h, respectively for the containment spray system. The Grand Gulf containment spray system elemental and particulate iodine removal rates are stated as 6.7/h and 1.66/h, respectively. The Clinton FSAR did not address the use of containment sprays for fission product control.

Combustible gas control is provided by hydrogen mixing systems, containment purge systems, post-LOCA hydrogen recombiners, and hydrogen ignition systems (HIS). Hydrogen mixing systems are installed in each of the four Mark III plants, although the specific designs vary from plant to plant. At Grand Gulf and Perry, containment air is forced into the drywell where it mixes with hydrogen in the drywell volume. Return air flow to the containment passes through the suppression pool vents. At Clinton, air from the drywell is exhausted to spargers located below the suppression pool surface and return air flows through the containment vacuum breakers into the drywell. At River Bend, fans in the upper drywell exhaust to the containment air space while return air enters through two lines located just above the suppression pool. Containment purge is provided at each of the plants. The purge system utilizes the filter trains of the standby gas treatment systems (SGTS) (*annulus exhaust gas treatment system* at Perry) to filter releases from containment. Containment makeup air is provided by air compressors that draw from outside air.

The post-LOCA hydrogen recombiners, which are present at each of the plants, are designed to control long-term containment hydrogen concentrations produced as a result of:

1. Metal-water reactions involving the zirconium fuel cladding and the reactor coolant
2. Radiolytic decomposition of the post-accident emergency cooling solutions
3. Corrosion of metals by solutions used for emergency cooling or containment spray.

If ac power is available, the recombiners can be used from the onset of an accident in which severe core damage has resulted. The recombiners cannot, however, control the large-scale generation of hydrogen that would be expected to occur during a core degradation event.[3] Their recombination rate of 100 scfm was designed to protect against the hydrogen generation rates occurring during and after a design basis LOCA, not against the higher rates occurring during the core degradation phase of a severe accident. At these higher rates, hydrogen production will overwhelm the recombiners, allowing flammable concentrations to be reached, and the recombiners to become a nondistributed ignition source.

Hydrogen control at the rate required during postulated degraded core accidents relies, instead, on distributed ignition systems that are installed at each of the plants. There are ac-powered ignitors distributed throughout the containment and drywell, designed to burn the hydrogen in such a manner that containment overpressurization from hydrogen combustion does not occur.

3. DOMINANT CORE DAMAGE SEQUENCES

In this section, dominant accident sequences leading to core damage are discussed, with Grand Gulf being used as the Mark III reference plant. The latest NUREG/CR-4550 analysis of Grand Gulf (July 1989) has defined the dominant sequence classes to be those with a frequency greater than 1.0×10^{-8} per reactor–year.[4] Four classes of sequences have been identified that meet this criterion. They are short–term station blackout (SBO), long–term SBO, anticipated transients without scram (ATWS), and transients with loss of the power conversion system (PCS).

The importance of each class of sequence with respect to total core damage frequency is shown in Table 3–1. The largest contributors to core damage frequency are clearly those sequences involving SBO. Next in importance are the ATWS sequences (designated as TCUX). Least significant among the dominant sequences are those that result from transients with a loss of the PCS, designated as TQUX. Together these sequence classes contribute more than 99% of the total Grand Gulf core damage frequency. Note that the Draft NUREG–1150 Grand Gulf core damage profile differs significantly from past Grand Gulf risk assessments (RSSMAP and IDCOR studies), because of the predominance of SBO as a contributor to core damage instead of non–blackout sequences.

3.1 Plant Damage State Groupings

For the purpose of the accident progression analysis, it is convenient and useful to group accident sequences with similar characteristics into plant damage states (PDSs). Reference 5 used 12 PDSs to encompass all of the Grand Gulf dominant accident sequences, as identified in Table 3–2. For more details, refer to Reference 5.

There are five dominant PDSs that together comprise 98% of the total core damage frequency (CDF) at Grand Gulf. The dominant PDS (PDS 1, contributing 79% of CDF) is initiated when a loss of offsite power (LOSP) generates a successful reactor scram, followed by a loss of all three divisions of onsite ac power. The SRVs function to relieve the pressure transient caused by the closure of the turbine stop valves, and reactor water level drops below Level 2 as a result of decay heat–induced boiling. The automatic depressurization system (ADS) fails. RCIC fails to start and the core is uncovered, resulting in core damage with the reactor at high pressure.

Table 3–1. Grand Gulf dominant accident sequence contributions to core damage frequency

Accident Class	Sequence Designator	Mean Frequency (per ry[a])	Contribution to Core Damage Frequency (%)
Short–term SBO	TBU or TBUX	3.8E–06	94.2
Long–term SBO	TB	1.1E–07	2.6
ATWS	TCUX	1.1E–07	2.6
Loss of PCS	TQUX	1.3E–08	<1

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a. Reactor year.

Table 3–2. Grand Gulf plant damage states

PDS Group	Sequence Type	Mean Frequency (per ry[a])	Contribution to CDF (%)
PDS 1	Short–term SBO	3.2E–06	79
PDS 7	Short–term SBO	4.3E–07	11
PDS 3	Short–term SBO	1.8E–07	4
PDS 8	Long–term SBO	6.6E–08	2
PDS 10	Long–term ATWS	6.3E–08	2
PDS 9	Short–term ATWS	5.0E–08	1
PDS 2	Short–term SBO	4.8E–08	1
PDS 4	Long–term SBO	3.9E–08	1
PDS 11	Short–term loss of PCS	1.2E–08	<1
PDS 6	Long–term SBO	2.0E–09	<<1
PDS 5	Long–term SBO	1.2E–09	<<1
PDS 12	Long–term loss of PCS	2.7E–10	<<1

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a. Reactor year.

The second most significant PDS (PDS 7) is a short–term SBO and is responsible for 11% of the total CDF. In this PDS, offsite power is not recoverable because of common mode failure of the station batteries, which also prevents operation of the diesel generators. Core damage occurs in the short term with the reactor at high pressure; depressurization and RCIC operation are not possible because of the loss of dc power.

The third largest contributor to CDF, PDS 3, another short–term SBO (LOSP and failure of the diesel generators), contributes 4% of the total CDF. Core damage occurs at high pressure and containment heat removal via the containment sprays is not available in the event that ac power is recovered. Core damage results because RCIC and ADS fail. By using the available dc power, the fire water system (FWS) can be used for injection if the reactor can be depressurized.

The next most significant PDS (PDS 8) is a long–term SBO that contributes 2% of the total CDF. RCIC operates properly in this PDS until the RCIC turbine trips on high backpressure. During this time, the SRVs are properly limiting reactor pressure. After the RCIC turbine trip, the reactor is depressurized and firewater is connected as a source of reactor water makeup. The SRVs eventually fail due to battery depletion, but the reactor is able to be depressurized by using the RCIC steam line. However, the operators fail to maintain pressure below the firewater shutoff head, and core damage results when firewater injection is lost. Core damage occurs at high pressure and offsite power is not recovered within 12 hours and then is not recoverable because of the subsequent loss of dc power caused by battery depletion.

The fifth largest contributor to CDF is PDS 10, a long-term ATWS involving closure of the main steam isolation valves (MSIVs), contributes 2% of the total CDF. Coolant injection is lost late because of HPCS failure. Top cutsets involve mechanical failures of the pump and faults related to room heatup. Core damage occurs in the long term and with the vessel at high pressure because of operator failure to depressurize.

The remaining PDSs contribute <2% of the total CDF and are not discussed further.

4. CONTAINMENT CHALLENGES AND FAILURE MODES

This section provides a discussion of the containment challenges and failure modes resulting from the PDSs described in Section 3. These challenges include gradual (quasistatic) overpressurization, hydrogen–induced overpressurization, steam spike–induced overpressurization, and overpressurization as a result of gases generated by core–concrete interaction (CCI).

4.1 Inadequate Containment Heat Removal

Inadequate containment heat removal will cause the containment to pressurize gradually over a period of several hours to several days. Pressurization occurs because the containment heat removal capability is inadequate for the rate at which energy is being added, resulting in eventual saturation of the suppression pool and loss of the pressure suppression function. The associated containment failure mode is leakage or rupture that is sufficient to prevent further pressurization. The potential for mitigation is dependent on (a) reducing the rate of energy addition to containment, (b) enhancing containment venting capabilities, or (c) increasing containment heat removal capability.

4.1.1 Definition of Challenge. Overpressure challenges due to an imbalance between the energy addition rate to containment and the energy removal rate from containment typically are the result of either loss of long–term heat removal (TW) or ATWS sequences. The most recent Draft NUREG/CR–4550 analysis of Grand Gulf found TW to be a nondominant sequence, principally because early containment failure does not present a challenge to core integrity at Grand Gulf.[4] In this respect, Grand Gulf differs from the earlier Mark I and Mark II designs, in which containment failure can lead to a loss–of–coolant injection. This result may be generic to the Mark III plants, because the BWR/6 ECCS pumps are capable of pumping saturated water, and because the likely containment failure location may not present an operability threat to equipment located in the auxiliary building. However, ATWS is significant and results in both long– and short–term plant damage states. The long–term plant damage state, by definition, will result in suppression pool heating of sufficient duration to cause an early overpressure challenge, i.e., before core degradation. However, the CDF associated with ATWS at Grand Gulf may have been overestimated, as discussed below.

In the ATWS sequences analyzed for Grand Gulf in Draft NUREG/CR–4550,[4] failure to actuate the SLCS was combined in the human factors analysis with failure to depressurize the RPV; these two events, although separate on the event tree, were treated as one dependent event in the sequence cut sets. If failure to actuate the SLCS were to be treated as a separate event in the sequence cut sets, the mean ATWS sequence frequency could decrease by approximately one order of magnitude from the current NUREG/CR–4550 result.[4] As a result of combining the SLCS actuation failure with failure to depressurize, no SLCS hardware failures appear in the sequence cut sets. Table 4.8–4 in the 1989 draft of NUREG/CR–4550 indicates that these probabilities are dependent, although treating them as independent (i.e., multiplied together) may be more accurate.[4] If SLCS initiation failure were separated from failure to depressurize, and a larger human error probability were used, the SLCS hardware failures could become more important

The two dominant cut sets in the long–term ATWS plant damage state involve failure of the HPCS suction transfer from the CST to the suppression pool (sequence 74–B in Reference 4). The fault tree model used to generate these cut sets appears to be excessively conservative and, although the HPCS fault tree does not explicitly show it, the discussion in Reference 4 indicates that this transfer is questioned at the point of low level in the CST, not high level in the suppression pool (which occurs first).[4] With a *minimum* of 100,000 gal in the CST reserved for HPCS, and with HPCS injecting at ~1000 gpm (the reactor is not depressurized in this sequence), low level in the CST would not be reached for at least

100 min. With continued steaming to the suppression pool at 18–20% of rated power [level assumed to be controlled at top of active fuel (TAF)], the containment will be overpressurized or vented before the CST is depleted (this assumes that the automatic HPCS transfer to the suppression pool on high pool level either failed or was overridden). Therefore, the findings presented in this report conclude that sequence 74–B is not a contributor to CDF. It may contribute to early containment overpressurization but should not result in core damage, because neither venting nor containment failure (failure assumed to be at the containment springline) should impair injection.

Another failure that appears in the cut sets for long–term ATWS is loss of HPCS room cooling, specifically, from failures in the standby service water (SSW) system. However, the text of Reference 4 states that HPCS will continue to operate for 12 hours following a loss of room cooling. Again, the containment would be overpressurized long before this time or the reactor would be successfully shut down. Neither of these outcomes would result in core damage. Also, it is not credible that an ATWS sequence could continue for 12 hours without the reactor being shut down by either manual rod insertion or by SLCS injection (even with failure of the SLCS pumps, boron can be injected via alternate means, or repairs can be made to the SLCS).

Based on prior understanding of the long–term ATWS sequence, and upon discussions with personnel from Sandia National Laboratory,[a] a dominant mode of HPCS failure was thought to be failure of the operator to override the automatic suction transfer to the suppression pool on high pool level. Failure to override this transfer would be postulated to fail HPCS, because the hot suppression pool water would provide inadequate lube oil cooling. However, this failure does not appear in *any* ATWS cut sets; indicating the high probability that it was not modeled. Mary Drouin of Science Applications International Corporation, who performed the Grand Gulf front–end analysis described in Reference 4, later confirmed this assumption during a telephone conversation. She indicated that this transfer was not modeled as a HPCS failure, because the HPCS motor bearings could withstand a fluid temperature of 350°F for up to 24 hours; seal failure would occur prior to bearing failure, but seal failure was not postulated to fail HPCS.

Furthermore, the existing analysis is based on Revision 3 of the BWR Owners Group Emergency Procedure Guidelines (EPGs). Revision 4 would require significant revisions to the ATWS event trees. Under the new EPGs, injection would be maintained from the CST and RPV level control would first be attempted using CRD flow and systems that inject outside the core shroud (this assumes that the feed pumps are unavailable due to closure of the MSIVs). At Grand Gulf, this implies use of only the RCIC, CRD, and condensate systems. Because the condensate system is a low–pressure system, and RCIC and CRD are inadequate to maintain level above the minimum steam cooling water level (MSCWL) defined in the EPG, the result is that depressurization would be called for early in the sequence, even if HPCS and RCIC were available. After depressurization, several systems would be available for level control. Because of the high injection flow rates available at low pressure, control of flow rate and reactor power would be more difficult, hence human error probabilities should also change because of the increased complexity of actions required to maintain level control. The result is that the existing ATWS sequences are expected to be out of context with Revision 4 of the EPGs.

Thus, the Reference 4 estimate of ATWS core damage frequency appears to be overly conservative. Requantification could eliminate ATWS as a dominant core melt challenge and, in turn, the associated containment failure mode of overpressure prior to core damage. However, for the present, this mode of failure must be considered as a significant containment challenge, especially in light of the Grand Gulf–specific nature of the analysis in this report.

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[a] Informal meeting between Sandia NUREG/CR–4551 analysts and CPI contractors, June 1989.

4.1.2 Potential Failure Modes. The specific containment failure mode associated with inadequate containment heat removal will be leakage or rupture caused by quasistatic overpressurization. The most likely failure location is at the head knuckle for steel containments, although both the cylinder wall and the personnel airlock have also been identified as possible failure locations.[1] (Reference 1 summarizes the probable containment failure locations for quasistatic overpressurization.) Estimated failure pressures range from 55 to 100 psig, depending on analysis technique and failure criteria used. The Perry containment, with its free-standing steel construction, is predicted to have an ultimate pressure of 100 psig, with failure occurring at the head knuckle. The Grand Gulf containment, with its reinforced concrete design, is predicted to fail at 55 psig, with failure occurring at the cylinder near the springline.

4.1.3 Potential for Mitigation. Containment venting could be used to protect the containment from inadequate heat removal. Venting procedures that are in accordance with the EPGs are in place at Grand Gulf, and the existing vent path could reasonably be expected to prevent overpressurization during ATWS scenarios. The vent path is composed of two 20-in. lines made up of hard pipe and heating, ventilating, and air conditioning (HVAC) ducting. Failure of the HVAC duct portion of the path would not necessarily create adverse environmental conditions in the auxiliary building that would force an end to recovery efforts.

4.2 Hydrogen–Related Challenges

Hydrogen deflagrations and detonations could lead to containment failure from both quasistatic and dynamic overpressurization. Prolonged diffusion burns can cause failure of sealing materials in the drywell, and at the containment boundaries. The consequences of failures resulting from hydrogen combustion are aggravated by the possibility of simultaneous failure of both the containment and drywell. This creates the possibility of a highly energetic release that is unfiltered by suppression pool scrubbing. The probability that combustion will occur and create a pressure load capable of failing containment is relatively high for the dominant Grand Gulf plant damage states.[6] Because of the relatively high probability of combustion–induced overpressure failures, and because of the severity of the resulting releases, hydrogen–related challenges are the most risk–significant category of containment challenge at Grand Gulf.

Hydrogen–induced overpressurization is prominent at Grand Gulf because the containment is not inerted, and because the ac–powered HIS will not function during SBO sequences, which dominate the core damage and risk profiles. During short–term SBOs, hydrogen deflagrations and detonations can occur as the result of spontaneous ignition. During some long–term SBOs, the containment is postulated to become steam–inerted. However, should the plant recover power after the onset of core damage, hydrogen deflagrations and detonations can still occur, because containment spray operation (if available) will condense steam from the containment atmosphere. An ignition under these circumstances is likely and could have severe consequences due to the large amount of hydrogen available for combustion.

Actions with the potential to reduce the consequences of combustion are: (a) ensuring ignition occurs while hydrogen concentrations are within the range of 4–6 v/o, (b) post–accident inerting of the containment, and (c) removal of hydrogen and oxygen (along with fission products) via containment venting.

4.2.1 Definition of Challenge. Oxidation of Zircaloy and stainless steel core components during core damage produces the hydrogen that threatens containment integrity in severe accidents. The source of Zircaloy is the fuel cladding and channel boxes. The stainless steel in the control rod sheaths may also react to generate hydrogen, but to a much lesser extent. Several analyses have been documented that predict the amount of hydrogen generated during postulated core damage events at Grand Gulf. The results obtained differ widely depending on the analytical tool and key assumptions used in developing the analytical model.

IDCOR published (in March of 1985) the results of MAAP calculations for T_1QUV, AE, T_{23}QW, and T_{23}C sequences.[7] These sequences, as defined by IDCOR, differ substantially from the current Draft NUREG–1150 dominant core damage sequences, making useful comparisons difficult. However, the T_1QUV sequence is similar enough to the Draft NUREG–1150 short–term SBO sequence to provide useful insights into the kinds of results that are obtained with the MAAP code. The IDCOR T_1QUV sequence assumes an initiator that results in the complete loss of injection when both the main feedwater and condensate systems are unavailable. Thus, neither the primary injection system nor containment heat removal is available. The key difference between the IDCOR sequence and the Draft NUREG–1150 short–term SBO sequence is that the IDCOR analysis assumes the operators depressurize the reactor when reactor water level drops to Level 1 (~20–30 in. above TAF). Core damage occurs at low pressure, resulting in the release of up to 0.05 lbm/sec of hydrogen gas. Because MAAP assumes channel blockage by molten fuel and cladding, the reaction is predicted to become limited by steam starvation, and to result in the release of only 10 lbm of hydrogen from in–vessel production sources. A total release of 3000 lbm is predicted, nearly all of which results from reactions occurring in the debris bed after vessel failure.

IDCOR ran a variation of the T_1QUV sequence to study the effects of failure to depressurize on the amount of hydrogen generated. This sequence, in which core damage occurs at high pressure, is very similar to the short–term SBO sequences currently responsible for 94% of the core damage frequency at Grand Gulf. With no depressurization before vessel failure, MAAP predicts 430 lbm of hydrogen will be generated by in–vessel oxidation, as opposed to 10 lbm when the vessel is depressurized at Level 1. The total amount of hydrogen produced in this case is also higher, at 3,200 lbm as opposed to 3000 lbm when the vessel is depressurized at Level 1.

Battelle has published the results of STCP calculations for short–term SBO, long–term SBO, and ATWS sequences.[8] Their short–term SBO analysis (TBS in their nomenclature), which is very similar to the IDCOR T_1QUV sequence with depressurization at Level 1, shows 39% of the active fuel cladding will oxidize before vessel breach. The referenced report does not state the mass of hydrogen released, either before vessel breach or later, during reactions in the debris bed. However, the long–term SBO sequence is stated to result in the oxidation of 32% of the active fuel clad, 12% of the Zircaloy in the channel boxes, and 10% of the stainless steel in the control blade sheaths, for a total of 26% of the Zircaloy in the core. With only 32% of the clad reacted, this sequence resulted in the generation of 2000 lbm of hydrogen by the time of vessel breach. Because the long–term SBO sequence assumes injection from RCIC until battery failure at 6 hours, and subsequent core damage at high pressure due to failure to depressurize, this sequence is not directly comparable to any of the IDCOR analyses described above.

The Draft NUREG–1150 analysis of the short–term SBO sequence is based on preliminary MELCOR and BWR–LTAS calculations.[a] These calculations have not yet been published, but results have been made available to CPI personnel in the form of a pre–draft report. The MELCOR portion of the analysis, used to determine containment response after core uncovery, predicts an average hydrogen production rate of 0.24 lbm/sec from the onset of Zircaloy oxidation until vessel breach, which occurs approximately 3 hours later. A total of 2700 lbm of hydrogen is generated before vessel breach, followed by an additional 820 lbm after vessel breach. Another 1320 lbm is predicted to be generated during CCI.

The SNL MELCOR analysis utilizes a hybrid BWR/6 model that was scaled up from an existing La Salle BWR/5 input deck. In addition, the containment model was designed with a

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[a] S. E. Dingman et al., *MELCOR Analyses for Accident Progression Issues*, to be issued.

relatively coarse nodalization scheme in the interest of time.

Most of the hydrogen generated from in-vessel oxidation is transported to the suppression pool through the SRVs. Hydrogen is noncondensible and has minimal solubility in water; therefore, hydrogen released into the suppression pool will generally relocate into the containment air spaces. Hydrogen leaving the suppression pool will tend to stratify in the upper regions of the containment in the absence of a mixing force. Quarter Scale Test Facility results have provided some evidence that enough mixing occurs in the containment to prevent this stratification. Therefore, if the ignitors have been turned on and are operational during core degradation, hydrogen should ignite as it evolves from the pool surface, as was evidenced in the Quarter Scale Tests. The result would be a diffusion flame that may persist at locations above the SRV discharge into the suppression pool. The nature of the containment challenge resulting from a diffusion flame will depend very strongly on the rate and duration of the hydrogen release through the SRVs. If the burn persists long enough, elastomeric seals in both the containment and drywell could be threatened by overtemperature. In addition, there is a chance that the wetwell-to-drywell vacuum breakers could be failed by the hot gases that result from the diffusion burns. This failure would create a large suppression pool bypass path. This failure mechanism was modeled in the latest Draft NUREG-1150 accident progression analysis for Grand Gulf.[5] Analysis by ORNL for the CPI program indicates that this is an unlikely failure mode at Grand Gulf.[a] Finally, containment overpressurization is not considered to be a likely result of a diffusion burn.

In sequences where there is some probability of an SRV tailpipe vacuum breaker sticking open, some of the hydrogen generated in-vessel will relieve through the stuck-open vacuum breaker to the drywell. Pre-draft NUREG-1150 MELCOR analyses (S.E. Dingman et al. draft report) indicate that blowdown of steam and hydrogen to the drywell will tend to push air out into the wetwell through the suppression pool vents, leaving the drywell atmosphere inert to hydrogen burns. A stuck-open tailpipe vacuum breaker could, if it failed open during peak release, cause flammable conditions in the drywell for approximately 20 min before the drywell inerted from either steam buildup or oxygen depletion. The referenced analysis states that, under these conditions, the hydrogen released from the RPV would be hot enough to autoignite and would burn as a jet at the release point. Calculations predict that it would take 500 sec for the hydrogen burn to deplete the oxygen in the drywell and that the resulting pressure rise would not challenge containment integrity. Therefore, while there is some chance of a hydrogen burn in the drywell prior to vessel breach, containment integrity is not likely to be challenged as a result.

During SBO, none of the installed hydrogen control systems will be operable because of the unavailability of ac power, and the possibility exists that hydrogen may accumulate in the wetwell in explosive concentrations before a random ignition trigger occurs. However, the absence of an assured ignition source creates a very uncertain situation in these sequences. Hydrogen burns have occurred in systems with no moving parts or electrical components. However, there is no guarantee that spontaneous ignition will occur at hydrogen concentrations low enough for the resulting burn to be benign. If either a deflagration or detonation occurred, it would likely occur in the wetwell and both the drywell and containment would be vulnerable to overpressure failure.

In long-term SBO sequences, the SRV discharge will heat the suppression pool to its saturation temperature prior to the onset of core degradation. This makes steam-inerting of the wetwell likely. Assuming recovery of offsite power after the onset of core damage, operation of containment sprays could potentially deinert the containment atmosphere after large amounts of hydrogen have accumulated in the wetwell. Should this happen, both the containment and drywell could be failed by a deflagration or

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[a] S. R. Greene et al., *The Response of BWR Mark III Containment to Short-Term Station Blackout Severe Accident Sequences*, to be issued.

detonation. Note that if the operators at Grand Gulf cannot verify that power *has not* been lost to the ignitors, procedures instruct them to prevent power from being restored to the ignitors. Furthermore, during site visits to Grand Gulf as part of the NUREG–1150 effort and separately, as part of the CPI program, no trigger sources for hydrogen ignition could be identified. Therefore, ignition under blackout conditions would have to be either spontaneous or the result of operator error. Finally, it should be noted that containment sprays are unavailable in the dominant long–term SBO PDS at Grand Gulf as a result of failures in the service water system. Therefore, recovery of sprays is not possible. However, this may not be applicable to the other two Mark III plants with containment sprays, Perry and Clinton.

When the accident progresses to the point of vessel failure, any hydrogen remaining within the reactor vessel will be released to the drywell, where the molten core material will provide an ignition source, but the hydrogen will be released along with any water or steam remaining in the vessel. This may result in immediate inerting of the drywell atmosphere as air, steam, and hydrogen are pushed out of the drywell through the suppression pool vents. Furthermore, the molten fuel will likely be released into a flooded reactor cavity. Sufficient water is likely to be present to quench the fuel and slow any oxidation processes. However, the presence of water in the in–pedestal area at the time of vessel failure presents the possibility of an energetic FCI (steam spike or steam explosion).

After vessel breach, hydrogen production may continue, both in core debris remaining in the vessel, and in debris scattered about the drywell and in–pedestal cavity. However, the main source of hydrogen production will be the thermal decomposition of concrete floors and walls in the drywell. CCI generates large amounts of carbon dioxide and steam. When these gases pass through partially molten core debris, they oxidize the zirconium and other metals in the debris, producing hydrogen gas and carbon. Later, the carbon will react with steam and carbon dioxide, evolving more hydrogen along with carbon monoxide.[7] The MAAP calculations in Reference 7 predict hydrogen production after vessel breach to be the dominant source of hydrogen during short–term SBO sequences. The above–referenced STCP and MELCOR calculations both indicate that hydrogen production after vessel breach is secondary in importance to in–vessel production.

4.2.2 Potential Failure Modes. The Containment Performance Working Group (CPWG) analyzed local pressure and temperature histories during diffusion–type hydrogen burns.[9] Their analysis covered the case where hydrogen is released to the wetwell through the SRVs during core degradation. Local heat fluxes on the drywell and containment walls were calculated and the impact on elastomeric sealing materials was assessed. The CPWG concluded that local heat fluxes caused by diffusion burns at the suppression pool surface do not degrade either the drywell or containment seals.

The containment response to the slow pressurization caused by a diffusion burn was also analyzed. The CPWG analysis assumed that 65% of the zirconium in the cladding was oxidized, and that the resulting hydrogen was burned continuously as it was released into the wetwell. The resulting pressure increase was calculated to be no more than 15 psi. The CPWG assessed the probability of containment failure by this mechanism to be extremely low.[9]

More recent SNL MELCOR studies (S. E. Dingman et al. draft report) generally confirm the CPWG conclusions for diffusion burns and provide additional insight into the likelihood of containment failure from the more rapid burns that characterize deflagration or detonation. MELCOR will identify detonable mixtures based on user– supplied detonation limits, but cannot predict hydrogen detonation or the pressure spike caused by a detonation. Only rapid hydrogen burns at user–specified concentrations and flame speeds can be analyzed. Note, also, that MELCOR cannot accurately model diffusion burns because it is a control volume code that assumes a uniform concentration throughout the control volume. Again, it should be noted that the

Mark III MELCOR containment model used by SNL was coarsely nodalized, which means that more hydrogen would be required to be inside containment before the code would predict burning (or pseudo-detonation), thus resulting in larger than anticipated pressure spikes. A more detailed model should allow burning at the pool surface. MELCOR calculation performed by ORNL used a finer nodalization for Mark III containment analysis. The ORNL calculations showed a significantly lower containment pressure for diffusion burns. The ORNL results compare favorably with the HCOG Quarter Scale Test. Some SBO sensitivity calculations by SNL indicated that wetwell hydrogen deflagrations are capable of simultaneously failing both the containment and drywell by overpressure. These high-pressure burns correspond to relatively high values for initial containment pressure, hydrogen concentration, flame speed, and percent burn completion, and are characteristic of deflagrations or detonations rather than diffusion burns.

The results from the MELCOR analyses, as well as the HECTR, MARCH2, MARCH3, and MAAP analyses published in a number of separate reports, were evaluated by an expert panel. The panelists estimated the probability of hydrogen combustion generating enough of a pressure load to threaten containment integrity.[6] The issue was defined both in terms of the probability that hydrogen combustion will occur prior to vessel breach, and in terms of the probability that, given combustion occurs, either the containment or the drywell will fail from the resulting pressure load. The panelists did not address the possibility of ignition, or the probability of containment failure after vessel breach. They presented their results in terms of cumulative probability distributions for the expected containment load resulting for each of four distinct ranges of hydrogen concentration. These curves, reflecting the experts' degree of belief that a particular combustion event would be capable of failing containment, were used in quantifying the Draft NUREG-1150 Grand Gulf accident progression event trees.

The findings of the expert panel indicate that the probability of ignition in the wetwell can be as high as 0.8 when core damage occurs with the reactor at high pressure. For hydrogen concentrations between 4 and 8 v/o, the probability of the containment surviving the maximum deflagration is essentially 1.0. At concentrations above 16 v/o, the probability that the containment will survive the maximum deflagration drops to nearly 0, and the probability that the drywell will survive drops to less than 0.20. These numbers are for high initial steam concentrations in the containment. At low initial steam concentrations, these numbers vary somewhat but are still indicative of a high probability of containment and drywell failure for high hydrogen concentrations.

4.2.3 Potential for Mitigation. Mitigating the consequences of hydrogen-related challenges is dependant on the ability to burn the hydrogen in a controlled manner as it is formed, so that dangerous concentrations are avoided. This approach has a high probability of success as long as power is maintained to the HIS. It is during SBO, when the normal ignitor power supply is lost, that this approach fails. Possible solutions include providing uninterruptible backup power that will be available during SBO, or relying on catalytic ignition systems that do not require electric power.

During some long-term SBO sequences, the potential for the accumulation of dangerous concentrations of hydrogen exists even with the ignitors turned on. In these sequences, the containment is inert during hydrogen generation due to the presence of large amounts of steam. Containment deinerting can result from containment spray actuation when power is restored. A solution to the steam-inerting aspect of the hydrogen challenge might be to ensure that the containment can be inerted intentionally and kept inert for the duration of any postulated severe accident. This could be accomplished by post-accident inerting with gas injection systems, Halon injection systems, or water fog systems, all of which have been considered in previous studies.

Post-accident inerting by gas injection was studied in the April 1987 draft of NUREG/CR-4551 for Grand Gulf.[10] The system studied relied on the injection of carbon dioxide gas to dilute oxygen to below flammability limits. The system would be supplied with dc power to ensure that actuation would be possible during SBO, when normal hydrogen control systems would be unavailable. Actuation would be required, by procedure, in place of the ignitors during these sequences. The containment would require venting when the system was first actuated, and the vent path would be secured after the gas had been discharged.

The hardware required by this system would consist of carbon dioxide tanks stored outside of containment, the piping and spray headers required to distribute the gas to locations within containment below the level of the upper containment pool, isolation valves and controls, and safety interlocks to prevent inadvertent operation. Problems with this system include the possibility of actuation during a design basis accident, when containment venting would be undesirable, and the possibility of inadvertent actuation when personnel are inside containment. Total cost for installation of this system was estimated to range from $12,000,000 to $34,000,000.

A paper published at the Second International Conference on the Impact of Hydrogen on Water Reactor Safety elaborated on the shortcomings of a system similar to the one in the NUREG/CR-4551 study.[10,11] Among the shortcomings identified were: (a) the high likelihood of human error involved in initiating the system, (b) the long-term containment pressurization (as high as 37 psia) above design pressure should actuation occur without simultaneous venting, (c) the higher offsite dose caused by the higher leak rates associated with the elevated pressures, (d) the requirement to inhibit sprays when the inerting system is actuated to prevent even higher containment pressures, the reverse of present safety logic, and (e) the difficulty of ensuring high system reliability.

Halon gas, which has also been proposed as a post-accident inerting agent, interferes with the combustion process itself. While the exact mechanism by which this occurs is not completely understood, the result is that inerting can be achieved with significantly smaller amounts of Halon than would be required for inerting by dilution (as with the carbon dioxide system). The operational advantages of Halon are that a system can be installed that has few moving parts, minimal power requirements, high reliability, relative hardware economy, storage convenience, and ease of testing. The design of a Halon injection system would be very similar to that of the carbon dioxide system discussed above. One disadvantage of Halon injection is the decomposition of Halon to extremely toxic halogenic acids and carbonyl halides at temperatures over 900°F. Halon and its decomposition products are also very corrosive and could cause potential long-term degradation of safety systems. Halon is also expensive. It will increase containment pressure at initiation, and must remain at a concentration above the required inertion level at all times or it could become an aid to combustion. Finally, it could be impractical for Mark III containments because of the large amount of equipment required.

Reference 11 also describes a report issued by the Tennessee Valley Authority (TVA) rejecting the use of Halon as a permanent mitigation scheme for Sequoyah (a PWR with an ice condenser containment). TVA's objections were based on the uncertainty about the radiolytic decomposition of Halon and subsequent metal corrosion, uncertainty concerning suitable post-accident water chemistry control, Halon's toxicity at the concentrations required, and the difficulty in finding room for and installing the required tanks and components.

Laboratory tests of water fog inerting systems have demonstrated that water fogs applied to hydrogen-air mixtures cause only a marginal increase in the hydrogen lower flammability limit (LFL) at room temperature.[11] Increases noted were 4.0 v/o to 4.4–5.3 v/o. Fogs generated from an air-driven nozzle resulted in a slightly higher LFL of 7.2 v/o at 20°C. Higher gas temperatures were found to increase the LFL, and the fog density required to achieve a given level of inerting was found to be strongly dependent upon droplet size. In addition to increasing the LFL, fogs are thought to reduce the pressure rise associated with burning hydrogen at a given concentration. While laboratory tests have shown that this concept is viable, the practical application is limited. For fog systems to be fully advantageous, they should be used in conjunction with the HIS, because their function is more to reduce the pressure rise associated with combustion than to prevent ignition. Therefore, it is not likely that the dominant short–term SBO sequences would benefit from the installation of a fog generating system unless it was designed with an independent power supply that was also capable of powering the HIS. However, with the ignitors powered, the fog system would provide little additional benefit, because a controlled burn of hydrogen will not threaten containment even without the fog system. In the long–term SBO sequence, in which the containment is likely to be steam–inerted at the time of power recovery, actuation of a water fog system would have a similar effect to actuating the containment sprays, namely deinerting of the containment due to steam condensation. As discussed earlier, this is an undesirable effect, because it could lead to a hydrogen burn when the ignitors are recovered.

Containment venting also has the potential to prevent hydrogen–related overpressurization by removing both oxygen and hydrogen from the containment. If venting were accomplished during the long–term SBO sequences, sufficient oxygen could be removed to maintain an inerted containment, even given the condensation of steam from the containment atmosphere caused by spray recovery. Condensation of steam in a vented containment could lead to sufficient depressurization to pull oxygen back into the containment from the outside atmosphere. Condensation of steam in a vented, and then sealed, containment could lead to dangerous negative pressure differentials between the containment and outside atmosphere. An alternative would be to have a nitrogen gas supply system to maintain containment pressure by injecting nitrogen into the containment as the steam is condensed. This would prevent oxygen from being pulled back into containment and would prevent the containment from being deinerted. However, a system capable of this would have many of the disadvantages of the carbon dioxide inerting system previously discussed. It would be costly, and could be a personnel hazard in the event of inadvertent actuation.

ORNL has analyzed the effectiveness of preemptive venting in removing hydrogen from containment during a short–term SBO sequence (addressed in the S.R. Greene et al. draft report, *The Response of BWR MARK III Containment to Short–Term Station Blackout Severe Accident Sequences*). The results of this calculation indicate that venting (via two 20–in. wetwell vents to the environment) is not effective at reducing the hydrogen detonation threat to containment during the first 7.5 h of the accident. In fact, the preemptive venting strategy appears to *aggravate* the wetwell detonation problem.

This result is explained by considering the details of the Mark III design. The wetwell is relatively open above the upper containment pool. However, the drywell–wetwell annular region has many obstructions to upward flow, causing the upward flow to be very turbulent and well–mixed. Therefore, any gaseous material vented from the containment will be well–mixed. Thus, while venting does remove large amounts of hydrogen, it also removes large amounts of other gases, leaving the relative wetwell gas concentrations unchanged. In addition, the increased drywell–to–wetwell leakage of gaseous material as the result of higher drywell–to–wetwell differential pressure (the drywell hydrogen concentration is even higher than that in the wetwell) causes a net increase in the wetwell hydrogen concentration. ORNL concluded that venting would not be useful in removing hydrogen from containment. The effects of containment venting on the radionuclide release from containment will be examined in Section 11.

Finally, minimizing the quantity of hydrogen generated in–vessel can reduce the amount of hydrogen entering the containment prior to vessel failure. This latter mitigation approach, for station blackout events, means that the reactor should be depressurized at an optimum water level, which current calculations for the Mark II CPI program indicate to be when the core is approximately two-thirds uncovered, in accordance with Revision 3 of the EPG.

4.3 Rapid Steam Pressure, Missiles, and Direct Containment Heating

The containment challenges described in this section all occur very near the time of vessel failure and belong to the broader classification of early containment failure challenges. Included are in-vessel phenomena such as rapid steam pressurization and missiles generated at the time of core collapse, and ex-vessel phenomena occurring at the time of vessel failure, such as direct containment heating (DCH) and ex-vessel steam explosions. Because the creation of missiles with sufficient energy to fail the containment is not considered likely,[12] the predominant containment failure mechanism in this category is dynamic overpressurization.

4.3.1 Definition of Challenge. Rapid steam pressurizations and steam explosions, both within and external to the reactor vessel, are characterized by rapid fragmentation of molten fuel as it is quenched in water, resulting in a large and rapid transfer of thermal energy to the coolant. This in turn leads to steam generation, shock waves, and possible mechanical damage. The Severe Accident Risk Reduction Program (SARRP) analysis of these phenomena relied on expert opinion to quantify the vessel failure mode, the amount of core participating in the reaction, and the resulting pressure rise from both in-vessel and ex-vessel reactions.[10]

Experts determined from the NUREG-1150 analyses that the status of the in-pedestal cavity at the time of vessel breach has a major impact on the probability of a rapid steam pressurization event. They agreed that it is statistically certain that the Mark III drywell will be flooded at the time of vessel failure during ATWS sequences with upper containment pool dump, and that the probability of flooding is greater than 80% during SBO sequences that preclude upper pool dump. The primary cause of drywell flooding is the manometer effect that results from quasistatic pressurization of the wetwell. This flooding occurs when the pressure in the wetwell becomes high enough to lift the suppression pool level in the drywell over the top of the weir wall. The pressure differential required is at a minimum when both the suppression pool and the upper containment pool are both filled to the top of their respective operating ranges, and the upper containment pool is then dumped into the suppression pool. The Grand Gulf FSAR states that, under these conditions, a wetwell pressure 0.16 psi higher than the drywell pressure will cause overflow of the weir wall. The required pressure will be higher when the respective pool levels are at their lower limits, or when the upper containment pool has not been dumped, as would be the case in SBO sequences. The amount of water in the suppression pool prior to vessel breach, and hence the differential pressure required to cause flooding, is sequence-specific. During sequences in which core damage occurs in the long term, a significant volume of water may have been injected into the reactor vessel from the CST, or from other sources such as fire water. Most of this water will be boiled off to the suppression pool before the onset of core damage. In addition to the extra inventory from reactor vessel blowdown through the SRVs, the suppression pool water will be undergoing volumetric expansion caused by energy addition from condensation of the SRV discharge.

The extent to which the wetwell is pressurized with respect to the drywell is also sequence-specific. During SBO accident sequences, the wetwell-to-drywell vacuum breakers will not be functional, because the motor-operated damper is normally closed, and would require ac power to open. Leakage from the wetwell back to the drywell can still occur but only at Technical Specification-allowed leakage rates, which are estimated to be too low to offset wetwell pressurization from evaporation of the suppression pool, and from the accumulation of hydrogen released through the SRVs during core degradation.

A number of calculations have been performed to determine the extent of drywell flooding. Calculations performed with BWR-LTAS did not predict drywell flooding, perhaps because the drywell-to-wetwell leakage area used was four times the nominal value determined from leak rate tests at Grand Gulf. A second calculation performed using the HECTR code with the same assumed leakage area and drywell heat load *did* predict drywell flooding (to a depth of 3 ft in the drywell and 9 to 10 ft in the in-pedestal cavity). SNL MELCOR calculations in the draft report by Dingman have confirmed the HECTR results and have indicated that flooding during SBO is very dependent upon the rate of in-vessel hydrogen production, with higher generation rates making flooding more likely. These calculations have also shown that hydrogen burns in the wetwell can cause a sufficient pressure differential to flood the drywell. MELCOR calculations performed by ORNL for the CPI program also predict drywell flooding as a result of hydrogen diffusion burns when no or inadequate mitigative actions are taken (see S.R. Greene et al. draft report).

In addition to the above mechanisms for drywell flooding, some experts thought the suppression pool level would oscillate as a result of the release of noncondensible gases through the SRVs.[10] The level oscillations were thought to be sufficient to cause drywell flooding regardless of the amount of wetwell pressurization from the noncondensibles.

With flooding of the drywell virtually ensured, a secondary issue becomes the path by which water can flow into the in-pedestal cavity. Flow is expected to pass through the in-pedestal access doorway or through the drain lines to the drywell floor drain sump. Three feet of water on the drywell floor (predicted by HECTR calculations) will not reach the access doorway. This leaves sump overflow as the primary mechanism for filling the in-pedestal cavity. It is anticipated that drainage from the drywell floor into the cavity via sump overflow will occur with sufficient speed to ensure cavity flooding prior to vessel breach.

Given that the cavity is flooded at vessel breach, the possibility of an ex-vessel steam explosion has to be considered. If a steam explosion occurs, the potential exists to create a pressure impulse sufficient to collapse the reactor vessel pedestal. Pedestal collapse could cause the reactor vessel to relocate, potentially damaging the drywell wall, or damaging seals at piping penetrations through the drywell or containment. The result would be the creation of a large suppression pool bypass path with the potential for a high consequence fission product release.

The likelihood of an ex-vessel steam explosion sufficient to challenge containment integrity was evaluated in terms of three parameters: (a) the probability that the explosion will occur, contingent on a flooded in-pedestal cavity, (b) the probability that the pedestal will fail, contingent on the occurrence of an explosion, and (c) the probability of drywell failure due to collapse of the pedestal.[1] In Reference 6, the conditional probability of an explosion was evaluated as 0.86, based on intermediate-scale tests using molten thermite and water. The conditional probability of pedestal failure, given an explosion, was assigned a uniform distribution over the interval 0.0 to 1.0 (i.e., a point estimate probability of 0.50). The conditional probability of drywell failure given failure of the pedestal was estimated as 0.17. The probability of containment failure resulting from the explosion was not stated in Reference 6. Recent work on Mark II containments, using state-of-the-art corium discharge computations to estimate the pressure response in Mark II containments, indicates that steam pressure spikes at vessel breach due to fuel-coolant interactions will not fail containment.[13] While this work is not directly applicable to the Mark III containment, it does provide data that suggest the threat from steam explosions may be conservatively overstated in the Draft NUREG-1150 analyses. A July 1983 report specific to Mark III containments also concluded that direct failure by steam explosion would be extremely unlikely.[14] Corraclini has also concluded in his 1981 report that steam explosions are extremely unlikely.[15]

In-vessel steam explosions can result in two types of vessel failures, both of which could lead to sudden containment pressurization. In the α mode steam explosion, upper head failure occurs with sufficient energy to fail containment directly. The second mode postulates catastrophic failure of both the upper and lower vessel heads. Neither of these failure modes was considered likely by the majority of NUREG–1150 experts. In a BWR, the reactor vessel internals located above the core, namely the steam separators and dryers, would tend to absorb the impact of an upwardly directed in–vessel steam explosion. The control [illegible]ve and instrumentation supports in BW[illegible]d likewise tend to minimize the pote[illegible]ttom head failure.

Direct containment heating (DCH) refers to the high pressure ejection of molten core materials from a breach in the vessel. Under certain conditions, the material could be rapidly dispersed out of the pedestal into the drywell volume as fine particles. The combination of direct heat transfer and rapid exothermic chemical reactions between the melt and the drywell atmosphere can lead to rapid containment pressurization and possible containment failure. In addition, the chemical reactions can result in significant hydrogen production, increasing the probability of hydrogen burns. The NUREG–1150 expert panel has indicated that DCH would be unlikely to occur with a flooded in–pedestal cavity.[10] Therefore, because of the high probability of a flooded cavity at Grand Gulf, DCH may not be a significant generic threat to Mark III containments. Alternatively, the high pressure ejection of molten debris can only occur if the reactor is at high pressure; therefore, depressurizing the reactor before vessel failure will preclude DCH.

4.3.2 Potential Failure Modes. The potential containment failure modes associated with challenges from ex–vessel steam explosions include gross failure of either the concrete reactor vessel pedestal or the vessel supports, resulting in movement of the reactor vessel. The vessel movement causes seal failure of attached piping at the drywell wall, resulting in suppression pool bypass.

Potential containment failure from quasistatic or dynamic overpressurization at vessel breach is possible, but this failure mode is not adequately documented in existing Draft NUREG–1150 supporting documents.

4.3.3 Potential for Mitigation. Some reduction in the probability of drywell failure could be achieved by minimizing the hydrogen generated in–vessel prior to reactor vessel failure, resulting in the release of unoxidized zirconium to the containment, thus postponing the hydrogen threat relative to the time of fission product release. This minimization of the in–vessel hydrogen release might be accomplished by revising the EPGs to call for depressurization only when two–thirds of the core has been uncovered, as was stipulated in Revision 3. Further reductions might be achieved by timing upper containment pool dump so that it occurs only after vessel breach, thus lessening the probability of an ex–vessel steam explosion in the reactor cavity at the time of vessel failure. However, this will not ensure that the drywell is dry prior to vessel breach. Venting containment would ensure that a positive drywell–to–wetwell differential pressure exists. This pressure differential would prevent water from refluxing over the weir wall, and thus, would ensure a dry cavity at the time of vessel breach. However, in the absence of an external filter, containment venting is likely to lead to an increase in offsite consequences, because of the likelihood of suppression pool bypass. It is not clear that any mechanism currently exists to flood the drywell after vessel breach, if flooding is prevented before vessel breach. However, when power is recovered or an ac–independent water supply is available, water can be injected into the reactor vessel; the molten debris and water will end up in the same place. Thus, any core materials still in the reactor vessel when injection is recovered would be cooled, preventing further in–vessel core degradation. In addition, injecting into a failed reactor vessel should allow an overlying pool of water to be established for debris outside the vessel.

DCH can be prevented by ensuring the reactor is depressurized before vessel failure. Because failures to depressurize in the Grand Gulf accident sequence analysis are mostly the result of operator errors, any actions taken to reduce the chance of operator error would be beneficial in reducing the likelihood of DCH, and would have the added benefit of reducing the amount of hydrogen generated in-vessel during core degradation. However, the probability of an ex-vessel steam explosion is increased when the vessel is breached at low pressure and there is water in the reactor cavity.

The balance between actions taken to mitigate DCH and actions taken to mitigate ex-vessel steam explosions cannot be resolved qualitatively.

4.4 Core–Concrete Interaction

The containment challenges described in this section occur extremely late in the accident sequence and are the result of CCI. Included are gradual overpressurization from noncondensible gases, quasistatic and dynamic overpressurization as the result of hydrogen deflagrations and detonations, pedestal failure, and seal failure.

4.4.1 Definition of Challenge. Following melt-through of the vessel bottom head, core debris would collect in the in-pedestal area, where it would interact with and ablate the concrete in the reactor cavity. The consequences of CCI depend on the concrete composition and whether the cavity is initially flooded. If sufficient water is present at the time of vessel failure, corium entering the cavity may be quenched and a coolable debris bed may be formed. In this case, concrete attack may be reduced significantly by maintaining an adequate coolant flow to the debris bed to compensate for boiloff. Cooling could be provided by firewater injection to the breached vessel, or by recovery of one of the higher capacity systems. In the case of a dry in-pedestal cavity, corium entering the pedestal would react with the concrete, liberating steam and noncondensible gases. Steam generated in the process would react with zirconium in the melt to release heat and combustible gases, such as hydrogen and carbon monoxide. Noncondensible gas generation could lead to gradual overpressurization and eventual failure of containment, while ignition of the combustible gases in the dry case could result in a pressure spike that could contribute to the probability of drywell or containment failure.

The other major concern from CCI is the loss of structural integrity of the reactor vessel pedestal as a result of concrete ablation. If CCI ablates a significant portion of the pedestal, a loss of structural integrity could potentially lead to relocation of the vessel. As discussed in Section 4.3, relocation of the reactor vessel could result in suppression pool bypass. The impact of CCI on the structural integrity of the pedestal has not been fully investigated and many of the assumptions regarding its effects are based on expert opinion.[10] The Reference 10 analysis listed several important points brought out by the reviewers. Dehydration of the concrete, which is enhanced by heat conduction in the metal rebar, will likely make the loss of structural integrity greater than might be predicted from the actual ablation depth. The ablation would preferentially be directed downward rather than radially, lessening the impact on pedestal integrity. Structural integrity might also be maintained by the rebar even if nearly all the concrete in the pedestal region were ablated. Because of the design of the basemat and the pedestal wall in the Mark III containments, most of the concrete ablation is taken in the basemat, both axially and radially. Only a few inches of the 3.5 ft thick pedestal wall have been predicted to be ablated by CCI (see draft report by Greene et al.) Therefore, it seems unlikely that sufficient pedestal wall ablation will result to cause in reactor vessel relocation in the short term.

The drywell temperature is expected to approach 600–1000°F during dry CCI. Under these conditions, the elastomeric seals separating the drywell from the wetwell are expected to degrade over about a 5-hour period, resulting in a suppression pool bypass area of 0.9 ft^2.[9] Given the relatively slow rate of gas production during CCI, a 0.9 ft^2 opening may be sufficient to prevent drywell pressure from being relieved through the suppression pool. The result is that fission products released after about 5 hours of CCI may not be scrubbed by the suppression pool. This bypass is not expected to have a significant impact on the *time* at which the ultimate containment pressure is reached. The dominant contributor to containment pressure during CCI is the buildup of noncondensible gases (and steam depending on the sequence) in the containment, which occurs regardless of whether the suppression pool is bypassed. If the CCI initially occurs under an overlying pool of water, no seal damage would be expected. However, the water will be boiled away without a source of makeup.

4.4.2 Potential Failure Modes. Potential containment failure modes from CCI include gradual overpressurization from the production of noncondensibles, rapid overpressurization from combustion of hydrogen and carbon monoxide, pedestal failure resulting in vessel relocation, and drywell seal failure resulting in suppression pool bypass.

4.4.3 Potential for Mitigation. Potential actions to mitigate the threat to the containment from CCI include increasing the likelihood that the interior of the drywell pedestal is flooded, ensuring that adequate venting of noncondensible gases is provided, and providing a source of water to ensure that any CCI occurs with an overlying pool of water. Flooding of the drywell and in-pedestal cavity during severe accident sequences is likely and this probability can be increased by ensuring operator control of the upper containment pool dump valves during SBO sequences. However, any action to ensure flooding must be balanced against the increased likelihood of steam explosions. When the cavity is filled with molten core debris, the availability of one of the two paths for flooding becomes questionable. It appears likely that the mass of corium covering the containment drain sump would prevent the drainage of water into the pedestal from the drywell floor drains. Should this occur, the drywell water level will have to be higher than the pedestal access doorway before flooding can occur. It is not clear that any mechanism exists, after vessel breach, to cause this much flooding even if the upper containment pool has dumped. Recovery of injection after vessel breach can provide flooding.

The benefits associated with venting after vessel breach are questionable because of the high likelihood that suppression pool bypass will produce an unscrubbed release in the absence of an external filter.

5. POTENTIAL IMPROVEMENTS

Improvements for the Mark III plants can be obtained by reducing the likelihood of core damage, by increasing the containment's capability for resisting challenges, or by reducing the offsite consequences of containment failure. The basic event importance analysis performed as part of draft NUREG/CR-4550 identified those events most capable of lowering CDF if reduced or eliminated.[4] The top CDF reduction events identified are as follows:

- Failure to recover diesel generators
- Failure to recover offsite power
- Failure of the RCIC turbine pump to run.

These events and a number of other diesel generator-related faults dominate the CDF reduction potential for Grand Gulf. Note that these events are specific to Grand Gulf; evaluations of other Mark III plants would probably identify a different set of events. Therefore, in the discussion that follows, some attention will be given to systems that, while not important at Grand Gulf, might be of importance at other Mark III plants.

A comprehensive strategy to reduce offsite risk should address the timing and reliability of reactor vessel depressurization. First, depressurizing the reactor allows injection from low-pressure systems. At Grand Gulf, a significant portion of the SBO CDF could be eliminated if a backup source of dc power were available to the SRV solenoids. In this respect, depressurization is tied to the backup water supply to be discussed later, because depressurization could also greatly reduce the short-term SBO CDF if an alternative source of vessel injection, such as the fire water system (FWS), were available within a short period of time following depressurization. Secondly, the reactor should be depressurized at a water level that minimizes the in-vessel production of hydrogen. Revision 4 of the EPGs requires depressurization at approximately one-third core uncovery. However, BWRSAR calculations performed by ORNL for the Mark II CPI Program indicate that the reactor should be depressurized when the core is approximately two-thirds uncovered if in-vessel hydrogen generation during SBO is to be minimized. Two-thirds core uncovery is the depressurization level specified in Revision 3 of the EPG, a lower level than in Revision 4.[a]

Next, the installed hydrogen ignition system (HIS) should function throughout a SBO in order to prevent the accumulation of a quantity of hydrogen in the containment that could threaten containment integrity in the event of an uncontrolled burn. This would provide a large reduction in the likelihood of the most risk-significant containment challenge at Grand Gulf.

The in-pedestal floor should also be dry *before*, and kept flooded *after* vessel breach. This will reduce the likelihood of FCI and CCI, and will enhance fission product retention should CCI occur.

The above actions are those expected to provide the most economical reduction in offsite risk. The following sections also include discussions of alternative injection systems, improved vacuum breaker operation, and containment venting (with and without an external filter). These improvements partially address issues already covered by previous potential improvements, and provide small, or highly uncertain benefits at Grand Gulf. They are included because the plant risk profile, and hence the value of the improvements, may be different at other Mark III facilities. The benefits and drawbacks of each of the proposed improvements are summarized in Table 5-1 and discussed in following sections.

5.1 Enhanced Reactor Depressurization Capability

If no high-pressure injection is available for coolant makeup, the vessel must be depressurized

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[a] S. R. Greene et al., *The Response of BWR Mark III Containment to Short-Term Station Blackout Severe Accident Sequences*, to be issued.

Table 5–1. Qualitative assessment of benefits and drawbacks of potential Mark III containment improvements

Potential Improvement	Potential Benefits	Potential Drawbacks
Enhanced reactor depressurization system ($0.5M–1.4M)	Reduces frequency of some core damage sequences	Increases likelihood of ex–vessel FCI
	Reduces amount of hydrogen generated in–vessel	
	Reduces likelihood of Direct containment heating (DCH)	
	Increases the ability to add water to the RPV	
Post–core damage reactor depressurization system ($0.5M–1.4M)	Reduces likelihood of DCH	Increases likelihood of ex–vessel FCI
	Increases the ability to add water to the RPV	Does not change frequency of core damage
		Increases amount of hydrogen generated in–vessel
Backup water supply system ($0.81M–2.4M)	Reduces frequency of some core damage sequences	New hardware may be expensive
	Increases likelihood of cavity flooding (see below)	
	Relatively low cost if fire protection system is used	
Hydrogen control by improved ignition system—backup power to the ignitors ($300K)	Reduces containment failures due to hydrogen deflagrations and detonations [short–term station blackout (ST–SBO) sequences]	Increases likelihood of containment failure for [long–term station blackout (LT–SBO) sequences]

Table 5–1. (continued)

Potential Improvement	Potential Benefits	Potential Drawbacks
Prevention of weir wall overflow	Reduces likelihood of ex–vessel FCI	May increase likelihood of suppression pool bypass
		Increases likelihood of dry CCI
Cavity flooding via upper pool dump	Reduces likelihood of dry CCI	Increases likelihood of FCI
	Provides scrubbing of fission products should suppression pool bypass occur	Increases likelihood of hydrogen burn if dump occurs after core damage
Containment venting		
Hard–pipe vent system with dedicated power source ($0.69M–6.1M)	Prevents late overpressure failures for transients with scram	High likelihood of suppression pool bypass may lead to increase in risk
	Preemptive venting reduces containment base pressure prior to core damage	Moderately high cost
		May not prevent thermal failure or FCI
	Reduces probability of ex–vessel steam explosion by reducing weir wall overflow	Can lead to inadvertent release
Filtered containment vent system with dedicated power source ($5M–50M)	See above	See above
	Ensures scrubbing of releases	High cost

to allow injection from low–pressure systems. This can be done using the ADS, with manual depressurization by the operator as a backup, should ADS fail. Since the issuance of the TMI Action Plan in NUREG–0737, the initiation logic for the ADS has been modified at some plants to increase the likelihood that the reactor will be depressurized when needed. A dedicated source of dc power to the SRV solenoids would increase the operability of the SRVs during severe accidents. Because of the possibility of concurrent failure of both the ac and dc power systems, the addition of a dedicated dc power supply for the SRV solenoids could potentially reduce the core damage frequency.

Revision 4 of the EPGs discusses various alternative means of depressurizing the vessel. For example, interlocks could be bypassed to allow the MSIVs to be opened. This would allow use of the turbine bypass valves to reject steam to the main condenser, assuming that the main condenser was available to condense the steam. The use of these alternative methods is indicated if less than the minimum number of SRVs required for emergency depressurization is open, and the differential pressure between the vessel and the suppression chamber is above the minimum pressure required to open an SRV (50 psig is a typical value).

Once the vessel has been depressurized, a number of systems can be used for low–pressure makeup. Examples include: the condensate system, the RHR system in the LPCI mode, the LPCS system, the condensate transfer system, the fire protection system, and the service water system. Each of these sources is discussed below, along with possible difficulties that might have to be overcome before the source can be used:

1. *Condensate system*: Use of the condensate system may be limited by two basic interrelated considerations. First, if the MSIVs were closed, condenser vacuum would be required if makeup to the condenser were via a "vacuum drag" line from the CST. The available flow rate from the condensate pumps would then be limited to this makeup rate, because condenser hotwell inventory is only sufficient for a few minutes of operation at full flow although only a fraction of the full flow rate is needed in most sequences. Maintaining condenser vacuum could be difficult if auxiliary steam were not available as a motive force for the steam jet air ejectors. Steam from the auxiliary boiler could be used, but this would of course be dependent upon the availability of the auxiliary boiler. The mechanical air removal pumps could also be used, but these pumps discharge directly to the turbine building exhaust plenum, bypassing the offgas treatment system. Plant–specific design differences in the balance–of–plant may also affect the condensate pump availability. During SBO, the condensate pumps would be unavailable, because they require ac power.

2. *RHR system in LPCI mode*: The RHR pumps get a signal to start upon receipt of either a low vessel level signal (30 to 36 in. above TAF) or a high drywell pressure signal (approximately 2 psig). These signals also cause the RHR system to realign to the LPCI mode; the LPCI injection valves do not open, however, until vessel pressure decreases below a set value. Typical LPCI flow rates are on the order of 10,000 gpm per loop. The operator cannot throttle the LPCI injection flow or realign the RHR system to any other operating mode during the first few minutes of LPCI operation. However, LPCI flow can be terminated by stopping the RHR pumps. This might be an action taken during an ATWS to prevent injection of cold water into a critical reactor. Again, during SBO, the RHR pumps would be unavailable because of the loss of ac power.

3. *LPCS system*: The LPCS pump generally receives a signal to start at approximately the same time as the RHR pumps. Either LPCS or LPCI is capable of mitigating a design basis LOCA. The LPCS pump may also be capable of taking suction from the CST at some plants. Again, like the RHR pumps, LPCS would be unavailable during SBO.

4. *Condensate transfer system*: The above systems constitute what might be called the "normal" means of low–pressure injection. The remaining systems are sometimes referred to as "alternative" means of injection. The first of these is the condensate transfer

system. Interconnections between the condensate transfer system and the RHR and LPCS systems could allow the condensate transfer pumps to be used to inject water into the vessel via the RHR or LPCS piping. Two restrictions apply, however. First, the connections are via manual valves in the auxiliary building; an operator would have to be dispatched to the auxiliary building to open these valves. Under some circumstances, the environment in the auxiliary building could prohibit doing this. Second, the lines are rather small (on the order of 4 in. in diameter), thus limiting the injection flow rate. However, this is a source that should be considered when evaluating the overall failure probability of low–pressure injection. As for the above systems, the condensate transfer pumps would be unavailable during SBO.

5. *Fire protection system*: Plants typically have both motor–driven and diesel–driven fire pumps, which are used to supply water to the fire mains for fire protection. However, via a hose or spoolpiece connection from the fire main to the service water system or some other system, they could also be used to inject water into the reactor vessel or the containment. The above restrictions on the use of the condensate transfer pumps also apply to the fire pumps. An operator must manually connect the fire main to some other system, like the service water system, and the flow rate is limited by the size of the hose or spoolpiece used to make the connection. Note that ac power is required, even if the diesel fire pumps are used, unless the MOVs connecting the service water system to the RHR system can be opened manually. Manual operation of these valves would require operator entry into the auxiliary building.

6. *Service water system*: As a last–ditch effort, plant EOPs direct the operator to line up the service water system to inject into the vessel from the ultimate heat sink connection to the RHR system. These two systems are isolated from one another by two MOVs, which are operated from keylock switches in the main control room. The valves could also be opened locally, using a manual handwheel attached to the valve operator. This means of injection would also be unavailable during SBO, because ac power is needed to operate the service water pumps.

Typical PRAs only give credit to the first three of these systems when evaluating the availability of low–pressure injection. The lack of operator familiarity with using the systems for this purpose is the reason the other systems are not included. This is not felt to be a valid reason for excluding them from consideration, because operators receive extensive training on potential sources of water to be used in an emergency. The use of these systems is spelled out in Revision 4 to the EPGs, further reducing the likelihood that operators would overlook them in an emergency. Inclusion of these sources would result in a reduction in the CDF contribution from TQUV sequences. At Grand Gulf, this sequence was not a dominant contributor to CDF or risk. However, it might be found to be a more important contributor at some other Mark III plant.

The following information is provided from the ORNL work documented in the S.R. Greene et al. draft report:

> "The BWRSAR calculations were performed, however, with one very important difference in assumed operator action as opposed to the procedures currently in effect at Grand Gulf. This difference has to do with the time in the short–term station blackout accident sequence at which the operators would manually actuate the ADS. Grand Gulf has implemented Revision 4 of the BWR Owners Group Emergency Procedure

Guidelines (EPGs), which provide [Contingency #3 (Steam Cooling) and WS-10 (RPV Variables Worksheet)] for manual ADS actuation at a water level equivalent to 71.33% of core height, or 323 in. above vessel zero. In contrast, the Susquehanna (Mark II) procedures are based upon Revision 3 of the EPGs and call for manual ADS actuation under station blackout conditions at a water level of 28% of core height.

"In considering the question of the optimum time to manually actuate the ADS under conditions in which the core is partially uncovered and no reactor vessel water injection systems are available, it is important to consider both the temporary core cooling to be achieved and the effect upon the subsequent metal–water reactions when the core has reheated to runaway oxidation temperatures. With the core partially uncovered at the time of ADS actuation, the flashing attendant to vessel depressurization will cause the water level to fall below the core plate so that the core will later be in a steam–starved condition during the period of runaway metal–water reaction.

"Although actuation of the ADS with the reactor vessel water level at either 71% or 33% of core height will result in rapid dryout of the core region, there is a significant difference in the amount of core cooling that is achieved during the blowdown. By the time that coolant boilaway has reduced the reactor vessel water level to 33% of core height, BWRSAR predicts the highest clad temperature in the uncovered portion of the core to be about 1650°F. Three min later, the steam cooling provided by the ADS actuation is predicted to have reduced the maximum clad temperature to about 950°F. The ADS maneuver thus delays the onset of core degradation, buying time for the operators to continue efforts to restore reactor vessel water injection capability. The maximum clad temperature does not again reach 1650°F until about 15 min after the time of ADS actuation.

"If the ADS is actuated with the reactor vessel water level at 71% of core height, the maximum clad temperature in the uncovered portion of the core at the time is only about 700°F. Therefore, only a small temperature reduction is achieved by steam cooling. Table 5-2 provides a comparison of the times at which major core damage events occur for the two ADS strategies. As indicated, delaying the manual ADS actuation until the water level has decreased to about one–third core height results in a corresponding delay of 25 to 30 min in the onset of debris relocation and the subsequent core degradation events. Obviously, the delay should not be too long; it would be very undesirable to have the core already in the process of runaway metal–water reaction at the time that ADS was actuated."

5.2 Backup Water Supply System

To arrest the SBO sequences with the reactor depressurized, a low pressure source of water that is independent of ac power is needed. One such source of water is the diesel–driven fire pump. The fire pumps could be manually connected to the RHR system as outlined above. Some plants, such as Grand Gulf, may already have such a connection; others may have only a small diameter spoolpiece or a hose connection, which would severely limit the flow rate into containment. Note that the June 1989 Draft NUREG–1150 analysis of Grand Gulf (see Reference 6) did not take credit for fire water injection for preventing core damage during short-term SBO. An improvement that allows rapid alignment of firewater injection could be of great benefit. This improvement would involve training and hardware modifications to produce a high probability of successful alignment of the system in the time frame required for preventing core damage during short–term SBO. Drawbacks to using the fire pumps include the manual connection that must be made to align the system, and the limited flow rates and lower discharge head that the fire pumps can produce in comparison with the RHR pumps. Also, ac power or local manual operation would

Table 5–2. Calculated timing of significant events for two ADS actuation strategies for the short–term station blackout accident sequence at Grand Gulf

	Time (min)	
	ADS at 33% Core Height	ADS at 71% Core Height
Station blackout–initiated scram from 100% power. Independent loss of the steam turbine–driven HPCI and RCIC injection systems	0.0	0.0
Swollen water level falls below top of core	42.0	42.0
ADS system actuation	75.0	48.2
Core plate dryout	75.6	50.3
Relocation of core debris begins	106.9	79.0
First local core plate failure	111.0	82.8
Collapse of fuel pellet stacks in central core	184.2	153.1

be required to operate valves, unless the valve operators are dc–powered, which is typically not the case.

The other identified improvement would be to ensure that power is available to the valves that must be operated. This could be done by utilizing an uninterruptible power source (a large one), or by using dc–powered motor operators for these valves.

If the reactor vessel has been depressurized when the backup water supply becomes available, the backup water could be directed into the reactor vessel. For accident sequences where the reactor has been successfully shut down, the backup water supply would only have to remove the decay heat and thus could prevent core degradation or terminate core failure. For ATWS sequences, the reactor is still producing between 10 and 30% of rated steam flow (following recirculation pump trip) and thus the backup water supply could only delay core failure. If backup injection failed to prevent core damage and vessel failure, it still could be used to some benefit for reducing the threat from CCI by providing an overlying pool of water, and for adding water to the suppression pool.

5.3 Hydrogen Control by Improved Ignition Systems

This option involves either backfitting the current ac–powered HIS with an independent power supply or installing advanced hydrogen ignition devices that will operate without power. This potential improvement would ensure hydrogen control during the SBO sequences that currently dominate the Grand Gulf core damage profile. These improvements are primarily aimed at mitigating the consequences of short–term SBO sequences, because the likelihood of steam–inerting during long–term SBO sequences would reduce the effectiveness of any enhanced ignition system. There is some possibility that a continuously operating ignition system could aggravate the consequences of some long–term SBO sequences by triggering a detonation should recovery of offsite power lead to containment deinerting through containment spray actuation. Two possibilities exist for this case. First, the Emergency Operating Procedures (EOPs) could instruct the operators to *turn off* the power to the ignitors for the long-term SBO *before* initiation of containment sprays (i.e., deinerting containment). This would allow the burning of the hydrogen until the containment became inerted and would prevent detonations when the containment became deinerted (due to operation of the sprays) from the operation of the ignitors. While this would not ensure that there would be no detonation from other ignition sources, it would minimize the hydrogen available and the potential for detonation. The second possibility could be to operate only selected ignitors. For example, operation of the drywell ignitors could burn the hydrogen until the oxygen had been consumed, thereby reducing the amount of hydrogen available for participation in later deflagrations or detonations. Additional analysis or experimentation might reveal a potential pattern of operable ignitors and sprays that could gradually deinert containment and burn the hydrogen without any deflagration or detonation. The possibility of detonation under these circumstances is uncertain. According to Draft NUREG-1150, the short-term SBO sequences clearly dominate the offsite risk so it is expected that the decrease in risk from short-term SBO will be significantly greater than any increase in risk for the long-term SBO.[6] Again, these conclusions are specific to Grand Gulf and may not apply to other Mark III plants with a different core damage profile.

A 10-15 kW(e) generator would be needed to power the existing hydrogen ignitors. A non-Class IE generator of this size would have the advantage of being able to supply other emergency loads if desired. A dc system capable of supplying the required load could also be installed, and would have the advantage of increased reliability. However, a dc system would pose additional installation and maintenance problems.

The use of powerless catalytic ignitors is a very promising means of mitigating the threat from short-term SBO. During long-term SBO, slow ATWS, and TW sequences, steam-inerting of the containment would reduce the effectiveness of the ignitors. However, at Grand Gulf, these sequences are much less significant to risk than short-term SBO. The risk reduction is therefore expected to be significant even though inert sequences are not affected. Such a system would be relatively inexpensive, simple, passive, and independent of any power system. However, because the powerless catalytic ignitors are larger and therefore heavier than the existing ignitors, a seismic re-analysis of the containment may be required. Further, hanging these powerless catalytic ignitors from the existing structures (such as the containment dome) poses a new potential threat to equipment below from a gravitational missile, and would thus require additional analysis. Sandia National Laboratories at Livermore has developed a prototype catalytic ignitor that is capable of burning hydrogen-air mixtures at hydrogen concentrations as low as 5.1 v/o.[16] The Sandia design is a wetproof improvement to an earlier design that was impaired by steam-condensing environments. Also reported is the development of a low-power design that uses a fraction of the power currently required by installed systems, and that would be well suited to battery-backed operation. Siemens/Kraftwerk Union (KWU) in West Germany has also developed a passive ignitor. The KWU design has been fully tested and qualified for use in German reactors, and would presumably be available in the United States. Reference 16 provides a comparison of the KWU and Sandia designs. Either would be suitable for use in the Mark III containment and the passive design is potentially less expensive to install than an additional power supply.

5.4 Modifications to Ensure a Dry Cavity at Vessel Breach

Drywell-to-wetwell vacuum breakers are installed at three out of four of the Mark III plants. Operation of the vacuum breakers would allow hydrogen from the wetwell to flow into the drywell and would create the potential for suppression pool bypass should they fail open or partially open. However, operation of the vacuum breakers could reduce the pressure transient from hydrogen diffusion burns and deflagrations (and some detonations, depending on the length of the pressure pulse as compared to the operating time of the vacuum breaker). This could prevent the hydrogen burns from pushing the suppression pool water over the drywell weir wall and thus flooding the drywell in–pedestal cavity. As discussed previously, this would reduce the potential for steam spikes or explosions when the reactor vessel fails. The resulting potential risk benefit from this improvement is discussed in Section 13.

During sequences with the vacuum breakers operable and open, the check valves in series with the large motor–operated vacuum breakers may cycle open and shut repeatedly. Should this occur, there is a chance that one or more of these check valves could stick open, creating a suppression pool bypass path.

The major uncertainty associated with extending vacuum breaker operation to SBO is whether the available vacuum breaker flow area is sufficient to prevent weir wall overflow. Current Draft NUREG–1150 MELCOR predictions suggest that the area is inadequate as indicated in the S.E. Dingman et al. draft report. The CPI program calculations also support this prediction, although the pressure rise calculated by MELCOR for a diffusion burn is larger than was observed in the Quarter Scale Test.

5.5 Cavity Flooding

This option would extend the operation of the upper containment pool dump valves to SBO sequences by providing backup power for valve control. By ensuring operator control of the upper pool dump valves during SBO, it should be possible to reduce the probability of dry CCI. Dumping the upper containment pool water volume to the suppression pool does not, of itself, ensure flow over the weir wall and flooding of the drywell. The weir wall is designed to hold the normal maximum suppression pool water plus the water in the upper containment pool. However, upper pool dump will increase the likelihood that other mechanisms will cause flooding, as discussed in Section 4.3.1. The Draft NUREG–1150 analysis has estimated the amount of water that would be expected to overflow the weir wall. The ORNL MELCOR analysis will provide additional information on the level of the water in the drywell in–pedestal area, and the timing of the weir wall overflow. Given that sufficient water enters the drywell in–pedestal area, any CCI that occurs will occur under water. However, the chance of steam explosion will be increased if the drywell is flooded when the reactor vessel fails.

There is a potential drawback to providing a backup source of power to the upper containment pool dump valves and that is the threat that operation of the valves late in the sequence could result in an uncontrolled hydrogen burn inside the containment. This could be a particular problem if the valves were backfitted with dc–powered motor operators, because the brushes and commutators in the dc motor would provide a very good ignition source. Therefore, it is important that procedural guidance be provided to ensure the valves are operated very early during SBO, before core damage occurs, so that the threat to the containment from uncontrolled hydrogen burns is minimized and the probability of flooding is maximized. Unfortunately, this also maximizes the potential for a steam explosion.

5.6 Containment Venting

Containment venting to prevent overpressurization or to control hydrogen concentration in the wetwell is currently only considered as a last resort, when other means are unavailable or ineffective. By deliberately venting the containment, instead of allowing it to fail at its ultimate pressure capacity, it may be possible to reseal the containment at some later point in the accident and thereby reduce releases. Venting, when performed from the containment wetwell airspace, also helps reduce releases by scrubbing the effluent through the suppression pool, as long as the suppression pool has not been bypassed. The non–noble gas fission products will be scrubbed, but fission product noble gases will only be cooled. Venting may also be useful in controlling the buildup of hydrogen in the drywell, but current ORNL MELCOR calculations (S.R. Greene et al. draft report) indicate that venting would be ineffective in reducing the hydrogen threat to containment, and may actually increase the wetwell hydrogen concentration.

Venting the containment is not without potential negative consequences, also. Given an assumed drywell–to–wetwell leakage area, the Draft NUREG–1150 MELCOR calculations (S.E. Dingman et al. draft report) show the generation of gases will not occur at a high enough rate to clear the wetwell vents. The result will be releases that are unfiltered by suppression pool scrubbing if the containment is vented.

There is concern in some BWRs with Mark I and Mark II containments that saturated suppression pool water conditions could lead to injection failure following venting. In BWRs with Mark III containments, the ECCS pumps can pump saturated water, thus injection will continue even with a saturated pool. Therefore, sequences that are vented will not lead automatically to core damage.

The vent path at Grand Gulf is considered to be a hard–pipe system. It consists of 20–in. diameter containment supply and purge exhaust lines. The exhaust line discharges to the roof after passing through approximately 20 ft of the auxiliary building. Most of this path consists of 20–in. diameter hard pipe, with about 10 ft of HVAC ducting midway along the path. Should the HVAC ducting segment fail, the compartment at the failure location would be filled with steam. This compartment is connected to the blowout tunnels via a vent that would probably be capable of relieving enough pressure to prevent failure of the compartment door. This compartment pressure relief capability and the location of ECCS pumps in separate watertight compartments provide a measure of assurance that failure of the ductwork will not result in environmental conditions that would fail the injection systems. This venting arrangement is most likely different at each Mark III plant.

Hardened vent modifications have been considered at other BWR facilities. However, it is doubtful that the risk reduction provided by the improved systems would be sufficient to justify the cost. A minimal upgrade could consist of replacing the short segment of HVAC pipe with piping capable of handling containment pressures of 17.24 psig (the current venting limit). The addition of ac–independent vent valves that can be remotely operated would increase the usefulness of the system during SBO sequences, as the existing valves would have to be opened manually during SBO and would require entry into containment to complete the valve lineup. This would have to be done in anticipation of a severe containment challenge, because the only guidance provided in Revision 4 of the EPGs is to vent before reaching the PCPL and environmental conditions in the containment would likely preclude entry into containment after the onset of severe core damage.

Venting could encompass the use of an external filter, such as the Filtra system proposed by the Long Island Lighting Company (Lilco) for Shoreham or the Multi–Venturi Scrubbing System (MVSS). Briefly, the Filtra system would be a gravel–filled concrete structure separate from the secondary containment, but connected to the primary containment by a high capacity hardened vent line. The system would be actuated by operator action. The gravel bed would scrub non–noble gas fission products and the height of the structure would provide for an elevated release. Reference 17 analyzed the proposed Shoreham installation and found that reductions in both core melt frequency and risk could be achieved. The decontamination factor (DF) for the Filtra design could be on the order of 1000 for fission product particulates, as compared to a DF of 10 to 100 for the suppression pool. Such a system is currently in use at the Barseback Nuclear Power Station in southern Sweden. The MVSS (Asea–Atom design) is being incorporated at the Oskarshamm, Forsmark, and Ringhals reactor facilities. This design uses approximately 80,000 gal of water and does not rely on ac or dc power. This design is less expensive than the gravel bed Filtra design (approximately $5M as compared to $10–$50M for Filtra). Given that there is normally some amount of suppression pool bypass in the Mark III containment because of drywell–to–wetwell leakage, and that venting exacerbates the release of fission products from containment, the external filter could significantly reduce the release of non–noble gas fission products.

6. QUANTITATIVE ANALYSIS METHODOLOGY

This section of the report describes the process used to analyze the severe accident response of the containment. The June 1989 Draft NUREG-1150 models for Grand Gulf were used for the quantitative analysis. The Grand Gulf-specific computer codes, databases, and inputs were provided on tape from Sandia National Laboratory (SNL).

The process begins at core damage, with the response of the containment modeled using an accident progression event tree (APET). The APET models relevant severe accident phenomenology up until the point at which the sequence is terminated, either by a release of fission products from containment or by recovery of the sequence. The end states of the APET describe the possible final conditions of the containment, that is, failed, vented, or intact. Also contained in the APET end states is information describing the fission product release from containment if there is a release. This information is used to group APET end states with similar characteristics into accident progression bins. For each of the accident progression bins, a source term is parametrically generated. These source terms are then used to calculate the offsite consequences of the release. A flowchart of the overall analysis process is provided in Figure 6-1.

The APETs constructed for the June 1989 Grand Gulf Draft NUREG-1150 analysis were used to model containment response in this report. Each APET contains 125 questions, or top events, with many questions having several possible outcomes or branches. Therefore, the APET cannot easily be visualized; it is too large for graphical representation and the large number of end states makes it amenable only to computer manipulation.

In the Draft NUREG-1150 analysis of Grand Gulf, an APET was constructed for each of the 12 plant damage states (PDSs) identified in the front-end accident sequence analysis.[4] The APETs themselves were analyzed using the EVNTRE event progression analysis computer code,[18] which was provided, along with the necessary input data files, by SNL.

Because the APETs are so large, there are generally thousands of end states produced for each PDS that is evaluated. This is particularly true when evaluating an APET in the EVNTRE sampling mode (mode 4), where several hundred observations of the same APET produce extremely large output files. Because it is not practicable to calculate a fission product source term and offsite consequences for each end state that is generated, end states with similar characteristics are grouped into a smaller number of accident progression bins prior to performing the source term calculations. This grouping is done with the PSTEVNT computer code.[19] The output from PSTEVNT consists of a set of accident progression bins associated with each PDS, along with the conditional probability of occurrence of each bin.

Source terms are then calculated for each accident progression bin using the GGSOR parametric source term generation code.[5] GGSOR's output consists of the isotopic release fractions and release information (timing, energy, etc.) associated with each accident progression bin.

The MELCOR Accident Consequence Code System (MACCS) is used to calculate the offsite consequences of a release.[20] However, because of the large number of accident progression bins involved, consequence calculations could not be performed for each bin. To reduce the required number of MACCS calculations, the PARTITION code was used to map the accident progression bins into source term groups.[21] The output of PARTITION is a set of source term groups, along with their associated characteristics. The mapping assignments of the APET accident progression bins are also contained in the PARTITION output. This information has to be retained for input into the final risk calculation.

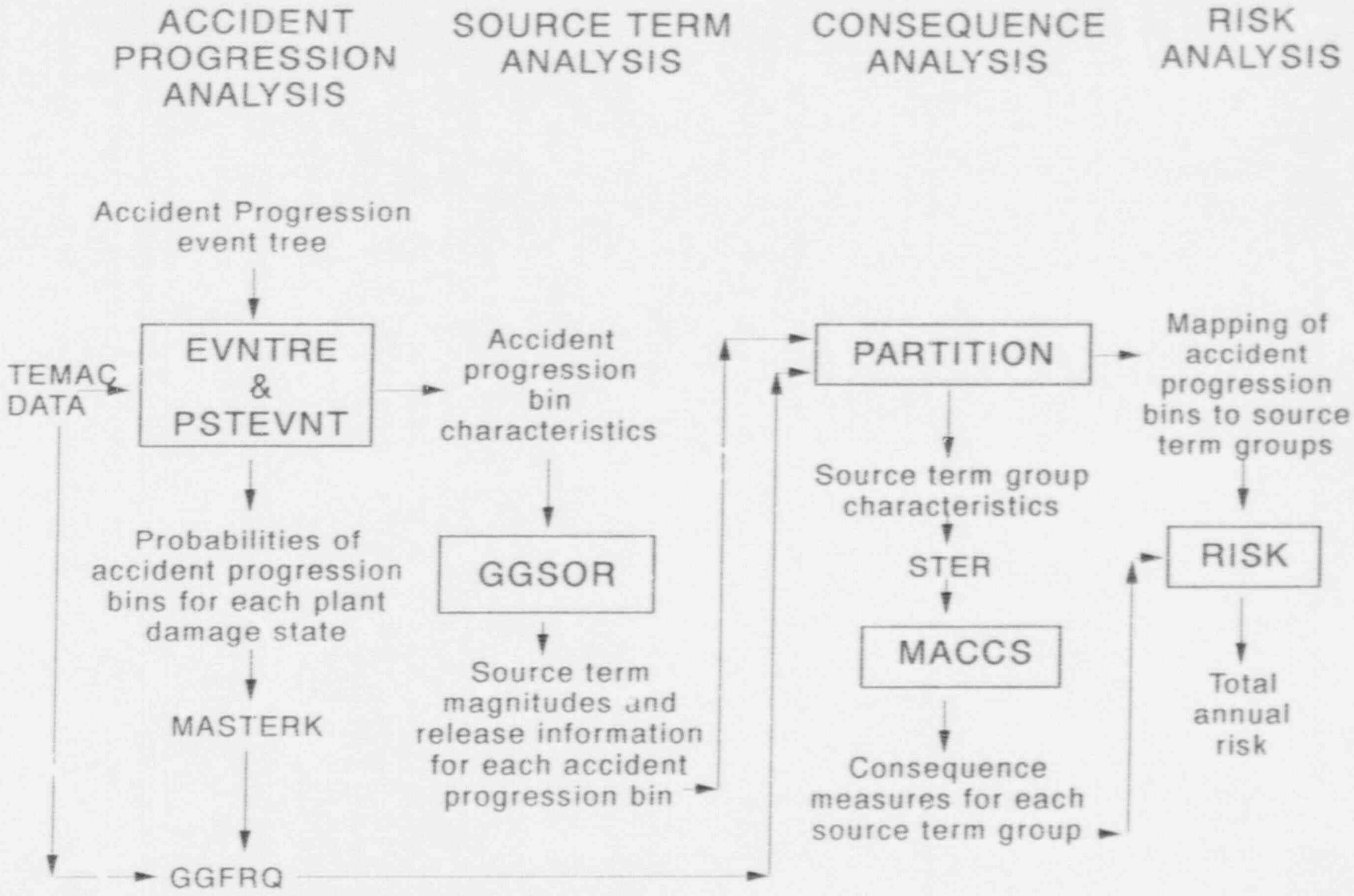

Figure 6–1. Flowchart of accident analysis process.

The next step in the analysis is to calculate conditional offsite consequences for each source term group generated by PARTITION. The following consequence measures are used in this report: (a) mean number of early fatalities, (b) mean number of latent fatalities, (c) mean population dose within a 50-mile radius of the plant, (d) mean population dose over the entire calculational grid (1000-mile radius), and (e) mean offsite costs associated with the release. Only item (c) is used in regulatory analysis of a potential plant improvement. The Draft NUREG-1150 MACCS input deck for Grand Gulf provided the required meteorological data, emergency response information, etc.

The final step in the analysis is to combine the plant damage state frequencies with the PARTITION source term group conditional probabilities and the conditional offsite consequences from MACCS to produce an annual risk (risk per reactor-year of operation) for each of the reported consequence measures.

The above discussion has presented a brief overview of the analysis process. Appendix A provides more details of the individual steps in the process, with the objective of tracking the flow of information through the analysis. Some of the computer files discussed in these sections are listed in Appendix B; however, some of the larger files are not listed because of space limitations. Furthermore, some details of the process are omitted, either because of lack of detailed knowledge or a decision that the information was not especially pertinent to the report.[a] Current plans call for a revision to these codes by SNL to simplify the analytical process, and for these codes to be available from the National Energy Software Center at the Argonne National Laboratory in Argonne, Illinois.

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[a] Computer models and data not provided in this report may currently be obtained by sending a formal request to the Director, Division of Systems Research, Office of Nuclear Regulatory Research, USNRC, Washington, D.C. 20555.

7. BASE CASE BENCHMARK ANALYSIS

The initial portion of the quantitative analysis focused on benchmarking the computer codes and data files obtained from SNL, as well as those the authors wrote or modified. The objective of this benchmark exercise was to reproduce the containment failure mode probabilities and off-site risk measures reported for Grand Gulf in the June 1989 draft of NUREG–1150.[6] Success in reproducing the Draft NUREG–1150 results would be a good indication that the various computer codes were working correctly and that the input files were correct.

7.1 Results of Accident Progression Analysis

This section presents the results of the APET analysis for each PDS and compares the results to the published results in Reference 5. Because Reference 5 presents only a limited subset of the accident progression information that is available, a full comparison could not be made. The tables in the following sections present the results of the calculations performed for this report and compare them to the published information in Reference 5.

Tables 7–1 through 7–12 present the accident progression analysis results for PDSs 1–12. For a more detailed discussion of these results, refer to Sections 2.5.1.1 through 2.5.1.12 of Reference 5.

The results from these tables agree to within 1% with those in Tables 2.5.1–1 through 2.5.1–12 in Reference 5. Thus, the base case accident progression analysis has succeeded in reproducing the results published in Reference 5.

7.2 Results of Risk Analysis

As discussed in Appendix A, the final risk calculation for this report was performed using the RISK program (see source code listing in Appendix C). This code combines the conditional consequences from MACCS with the conditional probabilities of a release from containment and the PDS frequencies from the front–end analysis.

As discussed in Appendix A, two MACCS consequence calculations were performed for the base case benchmark exercise. This was necessary because the current version of MACCS reflects significant revisions from the version used for the June 1989 draft of NUREG–1150. The revised base case uses reference time points for dispersion and radioactive decay of 0.5 for both the first and second plumes. The original case used values of 0.0 and 0.5, corresponding to the head and midpoint of the respective plume segments. Also, the revised base case specified that the growing season actions are independent of long–term actions. The original case specified that these two actions were coupled. Also, the protective action guides (permissible surface concentration) for the direct deposition pathway to milk and crops and their products by food ingestion have been corrected in the revised case. In the original analysis, the permissible surface concentrations were overly restrictive. Finally, the revised base case utilizes a corrected dose conversion file, because of a problem identified in the lung conversion dose.

Table 7–13 illustrates the base case Grand Gulf risk as published in Reference 5, the base case Grand Gulf risk that was calculated with the MACCS Version 1.5.5 input deck, and the base case Grand Gulf risk as calculated with the corrected MACCS input deck. This input deck is for MACCS 1.5.11, which is the version of MACCS that is to be released to the public. As this table indicates, the calculated results with the MACCS 1.5.5 input deck agree quite well with the values published in Draft NUREG–1150. The consequences calculated by MACCS 1.5.11 differ from those calculated by MACCS 1.5.5, but the differences are not great. As this table indicates, the base case calculations have succeeded in reproducing the Draft NUREG–1150 results. These results provide confidence that the converted NUREG–1150 code suite is running correctly with the correct input files. The following sections of the report will quantitatively evaluate the benefits of several potential containment performance improvements.

Table 7–1. Results of the accident progression analysis for PDS 1

Order	Bin	Conditional Probabilities[a]	ASeq	ZrOxid	VB	DCH–SE	SPB	CF	Sprays	MCCI	SRVBkr
Ten most probable bins											
1	ABBDDGCCB	3.2038E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L3	CL–Rpt	LCS	FLDCCI	cSRVBkr
2	ABEEAICEB	2.9264E–02	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CnFail	LCS	noCCI	cSRVBkr
3	ABEEAGCEB	2.7369E–02	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CL–Rpt	LCS	noCCI	cSRVBkr
4	ABEEAFCEB	2.6079E–02	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CL–Lk	LCS	noCCI	cSRVBkr
5	ABEEAHCEB	1.9375E–02	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CL–VENT	LCS	noCCI	cSRVBkr
6	AAEEAFCEB	1.3074E–02	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE0L0	CL–Lk	LCS	noCCI	cSRVBkr
7	AAEEABAEB	1.2814E–02	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE0L0	CE–Rpt	noCS	noCCI	cSRVBkr
8	AAEEAICEB	1.2597E–02	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE0L0	CnFail	LCS	noCCI	cSRVBkr
9	ABDDDGCCB	1.1660E–02	Fst–SB	LoZrOx	LoP–LPI	LoEXSE	SPBE0L3	CL–Rpt	LCS	FLDCCI	cSRVBkr
10	AAEEEBAEB	1.1197E–02	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE2L2	CE–Rpt	noCS	noCCI	cSRVBkr
Five most probable bins that have VB											
1	ABBDDGCCB	3.2038E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L3	CL–Rpt	LCS	FLDCCI	cSRVBkr
9	ABDDDGCCB	1.1660E–02	Fst–SB	LoZrOx	LoP–LPI	LoEXSE	SPBE0L3	CL–Rpt	LCS	FLDCCI	cSRVBkr
12	ABBDDGACB	1.0164E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	cSRVBkr
13	ABBDDGCCA	1.0150E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L3	CL–Rpt	LCS	FLDCCI	oSRVBkr
14	ABBDAICEB	8.5953E–03	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CnFail	LCS	noCCI	cSRVBkr
Five most probable bins that have early CF											
7	AAEEABAEB	1.2814E–02	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE0L0	CE–Rpt	noCS	noCCI	cSRVBkr
10	AAEEEBAEB	1.1197E–02	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE2L2	CE–Rpt	noCS	noCCI	cSRVBkr
15	AAEEAACEB	7.8431E–03	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE0L0	CE–Lk	LCS	noCCI	cSRVBkr
18	AAEEHBAEB	7.1341E–03	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE3L3	CE–Rpt	noCS	noCCI	cSRVBkr
31	AABDABACB	4.2698E–03	Fst–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CE–Rpt	noCS	FLDCCI	cSRVBkr

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[a] Probability of occurrence, given the occurrence of the PDS, averaged over 250 observations of the APET.

Table 7–2. Results of the accident progression analysis for PDS 2

Order	Bin	Conditional Probabilities[a]	ASeq	ZrOxid	VB	DCH–SE	SPB	CF	Sprays	MCCI	SRVBkr
Ten most probable bins											
1	ABBDDGACB	4.2840E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	cSRVBkr
2	ABEEAIAEB	3.4970E–02	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CnFail	noCS	noCCI	cSRVBkr
3	ABEEAGAEB	3.4538E–02	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CL–Rpt	noCS	noCCI	cSRVBkr
4	ABEEAFAEB	3.1825E–02	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CL–Lk	noCS	noCCI	cSRVBkr
5	ABEEAHAEB	2.0970E–02	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CL–VENT	noCS	noCCI	cSRVBkr
6	AAEEAFAEB	1.6668E–02	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE0L0	CL–Lk	noCS	noCCI	cSRVBkr
7	ABDDDGACB	1.5021E–02	Fst–SB	LoZrOx	LoP–LPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	cSRVBkr
8	AAEEABAEB	1.3645E–02	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE0L0	CE–Rpt	noCS	noCCI	cSRVBkr
9	AAEEAIAEB	1.3596E–02	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE0L0	CnFail	noCS	noCCI	cSRVBkr
10	ABBDDGACA	1.2610E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	oSRVBkr
Five most probable bins that have VB											
1	ABBDDGACB	4.2840E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	cSRVBkr
7	ABDDDGACB	1.5021E–02	Fst–SB	LoZrOx	LoP–LPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	cSRVBkr
10	ABBDDGACA	1.2610E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	oSRVBkr
13	ABBDAIAEB	1.0565E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CnFail	noCS	noCCI	cSRVBkr
14	ABBDAFAEB	1.0261E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Lk	noCS	noCCI	cSRVBkr
Five most probable bins that have early CF											
8	AAEEABAEB	1.3645E–02	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE0L0	CE–Rpt	noCS	noCCI	cSRVBkr
12	AAEEEBAEB	1.1778E–02	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE2L2	CE–Rpt	noCS	noCCI	cSRVBkr
17	AAEEHBAEB	9.1099E–03	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE3L3	CE–Rpt	noCS	noCCI	cSRVBkr
18	AAEEAAAEB	8.8185E–03	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE0L0	CE–Lk	noCS	noCCI	cSRVBkr
30	ABEEAAAEB	4.7237E–03	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CE–Lk	noCS	noCCI	cSRVBkr

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a. Probability of occurrence, given the occurrence of the PDS, averaged over 250 observations of the APET.

Table 7–3. Results of the accident progression analysis for PDS 3

Order	Bin	Conditional Probabilities[a]	ASeq	ZrOxid	VB	DCH–SE	SPB	CF	Sprays	MCCI	SRVBkr
Ten most probable bins											
1	ABBDDGACB	4.0622E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	cSRVBkr
2	ABEEAGAEB	2.4206E–02	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CL–Rpt	noCS	noCCI	cSRVBkr
3	ABEEAIAEB	2.1870E–02	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CnFail	noCS	noCCI	cSRVBkr
4	ABEEAFAEB	1.9836E–02	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CL–Lk	noCS	noCCI	cSRVBkr
5	ABDDDGACB	1.4050E–02	Fst–SB	LoZrOx	LoP–LPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	cSRVBkr
6	ABABAEAEB	1.3065E–02	Fst–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	noCS	noCCI	cSRVBkr
7	ABBDDGACA	1.2753E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	oSRVBkr
8	ABEEAHAEB	1.2753E–02	Fst–SB	LoZrOx	nVB	nDCH–SE	SPBE0L0	CL–VENT	noCS	noCCI	cSRVBkr
9	AAEEAFAEB	1.0789E–02	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE0L0	CL–Lk	noCS	noCCI	cSRVBkr
10	ABBDAIAEB	1.0067E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CnFail	noCS	noCCI	cSRVBkr
Five most probable bins that have VB											
1	ABBDDGACB	4.0622E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	cSRVBkr
5	ABDDDGACB	1.4050E–02	Fst–SB	LoZrOx	LoP–LPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	cSRVBkr
6	ABABAEAEB	1.3065E–02	Fst–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	noCS	noCCI	cSRVBkr
7	ABBDDGACA	1.2753E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L3	CL–Rpt	noCS	FLDCCI	oSRVBkr
10	ABBDAIAEB	1.0067E–02	Fst–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CnFail	noCS	noCCI	cSRVBkr
Five most probable bins that have early CF											
6	ABABAEAEB	1.3065E–02	Fst–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	noCS	noCCI	cSRVBkr
16	AAEEABAEB	7.2484E–03	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE0L0	CE–Rpt	noCS	noCCI	cSRVBkr
18	AAEEEBAEB	6.8120E–03	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE2L2	CE–Rpt	noCS	noCCI	cSRVBkr
20	ABABBEAEB	6.7908E–03	Fst–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	noCS	noCCI	cSRVBkr
22	AAEEHBAEB	6.3324E–03	Fst–SB	HiZrOx	nVB	nDCH–SE	SPBE3L3	CE–Rpt	noCS	noCCI	cSRVBkr

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a. Probability of occurrence, given the occurrence of the PDS, averaged over 250 observations of the APET.

Table 7–4. Results of the accident progression analysis for PDS 4

Order	Bin	Conditional Probabilities[a]	ASeq	ZrOxid	VB	DCH–SE	SPB	CF	Sprays	MCCI	SRVBkr
Ten most probable bins											
1	BABDAGACB	3.2412E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Rpt	noCS	FLDCCI	cSRVBkr
2	BABDAEACB	3.0998E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CVB–Rpt	noCS	FLDCCI	cSRVBkr
3	BABDHBACB	2.6422E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE3L3	CE–Rpt	noCS	FLDCCI	cSRVBkr
4	BBBDAGACB	2.5715E–02	Slw–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Rpt	noCS	FLDCCI	cSRVBkr
5	BABDAEAEB	2.1786E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CVB–Rpt	noCS	noCCI	cSRVBkr
6	BABDBEACB	1.9932E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0I3	CVB–Rpt	noCS	FLDCCI	cSRVBkr
7	BABDAGAEB	1.9923E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Rpt	noCS	noCCI	cSRVBkr
8	BABDHBAEB	1.7605E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE3L3	CE–Rpt	noCS	noCCI	cSRVBkr
9	BBBDAEACB	1.6412E–02	Slw–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CVB–Rpt	noCS	FLDCCI	cSRVBkr
10	BBBDAGAEB	1.5118E–02	Slw–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Rpt	noCS	noCCI	cSRVBkr
Five most probable bins that have early CF and early suppression pool bypass											
3	BABDHBACB	2.6422E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE3L3	CE–Rpt	noCS	FLDCCI	cSRVBkr
6	BABDBEACB	1.9932E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0I3	CVB–Rpt	noCS	FLDCCI	cSRVBkr
8	BABDHBAEB	1.7605E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE3L3	CE–Rpt	noCS	noCCI	cSRVBkr
11	BABDBEAEB	1.3284E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0I3	CVB–Rpt	noCS	noCCI	cSRVBkr
12	BBBDBEACB	1.1899E–02	Slw–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0I3	CVB–Rpt	noCS	FLDCCI	cSRVBkr

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[a] Probability of occurrence, given the occurrence of the PDS, averaged over 250 observations of the APET.

Table 7–5. Results of the accident progression analysis for PDS 5

Order	Bin	Conditional Probabilities[a]	ASeq	ZrOxid	VB	DCH–SE	SPB	CF	Sprays	MCCI	SRVBkr
Ten most probable bins											
1	BABDAGACB	3.6004E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Rpt	noCS	FLDCCI	cSRVBkr
2	BABDAEACB	3.3705E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CVB–Rpt	noCS	FLDCCI	cSRVBkr
3	BABDHBACB	3.0306E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE3L3	CE–Rpt	noCS	FLDCCI	cSRVBkr
4	BBBDAGACB	2.8669E–02	Slw–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Rpt	noCS	FLDCCI	cSRVBkr
5	BBBDAEACB	2.7144E–02	Slw–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CVB–Rpt	noCS	FLDCCI	cSRVBkr
6	BABDAEAEB	2.3639E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CVB–Rpt	noCS	noCCI	cSRVBkr
7	BABDAGAEB	2.2245E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Rpt	noCS	noCCI	cSRVBkr
8	BABDBEACB	2.2193E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0I3	CVB–Rpt	noCS	FLDCCI	cSRVBkr
9	BABDHBAEB	2.0194E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE3L3	CE–Rpt	noCS	noCCI	cSRVBkr
10	BBBDAGAEB	1.9726E–02	Slw–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Rpt	noCS	noCCI	cSRVBkr
Five most probable bins that have early CF and early suppression pool bypass											
3	BABDHBACB	3.0306E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE3L3	CE–Rpt	noCS	FLDCCI	cSRVBkr
8	BABDBEACB	2.2193E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0I3	CVB–Rpt	noCS	FLDCCI	cSRVBkr
9	BABDHBAEB	2.0194E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE3L3	CE–Rpt	noCS	noCCI	cSRVBkr
12	BBBDBEACB	1.5054E–02	Slw–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0I3	CVB–Rpt	noCS	FLDCCI	cSRVBkr
13	BABDBEAEB	1.4790E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0I3	CVB–Rpt	noCS	noCCI	cSRVBkr

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a. Probability of occurrence, given the occurrence of the PDS, averaged over 250 observations of the APET.

Table 7–6. Results of the accident progression analysis for PDS 6

Order	Bin	Conditional Probabilities[a]	ASeq	ZrOxid	VB	DCH–SE	SPB	CF	Sprays	MCCI	SRVBkr
Ten most probable bins											
1	BABDHBACB	4.4345E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE3L3	CE–Rpt	noCS	FLDCCI	cSRVBkr
2	BABDAGACB	4.1411E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Rpt	noCS	FLDCCI	cSRVBkr
3	BABDAEACB	3.6972E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CVB–Rpt	noCS	FLDCCI	cSRVBkr
4	BBBDAGACB	3.2926E–02	Slw–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Rpt	noCS	FLDCCI	cSRVBkr
5	BABDHBAEB	2.9551E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE3L3	CE–Rpt	noCS	noCCI	cSRVBkr
6	BABDAEAEB	2.5964E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CVB–Rpt	noCS	noCCI	cSRVBkr
7	BABDAGAEB	2.5961E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Rpt	noCS	noCCI	cSRVBkr
8	BBBDAEACB	2.5750E–02	Slw–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CVB–Rpt	noCS	FLDCCI	cSRVBkr
9	BABDBEACB	2.4213E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0I3	CVB–Rpt	noCS	FLDCCI	cSRVBkr
10	BBBDAGAEB	2.0052E–02	Slw–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0L0	CL–Rpt	noCS	noCCI	cSRVBkr
Five most probable bins that have early CF and early suppression pool bypass											
1	BABDHBACB	4.4345E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE3L3	CE–Rpt	noCS	FLDCCI	cSRVBkr
5	BABDHBAEB	2.9551E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE3L3	CE–Rpt	noCS	noCCI	cSRVBkr
9	BABDBEACB	2.4213E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0I3	CVB–Rpt	noCS	FLDCCI	cSRVBkr
12	BBBDBEACB	1.6483E–02	Slw–SB	LoZrOx	LoP–nLPI	LoEXSE	SPBE0I3	CVB–Rpt	noCS	FLDCCI	cSRVBkr
13	BABDBEAEB	1.6138E–02	Slw–SB	HiZrOx	LoP–nLPI	LoEXSE	SPBE0I3	CVB–Rpt	noCS	noCCI	cSRVBkr

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[a] Probability of occurrence, given the occurrence of the PDS, averaged over 250 observations of the APET.

Table 7–7. Results of the accident progression analysis for PDS 7

Order	Bin	Conditional Probabilities[a]	ASeq	ZrOxid	VB	DCH–SE	SPB	CF	Sprays	MCCI	SRVBkr
Ten most probable bins											
1	ABABAEAEB	4.1552E–02	Fst–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	noCS	noCCI	cSRVBkr
2	AAABAEAEB	2.8179E–02	Fst–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	noCS	noCCI	cSRVBkr
3	AAABAIAEB	2.5240E–02	Fst–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CnFail	noCS	noCCI	cSRVBkr
4	AAABAFAEB	2.4347E–02	Fst–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CL–Lk	noCS	noCCI	cSRVBkr
5	ABABBEAEB	1.8223E–02	Fst–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0L3	CVB–Rpt	noCS	noCCI	cSRVBkr
6	AAABEBAEB	1.5414E–02	Fst–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE2L2	CE–Rpt	noCS	noCCI	cSRVBkr
7	ABABAGAEB	1.5209E–02	Fst–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CL–Rpt	noCS	noCCI	cSRVBkr
8	ABABAFAEB	1.4255E–02	Fst–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CL–Lk	noCS	noCCI	cSRVBkr
9	AAABABAEB	1.3800E–02	Fst–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Rpt	noCS	noCCI	cSRVBkr
10	AACBAFAEB	1.3203E–02	Fst–SB	HiZrOx	HiP–LPI	LoDCH	SPBE0L0	CL–Lk	noCS	noCCI	cSRVBkr
Five most probable bins that have early CF and early suppression pool bypass											
5	ABABBEAEB	1.8223E–02	Fst–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0L3	CVB–Rpt	noCS	noCCI	cSRVBkr
6	AAABEBAEB	1.5414E–02	Fst–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE2L2	CE–Rpt	noCS	noCCI	cSRVBkr
13	AAABBEAEB	1.2330E–02	Fst–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0L3	CVB–Rpt	noCS	noCCI	cSRVBkr
16	AAABHBAEB	1.0746E–02	Fst–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE3L3	CE–Rpt	noCS	noCCI	cSRVBkr
18	AACBHBAEB	9.8298E–03	Fst–SB	HiZrOx	HiP–LPI	LoDCH	SPBE3L3	CE–Rpt	noCS	noCCI	cSRVBkr

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[a] Probability of occurrence, given the occurrence of the PDS, averaged over 250 observations of the APET.

Table 7–8. Results of the accident progression analysis for PDS 8

Order	Bin	Conditional Probabilities[a]	ASeq	ZrOxid	VB	DCH–SE	SPB	CF	Sprays	MCCI	SRVBkr
Ten most probable bins											
1	BAABAAAEB	6.7501E–02	Slw–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Lk	noCS	noCCI	cSRVBkr
2	BBABAAAEB	4.0410E–02	Slw–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Lk	noCS	noCCI	cSRVBkr
3	BAABAEAEB	2.9744E–02	Slw–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	noCS	noCCI	cSRVBkr
4	BACBAAAEB	2.9640E–02	Slw–SB	HiZrOx	HiP–LPI	LoDCH	SPBE0L0	CE–Lk	noCS	noCCI	cSRVBkr
5	BBABAEAEB	2.7446E–02	Slw–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	noCS	noCCI	cSRVBkr
6	BAABABAEB	2.6864E–02	Slw–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Rpt	noCS	noCCI	cSRVBkr
7	BAABAAAEA	2.0833E–02	Slw–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Lk	noCS	noCCI	cSRVBkr
8	BAABAAACB	1.6874E–02	Slw–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Lk	noCS	FLDCCI	cSRVBkr
9	BAABBBADB	1.6202E–02	Slw–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CE–Rpt	noCS	DlyCCI	cSRVBkr
10	BAABAGAEB	1.5858E–02	Slw–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Rpt	noCS	noCCI	cSRVBkr
Five most probable bins that have early CF and early suppression pool bypass											
9	BAABBBADB	1.6202E–02	Slw–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CE–Rpt	noCS	DlyCCI	cSRVBkr
13	BAABBAADB	1.4372E–02	Slw–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CE–Lk	noCS	DlyCCI	cSRVBkr
18	BAABEAAEB	1.0326E–02	Slw–SB	HiZrOx	HiP–nLPI	LoDCH	SPBE2L2	CE–Lk	noCS	noCCI	cSRVBkr
21	BBABBAADB	9.0005E–03	Slw–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0I3	CE–Lk	noCS	DlyCCI	cSRVBkr
23	BBABBBADB	8.9209E–03	Slw–SB	LoZrOx	HiP–nLPI	LoDCH	SPBE0I3	CE–Rpt	noCS	DlyCCI	cSRVBkr

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a. Probability of occurrence, given the occurrence of the PDS, averaged over 250 observations of the APET.

Table 7–9. Results of the accident progression analysis for PDS 9

Order	Bin	Conditional Probabilities[a]	ASeq	ZrOxid	VB	DCH–SE	SPB	CF	Sprays	MCCI	SRVBkr
Ten most probable bins											
1	EAABAECEB	8.7130E–02	Fst–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
2	EBABAECEB	5.5191E–02	Fst–TC	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
3	EACBAECEB	3.5098E–02	Fst–TC	HiZrOx	HiP–LPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
4	EAABBECEB	3.2721E–02	Fst–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
5	EBABBECEB	2.8106E–02	Fst–TC	LoZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
6	EBCBAECEB	2.1369E–02	Fst–TC	LoZrOx	HiP–LPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
7	EAABAECCB	2.1191E–02	Fst–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	FLDCCI	cSRVBkr
8	EAADAECEB	1.7610E–02	Fst–TC	HiZrOx	HiP–nLPI	LoEXSE	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
9	EAABAFCEB	1.7548E–02	Fst–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CL–Lk	LCS	noCCI	cSRVBkr
10	EACBBECEB	1.7120E–02	Fst–TC	HiZrOx	HiP–LPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
Five most probable bins that have early CF and early suppression pool bypass											
4	EAABBECEB	3.2721E–02	Fst–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
5	EBABBECEB	2.8106E–02	Fst–TC	LoZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
10	EACBBECEB	1.7120E–02	Fst–TC	HiZrOx	HiP–LPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
15	EACBHECEB	1.2181E–02	Fst–TC	HiZrOx	HiP–LPI	LoDCH	SPBE3L3	CVB–Rpt	LCS	noCCI	cSRVBkr
20	EAABEECEB	8.3463E–03	Fst–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE2L2	CVB–Rpt	LCS	noCCI	cSRVBkr

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a. Probability of occurrence, given the occurrence of the PDS, averaged over 250 observations of the APET.

Table 7–10. Results of the accident progression analysis for PDS 10

Order	Bin	Conditional Probabilities[a]	ASeq	ZrOxid	VB	DCH–SE	SPB	CF	Sprays	MCCI	SRVBkr
Ten most probable bins											
1	FAABAADEB	4.7479E–02	Slw–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Lk	ECS	noCCI	cSRVBkr
2	FACBAADEB	2.6238E–02	Slw–TC	HiZrOx	HiP–LPI	LoDCH	SPBE0L0	CE–Lk	ECS	noCCI	cSRVBkr
3	FACBABDEB	2.5470E–02	Slw–TC	HiZrOx	HiP–LPI	LoDCH	SPBE0L0	CE–Rpt	ECS	noCCI	cSRVBkr
4	FAABABBEB	2.4590E–02	Slw–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Rpt	ECSnoL	noCCI	cSRVBkr
5	FBABAADEB	1.6100E–02	Slw–TC	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Lk	ECS	noCCI	cSRVBkr
6	FACBBADEB	1.6055E–02	Slw–TC	HiZrOx	HiP–LPI	LoDCH	SPBE0I3	CE–Lk	ECS	noCCI	cSRVBkr
7	FAABAADDB	1.5188E–02	Slw–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Lk	ECS	DlyCCI	cSRVBkr
8	FAABABDEB	1.5020E–02	Slw–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Rpt	ECS	noCCI	cSRVBkr
9	FBABABDEB	1.4284E–02	Slw–TC	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Rpt	ECS	noCCI	cSRVBkr
10	FAABABBDB	1.3589E–02	Slw–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CE–Rpt	ECSnoL	DlyCCI	cSRVBkr
Five most probable bins that have early CF and early suppression pool bypass											
6	FACBBADEB	1.6055E–02	Slw–TC	HiZrOx	HiP–LPI	LoDCH	SPBE0I3	CE–Lk	ECS	noCCI	cSRVBkr
13	FBABBADEB	1.1330E–02	Slw–TC	LoZrOx	HiP–nLPI	LoDCH	SPBE0I3	CE–Lk	ECS	noCCI	cSRVBkr
16	FAABBBBEB	1.0086E–02	Slw–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CE–Rpt	ECSnoL	noCCI	cSRVBkr
17	FAABBADEB	9.7688E–03	Slw–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CE–Lk	ECS	noCCI	cSRVBkr
22	FAABBBDEB	8.0123E–03	Slw–TC	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CE–Rpt	ECS	noCCI	cSRVBkr

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a. Probability of occurrence, given the occurrence of the PDS, averaged over 250 observations of the APET.

Table 7–11. Results of the accident progression analysis for PDS 11

Order	Bin	Conditional Probabilities[a]	ASeq	ZrOxid	VB	DCH–SE	SPB	CF	Sprays	MCCI	SRVBkr
Ten most probable bins											
1	CAABAECEB	5.9874E–02	Fst–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
2	CBABAECEB	2.9842E–02	Fst–T2	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
3	CACBAECEB	2.5372E–02	Fst–T2	HiZrOx	HiP–LPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
4	CBABBECEB	1.8297E–02	Fst–T2	LoZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
5	CAABBECEB	1.8139E–02	Fst–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
6	CBCBAECEB	1.6248E–02	Fst–T2	LoZrOx	HiP–LPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
7	CAABAECEA	1.5046E–02	Fst–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	oSRVBkr
8	CAABAECCB	1.4554E–02	Fst–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	FLDCCI	cSRVBkr
9	CAABAFCEB	1.4449E–02	Fst–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CL–Lk	LCS	noCCI	cSRVBkr
10	CAABAICEB	1.2698E–02	Fst–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CnFaiL	LCS	noCCI	cSRVBkr
Five most probable bins that have early CF and early suppression pool bypass											
4	CBABBECEB	1.8297E–02	Fst–T2	LoZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
5	CAABBECEB	1.8139E–02	Fst–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
13	CACBBECEB	1.1169E–02	Fst–T2	HiZrOx	HiP–LPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
18	CAABBECEA	9.0260E–03	Fst–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	oSRVBkr
20	CACBHECEB	7.9503E–03	Fst–T2	HiZrOx	HiP–LPI	LoDCH	SPBE3L3	CVB–Rpt	LCS	noCCI	cSRVBkr

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a. Probability of occurrence, given the occurrence of the PDS, averaged over 250 observations of the APET.

Table 7–12. Results of the accident progression analysis for PDS 12

Order	Bin	Conditional Probabilities[a]	ASeq	ZrOxid	VB	DCH–SE	SPB	CF	Sprays	MCCI	SRVBkr
Ten most probable bins											
1	DAABAECEB	5.9874E–02	Slw–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
2	DBABAECEB	2.9842E–02	Slw–T2	LoZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
3	DACBAECEB	2.5372E–02	Slw–T2	HiZrOx	HiP–LPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
4	DBABBECEB	1.8297E–02	Slw–T2	LoZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
5	DAABBECEB	1.8139E–02	Slw–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
6	DBCBAECEB	1.6248E–02	Slw–T2	LoZrOx	HiP–LPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	cSRVBkr
7	DAABAECEA	1.5046E–02	Slw–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	noCCI	oSRVBkr
8	DAABAECCB	1.4554E–02	Slw–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CVB–Rpt	LCS	FLDCCI	cSRVBkr
9	DAABAFCEB	1.4449E–02	Slw–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CL–Lk	LCS	noCCI	cSRVBkr
10	DAABAICEB	1.2698E–02	Slw–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0L0	CnFail	LCS	noCCI	cSRVBkr
Five most probable bins that have early CF and early suppression pool bypass											
4	DBABBECEB	1.8297E–02	Slw–T2	LoZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
5	DAABBECEB	1.8139E–02	Slw–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
13	DACBBECEB	1.1169E–02	Slw–T2	HiZrOx	HiP–LPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	cSRVBkr
18	DAABBECEA	9.0260E–03	Slw–T2	HiZrOx	HiP–nLPI	LoDCH	SPBE0I3	CVB–Rpt	LCS	noCCI	oSRVBkr
20	DACBHECEB	7.9503E–03	Slw–T2	HiZrOx	HiP–LPI	LoDCH	SPBE3L3	CVB–Rpt	LCS	noCCI	cSRVBkr

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a. Probability of occurrence, given the occurrence of the PDS, averaged over 250 observations of the APET.

Table 7–13. Grand Gulf base case risk comparison

	Mean Early Fatalities (per ry[a])	Mean Latent Fatalities (per ry)	Mean 50–Mile Dose (man–rem/ry)	Mean 1000–Mile Dose (man–rem/ry)	Mean Offsite Costs ($/ry)
NUREG–1150	8.2E–09	9.4E–04	5.2E–01	5.8	8.5E+03
MACCS 1.5.5	7.6E–09	9.3E–04	5.3E–01	5.7	8.5E+03
MACCS 1.5.11	6.2E–09	1.7E–03	7.8E–01	10.4	2.2E+03

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[a] Reactor year.

8. QUANTITATIVE RISK ANALYSIS OF STAND–ALONE IMPROVED HYDROGEN IGNITION SYSTEM

The improvement to the HIS that was modeled was installation of a backup dc power supply to the existing ignitors, so that the HIS would be operable under SBO conditions. The backup dc power supply was modeled as having an availability of 0.95. The probability that the operators fail to actuate the HIS when required was retained from the base case APETs. Only PDSs 1, 3, 7, 8, and 10 were evaluated. These PDSs contribute over 97% of the base case risk, so limiting the evaluation to these PDSs provided a good approximation of the total benefit.

8.1 Effects of Improved HIS on Containment Response

This section discusses the effects on containment response of a modification to supply backup power to the HIS, so that it is functional during SBO sequences. Refer to Appendix D for the APET modifications used to model the improved HIS.

Continuously available hydrogen ignitors provide a distributed ignition source that burns the hydrogen released during core degradation in a diffusion flame whenever flammable conditions exist in containment. Table 8–1 shows the effects of the improved HIS on the conditional probabilities of the presentation bins used in the June 1989 draft of NUREG–1150. These bins are arranged in decreasing order of severity of failure mode (in terms of risk potential).

Table 8–1 illustrates a number of interesting effects of the improved HIS on containment response, some of which may not be intuitive. First, note that backup power to the ignitors does not affect PDSs 8 and 10. In PDS 8 (long–term SBO), the drywell and containment are inert to hydrogen burns; therefore, the ignitors cannot burn hydrogen, so there is no change from the base case. Note that containment sprays are failed in PDS 8, so the containment is not deinerted by late recovery of sprays. This is typical of all but one of the long–term SBO PDSs at Grand Gulf. However, this result may not be generically applicable to all Mark III plants. In PDS 10 (ATWS), ac power is available in the base case, so adding a backup power source has no effect.

The probability of diffusion flames consuming the hydrogen prior to vessel breach is increased in the short–term SBO PDSs. The probability of diffusion burns remains <1.0 because the ignitors are assumed to be available 95% of the time, with the human error probability for failure to turn the ignitors on remaining unchanged from the base case value. The probability of a deflagration or detonation in the wetwell prior to vessel breach is significantly reduced in the short–term SBO PDSs. Again, there is no change in PDSs 8 and 10, because there were no deflagrations or detonations in the base case. As a result of the reduction in deflagrations and detonations, the level of containment impulse loading before vessel breach is reduced. The frequency of the higher combustion pressure loads is redistributed to the two lowest pressure categories.

The amount of containment and drywell leakage induced by deflagrations and detonations prior to vessel breach is reduced in the short–term SBO PDSs. The amount of *no leakage* is increased significantly. The amount of suppression pool bypass following early combustion is also reduced from the base case.

In the short–term SBO PDSs, there is a reduced probability that the reactor cavity will be flooded (defined as $\geq$16.4 ft of water) at the time of vessel breach. However, the reduction in the frequency of flooding is redistributed to an increased probability of having a wet cavity (0–16.4 ft of water). The probability of having a dry cavity at the time of vessel breach is also reduced. The implication is that a reduction in wetwell deflagrations prior to vessel breach decreases the probability of cavity flooding, but the diffusion burns in the

Table 8–1. Conditional probability of accident progression bins at Grand Gulf—improved HIS case (initial run)

Accident Progression Bin	Conditional Probability PDS 1 (ST–SBO)	PDS 3 (ST–SBO)	PDS 7 (ST–SBO)	PDS 8 (LT–SBO)	PDS 10 (ATWS)
VB,[a] early CF,[b] early SPB,[c] no CS[d]	HIS: 3.97E–02 Base: 9.63E–02	HIS: 1.43E–01 Base: 2.00E–01	HIS: 1.77E–01 Base: 2.84E–01	HIS: 2.94E–01 Base: 2.94E–01	HIS: 1.04E–03 Base: 1.03E–03
VB, early CF, early SPB, CS	HIS: 6.96E–02 Base: 4.81E–02	HIS: 0.00E+00 Base: 0.00E+00	HIS: 0.00E+00 Base: 0.00E+00	HIS: 0.00E+00 Base: 0.00E+00	HIS: 2.48E–01 Base: 2.46E–01
VB, early CF, late SPB	HIS: 9.61E–03 Base: 7.91E–03	HIS: 1.02E–02 Base: 8.39E–03	HIS: 4.14E–03 Base: 3.15E–03	HIS: 1.42E–03 Base: 1.42E–03	HIS: 3.66E–03 Base: 3.63E–03
VB, early CF, no SPB	HIS: 1.91E–01 Base: 1.13E–01	HIS: 2.42E–01 Base: 1.68E–01	HIS: 3.77E–01 Base: 3.04E–01	HIS: 6.58E–01 Base: 6.58E–01	HIS: 5.91E–01 Base: 5.86E–01
VB, late CF	HIS: 2.47E–01 Base: 2.88E–01	HIS: 2.85E–01 Base: 3.10E–01	HIS: 3.55E–01 Base: 3.31E–01	HIS: 4.65E–02 Base: 4.65E–02	HIS: 0.00E+00 Base: 0.00E+00
VB, vented	HIS: 5.32E–02 Base: 4.93E–02	HIS: 5.84E–02 Base: 5.07E–02	HIS: 0.00E+00 Base: 0.00E+00	HIS: 0.00E+00 Base: 0.00E+00	HIS: 1.47E–01 Base: 1.55E–01
VB, no CF	HIS: 5.56E–02 Base: 5.61E–02	HIS: 4.30E–02 Base: 3.75E–02	HIS: 7.48E–02 Base: 6.53E–02	HIS: 0.00E+00 Base: 0.00E+00	HIS: 0.00E+00 Base: 0.00E+00
No VB	HIS: 3.24E–01 Base: 3.24E–01	HIS: 2.08E–01 Base: 2.09E–01	HIS: 1.06E–02 Base: 1.05E–02	HIS: 0.00E+00 Base: 0.00E+00	HIS: 8.43E–03 Base: 8.87E–03

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a. Vessel breach.

b. Containment failure.

c. Suppression pool bypass.

d. Containment sprays.

wetwell result in a reflux of water over the weir wall, which decreases the probability that the cavity will be dry at the time of vessel breach.

Table 8-1 also indicates an *increase* in early containment failure in the short-term SBO PDSs. There is an especially large increase in the conditional probability of early containment failure with no suppression pool bypass. This result was unexpected, and led to a detailed investigation of the Grand Gulf APET model and the user functions used to calculate various parameters in the APET.

The investigation began with a detailed examination of the frequency output files from EVNTRE. The first event with an unexpected behavior in the improved HIS sensitivity is Question 57, which addresses the level of hydrogen in the drywell before vessel breach. In the improved HIS case, there is an increase in the probability that the drywell hydrogen concentration will be detonable or combustible at this point in the sequence. This immediately leads to two questions: (a) how is the hydrogen getting into the drywell, and (b) why isn't it burned by the drywell ignitors?

The second question is easier to answer. The hydrogen is not burned by the drywell ignitors because the Draft NUREG-1150 model for Grand Gulf did not include these ignitors. This was confirmed by discussions with Sandia personnel, who indicated that these ignitors were not thought to be important for the sequences of interest, because of the very limited time window of drywell flammability expected in the base case sequences.

The question about how the hydrogen gets into the drywell is harder to answer. The obvious place to begin looking is with those questions that address suppression pool bypass prior to vessel breach. Question 52, which addresses pool bypass following early combustion events, turns out to be the relevant question. As mentioned above, the overall conditional probability of pool bypass is lower in the improved HIS case than in the base case. However, there is an increase in Case 4 of Question 52. The mode of pool bypass in Case 4 involves failure of the large drywell-to-wetwell vacuum breakers as a result of diffusion burns in the wetwell. Recovery of ac power makes these vacuum breakers operable, and when wetwell pressure exceeds drywell pressure by a predetermined amount, these vacuum breakers are opened to eliminate the pressure differential. If diffusion burns are occurring in the wetwell when these valves open, hot combustion gases can pass through the valves, potentially causing them to fail in the open position. Although the probability of valve failure is low (mean failure probability is 0.05), the large increase in the likelihood of diffusion burns in the improved HIS case causes a significant increase in this mode of pool bypass.

The next step in the investigation was to examine how the hydrogen concentrations in the drywell and wetwell are manipulated within the APET user function. The function of interest is IBASP, which is called by Question 55 and calculates containment pressure prior to vessel breach. The portion of this user function that evaluates Case 3 of Question 55 (large pool bypass) calculates the concentration of hydrogen in the drywell by multiplying the wetwell hydrogen concentration by the ratio of drywell-to-wetwell volume. In other words, the drywell and wetwell volumes are assumed to be well-mixed and a fraction of the wetwell hydrogen is transported by the user function into the drywell via the bypass path afforded by the failed vacuum breaker. This "extra" hydrogen that goes back into the drywell increases the drywell flammability, leading to an increased probability of drywell failure from impulse loading at the time of vessel breach, as a result of hydrogen detonation in the drywell.

However, answering the two questions above about hydrogen concentration in the drywell does not resolve all the difficulties with the improved HIS sensitivity. Although the path by which hydrogen enters the drywell from the wetwell has been identified, a question remains as to why this hydrogen is not consumed by the diffusion burns in the wetwell. The answer to this question, and the real deficiency with the Grand Gulf model, lies in Question 46, which asks about the efficiency with which hydrogen is burned in the containment prior to vessel breach.

There are two parameters in Question 46: the effective efficiency and the actual efficiency. The meaning of these parameters is not documented in the APET, so a discussion of these parameters was held with personnel from SNL. SNL explained that the effective efficiency is used as a non–adiabatic correction factor in calculating the pressure rise resulting from a hydrogen burn. The actual efficiency is used in calculating the amount of hydrogen (and oxygen) consumed in a burn. These parameters are inputs to user function EPBRN, which calculates the peak pressure rise in containment from a hydrogen burn prior to vessel breach. EPBRN also calculates the fraction of hydrogen consumed by the burn, based on the actual burn efficiency read in from the APET.

Case 1 of Question 46 addresses diffusion burns. Both the effective and actual burn efficiencies are set to zero in this case. Therefore, the diffusion burns consume *no* hydrogen; the molar fraction of hydrogen is the same before and after a diffusion burn. This effect was acknowledged by SNL personnel, who suggested that an actual efficiency of 100% would more closely approximate available data from the Quarter–Scale Tests.

An actual diffusion burn efficiency of 0% allows hydrogen to build up in the wetwell even in those case where the ignitors operate. When the vacuum breakers fail, a fraction of this hydrogen is transported into the drywell, where it can detonate at vessel breach. However, the larger problem is the hydrogen that remains unburned in the wetwell, because this hydrogen presents a particularly severe threat to containment integrity as a result of deflagrations and detonations following vessel breach. Because the improved HIS reduces the probability of deflagration– and detonation–induced containment failure before vessel breach (via APET logic, not via user function calculation), hydrogen that does not burn early (before vessel breach) is more likely to burn at or following vessel breach if an ignition source is available. This is the reason for the increased probability of containment failure at the time of vessel breach in the improved HIS case.

To more realistically model the HIS improvement, Question 46 was modified by replacing the actual diffusion burn efficiency of 0% with the recommended efficiency of 100%. With this change, a diffusion burn in the wetwell removes all of the hydrogen, unless the reaction becomes oxygen–limited. No attempts were made to model ignitors in the drywell, because they are not expected to have a significant effect on the progression of the sequence.

Changes were made to the improved HIS APETs and sampling files for PDSs 1, 3, and 7. No changes were made for PDSs 8 and 10, because no hydrogen burns were predicted in the base case for these sequences (containment is inert). The base case APET and sampling files for PDS 1 were also modified to ensure that the change in actual burn efficiency does not significantly alter the base case results. No significant change to the base case was observed, because the dominant PDSs are SBOs, where the HIS is generally unavailable due to a lack of ac power. Table 8–2 indicates the presentation bins for PDS 1, for the original and revised base case.

As Table 8–2 indicates, increasing the diffusion burn actual efficiency from 0% to 100% produces only slight changes in the base case conditional containment failure probabilities. There is a slight decrease in early containment failures, due to the elimination of detonations in the drywell at the time of vessel breach. The slight increase in late containment failures is the result of shifting some failures that originally would have occurred early to late failures occurring after vessel breach.

Table 8–3 shows the effects of increasing the diffusion burn efficiency in the improved HIS case. Results are presented only for PDSs 1, 3, and 7, because no hydrogen burns were predicted for PDS's 8 and 10.

The 100% efficiency values from Table 8-3 should be compared with the base case containment failure probabilities from Table 8-1 to judge the effect of the HIS improvement. This comparison indicates a significant shift from early containment failure to no containment failure and late containment failure. Although overall risk is not calculated for the HIS improvement, this shift away from early containment failure is expected to bring about a reduction in offsite risk.

Table 8-4 compares the weighted average accident progression bin probabilities for the improved HIS case with the base case. Again, these results are from the improved HIS case with a 100% actual diffusion burn efficiency.

Table 8-2. Effect of diffusion burn efficiency on base case containment failure probabilities—PDS 1

Containment Failure Bin	Conditional Probability Burn Efficiency = 0%	Conditional Probability Burn Efficiency = 100%
VB,[a] early CF,[b] early SPB,[c] no CS[d]	9.63E-02	9.63E-02
VB, early CF, early SPB, CS	4.81E-02	4.48E-02
VB, early CF, late SPB	7.91E-0[illegible]	7.49E-03
VB, early CF, no SPB	1.13E-01	1.07E-01
VB, late CF	2.88E-01	2.94E-01
VB, vented	4.93E-02	5.07E-02
VB, no CF	5.62E-02	5.79E-02
No VB	3.24E-01	3.24E-01

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[a] Vessel breach.

[b] Containment failure.

[c] Suppression pool bypass.

[d] Containment sprays.

Table 8–3. Effect of diffusion burn efficiency on containment failure probabilities—improved HIS case

Containment Failure Bin	PDS 1		PDS 3		PDS 7	
VB,[a] early CF,[b] early SPB,[c] no CS[d]	0%:[e] 100%:[f]	3.97E–02 2.59E–02	0%: 100%:	1.43E–01 7.47E–02	0%: 100%:	1.77E–01 1.34E–01
VB, early CF, early SPB, CS	0%: 100%:	6.96E–02 2.10E–02	0%: 100%:	0.00E+00 0.00E+00	0%: 100%:	0.00E+00 0.00E+00
VB, early CF, late SPB	0%: 100%:	9.61E–03 1.90E–03	0%: 100%:	1.02E–02 2.19E–03	0%: 100%:	4.14E–03 3.10E–03
VB, early CF, no SPB	0%: 100%:	1.91E–01 5.31E–02	0%: 100%:	2.42E–01 9.87E–02	0%: 100%:	3.77E–01 2.92E–01
VB, late CF	0%: 100%:	2.47E–01 3.88E–01	0%: 100%:	2.86E–01 4.51E–01	0%: 100%:	3.55E–01 4.54E–01
VB, vented	0%: 100%:	6.32E–02 9.47E–02	0%: 100%:	5.84E–02 9.30E–02	0%: 100%:	0.00E+00 0.00E+00
VB, no CF	0%: 100%:	5.56E–02 9.14E–02	0%: 100%:	4.30E–02 6.61E–02	0%: 100%:	7.48E–02 1.05E–01
No VB	0%: 100%:	3.24E–01 3.24E–01	0%: 100%:	2.08E–01 2.08E–01	0%: 100%:	1.06E–02 1.06E–02

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a. Vessel breach.

b. Containment failure.

c. Suppression pool bypass.

d. Containment sprays.

e. 0%: Original improved HIS case with diffusion burn efficiency of 0%

f. 100%: [illegible] HIS improvement with diffusion burn efficiency of 100%

Table 8–4. Weighted average accident progression bin probabilities—improved HIS

Accident Progression Bin	Base Case Conditional Probability	Improved HIS Conditional Probability
VB,[a] early CF,[b] early SPB,[c] no CS[d]	1.22E–01	4.65E–02
VB, early CF, early SPB, CS	4.61E–02	2.47E–02
VB, early CF, late SPB	7.23E–03	2.24E–03
VB, early CF, no SPB	1.57E–01	1.06E–01
VB, late CF	2.83E–01	3.80E–01
VB, vented	4.49E–02	7.42E–02
VB, No CF	5.44E–02	8.75E–02
No VB	2.70E–01	2.70E–01

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[a] Vessel breach.

[b] Containment failure.

[c] Suppression pool bypass.

[d] Containment sprays.

9. QUANTITATIVE RISK ANALYSIS OF STAND–ALONE POST–CORE DAMAGE REACTOR DEPRESSURIZATION

This improvement consists of a backup supply of dc power to the SRV solenoids, allowing the reactor to be depressurized during sequences in which the station batteries (the normal source of power to the SRV solenoids) are failed or depleted. There are three aspects to enhanced depressurization, as follows. (a) it can prevent core damage in those sequences where a low–pressure injection system is available, (b) it can allow sequences that have progressed to core damage to be recovered in–vessel, and (c) it can prevent high–pressure melt ejection in those cases where in–vessel recovery is not successful. It should be noted that the potential improvement, as modeled in this analysis, addresses only items (b) and (c). Item (a) was to be addressed, but calculations could not be completed because of difficulties in obtaining Level–1 PRA data in a format suitable for evaluation.

9.1 Effects of Post–Core Damage Depressurization on Containment Response

Table 9–1 presents the effects of the post–core damage depressurization system on the conditional probabilities of the accident progression presentation bins used in the June 1989 draft of NUREG–1150. These bins are arranged in decreasing order of severity of the failure mode (in terms of risk potential). Refer to Appendix D for the APET modifications used to model potential improvements.

Post–core damage depressurization has a number of effects on the progression of the accident sequence after the onset of core degradation. First, depressurization decreases the probability that an SRV tailpipe vacuum breaker will stick open. This effect is attributable to the fewer number of demands placed on the SRVs when the RPV is depressurized. This effect would be greater if the depressurization occurred *before* core damage (i.e., in accordance with Revision 3 of the EPGs). Secondly, and perhaps more interesting, is the effect of depressurization on the probability of in–vessel recovery. As Table 9–1 indicates, the probability of in–vessel recovery (no VB) is higher in the depressurized case for all PDSs except 1 and 8. The increase in vessel breach probability in PDS 1 occurs in spite of the fact that the probability of recovering injection during core degradation is higher for all PDSs in the depressurized case, except PDS 8, where it is 0.0 in both the sensitivity and base case. The reason is the increased probability of in–vessel steam explosions that fail the RPV in the depressurized case.

The expert panel convened for NUREG–1150 quantified in–vessel steam explosion as a pressure–dependent phenomenon. The mean probability of an in–vessel steam explosion is approximately one order of magnitude higher at low pressure than at normal operating pressure, because the necessary trigger for the explosion is thought to be more likely at low pressures. In PDS 1, there is a significant probability of recovering injection in the base case. This probability does increase in the depressurized case, but the increase is not enough to offset the increased probability of in–vessel steam explosion in the cases where injection is not recovered. In the other PDSs (except PDS 8), the increase in the probability of recovering injection *is* large enough to offset the increased explosion probability; thus, the probability of vessel breach increases in PDS 1 and decreases in the other PDSs.

The increased probability of in–vessel steam explosion is also the reason for the increased probability of early containment failure indicated for PDSs 1 and 8 in Table 9–1. The increased probability of in–vessel steam explosions makes α mode failure of the containment more likely in the depressurized case, resulting in an increased probability of early containment failure at the time of vessel breach. Several points need to be grasped to completely understand why these results are being observed. First, the NUREG–1150 work on Grand Gulf followed the work on other plants,

Table 9–1. Conditional probability of accident progression bins at Grand Gulf—post–core damage reactor depressurized case

Accident Progression Bin	Conditional Probability PDS 1 (ST–SBO)	PDS 3 (ST–SBO)	PDS 7 (ST–SBO)	PDS 8 (LT–SBO)	PDS 10 (ATWS)
VB,[a] early CF,[b] early SPB,[c] no CS[d]	Dep.: 1.13E–01 Base: 9.63E–02	Dep.: 1.74E–01 Base: 2.00E–01	Dep.: 1.47E–01 Base: 2.84E–01	Dep.: 3.56E–01 Base: 2.94E–01	Dep.: 4.11E–04 Base: 1.03E–03
VB, early CF, early SPB, CS	Dep.: 5.42E–02 Base: 4.81E–02	Dep.: 0.00E+00 Base: 0.00E+00	Dep.: 0.00E+00 Base: 0.00E+00	Dep.: 0.00E+00 Base: 0.00E+00	Dep.: 1.46E–01 Base: 2.46E–01
VB, early CF, late SPB	Dep.: 1.23E–02 Base: 7.91E–03	Dep.: 1.24E–02 Base: 8.39E–03	Dep.: 1.06E–02 Base: 3.15E–03	Dep.: 1.22E–02 Base: 1.42E–03	Dep.: 2.25E–02 Base: 3.63E–03
VB, early CF, no SPB	Dep.: 1.28E–01 Base: 1.13E–01	Dep.: 1.33E–01 Base: 1.68E–01	Dep.: 1.59E–01 Base: 3.04E–01	Dep.: 2.69E–01 Base: 6.58E–01	Dep.: 4.35E–01 Base: 5.86E–01
VB, late CF	Dep.: 2.95E–01 Base: 2.88E–01	Dep.: 3.08E–01 Base: 3.10E–01	Dep.: 3.66E–01 Base: 3.31E–01	Dep.: 3.60E–01 Base: 4.65E–02	Dep.: 0.00E+00 Base: 0.00E+00
VB, vented	Dep.: 4.67E–02 Base: 4.93E–02	Dep.: 4.70E–02 Base: 5.07E–02	Dep.: 0.00E+00 Base: 0.00E+00	Dep.: 0.00E+00 Base: 0.00E+00	Dep.: 1.18E–01 Base: 1.55E–01
VB, no CF	Dep.: 4.86E–02 Base: 5.61E–02	Dep.: 3.57E–02 Base: 3.75E–02	Dep.: 4.87E–02 Base: 6.53E–02	Dep.: 2.37E–03 Base: 0.00E+00	Dep.: 0.00E+00 Base: 0.00E+00
No VB	Dep.: 2.91E–01 Base: 3.24E–01	Dep.: 2.78E–01 Base: 2.09E–01	Dep.: 2.67E–01 Base: 1.05E–02	Dep.: 0.00E+00 Base: 0.00E+00	Dep.: 2.78E+01 Base: 8.87E–03

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a. Vessel breach.

b. Containment failure.

c. Suppression pool bypass.

d. Containment sprays.

notably Peach Bottom. Thus, issues that were considered to be potentially important at Peach Bottom were carried over to Grand Gulf, at least as a starting point. Secondly, the important issues are those that were perceived to have the greatest probabilities or consequences. Once they were identified, the remaining small issues were ignored. And finally, this project is considering the effects of the "small" issues after the "large" issues have ostensibly been significantly reduced. In a Mark I plant, the reactor head is within a few feet of the containment (or drywell) head. If the reactor head in a Mark I were to be failed by in-vessel steam explosion, it would have a reasonable probability of hitting the containment head, and possibly a non-trivial probability of failing containment. In a Mark III (or a large dry containment such as at Zion), the reactor head is located approximately 100 feet below the containment. In this case, the reactor head would have to fail and travel a significant distance and still maintain sufficient energy to fail containment. In the case of Grand Gulf, this means failing the steel liner and a reinforced concrete structure. This result should not be of concern, in any event, because APET end states with alpha mode failure are of very low probability and do not have a large impact on offsite risk.

In PDSs 3, 7, and 10, the increase in the probability of recovering injection during core degradation is large enough to offset the increased probability of in-vessel steam explosion, thus giving rise to a decrease in the probability of vessel breach, and a corresponding decrease in the probability of early containment failure.

There is also an effect on the amount of zirconium oxidized at the time of vessel breach, and thus on the amount of hydrogen produced (Question 69). This question addresses ex-vessel oxidation phenomena, namely high-pressure melt ejection and ex-vessel steam explosion. In all PDSs except PDS 1, there is a significant shift toward lower zirconium oxidation, because of the elimination of high-pressure melt ejection. In PDS 1, there is an increase in the probability of ex-vessel steam explosion because of the increase in the probability of vessel breach at low pressure (see the discussion of in-vessel steam explosion above). Additional hydrogen is generated during the ex-vessel steam explosion, so there is a shift away from the lowest oxidation category toward the next higher one. This is accompanied by a decrease in the highest oxidation category, also, because of the elimination of high-pressure melt ejection in the depressurized case. Overall, there is a shift from the highest and lowest oxidation categories to the middle categories.

Table 9-2 presents the conditional accident progression bin probabilities weighted by the PDS frequencies. Post-core damage depressurization results in a slight overall decrease in the probability of early containment failure. Late containment failures have increased slightly, as has the probability of in-vessel recovery. This latter change occurs in spite of the decreased probability of in-vessel recovery in PDS 1 as previously discussed.

Table 9–2. Weighted average accident progression bin probabilities—enhanced depressurization

Accident Progression Bin	Base Case Conditional Probability	Depressurized Case Conditional Probability
VB,[a] early CF,[b] early SPB,[c] no CS[d]	1.22E–01	1.21E–01
VB, early CF early SPB, CS	4.61E–02	4.93E–02
VB, early CF, late SPB	7.23E–03	1.21E–02
VB, early CF, no SPB	1.57E–01	1.44E–01
VB, late CF	2.83E–01	2.98E–01
VB, vented	4.49E–02	4.21E–02
VB, no CF	5.44E–02	4.68E–02
No VB	2.70E–01	2.77E–01

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a. Vessel breach.

b. Containment failure.

c. Suppression pool bypass.

d. Containment sprays.

10. QUANTITATIVE RISK ANALYSIS OF STAND–ALONE ENHANCED VACUUM BREAKER OPERABILITY (NO WEIR WALL OVERFLOW)

Enhanced vacuum breaker operability was discussed earlier as a potential means of ensuring no weir wall overflow in order to mitigate the threat to containment from ex–vessel steam explosions. However, recent work by ORNL (S. R. Greene et al. draft report) indicates that enhanced vacuum breaker operability alone may not accomplish this task. Therefore, improvements to the vacuum breakers will not be examined further. The evaluated improvement is still prevention of weir wall overflow, but the means by which this could be ensured have not been examined in this analysis. Possible ways of implementing this improvement would be to increase the height of the weir wall or vent the containment prior to depressurizing the reactor vessel.

10.1 Effects of No Weir Wall Overflow on Containment Response

Table 10–1 presents the effects of not having weir wall overflow on the conditional probabilities of the accident progression presentation bins used in the June 1989 draft of NUREG–1150. These bins are arranged in decreasing order of severity of the failure modes (in terms of offsite consequence potential). See Appendix D for a discussion of the APET modifications used to model this improvement.

Table 10–1 indicates that preventing weir wall overflow results in a shift in early containment failures with early suppression pool bypass to early containment failures with either late pool bypass or no bypass. This shift appears to be due to the decrease in ex–vessel steam explosions; however, ex–vessel steam explosions are not eliminated. The conditional probability of an ex–vessel steam explosion is still quite large, even if weir wall overflow is prevented. This is especially so in PDSs 1 and 8, where there is little or no reduction in the conditional probability of an ex–vessel steam explosion. Eliminating weir wall overflow *does not* ensure a dry cavity. Water can still accumulate as a result of recirculation pump seal leakage or drywell upper head failure. If there is no water in the reactor pedestal cavity (i.e., <656 ft^3) before failure of the reactor vessel but injection is present, the *assumption* is made that sufficient water will come out of the reactor vessel concurrent with, or shortly after, the corium then there will be a possibility of an ex–vessel steam explosion.

Table 10–1 also indicates an increase in the conditional probability of late containment failure, with an accompanying decrease in the probability that the containment survives intact (VB, No CF). This increase is primarily attributed to a large increase in the probability of APET end states in which CCI occurs in a dry cavity. In this context, *dry* means there is insufficient water present to prevent a prompt and vigorous CCI. The CCI generates hydrogen and noncondensible gases, which can threaten containment integrity via hydrogen combustion and gradual overpressurization, respectively. With the prevention of weir wall overflow, there is generally a significant increase in the probability of late hydrogen deflagrations and detonations, accompanied by a smaller decrease in the probability of eventual overpressurization by noncondensible gases. The net effect is an increase in the probability of late containment failure and a decrease in the probability of containment survival, as indicated in Table 10–2.

Table 10–1. Conditional probability of accident progression bins at Grand Gulf—no weir wall overflow

Accident Progression Bin	Conditional Probability PDS 1 (ST–SBO)	PDS 3 (ST–SBO)	PDS 7 (ST–SBO)	PDS 8 (LT–SBO)	PDS 10 (ATWS)
VB,[a] early CF,[b] early SPB, no CS	NWWO[c]: 8.52E–02 Base: 9.63E–02	NWWO: 1.64E–01 Base: 2.00E–01	NWWO: 2.48E–01 Base: 2.84E–01	NWWO: 2.94E–01 Base: 2.94E–01	NWWO: 4.15E–04 Base: 1.03E–03
VB, early CF, early SPB,[d] CS[e]	NWWO: 3.63E–02 Base: 4.81E–02	NWWO: 0.00E+00 Base: 0.00E+00	NWWO: 0.00E+00 Base: 0.00E+00	NWWO: 0.00E+00 Base: 0.00E+00	NWWO: 1.21E–01 Base: 2.46E–01
VB, early CF, late SPB	NWWO: 2.09E–02 Base: 7.91E–03	NWWO: 2.70E–02 Base: 8.39E–03	NWWO: 2.80E–02 Base: 3.15E–03	NWWO: 2.09E–03 Base: 1.42E–03	NWWO: 3.12E–02 Base: 3.63E–03
VB, early CF, no SPB	NWWO: 1.22E–01 Base: 1.13E–01	NWWO: 1.82E–01 Base: 1.68E–01	NWWO: 3.14E–01 Base: 3.04E–01	NWWO: 6.57E–01 Base: 6.58E–01	NWWO: 6.84E–01 Base: 5.86E–01
VB, late CF	NWWO: 3.33E–01 Base: 2.88E–01	NWWO: 3.48E–01 Base: 3.10E–01	NWWO: 3.77E–01 Base: 3.31E–01	NWWO: 4.01E–02 Base: 4.65E–02	NWWO: 0.00E+00 Base: 0.00E+00
VB, vented	NWWO: 4.43E–02 Base: 4.93E–02	NWWO: 4.73E–02 Base: 5.07E–02	NWWO: 0.00E+00 Base: 0.00E+00	NWWO: 0.00E+00 Base: 0.00E+00	NWWO: 1.55E–01 Base: 1.55E–01
VB, no CF	NWWO: 2.23E–02 Base: 5.61E–02	NWWO: 1.21E–02 Base: 3.75E–02	NWWO: 2.22E–02 Base: 6.53E–02	NWWO: 6.36E–03 Base: 0.00E+00	NWWO: 0.00E+00 Base: 0.00E+00
No VB	NWWO: 3.24E–01 Base: 3.24E–01	NWWO: 2.10E–01 Base: 2.09E–01	NWWO: 1.05E–02 Base: 1.05E–02	NWWO: 0.00E+00 Base: 0.00E+00	NWWO: 8.87E–03 Base: 8.87E–03

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a. Vessel breach.

b. Containment failure.

c. No weir wall overflow.

d. Suppression pool bypass.

e. Containment sprays.

Table 10–2. Weighted average accident progression bin probabilities—no weir wall overflow

Accident Progression Bin	Base Case Conditional Probability	No Weir Wall Overflow Conditional Probability
VB,[a] early CF,[b] early SPB,[c] no CS[d]	1.22E–01	1.08E–01
VB, early CF, early SPB, CS	4.61E–02	3.48E–02
VB, early CF, late SPB	7.23E–03	2.12E–02
VB, early CF, no SPB	1.57E–01	1.67E–01
VB, late CF	2.83E–01	3.25E–01
VB, vented	4.49E–02	4.08E–02
VB, no CF	5.44E–02	2.24E–02
No VB	2.70E–01	2.70E–01

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[a] Vessel breach.

[b] Containment failure.

[c] Suppression pool bypass.

[d] Containment sprays.

11. QUANTITATIVE RISK ANALYSIS OF STAND–ALONE CONTAINMENT VENTING

Containment venting has been suggested in the past as a means of preventing containment overpressurization and reducing the threat from hydrogen burns during a severe accident. Venting was examined quantitatively in this report by assuming that a backup source of dc power is available to the solenoids of the containment vent valves, so that the valves can be opened remotely during SBO. The enhanced venting system is assumed to have an availability of 0.95. For short–term SBO, the containment is assumed to be vented prior to core degradation (preemptive venting), with no later closure of the vent valves. For long–term SBO and ATWS sequences, venting is not preemptive, because containment pressure will reach the PCPL prior to core degradation.

11.1 Effects of Venting on Containment Response

Table 11–1 presents the effects of venting on the conditional probabilities of the accident progression presentation bins used in the June 1989 draft of NUREG–1150. These bins are arranged in decreasing order of the severity of the failure mode (in terms of offsite consequence potential). See Appendix D for a discussion of the APET modifications used to model containment venting. As expected, early venting greatly reduces the threat to containment integrity. Table 11–2 presents the effects of venting on the weighted average accident progression bin probabilities.

These tables do not indicate whether venting is beneficial or detrimental in terms of the resulting offsite release. Because of the way in which PSTEVNT reads the binning file used to generate the presentation bins for these tables, vented sequences involving suppression pool bypass are picked up only as vented sequences. The bypass information is passed along to GGSOR for the source term calculation, but it is not retained in the accident progression presentation bins.

11.2 Risk Results

MACCS calculations were performed using the MACCS 1.5.11 input decks to determine the effect of containment venting on offsite consequences. Table 11–3 presents these results along with those of the base case. As this table indicates, venting (without an external filter) leads to an increase in offsite risk by an approximate factor of 2 because of the relatively high probability of suppression pool bypass in the Mark III containment. These results do not reflect the results of deterministic analyses performed since the publication of Draft 1150. ORNL MELCOR calculations showing that weir wall overflow, and therefore the probability of steam explosion, could be reduced by venting were not available in time for inclusion in this analysis.

Table 11–1. Conditional probability of accident progression bins at Grand Gulf—vented case

Accident Progression Bin	Conditional Probability				
	PDS 1 (ST–SBO)	PDS 3 (ST–SBO)	PDS 7 (ST–SBO)	PDS 8 (LT–SBO)	PDS 10 (ATWS)
VB,[a] early CF,[b] early SPB,[c] no CS[d]	Vent: 4.08E–03 Base: 9.63E–02	Vent: 8.68E–03 Base: 2.00E–01	Vent: 1.39E–02 Base: 2.84E–01	Vent: 1.46E–02 Base: 2.94E–01	Vent: 5.34E–05 Base: [illegible]
VB, early CF, early SPB, CS	Vent: 2.04E–03 Base: 4.81E–02	Vent: 0.00E+00 Base: 0.00E+00	Vent: 0.00E+00 Base: 0.00E+00	Vent: 0.00E+00 Base: 0.00E+00	Vent: [illegible] Base: [illegible]
VB, early CF, late SPB	Vent: 3.40E–04 Base: 7.91E–03	Vent: 3.60E–04 Base: 8.39E–03	Vent: 1.50E–04 Base: 3.15E–03	Vent: 6.97E–05 Base: 1.42E–03	Vent: 2.15E–04 Base: 3.63E–03
VB, early CF, no SPB	Vent: 4.60E–03 Base: 1.13E–01	Vent: 7.14E–03 Base: 1.68E–01	Vent: 1.49E–02 Base: 3.04E–01	Vent: 3.28E–02 Base: 6.58E–01	Vent: 3.49E–02 Base: 5.86E–01
VB, late CF	Vent: 1.22E–02 Base: 2.88E–01	Vent: 1.33E–02 Base: 3.10E–01	Vent: 1.32E–02 Base: 3.31E–01	Vent: 1.97E–03 Base: 4.65E–02	Vent: 0.00E+00 Base: 0.00E+00
VB, vented	Vent: 6.36E–01 Base: 4.93E–02	Vent: 7.45E–01 Base: 5.07E–02	Vent: 9.43E–01 Base: 0.00E+00	Vent: 9.50E–01 Base: 0.00E+00	Vent: 9.06E–01 Base: 1.55E–01
VB, no CF	Vent: 2.43E–03 Base: 5.61E–02	Vent: 1.60E–03 Base: 3.75E–02	Vent: 2.63E–03 Base: 6.53E–02	Vent: 0.00E+00 Base: 0.00E+00	Vent: 0.00E+00 Base: 0.00E+00
No VB	Vent: 3.24E–01 Base: 3.24E–01	Vent: 2.09E–01 Base: 2.09E–01	Vent: 1.05E–02 Base: 1.05E–02	Vent: 0.00E+00 Base: 0.00E+00	Vent: 4.33E–02 Base: 8.87E–03

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a. Vessel breach.

b. Containment failure.

c. Suppression pool bypass.

d. Containment sprays.

Table 11-2. Weighted average accident progression bin probabilities—containment venting

Accident Progression Bin	Base Case Conditional Probability	Conditional Probability with Venting
VB,[a] early CF,[b] early SPB,[c] no CS[d]	1.22E-01	9.95E-03
VB, early CF, early SPB, CS	4.61E-02	6.14E-03
VB, early CF, late SPB	7.23E-03	5.61E-04
VB, early CF, no SPB	1.57E-01	1.72E-02
VB, late CF	2.83E-01	2.11E-02
VB, vented	4.49E-02	6.58E-01
VB, no CF	5.44E-02	4.17E-03
No VB	2.70E-01	2.70E-01

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a. Vessel breach.

b. Containment failure.

c. Suppression pool bypass.

d. Containment sprays.

Table 11-3. Risk results for containment venting (stand-alone sensitivity)

	Mean Early Fatalities (per ry[a])	Mean Latent Fatalities (per ry)	Mean 50-Mile Dose (man-rem/ry)	Mean 1000-Mile Dose (man-rem/ry)	Mean Offsite Costs ($/ry)
Base case	6.2E-09	1.7E-03	0.78	10.4	2.2E+03
With venting	1.4E-08	3.4E-03	1.3	20.4	2.7E+03

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a. Reactor year.

12. QUANTITATIVE RISK ANALYSIS OF STAND–ALONE UPPER POOL DUMP

Because the valves used to dump the Mark III upper containment pool to the suppression pool are operated by ac motors, they are not available during SBO. A potential improvement would be to supply these valves with operators which could be actuated independently of ac power, or with operators supplied from an independent source of ac power. This would allow makeup to the suppression pool from the upper containment pool during SBO.

12.1 Effects on Containment Response

Table 12–1 presents the effects of the upper pool dump modification on the conditional probabilities of the accident progression presentation bins used in the June 1989 draft of NUREG–1150. These bins are arranged in decreasing order of the severity of the failure mode (in terms of offsite consequence potential). Refer to Appendix D for the APET modifications used to model this improvement.

The upper pool dump modification causes a significant increase in the probability of early containment failure with pool bypass in the short–term SBO PDSs. Table 12–2 presents this information in the form of a weighted average over all PDSs.

Based on the results in these tables, the upper pool dump modification does not appear to significantly reduce the threat to containment integrity. Pool dump results in a higher probability of a flooded or wet cavity at the time of vessel breach (the probability of having a dry cavity is 0.0). This increases the probability of a large ex–vessel steam explosion at the time of vessel breach, which increases the impulse loads on the drywell. An ex–vessel steam explosion may also fragment the melt, exposing it to oxygen in the steam and the containment atmosphere. This would accelerate oxidation, producing large quantities of hydrogen, which could ignite, further increasing the probability of containment failure at the time of vessel breach.

However, this analysis was based on the models in Draft 1150. Other evaluations[15] concluded that steam explosions would not occur when corium falls into water. If this is correct, then assuring the dumping of the upper pool would not increase the challenge to containment integrity but would increase the scrubbing of releases from the expelled corium.

Table 12–1. Conditional probability of accident progression bins at Grand Gulf—pool dump case

	Conditional Probability				
Accident Progression Bin	PDS 1 (ST–SBO)	PDS 3 (ST–SBO)	PDS 7 (ST–SBO)	PDS 8 (LT–SBO)	PDS 10 (ATWS)
VB,[a] early CF,[b] early SPB,[c] CS[d]	UCP: 1.02E–01 Base: 9.63E–02	UCP: 2.08E–01 Base: 2.00E–01	UCP: 3.11E–01 Base: 2.84E–01	UCP: 2.94E–01 Base: 2.94E–01	UCP: 1.03E–03 Base: 1.03E–03
VB, early CF, early SPB, CS	UCP: 5.05E–02 Base: 4.81E–02	UCP: 0.00E+00 Base: 0.00E+00	UCP: 0.00E+00 Base: 0.00E+00	UCP: 0.00E+00 Base: 0.00E+00	UCP: 2.46E–01 Base: 2.46E–01
VB, early CF, late SPB	UCP: 7.41E–03 Base: 7.91E–03	UCP: 7.89E–03 Base: 8.39E–03	UCP: 7.84E–04 Base: 3.15E–03	UCP: 1.42E–03 Base: 1.42E–03	UCP: 3.63E–03 Base: 3.63E–03
VB, early CF, no SPB	UCP: 1.08E–01 Base: 1.13E–01	UCP: 1.63E–01 Base: 1.68E–01	UCP: 2.72E–01 Base: 3.04E–01	UCP: 6.58E–01 Base: 6.58E–01	UCP: 5.86E–01 Base: 5.86E–01
VB, late CF	UCP: 2.83E–01 Base: 2.88E–01	UCP: 3.06E–01 Base: 3.10E–01	UCP: 3.38E–01 Base: 3.31E–01	UCP: 4.65E–02 Base: 4.65E–02	UCP: 0.00E+00 Base: 0.00E+00
VB, vented	UCP: 4.93E–02 Base: 4.93E–02	UCP: 5.06E–02 Base: 5.07E–02	UCP: 0.00E+00 Base: 0.00E+00	UCP: 0.00E+00 Base: 0.00E+00	UCP: 1.55E–01 Base: 1.55E–01
VB, no CF	UCP: 5.65E–02 Base: 5.61E–02	UCP: 3.76E–02 Base: 3.75E–02	UCP: 6.49E–02 Base: 6.53E–02	UCP: 0.00E+00 Base: 0.00E+00	UCP: 0.00E+00 Base: 0.00E+00
No VB	UCP: 3.24E–01 Base: 3.24E–01	UCP: 2.09E–01 Base: 2.09E–01	UCP: 1.05E–02 Base: 1.05E–02	UCP: 0.00E+00 Base: 0.00E+00	UCP: 8.87E–03 Base: 8.87E–03

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a. Vessel breach.

b. Containment failure.

c. Suppression pool bypass.

d. Containment sprays.

Table 12-2. Weighted average accident progression bin probabilities—pool dump case

Accident Progression Bin	Base Case Conditional Probability	Conditional Probability With UCP Dump
VB,[a] early CF,[b] early SPB,[c] no CS[d]	1.22E–01	1.30E–01
VB, early CF, early SPB, CS	4.61E–02	4.79E–02
VB, early CF, late SPB	7.23E–03	6.56E–03
VB, early CF, no SPB	1.57E–01	1.50E–01
VB, late CF	2.83E–01	2.81E–01
VB, vented	4.49E–02	4.49E–02
VB, no CF	5.44E–02	5.47E–02
No VB	2.70E–01	2.70E–01

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a. Vessel breach.

b. Containment failure.

c. Suppression pool bypass.

d. Containment sprays.

13. QUANTITATIVE RISK ANALYSIS OF COMBINED IMPROVEMENTS

Three additional sensitivities were examined in which several individual improvements were combined:

- The first combined sensitivity included an improved HIS with 100% diffusion burn efficiency, post–core damage reactor depressurization capability, no weir wall overflow, and an increased probability that the operators get the fire water system (FWS) aligned so that low–pressure injection into the RPV occurs in short–term SBO sequences with the FWS available and either no power recovery or all other emergency injection systems failed

- The second combined sensitivity was identical to the first except that water was permitted to overflow the weir wall

- The third combined sensitivity was also like the first, but with the probability of ex–vessel steam explosion set equal to zero.

The enhanced containment venting and upper pool dump modifications were not included in any of the combined improvement sensitivities and only PDSs 1, 3, 7, and 10 were evaluated. PDS 8 was not evaluated in any combined improvement sensitivity, because the enhanced depressurization and improved FWS modifications should preclude core damage for this PDS on the front end, thereby eliminating this PDS from the back–end accident progression analysis.

13.1 Combined Improvements with No Weir Wall Overflow

13.1.1 Effects on Containment Response.

Table 13–1 presents the effects of the combined improvements where no water is assumed to overflow the weir wall on the conditional probabilities of the accident progression bins used in the June 1989 draft of NUREG–1150. These bins are arranged in decreasing order of the severity of the failure mode (in terms of offsite consequence potential). Refer to Appendix D for the APET modifications used to model this combination of improvements. As this table indicates, the first combined improvement case with no weir wall overflow generally reduces the early threat to containment integrity. However, this combined improvement significantly increases the late threat to the containment, primarily as a result of the vigorous CCI that occurs after vessel breach.

The percentage of sequences for which the containment is vented increased in PDSs 1 and 3 and decreased for PDS 10. In PDS 7, the percentage of vented sequences remained zero, because ac power is never recovered during the accident progression. The increase in venting for PDSs 1 and 3 (short–term SBOs) is primarily due to the decrease in the probability of early containment failure. A secondary effect is the increased buildup of noncondensibles. The decrease in venting for PDS 10 (long–term ATWS) is due to the increase in the probability of in–vessel recovery, which increased from 0.009 in the base case to 0.265 in the combined sensitivity.

The effect of the combined improvements on the probability of in–vessel recovery (No VB accident progression bin) is similar to that seen for the stand–alone post–core damage reactor depressurization sensitivity. However, there are some notable variations due to the increased probability of fire water injection in the SBO PDSs and the 5% unavailability of the post–core damage reactor depressurization system assumed for the combined sensitivity. In PDS 1, the percentage of sequences with in–vessel recovery decreased from the base case value, as it did in the stand–alone post–core reactor damage depressurization sensitivity. This decrease is due to the increased probability of in–vessel steam

Table 13–1. Conditional probability of accident progression bins at Grand Gulf—combined sensitivity with no weir wall overflow

Accident Progression Bin	Conditional Probability			
	PDS 1 (ST–SBO)	PDS 3 (ST–SBO)	PDS 7 (ST–SBO)	PDS 10 (ATWS)
VB,[a] early CF,[b] early SPB,[d] no CS[e]	NWWO:[c] 2.17E–02 Base: 9.63E–02	NWWO: 3.74E–02 Base: 2.00E–01	NWWO: 3.32E–02 Base: 2.84E–01	NWWO: 2.21E–04 Base: 1.03E–03
VB, early CF, early SPB, CS	NWWO: 1.31E–02 Base: 4.81E–02	NWWO: 0.00E+00 Base: 0.00E+00	NWWO: 0.00E+00 Base: 0.00E+00	NWWO: 5.21E–02 Base: 2.46E–01
VB, early CF, late SPB	NWWO: 7.42E–03 Base: 7.91E–03	NWWO: 7.79E–03 Base: 8.39E–03	NWWO: 7.46E–03 Base: 3.15E–03	NWWO: 4.61E–02 Base: 3.63E–03
VB, early CF, no SPB	NWWO: 4.14E–02 Base: 1.13E–01	NWWO: 4.49E–02 Base: 1.68E–01	NWWO: 6.13E–02 Base: 3.04E–01	NWWO: 5.16E–01 Base: 5.86E–01
VB, late CF	NWWO: 4.79E–01 Base: 2.88E–01	NWWO: 5.08E–01 Base: 3.10E–01	NWWO: 5.95E–01 Base: 3.31E–01	NWWO: 0.00E+00 Base: 0.00E+00
VB, vented	NWWO: 9.26E–02 Base: 4.93E–02	NWWO: 9.47E–02 Base: 5.07E–02	NWWO: 0.00E+00 Base: 0.00E+00	NWWO: 1.20E–01 Base: 1.55E–01
VB, no CF	NWWO: 3.66E–02 Base: 5.61E–02	NWWO: 1.95E–02 Base: 3.75E–02	NWWO: 2.50E–02 Base: 6.53E–02	NWWO: 0.00E+00 Base: 0.00E+00
No VB	NWWO: 3.01E–01 Base: 3.24E–01	NWWO: 2.81E–01 Base: 2.09E–01	NWWO: 2.77E–01 Base: 1.05E–02	NWWO: 2.65E–01 Base: 8.87E–03

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a. Vessel breach.

b. Containment failure.

c. No weir wall overflow.

d. Suppression pool bypass.

e. Containment sprays.

explosion at low pressure, which offsets the increased probability of recovering vessel injection prior to vessel breach. However, the decrease in in–vessel recovery was not as large for the combined sensitivity as it was for the stand- alone post–core damage reactor depressurization sensitivity. The assumed 5% unavailability of post–core damage reactor depressurization causes the combined sensitivity case to behave more like the base case than the stand–alone improvement, which assumed 100% availability of post–core damage depressurization. The increased probability of aligning the FWS for vessel injection increases the percentage of sequences with injection to 97.7% from the base case percentage of 87%; for post–core damage reactor depressurization alone, the percentage was 95% (these percentages are for PDS 1 only). This increase in core injection contributes to increasing the probability of in–vessel recovery in PDS 1 to 0.301 from 0.291 for the case with post–core damage reactor depressurization alone.

In PDSs 3 and 7, the effect of the combined improvements on the probability of in–vessel recovery is somewhat different from that in PDS 1. In PDS 1, depressurization restricts in–vessel recovery because of an increased probability of steam explosions failing the vessel. In PDSs 3 and 7, the increase in core injection offsets the increased probability of steam explosions, resulting in an overall increase in the probability of in–vessel recovery. Therefore, the assumed 5% unavailability of post–core damage reactor depressurization inhibits core recovery by increasing the number of sequences that remain at high pressure without injection. However, for PDSs 3 and 7, the percentage of sequences with injection has increased a little above that of the stand–alone post–core damage depressurization sensitivity, and significantly above that for the base case. For PDS 3, the percentages of sequences with injection are 92, 91, and 69%, for the combined improvements, stand–alone post–core damage reactore depressurization, and base cases, respectively. For PDS 7, the corresponding percentages are 90, 87, and 3%.

Finally, for PDS 10, the effect of the combined improvements on the probability of in–vessel recovery is different from that seen in the SBO PDSs discussed above. The percentage of sequences with in–vessel recovery is increased significantly from 0.9 to 26.5% in the base case, but is slightly less than the 27.8% seen in the stand–alone post–core damage reactor depressurization case. This PDS, a long–term ATWS, is not affected by the modifications to the fire water system, so the percentage of sequences with injection is equal to the percentage of depressurized sequences, 95%. With 100% post–core damage reactor depressurization availability, 100% of the sequences had injection and, thus, there was a greater potential for in–vessel recovery.

As indicated in Table 13–2, the net effect on the Draft NUREG–1150 presentation bins is a shift from early containment failure to late containment failure and venting. This increase in the probability of late containment failure is augmented by an increase in the overall probability of containment failure. The small increase in the probability of in–vessel recovery (No VB) helps to mitigate the increase in late containment failure. These findings would be expected to change if steam explosions were not a credible result of corium pours at vessel breach.[15]

13.1.2 Risk Results. MACCS calculations were performed using the MACCS 1.5.11 input decks to determine the effect of the first dry cavity combined sensitivity with no weir wall overflow on offsite consequences. Table 13–3 presents these results along with those of the base case. As this table indicates, the combined sensitivity with no weir wall overflow has mixed effects on the offsite risk measures. While the mean number of early fatalities and offsite costs increased, the mean 50– and 1000–mile doses decreased, and the mean number of latent fatalities remained the same. Considering the substantial decrease in the probability of early containment failure in the combined sensitivity, these results—insignificant decreases in dose and sharp increases in early fatalities and costs—were not expected. However, careful scrutiny of the PARTITION output files revealed that, in general, the conditional probabilities of the releases were down, but the severity of the releases was

Table 13–2. Weighted average accident progression bin probabilities—combined improvements with no weir wall overflow

Accident Progression Bin	Base Case Conditional Probability	Combined Case Conditional Probability
VB,[a] early CF,[b] early SPB,[c] no CS[d]	1.22E–01	2.71E–02
VB, early CF, early SPB, CS	4.61E–02	1.57E–02
VB, early CF, late SPB	7.23E–03	8.01E–03
VB, early CF, no SPB	1.57E–01	6.03E–02
VB, late CF	2.83E–01	4.76E–01
VB, vented	4.49E–02	8.15E–02
VB, no CF	5.44E–02	3.47E–02
No VB	2.70E–01	2.90E–01

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a. Vessel breach.

b. Containment failure.

c. Suppression pool bypass.

d. Containment sprays.

Table 13–3. Grand Gulf combined improvements with no weir wall overflow risk comparison

	Mean Early Fatalities (per ry[a])	Mean Latent Fatalities (per ry)	Mean 50–Mile Dose (man–rem/ry)	Mean 1000–Mile Dose (man–rem/ry)	Mean Offsite Costs ($/ry)
Base case	6.2E–09	1.7E–03	7.8E–01	10.4	2.2E+03
Combined improvements with no weir wall overflow	6.8E–09	1.7E–03	7.6E–01	10.3	2.7E+03

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a. Reactor year.

increased from the base case. The explanation for these apparently anomalous effects was that with no weir wall overflow, the severity of a given release increases, because there is little or no scrubbing of the release for APET end states having drywell leakage. Also, the combined improvement case increased the probability of containment failure and this was partially accountable for the increase in late containment failures, given vessel breach.

It should be noted that according to the SNL APET model, preventing weir wall overflow into the drywell does not ensure a dry reactor cavity at the time of vessel breach, nor does it prevent ex–vessel steam explosions in sequences that have injection at or shortly after vessel breach. Drywell head failure and recirculation pump seal leakage during long–term SBO sequences can both result in a wet (water volume more than 656 ft^3 and water depth less than 16.4 ft) or flooded (water depth more than 16.4 ft) drywell. The reactor cavity can be flooded at vessel breach if water remaining in the reactor vessel is released into the cavity prior to any release of corium. Alternatively, the reactor vessel failure may yield a minor release of corium followed by a substantial amount of water. A subsequent pour of corium into the now flooded cavity could result in a postulated ex–vessel steam explosion. Finally, it could conceivably exit the reactor vessel concurrently with the corium, or after release of corium to the cavity. Each of these hypotheses may have a potential for a steam explosion. Therefore, this case does not eliminate all APET end states in which the corium enters a wet or flooded cavity. Conversely, if steam explosions with corium are not considered to be credible,[15] then these results could be significantly different.

13.2 Combined Improvement Sensitivity Permitting Weir Wall Overflow

13.2.1 Effects on Containment Response. Table 13–4 presents the effects of the combined improvements with weir wall overflow permitted on the conditional probabilities of the accident progression bins. Comparing these effects with those of the combined improvements in Table 13–1 indicates that the conditional probability of early containment failure is essentially the same for both cases. However, the conditional probability of late containment failure is decreased in the present case for all of the PDSs analyzed, with the exception of PDS 10, for which the probability remains zero. The decreases are 10, 7, and 8% for PDSs 1, 3, and 7, respectively. Furthermore, the conditional probability of containment survival following vessel breach has increased for all of the PDSs analyzed, with the exception of PDS 10, for which the probability remains zero. The increases are 128, 183, and 168% for PDSs 1, 3, and 7, respectively. Finally, it should be noted that the probability of late containment failure in PDSs 1, 3, and 7 is higher than in the base case. The increases above the base case values are 49, 52, and 66% for PDSs 1, 3, and 7, respectively. The probability of vessel breach with no containment failure for PDSs 1, 3, and 7 is larger than in the base case by 4[illegible], 47, and 3%, respectively. The dominant difference between the first combined improvement case and this case is that the corium is now more likely to pour into a flooded in-pedestal drywell cavity which: (a) increases the probability of an ex–vessel steam explosion, (b) provides a greater depth of water for scrubbing the fission products, and (c) reduces the energetics of CCI.

Table 13–5 compares the weighted average accident progression bin probabilities for the combined improvements with and without weir wall overflow. The net effect of permitting weir wall overflow is a decrease in the conditional probability of late containment failure and a corresponding increase in the probability of containment survival. Although the probability of early containment failure is virtually the same in both cases, there is some shifting among the four early containment failure bins, with the probability of late and no suppression pool bypass decreasing, and the probability of early suppression pool bypass increasing. Table 13–6 compares the weighted average accident progression bin probabilities of the combined improvements with

Table 13–4. Conditional probability of accident progression bins at Grand Gulf—combined sensitivity permitting weir wall overflow

Accident Progression Bin	Conditional Probability			
	PDS 1 (ST–SBO)	PDS 3 (ST–SBO)	PDS 7 (ST–SBO)	PDS 10 (ATWS)
VB,[a] early CF,[b] early SPB,[d] no CS[e]	WWO:[c] 2.47E–02 Base: 9.63E–02	WWO: 5.05E–02 Base: 2.00E–01	WWO: 4.41E–02 Base: 2.84E–01	WWO: 4.33E–04 Base: 1.03E–03
VB, early CF, early SPB, CS	WWO: 2.13E–02 Base: 4.81E–02	WWO: 0.00E+00 Base: 0.00E+00	WWO: 0.00E+00 Base: 0.00E+00	WWO: 1.50E–01 Base: 2.46E–01
VB, early CF, late SPB	WWO: 2.47E–03 Base: 7.91E–03	WWO: 2.61E–03 Base: 8.39E–03	WWO: 2.38E–03 Base: 3.15E–03	WWO: 2.16E–02 Base: 3.63E–03
VB, early CF, no SPB	WWO: 3.55E–02 Base: 1.13E–01	WWO: 4.02E–02 Base: 1.68E–01	WWO: 5.89E–02 Base: 3.04E–01	WWO: 4.42E–01 Base: 5.86E–01
VB, late CF	WWO: 4.30E–01 Base: 2.88E–01	WWO: 4.70E–01 Base: 3.10E–01	WWO: 5.49E–01 Base: 3.31E–01	WWO: 0.00E+00 Base: 0.00E+00
VB, vented	WWO: 9.22E–02 Base: 4.93E–02	WWO: 9.10E–02 Base: 5.07E–02	WWO: 0.00E+00 Base: 0.00E+00	WWO: 1.20E–01 Base: 1.55E–01
VB, no CF	WWO: 8.33E–02 Base: 5.61E–02	WWO: 5.52E–02 Base: 3.75E–02	WWO: 6.70E–02 Base: 6.53E–02	WWO: 0.00E+00 Base: 0.00E+00
No VB	WWO: 3.01E–01 Base: 3.24E–01	WWO: 2.81E–01 Base: 2.09E–01	WWO: 2.77E–01 Base: 1.05E–02	WWO: 2.65E–01 Base: 8.87E–03

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a. Vessel breach.

b. Containment failure.

c. Weir wall overflow.

d. Suppression pool bypass.

e. Containment sprays.

Table 13–5. Weighted average accident progression bin probabilities—combined improvements with and without weir wall overflow

Accident Progression Bin	Conditional Probability Without Weir Wall Overflow	Conditional Probability With Weir Wall Overflow
VB,[a] early CF,[b] early SPB,[c] no CS[d]	2.71E–02	3.12E–02
VB, early CF, early SPB, CS	1.57E–02	2.38E–02
VB, early CF, late SPB	8.01E–03	2.93E–03
VB, early CF, no SPB	6.03E–02	5.04E–02
VB, late CF	4.76E–01	4.30E–01
VB, vented	8.15E–02	8.10E–02
VB, no CF	3.47E–02	7.79E–02
No VB	2.70E–01	2.90E–01

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a. Vessel breach.

b. Containment failure.

c. Suppression pool bypass.

d. Containment sprays.

weir wall overflow with those for the base case. Compared with the base case, as indicated in Table 13–6, the net effects are decreases in every early containment failure mode and increases in the conditional probabilities of late containment failure, venting, no containment failure, and in–vessel recovery.

13.2.2 Risk Results. MACCS consequence calculations were performed for the combined improvement sensitivity permitting weir wall overflow, again using the MACCS 1.5.11 input decks. Table 13–7 presents these results, along with those for the base case. As indicated in the table, the offsite risk for the combined sensitivity permitting weir wall overflow is less than that for the base case.

Preventing weir wall overflow decreases, but does not eliminate, the probability of an ex–vessel steam explosion. In addition, preventing weir wall overflow increases the probability that dry CCI will occur. A comparison of the results in Tables 13–3 and 13–7 indicates that the effects on risk of the increased probability of dry CCI (minimal scrubbing of fission products through an overlying pool of water) in the case without weir wall overflow outweigh those brought about by the decrease in the probability of ex–vessel steam explosions. It should be remembered that this

Table 13–6. Weighted average accident progression bin probabilities—combined improvements with weir wall overflow

Accident Progression Bin	Base Case Conditional Probability	Combined Case Conditional Probability
VB,[a] early CF,[b] early SPB,[c] no CS[d]	1.22E–01	3.12E–02
VB, early CF, early SPB, CS	4.61E–02	2.38E–02
VB, early CF, late SPB	7.23E–03	2.93E–03
VB, early CF, no SPB	1.57E–01	5.04E–02
VB, late CF	2.83E–01	4.30E–01
VB, vented	4.49E–02	8.10E–02
VB, no CF	5.44E–02	7.79E–02
No VB	2.70E–01	2.90E–01

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a. Vessel breach.

b. Containment failure.

c. Suppression pool bypass.

d. Containment spray.

Table 13–7. Grand Gulf combined improvement permitting weir wall overflow risk comparison

	Mean Early Fatalities (per ry[a])	Mean Latent Fatalities (per ry)	Mean 50–Mile Dose (man–rem/ry)	Mean 1000–Mile Dose (man–rem/ry)	Mean Offsite Costs ($/ry)
Base case	6.2E–09	1.7E–03	7.8E–01	10.4	2.2E+03
Combined improvement permitting weir wall overflow	2.7E–09	1.2E–03	6.2E–01	7.66	1.5E+03

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a. Reactor year.

case allows an uncontrolled containment failure by over-pressurization (i.e., the containment is not vented) and produces increased probabilities for APET end states in which the release is neither scrubbed nor filtered (i.e, a shallow pool over the debris and drywell leakage). Also, this includes the effects of the depth of the water in the in-pedestal cavity, not just the absolute presence or absence of water.

13.3 Combined Sensitivity with No Weir Wall Overflow and No Ex-Vessel Steam Explosions

13.3.1 Effects on Containment Response. A third combined sensitivity identical to the first was analyzed in which the probability of ex-vessel steam explosion was set equal to zero.

Table 13-8 presents the effects of the combined improvements with no weir wall overflow and no ex-vessel steam explosions on the conditional probabilities of the Draft NUREG-1150 accident progression bins. For PDSs 1 and 3, eliminating ex-vessel steam explosion reduces the conditional containment failure probability for all categories except vessel failure with late containment failure or vessel failure with containment venting. This is as expected because the late containment failures are due to a buildup of noncondensible gases and non-condensing steam (as the result of suppression pool saturation and having heated the containment structure). PDSs 3, 7, and 10 show an increase in in-vessel recovery, as expected. The probability of in-vessel recovery decreases slightly for PDS 1 because of the increased probability of in-vessel steam explosion (see the discussion in Section 9). PDSs 7 and 10 show an increase in the probability of early containment failure with late suppression pool bypass due to the significant heatup of the containment and the suppression pool prior to reactor vessel failure.

While there is some shifting among accident progression bins, the general trend is a reduction in the probability of reactor vessel failure for all plant damage states and a shift from early containment failures to late containment failures. Thus, eliminating ex-vessel steam explosions in the combined sensitivity with no weir wall overflow reduces the conditional containment failure probability from the base case and provides additional time for operator actions and evacuation of the public.

Table 13-9 compares the weighted average accident progression bin probabilities for the combined case with no weir wall overflow and no ex-vessel steam explosion with the base case. Comparison of the data in Tables 13-2 and 13-9 indicates that eliminating ex-vessel steam explosions from the combined case with no weir wall overflow provides a slight additional reduction in the probability of early containment failure, along with a corresponding increase in the probabilities of late containment failure and containment survival.

13.3.2 Risk Results. MACCS consequence calculations were performed for the no weir wall overflow and no ex-vessel steam explosion case, again using the MACCS 1.5.11 input decks. Table 13-10 presents these results, along with those for the base case. As this table indicates, preventing weir wall overflow and ex-vessel steam explosion reduces the offsite consequences in all categories.

Table 13–8. Conditional probability of accident progression bins at Grand Gulf—combined sensitivity with no weir wall overflow and no ex–vessel steam explosion

Accident Progression Bin	Conditional Probability							
	PDS 1 (ST–SBO)		PDS 3 (ST–SBO)		PDS 7 (ST–SBO)		PDS 10 (ATWS)	
VB,[a] early CF,[b] early SPB,[d] no CS[e]	Com:[c] Base:	2.03E–02 9.63E–02	Com: Base:	3.53E–02 2.00E–01	Com: Base:	3.02E–02 2.84E–01	Com: Base:	7.82E–05 1.03E–03
VB, early CF, early SPB, CS	Com: Base:	1.23E–02 4.81E–02	Com: Base:	0.00E+00 0.00E+00	Com: Base:	0.00E+00 0.00E+00	Com: Base:	1.43E–02 2.46E–01
VB, early CF, late SPB	Com: Base:	5.58E–03 7.91E–03	Com: Base:	6.02E–03 8.39E–03	Com: Base:	5.64E–03 3.15E–03	Com: Base:	7.80E–02 3.63E–03
VB, early CF, no SPB	Com: Base:	2.01E–02 1.13E–01	Com: Base:	2.44E–02 1.68E–01	Com: Base:	3.26E–02 3.04E–01	Com: Base:	5.23E–01 5.86E–01
VB, late CF	Com: Base:	4.99E–01 2.88E–01	Com: Base:	5.24E–01 3.10E–01	Com: Base:	6.20E–01 3.31E–01	Com: Base:	0.00E+00 0.00E+00
VB, vented	Com: Base:	9.63E–02 4.93E–02	Com: Base:	9.89E–02 5.07E–02	Com: Base:	0.00E+00 0.00E+00	Com: Base:	1.20E–01 1.55E–01
VB, no CF	Com: Base:	4.08E–02 5.61E–02	Com: Base:	2.61E–02 3.75E–02	Com: Base:	3.47E–02 6.53E–02	Com: Base:	0.00E+00 0.00E+00
No VB	Com: Base:	3.01E–01 3.24E–01	Com: Base:	2.81E–01 2.09E–01	Com: Base:	2.77E–01 1.05E–02	Com: Base:	2.65E–01 8.87E–03

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[a] Vessel breach.

[b] Containment failure.

[c] Combined sensitivity with no ex–vessel steam explosion.

[d] Suppression pool bypass.

[e] Containment sprays.

Table 13–9. Weighted average accident progression bin probabilities—no weir wall overflow and no ex-vessel steam explosion

Accident Progression Bin	Conditional Probability of the Base Case	Conditional Probability With No Weir Wall Overflow and No EVSE [a]
VB,[b] early CF,[c] early SPB,[d] no CS[e]	1.22E–01	2.56E–02
VB, early CF, early SPB, CS	4.61E–02	1.45E–02
VB, early CF, late SPB	7.23E–03	6.78E–03
VB, early CF, no SPB	1.57E–01	3.95E–02
VB, late CF	2.83E–01	4.95E–01
VB, vented	4.49E–02	8.46E–02
VB, no CF	5.44E–02	3.93E–02
No VB	2.70E–01	2.90E–01

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a. Ex-vessel steam explosion.

b. Vessel breach.

c. Containment failure.

d. Suppression pool bypass.

e. Containment sprays.

Table 13–10. Grand Gulf combined improvement with no weir wall overflow and no ex-vessel steam explosion risk comparison

	Mean Early Fatalities (per ry[a])	Mean Latent Fatalities (per ry)	Mean 50-Mile Dose (man-rem/ry)	Mean 1000-Mile Dose (man-rem/ry)	Mean Offsite Costs ($/ry)
Base case	6.2E–09	1.7E–03	7.8E–01	10.4	2.2E+03
Combined improvement with no weir wall overflow and no EVSE[b]	5.3E–09	1.5E–03	7.4E–01	10.0	1.5E+03

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a. Reactor year.

b. Ex-vessel steam explosion.

14. SUMMARY OF TECHNICAL FINDINGS FROM QUANTITATIVE ANALYSIS

This section summarizes the significant results of the quantitative analysis presented in Sections 8–13. The discussion in this section is organized around the potential improvements evaluated in these previous sections.

14.1 Improved HIS

Continuously available hydrogen ignitors provide a distributed ignition source that burns the hydrogen released during core degradation in a diffusion flame whenever flammable conditions exist in containment. The improvement to the HIS that was modeled was the installation of a backup dc power supply to the existing ignitors, so that the HIS would be operable under SBO conditions. The backup dc power supply was modeled as having an availability of 0.95. The probability that the operators fail to actuate the HIS when required was retained from the base case APETs.

A hydrogen burn efficiency of 100% was also used to more closely approximate available hydrogen burn data from the Quarter–Scale Tests. With this burn efficiency change, a diffusion burn in the wetwell removes all of the hydrogen present, unless the reaction becomes oxygen–limited.

The improved HIS (with high burn efficiency) produced a significant decrease in the conditional probability of early containment failure, and an increase in the probabilities of containment survival and late containment failure. Although offsite consequences were not calculated for the stand–alone HIS improvement, this shift away from early containment failure is expected to bring about a reduction in offsite risk.

14.2 Post–Core Damage Reactor Vessel Depressurization

This improvement consists of a backup supply of dc power to the SRV solenoids, allowing the reactor to be depressurized during sequences in which the station batteries (the normal source of power to the SRV solenoids) are failed or depleted. There are three aspects to this improvement. Enhanced depressurization can (a) prevent core damage in those sequences where a low–pressure injection system is available, (b) allow sequences that have progressed to core damage to be recovered in–vessel, and (c) prevent high–pressure melt ejection in those cases where in–vessel recovery is not successful. The first of these aspects was not analyzed quantitatively.

Reactor depressurization has a number of interesting effects on the progression of the accident sequence after the onset of core degradation. First, depressurization decreases the probability that an SRV tailpipe vacuum breaker will stick open. This effect is due to the fewer number of demands placed on the SRVs when the RPV is depressurized. Secondly, the probability of in–vessel recovery is higher in the depressurized case for all PDSs except PDSs 1 and 8, where it is *decreased* for PDS 1. The increase in vessel breach probability in PDS 1 occurs in spite of the fact that the probability of recovering injection during core degradation is higher for all PDSs in the depressurized case, except PDS 8, where it is 0.0 in both the sensitivity and base case. The reason for this occurrence is the increased probability of in–vessel steam explosions that fail the RPV in the depressurized case.

The increased probability of in–vessel steam explosion is also the reason for the increased probability of early containment failure for PDSs 1 and 8. The increased probability of in–vessel steam explosions makes α mode failure of the containment more likely in the depressurized case, resulting in an increased probability of early containment failure at the time of vessel breach. In PDSs 3, 7, and 10, the increase in the probability of recovering injection during core degradation is large enough to offset the increased probability of in–vessel steam explosion, thus giving rise to a decrease in the probability of vessel breach, and a corresponding decrease in the probability of early containment failure.

Overall, post–core damage reactor depressurization results in a slight decrease in the conditional probability of early containment failure. Late containment failures increase slightly, as does the probability of in–vessel recovery. If steam explosions are not credible, as some researchers contend, then the probabilities would be further reduced. If the reactor were depressurized *before* core damage (in accordance with Revision 3 of the EPGs), significant reductions in core melt and containment failure probabilities and risk would be expected.

14.3 Enhanced Vacuum Breaker Operability (No Weir Wall Overflow)

Enhanced vacuum breaker operability is a potential means of ensuring that no water will overflow the weir wall, thus mitigating the threat to containment from ex–vessel steam explosions. However, because recent work by ORNL (S.R. Greene et al. draft report) indicates that enhanced vacuum breaker operability alone may not accomplish this task, the improvement that was evaluated was prevention of weir wall overflow, but the means by which this could be ensured were not examined. Possible ways of implementing this improvement would be to increase the height of the weir wall or vent the containment prior to depressurizing the reactor vessel.

Preventing weir wall overflow results in a shift in early containment failures with early suppression pool bypass to early containment failures with either late pool bypass or no bypass. This shift appears to be due to the decrease in ex–vessel steam explosions; however, ex–vessel steam explosions are not eliminated. The conditional probability of an ex–vessel steam explosion is still quite large even if water is prevented from overflowing the weir wall.

There is also an increase in the conditional probability of late containment failure, with an accompanying decrease in the probability that the containment survives intact. This is due primarily to the very large increase in the probability of CCI if the suppression pool is prevented from flooding the drywell, and hence the reactor cavity. The CCI generates hydrogen and noncondensible gases, which can threaten containment integrity via hydrogen combustion and gradual overpressurization, respectively. The net effect was an increase in the probability of late containment failure and a decrease in the probability of containment survival.

14.4 Containment Venting

Containment venting was examined quantitatively by assuming that a backup source of dc power is available to the solenoids of the containment vent valves, so that the valves can be opened remotely during SBO. The enhanced venting system was assumed to have an availability of 0.95. For short–term SBO, the containment was assumed to be vented prior to core degradation (preemptive venting), with no later closure of the vent valves. For long–term SBO and ATWS sequences, venting was again assumed to occur prior to core degradation with a probability of 0.95; however, in this case the venting is not preemptive, because containment pressure will reach the PCPL prior to core degradation.

Containment venting was found to greatly reduce the conditional probability of containment failure. However, venting (without an external filter) leads to an increase in offsite risk because of the relatively high probability of suppression pool bypass in the Mark III containment.

14.5 Upper Containment Pool Dump

Because the valves used to dump the Mark III upper containment pool to the suppression pool are operated by ac motors, they are not available during SBO. A potential improvement would be to supply these valves with operators that could be actuated independently of ac power, or with operators supplied from an independent source of ac power. This would allow makeup to the suppression pool from the upper containment pool.

The upper pool dump modification was found to cause a significant increase in the conditional probability of early containment failure with pool bypass in the short-term SBO PDSs. Pool dump results in a higher probability of a flooded or wet cavity at the time of vessel breach (the probability of having a dry cavity is 0.0). This increases the probability of a large ex-vessel steam explosion at the time of vessel breach, which increases the impulse loads on the drywell and produces large quantities of hydrogen, which can ignite, further increasing the probability of containment failure at the time of vessel breach.

14.6 Improvement Combinations

Three sensitivities were examined in which several individual improvements were combined. The first combined sensitivity included an improved HIS with 100% diffusion burn efficiency, post-core damage reactor depressurization capability, no water refluxed over the weir wall, and an increased probability that the operators get the fire water system (FWS) aligned so that low-pressure injection into the RPV occurs in short-term SBO sequences with the FWS available and either no power recovery or all other emergency injection systems failed. The second combined sensitivity was identical to the first except that water was allowed to reflux over the weir wall. The third combined sensitivity was also like the first, but with all ex-vessel steam explosions eliminated. The enhanced containment venting and upper pool dump modifications were not included in any of the combined improvement sensitivities because of the observations in the stand-alone analyses.

The first combined improvement case without weir wall overflow generally reduced the early threat to containment integrity. However, this combined improvement significantly increased the late threat to the containment, primarily as a result of the CCI that occurs after vessel breach. As illustrated in Table 14-1, there were mixed effects on the offsite risk measures. While the mean number of early fatalities and offsite costs increased from the base case, the mean 50- and 1000-mile doses decreased, and the mean number of latent fatalities remained the same. Considering the substantial decrease in the probability of early containment failure in this first combined sensitivity, these results—minor decreases in dose and increases in early fatalities and costs—were not expected. However, careful scrutiny of the PARTITION output files revealed that, in general, the conditional probabilities of the releases were down, but the severity of the releases was increased from the base case. Not allowing water to overflow the weir wall increases the severity of a given release, because scrubbing of the release is reduced. Also, the conditional probability of containment failure increased and this was partially responsible for the increase in late containment failures, given vessel breach.

To further investigate these results, the combined improvement sensitivity was reanalyzed permitting reflux of water over the weir wall. Compared with the effects of the first case, there was a decrease in the conditional probability of late containment failure and a corresponding increase in the probability of containment survival. Although, the probability of early containment failure remained virtually the same, there was some shifting among the four early containment failure bins, with the probability of late and no suppression pool bypass decreasing, and the probability of early suppression pool bypass increasing. Compared to the base case, the net effects were decreases in every early containment failure mode and increases in the conditional probabilities of late containment failure, venting, containment survival, and in-vessel recovery.

The offsite risk, presented in Table 14-1, for the second combined sensitivity was less than that for either the base case or the combined case with no weir wall overflow described above. Prohibiting water from overflowing the weir wall decreases, but does not eliminate, the probability of an ex-vessel steam explosion. In addition, this increases the probability that dry CCI will occur. A comparison of these two combined sensitivities

Table 14–1. Grand Gulf combined improvement risk comparison

	Mean Early Fatalities (per ry[a])	Mean Latent Fatalities (per ry)	Mean 50-Mile Dose (man–rem/ry)	Mean 1000-Mile Dose (man–rem/ry)	Mean Offsite Costs ($/ry)
Base case	6.2E–09	1.7E–03	7.8E–01	10.4	2.2E+03
Combined improvement with no weir wall overflow	6.8E–09	1.7E–03	7.6E–01	10.3	2.7E+03
Combined improvement with weir wall overflow permitted	2.7E–09	1.2E–03	6.2E–01	7.66	1.5E+03
Combined improvement with no weir wall overflow, no EVSE[b]	5.3E–09	1.6E–03	7.4E–01	10.0	1.5E+03

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a. Reactor year.

b. Ex–vessel steam explosion.

indicates that the effects on risk of the increased probability of dry CCI (minimal scrubbing of fission products through an overlying pool of water) outweigh those brought about by the decrease in the probability of ex–vessel steam explosions.

A combined sensitivity was also analyzed in which there was no weir wall overflow, and ex–vessel steam explosion was eliminated. In comparison with the no–weir wall overflow combination, this combination provided a slight additional reduction in the conditional probability of early containment failure, along with a corresponding increase in the conditional probabilities of late containment failure and containment survival. In comparison with the base case, however, both sensitivities with no weir wall overflow showed decreases in all early containment failure modes, at the expense of an increased probability of late containment failure and a decreased probability of containment survival. The risk results for this combination are also presented in Table 14–1. Eliminating weir wall overflow and ex–vessel steam explosion reduced all categories of risk except cost and 1000 mile dose when compared to the base case and to the case where only weir wall overflow was eliminated.

14.7 Summary

As can be seen from these studies, each of the potential improvements can have an effect on others and thus the potential benefits of the combined improvements can have greater benefit than individual improvements. The combinations of improvements that have been discussed in this report are not necessarily the only or best combinations for Grand Gulf or any other Mark III facility, but were those that could have the greatest potential for reduction in containment failure probability or risk. The offsite risk and core damage frequency at Grand Gulf are low and are made up of many small contributors. Therefore, the potential benefits from these improvements are small. This analysis should not be viewed as a complete evaluation of the benefits (reductions in core damage frequency or in offsite consequences) for any BWR/6 with a Mark III containment.

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APPENDIX A

DETAILS OF QUANTITATIVE ANALYSIS METHODOLOGY

APPENDIX A

DETAILS OF QUANTITATIVE ANALYSIS METHODOLOGY

A.1 Computer Code Compilation

Initially, five main source codes were compiled on the various computer platforms that would be used in the analysis. EVNTRE[A-1] was used to analyze the accident progression event trees (APETs); PSTEVNT[A-2] was used to process the output from EVNTRE; GGSOR[A-3] was used to parametrically generate source terms for the various releases from containment; PARTITION[A-4] was used to process the source term output from GGSOR; and MACCS[A-5] was used to calculate the offsite consequences for each source term group generated by PARTITION. There were also several translation routines used to parse output data into the format required for input into a follow-on code in the analysis. The sources for these translator codes were also compiled.

The Draft NUREG-1150 accident progression analysis codes were written in FORTRAN-77 and developed on a VAX computer, using a VMS operating system. Because the authors intended to run the codes on both personal computers using a DOS operating system, and scientific workstations using a UNIX operating system, a number of changes were necessary to compensate for differences in syntax. As previously mentioned, a number of translation routines were also compiled. These routines are discussed further in the sections below.

A.2 EVNTRE Analysis

The EVNTRE event progression analysis code is documented in Reference A-1. It is a keyword-driven code used to analyze event trees that are constructed to model the progression of a severe reactor accident. EVNTRE was developed so that distributed parameters (i.e., the parameter has an associated probability distribution) could be tracked and manipulated using user-defined coding. The processing of distributed parameters was necessary to evaluate the uncertainties involved in the complex phenomena that can occur during severe accidents. The keyword file used to control the input for the Plant Damage State (PDS) 1 base case evaluation is listed below. The files used for the other PDSs are similar. The annotated comments in the file describe the functions of the keywords. The other required input files called out by the keyword file are listed in Appendix B. For more details on the keyword control features of EVNTRE, refer to Reference A-1.

```
MODE 4                          $ Specifies the calculational mode for
                                  EVNTRE.
$
TREEIN gl_apet.dat              $ Specifies the input file name for the
$                                 tree definition input file.
$
BININ ../ggbin.dat              $ Specifies the input file name for the
$                                 binning and sorting information input file.
$
SAMDIN gl_pntr.dat              $ Specifies the input file name for the
$                                 sample definition information input file.
$
SAM1IN ../temac.dat             $ Specifies the input file name for the
$                                 first set of sample input vectors.
$
$
SAM2IN ../hcube.dat             $ Specifies the input file name for the
$                                 second set of sample input vectors.
$
BIN                             $ Turns on the binning facility.
$
STATS                           $ Indicates that a branch and case frequency
$                                 table report will be generated.
$
NWRTBIN                         $ Indicates that a binning result report will
$                                 not be generated when the paths through the
$                                 tree are binned.
$
SAVEBIN                         $ Indicates that a binning results file will
$                                 be generated for post-processing.
$
RUN                             $ Indicates that the tree is to be evaluated
$                                 after the input data has been processed.
$
$
KEEPCUT 1.0E-5                  $ Specifies the path frequency below which a
$                                 path is terminated.
$
PRTCUT 1.0E-5                   $ Specifies the minimum bin frequency
                                  required to report a bin.
$
STATOUT gl_freq.out             $ Specifies the output file name for the
$                                 branch and case frequency table.
```

```
SAMROUT gl_samr.pst            $ Specifies the output file name for the
$                                post-processing file.
$
ENDKEY                         $ Indicates the end of keyword input.
$
```

As the file listing indicates, EVNTRE was run in the sampling mode (mode 4), with inputs from two sample vector files. The first of these, **temac.dat**, provides Latin Hypercube Sampling (LHS) data from the Grand Gulf front-end (accident sequence) analysis. These data were generated with the TEMAC code. The second file, **hcube.dat**, provides LHS data to be used in evaluating the accident progression questions in the APET. The APET split fractions and parameters that are to be sampled are specified in the sample definition input file **gl_pntr.dat**.

Another important input file is **ggbin.dat**. This file provides the information used to bin the end states of the APET into a smaller set of accident progression bins. The accident progression bins retain enough information about the accident to characterize the associated containment failure modes and the fission product source terms. For the base case analysis, the Grand Gulf Draft NUREG-1150 binning input file was used, as provided by SNL. This file is shown in Appendix B.

The output file generated by this binning process is **gl_samr.pst**. This file is in binary format, so it is not listed in this report. It will be mentioned again when it is used as the principal input file for running the PSTEVNT code.

EVNTRE produces several other output data files, some of which are immediately useful, others of which are primarily used with post-processor codes like PSTEVNT. One of the more useful output files is **gl_freq.out**, which shows the realized split fractions for each of the questions in the APET. This frequency output file allows the analyst to calculate the conditional probability of important paths through the APET. For example, the APET file listing in Appendix B, shows that the conditional probability of vessel breach is identified in Question 63, which also addresses the mode of vessel breach for those cases where in-vessel recovery is not successful. The frequency output file becomes particularly important in the analysis of improvements, where it allows the analyst to track changes effected by the improvements and compare the new conditional probabilities to those calculated for the base case.

A.3 PSTEVNT Analysis

EVNTRE was the primary tool used to evaluate the very large APETs in the back-end analysis performed for Draft NUREG-1150. However, a typical EVNTRE run for a single PDS can take 24 hours on a scientific workstation, and longer on a PC. Therefore, features were provided to save results from an EVNTRE run for later processing with a faster post-processor called PSTEVNT. The PSTEVNT post-processor code[A-2] is used to manipulate the EVNTRE output (listing of accident progression bins) in a variety of ways to produce input files for follow-on codes in the analysis, as well as output files that are directly useful to the analyst, such as the file showing the presentation bins used in Draft NUREG-1150.

As provided by SNL, PSTEVNT does not utilize keyword-driven input to the same extent as EVNTRE. Instead, an input file is read that contains the FORTRAN unit numbers of the required input files and desired output files, as well as a listing of input parameters used to control the PSTEVNT program. Under the VMS operating system, external file connections are made to associate data files with the unit numbers provided in the keyword file. For the UNIX and DOS operating systems in use at INEL, this is not possible; so the PSTEVNT source code was modified to allow keyword-driven input similar to that used for EVNTRE.

PSTEVNT is actually run three times for each PDS group. In the first run, PSTEVNT is used to produce a set of source term bins for input into the parametric source term generation code GGSOR. The input control file listing for this run is shown as follows:

```
$-- Calculation Control Keywords (for logical constants) -------------------- --
$
   COLLAPS  0.99999            $ Reduce rebinned results with weighting
$                                factor
```

```
$
    REBIN                          $ Causes rebinning of accident progression
$                                    bins
$
    RUN                            $ Causes PSTEVNT to proceed with data
$                                    calculations
$
    SAVEBIN                        $ Write results of rebin to post
$                                    processor file
$
    NOSORT                         $ Do not produce sort tables
$
$-- Calculation Control Keywords (for assigned values) -----------------------
$
    PCUTFR  0.99999                $ Specifies total rebinned frequency to
$                                    retain
$
    PRTCUT  0.00001                $ Print tolerance cutoff
$
    RCUT    0.00001                $ The relative weight cutoff minimum
$                                    value when collapsing bins
$
$-- Input File Specification Keywords ----------------------------------------
$
    ASCTRIN                        $ ASCII output from EVNTRE
$
    BININ   ../ggrebin.dat         $ Filename for rebinning input
$
    EVNTBIN gl_bin.asc             $ Filename for EVNTRE output file
$
$   SORTIN  sortin                 $ Filename for sort specification data
$
$-- Report Request Keywords --------------------------------------------------
$
    ASCSAV                         $ Rebinning result is ASCII
$
$   RPTMLST                        $ Write EVNTRE master bin list to message file
$
    RPTNPRB                        $ Report rebinned APBs by observation
$
$   RPTRBIN                        $ Write rebinned bins to message file
$
    NSPREAD                        $ Discarded bins are not spread over
$                                    kept bins
$
    KPBYRUN                        $ Report master bin list by observation
$
$-- Output File Specification Keywords ---------------------------------------
$
    BINOUT  rbin.out               $ Rebinning result data
$
$   INPOUT  inpout                 $ Annotated echo of input
```

```
$
   KEEPOUT keep.out            $ Master list of unique kept bins
$
   SBINOUT gxx_sbin.out        $ Rebinning results data (for additional
$                                post-processing)
$
$  SORTOUT sortout             $ Result of requested sorts
$
$  TABOUT  tabout              $ Rebinning result descriptive table(s)
$
ENDKEY                         $ Indicates the end of keyword input.
```

As indicated by this file listing, there are two input files for this PSTEVNT run. The first is the binned output file from EVNTRE, **gl_bin.asc**, which is the previously discussed binary file, **gl_samr.pst**, after convertion into ASCII using the conversion program BINTO. The second file is the rebinning input file **ggebin.dat**. This file, which is listed in Appendix B, specifies the accident pathway binning scheme required for input into GGSOR.

This first PSTEVNT run is performed on an by-observation basis, i.e., the code keeps track of each accident progression bin generated in each of the 250 samples in EVNTRE. Two output files are used: **gxx_sbin.out** (too large to be listed in this report) provides a listing of each accident progression bin generated in each sample observation, along with the conditional probability for each bin. This information will be combined with the PDS frequencies from **gg_temac.dat** in the GG-FRQ code, as described below. The other file is **keep.out**, which provides a list of unique accident progression bins for each sampling observation. A **keep.out** file is generated for each PDS, and these files form an input to the MASTERK routine, as described below.

The second PSTEVNT run is similar to the first, except that all information is aggregated; the output information is a weighted average over the 250 sampling observations made in EVNTRE. The only output file used from this run is the **gxx_rbin.out** file, which contains a listing of the unique accident progression bins. This file is used to compare accident progression bin results with the published information in Draft NUREG/CR-4551.

The third PSTEVNT run is also made on an aggregate basis. The purpose of *this* run is to combine the accident progression bins into the higher level presentation bins used in Draft NUREG-1150. The input binning file for this run, **reduce.dat**, is listed in Appendix B.

A.4 MASTERK Analysis

The MASTERK code is not described in any of the currently available Draft NUREG-1150 supporting documentation. Therefore, because the only documentation is the source code listing itself, a listing is provided in Appendix C. MASTERK is used to translate the format of the **keep.out** files from PSTEVNT into the correct format for input into GGSOR and PARTITION. MASTERK takes as input the **keep.out** files for all PDSs, on a by-observation (by-run) basis, and generates a master list of unique bins. The output can be either by observation or not by observation, as selected by the user. The by-run output file, **byr_mas.kep**, is a composite listing, over all PDSs, of the unique accident progression bins on a by-observation basis. This file is used as input to the GGSOR code, as described below. The not-by-run output file, **nbyr_mas.kep**, is a similar file, only on an aggregate basis, and is one of the required inputs to PARTITION. Both of these output files are too large to list in this report.

A.5 gg_frq Analysis

Another code not discussed in the current Draft NUREG-1150 supporting documentation is **gg_frq**; therefore, a listing of this code is provided in Appendix C. Basically, **gg_frq** merges the PDS frequencies from the file **gg_temac.dat** with the accident progression bin conditional probabilities contained in the **gxx_sbin.out** files to provide an input file for PARTITION. This output file, **gg.frq**, is much too large to list in this report. As mentioned above, the input files from PSTEVNT are **gxx_sbin.out** (one file for each PDS). The output file, **gg.frq**, is used as an input to PARTITION.

A.6 GGSOR Analysis

GGSOR is the parametric code used to generate fission product source terms for the accident progression bins. GGSOR is briefly described in Reference A-3. Basically, GGSOR generates source terms based on a parametric representation of more detailed mechanistic accident progression calculations. The code also represents uncertainties in key source term issues. The input control file for GGSOR, **ggsor.inp**, is listed below.

```
BINNED   $ EXECUTION MODE SWITCH (MUST BE FIRST KEYWORD; 2ND LINE MUST BE TITLE)
ALL POSSIBLE BIN COMBINATIONS WITH EXPERT OPINION MEDIAN INPUT FOR GGSOR
$ EXECUTION OPTIONS
PRTINP   $ ECHO INPUT
CONSFL   $ KEEP CONSEQUENCE INPUT DATA
$SUMWGT   $ PRODUCE REDUCED DIMENSION FILE
KPBYRUN  $ USE OBSERVATION SPECIFIC BINS
$REPORTB  $ PRINT BIN TRANSLATION RESULTS
$DIAG     $ PRINT INTERMEDIATE DIAGNOSTIC VALUES
$   FILE ASSIGNMENTS
EXPERT                       $ EXPERT OPINION TABLE
DEFAULT  median.dat          $ DEFAULT PARAMETER VALUES FILE
BINFILE  byr_mas.kep          $ BIN DEFINITIONS
VECPOS   g_vecpos.dat        $ SAMPLE VECTOR POSITIONS
SAMPLE  250  1  ../hcube.dat  $ SAMPLE VECTOR FILE, 250 SAMPLES STARTING WITH
SAMPLE 1
```

As indicated in this listing, four input files are required by GGSOR. Three of these files, **median.dat**, **g_vecpos.dat**, and **hcube.dat**, were provided by SNL. These files are used in sampling the various parameters in the equation used by GGSOR to calculate the fission product source term. The fourth file, **byr_mas.kep**, is one of the MASTERK output files discussed above. The output file of GGSOR is an enormous file (~40 MB) called **ggsor.cfl**. This file is one of the input files required by PARTITION. Basically, it provides information on the isotopic release fractions, timing of the release, duration of the release, etc., for each unique source term bin produced in the PSTEVNT rebinning process, for each sampling observation.

A.7 PARTITION Analysis

The PARTITION code[A-4] does essentially what its name implies; it partitions the source term information generated by GGSOR into a smaller set of source term groups for which consequences can be calculated using MACCS. It does this by locating each source term on a two-dimensional grid of potential chronic (latent) fatalities vs. potential early fatalities using the isotopic release fractions from GGSOR, the frequencies associated with each source term, and a dose factor table. The isotopic release fractions are supplied from GGSOR in a file named **ggsor.cfl**. The source term frequencies come from **gg.frq** and **gg_temac.dat**, and the dose factor table was supplied by SNL as file **ggwgt.inp**.

One of the output files from PARTITION is **maccs.inp**. This is the MACCS input data for each source term group generated by PARTITION. It is used in calculating the conditional consequences for each of the source term groups. It is not listed in this report, because it is fairly large and the format of the file makes it not particularly useful to these analyses.

More useful to the analyst is the consequence summary data file that PARTITION produces (**summcom.dat**). This file contains a summary of the overall source bins of the early and chronic fatality potential of all possible releases. These data are useful for estimating the consequence potential for sensitivity cases without actually performing new MACCS calculations.

PARTITION generates a number of other output files. However, these files were not used in the CPI analysis, so they will not be discussed further. Refer to Reference A-4 for more information on the capabilities of PARTITION.

A.8 MACCS Consequence Analysis

The MACCS code[A-5] is used to calculate the conditional offsite consequences for each source term group generated by PARTITION. The required output file from PARTITION is **maccs.inp**. However, this file is not in the correct format for input to MACCS; therefore, it is reformatted using the translator utility STER, which was supplied by SNL. Because the only reference for the STER program is the source code, a code listing is provided in Appendix C.

Two MACCS runs were made in the base case analysis. In the first of these, the input deck was modified to reflect the input decks used for MACCS Version 1.5.5 in the Draft NUREG-1150 analyses. The MACCS code has undergone several revisions since the completion of the June 1989 draft of NUREG-1150; currently, Version 1.5.11 is in use. Therefore, the second base case run used the input deck for this later version (modifications were made to the STER program to reflect input deck differences).

Five measures of offsite risk were chosen for use in this report. They include: (a) the mean number of early (acute) fatalities, (b) the mean number of latent (chronic) fatalities, (c) the mean population dose within a 50-mile radius, (d) the mean population dose over the entire calculational grid (1000-mile radius), and (e) the mean offsite costs. Site data files were taken from the Draft NUREG-1150 Grand Gulf MACCS deck. Dose data files were supplied by SNL; however, these were the old files for Version 1.5.5. For the Version 1.5.11 run, Zion Draft NUREG-1150 dose data files were used, because of the unavailability of revised Grand Gulf dose data files. Using the Zion dose data files does not present a problem, because the dose data file is the same for each plant.

A.9 Risk Calculation

To determine the annual risk, the conditional consequences from MACCS were combined with the conditional probabilities of a release from containment and the PDS frequencies from the front-end analysis. Because of the unavailability of the code that was used to perform this calculation for Draft NUREG-1150 (RISQUE), a FORTRAN routine called RISK was written to carry out this task. This code is listed in Appendix C.

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APPENDIX B

COMPUTER FILE LISTINGS

APPENDIX B
COMPUTER FILE LISTINGS

B.1 Grand Gulf APET for PDS 1

The file listed on the following page, **gol_aprt.dat**, is the input file to EVNTRE that describes the APET for PDS 1. The APETs for the other PDSs are similar.

```
      GRAND GULF ACCIDENT PROGRESSION EVENT TREE   - REV. 6.0 -        SARRP
      125
       NQ
        1     1.000
                 cen
1 What is the initiating event?
    3     TLOSP        T2        TC                          $ TLOSP : Loss of Offsite Power
    1         1         2         3                          $ TPCS : Power Conversion System is lost
          1.000     0.000     0.000                          $ TC : Anticipated Transient without Scram (ATWS)
2 Is there a Station Blackout (Diesel Generators fail)?
    2        SB       nSB                                    $ SB : Station Blackout, No ac power on Division 1 and 2.
    1         1         2                                    $ nSB : Not a station blackout
          1.000     0.000
3 Is dc Power not available?
    2     E1fDC     E1-DC                                    $ E1[illegible] : power on Divisions 1,2 and 3
    1         1         2                                    $ E1-[illegible] power is available from Division 3 and either Div. 1 or Div 2.
          0.000     1.000
4 Do one or more S/RVs fail to reclose?
    2    E1SORV   E1nSORV                                    $ E1SORV : One or more S/RVs fail to reclose
    1         1         2                                    $ E1nSORV : No S/RVs fail to reclose
          0.050     0.950
5 Does HPCS fail to inject?
    3  E1fHPInj  E1rHPInj  E1-HPInj                          $ E1fHPInj : HPCS fail to inject
    1         1         2         3                          $ E1rHPInj : HPCS is recoverable when ac power is restored
          0.000     1.000     0.000                          $ E1-HPInj : HPCS is available
6 Does RCIC fail to inject initially?
    2   E1fRCIC   E1-RCIC                                    $ E1fRCIC : RCIC is failed during core degradation
    1         1         2                                    $ E1-RCIC : RCIC is providing injection during core degradation
          1.000     0.000
7 Does the CRD hydraulic system fail to inject?
    3    E1fCRD    E1rCRD    E1-CRD                          $ E1fCRD : CRD is failed & is not recoverable
    1         1         2         3                          $ E1rCRD : CRD is recoverable once ac power is restored
          1.000     0.000     0.000                          $ E1-CRD : CRD is delivering water to the vessel
8 Does the condensate system fail?
    3   E1fCond   E1rCond   E1aCond                          $ E1fCond : Condensate system is failed and will remain unavailable
    1         1         2         3                          $ E1rCond : Condensate is recoverable when ac power is restored
          0.000     1.000     0.000                          $ E1aCond : Condensate system is available but not currently injecting water
9 Do the LPCS and LPCI systems fail?                         $ E1fLPC : Both LPCS and LPCI are failed
    4    E1fLPC    E1rLPC    E1aLPC    E1-LPC                $ E1rLPC : Either LPCS or LPCI are recoverable when ac power is restored
    1         1         2         3         4                $ E1aLPC : Either LPCS or LPCI are available but there is no injection
          0.000     1.000     0.000     0.000                $ E1-LPC : Either LPCS or LPCI are providing water injection to RPV
10 Does RHR fail (heat exchangers not available)?            $ E1fRHR : Both SPC and CSS are failed
    4    E1fRHR    E1rRHR    E1aRHR    E1-RHR                $ E1rRHR : Both SPC and CSS are recoverable when ac power is restored
    1         1         2         3         4                $ E1aRHR : Either SPC or CSS are available
          0.000     1.000     0.000     0.000                $ E1-RHR : Either SPC or CSS is being used for containment heat removal
11 Does the service water system or cross-tie to LPCI fail?
    3    E1fSSW    E1rSSW    E1aSSW                          $ E1fSSW : SSW cross-tie is unavailable and cannot be recovered
    1         1         2         3                          $ E1rSSW : SSW cross-tie is recoverable when ac power is restored
          1.000     0.000     0.000                          # E1aSSW : Service water cross-tie is available
12 Does the fire protection system cross-tie to LPCI fail?
    3    E1fFWS  E1offFWS    E1aFWS                          $ E1fFWS : Fire Water system is unavailable and cannot be recovered
    1         1         2         3                          $ E1offFWS: Operators failed to align Fire Water system
```

```
         0.000     0.000     1.000
13 Are the containment (wetwell) sprays failed?
    4    E1fCSS    E1rCSS    E1aCSS    E1-CSS
    1         1         2         3         4
         0.000     1.000     0.000     0.000
14 What is the status of vessel depressurization?
    4    E1fDep   E1ofDep    E1nDep    E1-Dep
    1         1         2         3         4
        0.0000    0.0000    1.0000    0.0000
15 When does core damage occur?
    2    CD-Fst    CD-Slw
    1         1         2
         1.000     0.000
16 What is the level of pre-existing leakage or isolation failure?
    3      E1nL      E1L2      E1L3
    1         1         2         3
        0.9935    0.0065     0.000
17 What is the level of pre-existing suppression pool bypass?
    3    E1nSPB   E1-SPB2   E1-SPB3
    1         1         2         3
        0.9996    0.0004    0.0000
18 What is the structural capacity of the containment?
    1   Contain
    3         1
         1.000
    4
   21    334.00
   22      0.20
   24     19.50
   25      0.50
19 What is the structural capacity of the drywell?
    1   Drywell
    3         1
         1.000
    5
   26    528.00
   30    659.00
   31 !18,1,2,1
   34     32.00
   35 !18,1,4,1
20 What type of sequence is this (summary of plant damage)?
    6    Fst-SB    Slw-SB    Fst-T2    Slw-T2  Fst-TC  Slw-TC
    2         1         2         3         4       5       6
    6
    2         2        15
              1       * 1
             SB    CD-Fst
          1.000     0.000     0.000     0.000   0.000   0.000
    1         2
              1
             SB
          0.000     1.000     0.000     0.000   0.000   0.000
```

```
$ E1aFWS : FWS is available to inject high pressure water into RPV
$ E1fCSS : Containment sprays failed
$ E1rCSS : Sprays are recoverable when ac power is restored
$ E1aCSS : Containment sprays are available
$ E1-CSS : Containment sprays are operating

$ E1fDep : The RPV cannot be depressurized
$ E1ofDep: The Operators failed to deprssurize the RPV
$ E1nDep : The RPV has not been depressurized
$ E1-Dep : RPV has been depressurized
$ CD-Fst : Core damage occurs in the short term (1 hr.)
$ CD-Slw : Core damage occurs in the long term (12 hr.s)


$ E1nL : Nominal leakage (within tech spec.) - will NOT prevent long-term press
$ E1L2 : Pre-existing leakage sufficient to slowly depressurize the containment
$ E1L3 : Large pre-existing leak sufficient to depressurize the containment

$ E1nSPB : No pre-existing SPB in excess of the nominal level
$ E1-SPB2 : Initial SPB larger than nominal - on the same order of tech spec le
$ E1-SPB3 : Large initial SPB - vents will NOT clear for slow pressurization

$ Initializes the parameters that define the pressure or impulse at which
$ the containment will fail.  For pressure loads, there are 3 modes of containm
$ failure: leak, rupture, and catastrophic rupture. For impulsive loads there
$ there are 2 modes: leak and rupture
$ PCFail: Containment failure pressure
$ CFRan: Random number used for containment failure mode (Pressure)
$ IMPCF: Impulse at which containment fails
$ IMRanC: Random number used for containment failure mode (Impulse)

$ Initializes the parameters that define the pressure or impulse at which
$ the drywell head and the drywell wall fail.  For both pressure and impulsive
$ loads there are 2 failure modes: leak and rupture.

$ IPDWF:   Internal pressure which results in drywell failure
$ EPDWF:   External pressure which results in drywell failure
$ DWFRan: Random number used for Drywell failure mode (Pressure)
$ IMPDWF:   External impulse which results in drywell failure
$ IMRanD: Random number used for drywell failure mode (Impulse)

$ TBUX : Fast SB at high pressure with no injection - ac power is not recoverab
$ TQUV/FTB : Fast core melt other than TBUX and ATWS
$ TB : Long-term station blackout
$ TC-fDeP : ATWS with failure to depressurize the RPV (TCUX)

$Case 1: Fast Station blackout sequences

$Case 2: Long-term Station blackout sequences
```

```
    2         1       15                                        $Case 3: Fast lost of power converstion system transient
              2      * 1
             T2   CD-Fst
          0.000    0.000     1.000     0.000   0.000   0.000
    1         1                                                 $Case 4: Long-term lost of power converstion system transient
              2
             T2
          0.000    0.000     0.000     1.000   0.006   0.000
    2         1       15                                        $Case 5: Fast ATWS - RPV at high pressure, no injection
              3      * 1
             TC   CD-Fst
          0.000    0.000     0.600     0.000   1.000   0.000
      Otherwise                                                 $Case 6: Long-Term ATWS - RPV at high pressure, (HPCS > 5 hr.s)
          0.000    0.000     0.000     0.000   0.000   1.000
21 Do the operators turn on the HIS before core degradation?
    2    E2-HIS   E2nHIS                                        $ E2-HIS : HIS turned on before core degradation
    2         1        2                                        $ E2nHIS : HIS is NOT turned on before core degradation
    2
    1         2                                                 $Case 1: Not a station blackout, ac power is available.  Some probability
              2                                                 $        the operators will fail to turn on the HIS before core degradation.
            nSB
          0.840    0.160
      Otherwise   --    Station Blackout                        $Case 2: Station blackout and ac power is NOT available, HIS
          0.500    0.500                                        $        can be turned on but operator training is to not actuate equipment
22 Is the containment not vented before core degradation?       $        that he knows to be inoperable (HIS requires AC power)
    2   E3nVENT   E3VENT
    2         1        2                                        $ E3nVENT : Containment NOT vented before core damage
    5                                                           $ E3VENT : Containment IS vented successfully before core damage
    3         1       15        21
              3      * 2       * 2                              $Case 1: ATWS where HPCS injects initially and the operators failed to
             TC   CD-Slw    E2nHIS                              $        turn on the HIS
          1.000    0.000
    2         1       15                                        $Case 2: ATWS where HPCS injects initially and the operator does turn on
              3      * 2                                        $        the HIS
             TC   CD-Slw
          0.805    0.195
    3         1        6        15                              $Case 3: ATWS where Core Damage occurs in the short term and RCIC is
              3      * 2       * 1                              $        injecting (although insufficient to prevent CD)
             TC  E1-RCIC    CD-Fst
          1.000    0.000
    1         2
              2                                                 $Case 4: Not a station blackout containment pressure remains below venting thre
            nSB                                                 $        pressure prior to core damage for PDSs considered
          1.000    0.000
      Otherwise                                                 $Case 5: Station blackout and ac power is not available, thus cannot vent
          1.000    0.000                                        $        Venting requires both ac power from both divisions.
23 Does (do) any S/RV tailpipe vacuum breaker(s) stick wide open?
    2   oSRVBkr  cSRVBkr                                        $ oSRVBkr : At least one S/RV tailpipe vaccum breaker IS stuck open
    2         1        2                                        $ cSRVBkr : NO S/RV tailpipe vacuum breakers are stuck open
    5
    1         4                                                 $Case 1: Stuck open SRV, thus, tailpipe vacuum breaker is not repeatedly opened
              1                                                 $        and closed
```

```
        E1SOkv
         0.000     1.000
   3        20        20        14
          ( 1     +   3)        -4
        Fst-SB    Fst-T2   nE1-Dep
         0.250     0.750
   4        20        20        20        14
          ( 2     +   4     +   6)        -4
        Slw-SB    Slw-T2    Slw-TC   nE1-Dep
     !23,2,1   !23,2,2
   1        20
             5
        Fst-TC
         0.055     0.945
     Otherwise
     !23,4,1   !23,4,2
24 Does ac power remain lost during core degradation?
   2     E4fAC     E4-AC
   2         1         2
   4
   1         3
             1
         E1fDC
         1.000     0.000
   2         2        15
             1         2
            SB    CD-Slw
         0.610     0.390
   1         2
             1
            SB
         0.370     0.630
     Otherwise
         0.000     1.000
25 Is dc power available during core degradation?
   2     E4fDC     E4-DC
   2         1         2
   4
   1         3
             1
         E1fDC
         1.000     0.000
   1        24
             2
         E4-AC
         0.000     1.000
   2         2        15
             1         2
            SB    CD-Slw
         0.200     0.800
     Otherwise
         0.000     1.000
```

```
$Case 2: Fast core melt with RPV at high pressure.  SRVs are cycled a [illegible]
$        small number of times (33 based on BWR/LTAS) and, thus, the [illegible]
$        of tailpipe vacuum breaker failure is low

$Case 3: Long-term core melt with RPV at high pressure.  SRVs are cycled a
$        large number of times (45 based on LTAS) and, thus, the probability
$        of tailpipe vacuum breaker failure is higher

$Case 4: Very fast core melt with RPV at high pressure.  Due to the rapid boil-
$        rate resulting from the ATWS the low-low-set SRV is held wide open pri
$        to core damage and its tailpipe vacuum breaker does not cycle

$Case 5: RPV is depressurized, SRVs not cycled repeatedly.


$  E4fAC : ac power is not available during core damage
$  E4-AC : ac power is available during some portion of the core damage process

$ Case 1: Failure of dc power precludes AC power recovery



$ Case 2: Long-term station blackout sequence
$  none @ 14.7 hr given none @ 12 hr


$ Case 3: Fast station blackout accident sequence
$ none @ 3.35 hr given none @ 1 hr


$ Case 4: Power was previously available


$  E4fDC : dc power is NOT available during core damage
$  E4-DC : dc power IS available during the core damage process

$ Case 1: dc power has already been lost



$ Case 2: ac power is available, thus, dc power is available



$ Case 3: Long-term station blackout sequence - Batteries may deplete
$  If the batteries deplete before ac power is recovered, both dc and ac
$  power are lost

$ Case 4: Fast station blackout accident sequence
```

```
26 What is the RPV pressure during ccre degradation?
     2    E4-HiP    E4-LoP
     2         1         2
     6
     2        14        25
               4       * 2
         E1-Dep     E4-DC
          0.000     1.000
     1         4
               1
        E1-SORV
          0.000     1.000
     2        14        25
               1       + 1
         E1fDep     E4fDC
          1.000     0.000
     2         2        14
               1         3
              SB    E1nDep
          0.260     0.740
     6        21         1         1        15        22        15
               1      * (2    +    3     * ( 2     *  2   +  1))
         E2-HIS        T2         TC    CD-Slw   E3VENT    CD-Fst
          0.805     0.195
      Otherwise
          1.000     0.000
27 What 4s the status of th- HIS before vessel breach?
     2    E4-HIS    E4nHIS
     2         1         2
     7
     1        21
               2
         E2nHIS
          0.000     1.000
     1         2
               2
             nSB
          1.000     0.000
     1        24
               1
          E4fAC
          1.000     0.000
     4        20        26        14        25
               1     *   1      *  3     *   2
         Fst-SB    E4-HiP    E1nDep     E4-DC
          0.128     0.872
     2        20        26
               1     *   2
         Fst-SB    E4-LoP
          0.064     0.936
     1        20
               2
```

```
$ E4-HiP: RPV is at high pressure ( approx. 1055 psia)
$ E4-LoP: RPV is at low pressure ( < 50 psia)

$Case 1: Vessel depressurized prior to core damage and dc power is still
$        available


$Case 2: Vessel will depressurize prior to core damage (based on LTAS calcs.)



$Case 3: RPV can not be depressurized because of hardware failure or
$        dc power was lost and the ADS valves can no longer be kept open


$Case 4: Station blackout in which the operators failed to depressurize prior
$        to core damage with ac power recovery. Some probability that ADS fails
$        and the operators will not depressurize the RPV

$Case 5: ATWS or T2 sequence (operators previously failed to depressurize RPV)
$        and the operators fail to turn on HIS OR long term ATWS and the
$        operators fail to vent.

$Case 6: ATWS or T2 sequence with multiiple operator errors


$ E4-HIS : HIS IS working before vessel breach
$ E4nHIS : HIS is NOT working before vessel breach

$Case 1: HIS was not turned on previously, thus, will not be turned on
$        (to turn on HIS now would be an error of commission)


\Case 2: Not a SB and HIS was turned on previously, thus, still on.



$Case 3: SB and ac power has not been recovered and HIS was on previously,
$        thus, HIS still on.


$Case 4: Fast SB with ac power recovery, however, the operators failed to
$        to depressurize the RPV. Some probability the operators will turn
$        HIS OFF when ac brought into plant.

$Case 5: Fast SB with ac power recovery with no previous operator failures
$        Some probability the operators will be turned
$        HIS OFF when ac brought into plant.

$Case 6: Long-term SB with ac power recovery (operator failures resulted in
$        core melt)
```

```
          Slw-SB
           0.160      0.840
        Otherwise
           0.000      1.000
28 Is RPV injection restored during core degradation?
     3    E4nLPI     E4-LPI     E4-HPI
     2         1          2          3
    10
     2         5         24
               2       *  2
        E1rHPInj      E4-AC
           0.000      0.000      1.000
     1        26
               1
          E4-HiP
           1.000      0.000      0.000
     2         9         24
              -1          2
         nE1fLPI      E4-AC
           0.000      1.000      0.000
     4         8         24         20         27
              -1       *  2       * -1       *  2
        nE1fCond      E4-AC    nFst-SB     E4nHIS
           0.161      0.839      0.000
     3         8         24         20
              -1       *  2       * -1
        nE1fCond      E4-AC    nFst-SB
           0.322      0.678      0.000
     3         8         24         27
              -1       *  2       *  2
        nE1fCond      E4-AC     E4nHIS
           0.064      0.936      0.000
     2         8         24
              -1       *  2
        nE1fCond      E4-AC
           0.128      0.872      0.000
     5        12         20         24         27         24
               3       *  1      * (  2       *  2      *  1)
          E1aFPS     Fst-SB      E4-AC     E4nHIS      E4fAC
           0.128      0.872      0.000
     2        12         20
               3       *  1
          E1aFPS     Fst-SB
           0.256      0.744      0.000
        Otherwise
           1.000      0.000      0.000
29 Is the core in a critical configuration following injection recovery?
     2    E4-Crit   E4nCrit
     2         1          2
     3
     2         1         28
               3          2
```

```
$Case 7:  Case should not be used


$ E4nLPI: No low pressure injection into the RPV
$ E4-LPI: There is LOW pressure injection into the RPV
$ E4-HPI: There is HIGH pressure injection into the RPV

$Case 1: HPCS was recoverable and ac power is restored, thus, there is
$         high pressure injection into the RPV

$Case 2: High RPV pressure precludes low pressure injection


$Case 3: No failure of low pressure injection system and ac power is available
$           injection is automatic


$Case 4: Condensate system has not failed and ac power is available
$         and NOT a Short term SBO (Operators have commited errors to get to CD)
$         and the operatorz turned the HIS off

$Case 5: Condensate system has not failed and ac power is available
$         and NOT a Short term SBO (Operators have commited errors to get to CD)
$         and the operators FAILED tc turn the HIS off

$Case 6: Condensate system has not failed and ac power is available
$         and a Short term SBO (No previous operators errors) and the
$          HIS is OFF (No operator errors)

$Case 7: Condensate system has not failed and ac power is available
$         and a Short term SBO (No previous operators errors) and the
$          HIS is ON (operator failed to turn HIS off)

$Case 8: Fast SBO sequence with the FWS available and either no power
$         recovery (almost certainly) or all emergency injection failed and
$         HIS is OFF. Some probability that operators get fire system aligned.

$Case 9: Same as previous case except operators failed to turn HIS off.


$Case 10: No low pres. inject source or slow accident with FWS (operators
$         failed to use FWS previously, negligible probability will use it now)

$ E4-Crit : Core IS in a critical configuration following injection recovery
$ E4nCrit : Core is NOT in a critical configuration following injection recover

$Case 1: ATWS accident sequence with low pressure injection
$         restored to the RPV
```

```
            TC    E4-LPI
         0.100     0.900
     2      28        28                                $Case 2: All other transients with either high or low pressure injection
             2     +   3                                $        restored to the RPV
        E4-LPI    E4-HPI
         0.010     0.990
     Otherwise                                          $Case 3: No injection recovery (no moderator)
         0.000     1.000
30 What is the status of containment sprays?            $ E4fCS : Containment sprays are failed and cannot be recovered
     4   E4fCS     E4rCS     E4aCS     E4-CS            $ E4rCS : Sprays are recoverable when ac power is restored
     2       1         2         3         4            $ E4aCS : Sprays are available
     5                                                  $ E4-CS : Containment sprays are operating
     1      13
             1                                          $Case 1: Conteinment sprays were previously failed
        E1fCSS
         1.000     0.000     0.000     0.000
     2      13        24                                $Case 2: Sprays were previously recoverable and ac power has NOT been restored
             2     *   1
        E1rCSS     E4fAC
         0.000     1.000     0.000     0.000
     2       1        15                                $Case 3: Long-term ATWS (ATWS with HPCS > 5 hr.s).  RHR is insufficient to
             3     *   2                                $        to keep the pool cool for this case
            TC    CD-Slw
         0.000     0.000     0.010     0.990
     2      20        24                                $Case 4: Long-term station blackout (thus, containment pressure is high enough
             2     *   2                                $        to trigger sprays) - some probability that automatic actuation fails.
        Slw-SB     E4-AC
         0.000     0.000     0.010     0.990
     Otherwise                                          $Case 5: Sprays are available but not operated because containment pressure is
         0.000     0.000     1.000     0.000            $        not sufficiently high
31 What amount of Oxygen is in the wetwell during core degradation?
     1    O2WW                                          $ O2WW : Amount of oxygen in wetwell prior to core damage
     3       1
         1.000
     2
     9   316.0                                          $Par. 9 : O2WW - Amount of O2 in wetwell (Kg-mole)
    44  1191.0                                          $Par. 44 : N2WW - Amount of N2 in wetwell (Kg-mole)
32 What amount of Oxygen is in the drywell during core degradation?
     1    O2DW                                          $ O2DW : Amount of oxygen in drywell prior to core damage
     3       1
         1.000
     1
    10    61.0                                          $Par. 10 : O2DW - Amount of O2 in drywell (Kg-mole)
33 What amount of steam is present in the containment at core damage?
     1   H2OWW                                          $ H2OWW : Amount of steam in containment during core damage
     4       1                                          $ Par 1: H2OWW - Amount of steam in wetwell (kg-mole)
     6
     2      16        22                                $Case 1: Either Pre-existing rupture or containment vented (currently NO
             3     +   2                                $        pre-existing rupture and the only time containment will be vented
          E1L3    E3VENT                                $        early is during a long term ATWS, thus, treat like case 2)
         1.000
     1
```

```
     1   1582.00
     2         1        15                                                     $Case 2: Long-term ATWS (HPCS operates > 5 hr.s - pool heats up
               3      *  2
              TC    CD-Slw
           1.000
     1
     1   1582.00
     2        10        13                                                     $Case 3: RHR and containment sprays working.  Spray temperature assumed at
               4         4                                                     $        110 F maximum since pool would not heat.
          E1-RHR    E1-CSS
           1.000
     1
     1     75.00
     3         2        14        15                                           $Case 4: Very Long-Term SB - Containment Steam Inert
               1      *  1     *   2
              SB    E1fDep    CD-Slw
           1.000
     1
     1   4235.00
     1        20                                                               $Case 5: Long-term station blackout without containment sprays
               2
          Slw-SB
           1.000
     1
     1   2290.00
       Otherwise                                                               $Case 6: Fast core melt (TBUX, TQUV/FTB, & TCUX) - subcooled pool
           1.000
     1
     1     75.00
34 What amount of steam is present in the drywell at core damage?
     1     H2ODW                                                               $ H2ODW : Amount of steam in drywell during core damage
     4         1                                                               $ Par 6: H2ODW: Amount of steam in drywell (kg-mole)
     6
     1        23                                                               $Case 1: Stuck open SRV tailpipe vacuum breaker
               1                                                               $       - Large amount of steam enters drywell through the tailpipe vacuum brea
         oSRVBkr
           1.000
     1
     6    305.00
     2         1        15                                                     $Case 2: Long-term ATWS (HPCS operates > 5 hr.s - pool heats up
               3      *  2
              TC    CD-Slw
           1.000
     1
     6    223.00
     2        10        13                                                     $Case 3: RHR and containment sprays working
               4         4
          E1-RHR    E1-CSS
           1.000
     1
     6     14.50
     3         2        14        15                                           $Case 4: Very Long-Term SB - Containment Steam Inert
```

```
               1      * 1      *   2
              SB    E1fDep    CD-Slw
           1.000
      1
      6   817.00
      1       20                                                              $Case 4: Long-term station blackout
               2
          Slw-SB
           1.000
      1
      6   424.00 $ STMDWELL: Amount of steam in drywell (kg-mole) from LTAS
       Otherwise                                                              $Case 5: Fast core melt (TBUX, TQUV/FTB, & TCUX)
           1.000
      1
      6    14.50 $ STMDWELL: Amount of steam in drywell (kg-mole) BMI-2139
35 Total amount of hydrogen released in-vessel during core degradation?
      1   In-VsH2                                                             $ In-VsH2: Amount of In-Vessel hydrogen production
      4        1
      6
      2        1        28                                                    $Case 1: ATWS sequence, RPV at high pressure, NO high pressure injection except
               3         2                                                    $         CRD (TCUX) and injection recovered
              TC    E4-LPI
           1.000
      1
      2    221.7 H2INVES - H2 released in-vessel (Kg-Mole)
      1        1                                                              $Case 2: ATWS sequence, RPV at high pressure, NO high pressure injection (TCUX)
               3                                                              $             NO injection recovered
              TC
           1.000
      1
      2    458.4
      3       14        28        28                                          $Case 3: Core degradation occurs at high pressure, however
              -4     * ( 2     +  3)                                          $         injection is restored before vessel breach.
         nE1-DeP    E4-LPI    E4-HPI
           1.000
      1
      2    326.1
      2       28        28                                                    $Case 4: Core degradation occurs at low pressure and
             ( 2     +  3)                                                    $         injection to the RPV before vessel breach.
          E4-LPI    E4-HPI
           1.000
      1
      2    277.1
      1       26                                                              $Case 5: Core degradation occurs at high pressure with no water injection
               1                                                              $         before vessel breach.
          E4-HiP
           1.000
      1
      2    442.3
       Otherwise                                                              $Case 6: Core degradation occurs at low pressure with no water injection
           1.000                                                              $         before vessel breach.
      1
```

```
    2     477.0
36 What is the level of In-Vessel zirconium oxidation?
    7    ZrOx75    ZrOx50    ZrOx40    ZrOx30  ZrOx21  ZrOx10 ZrOx<10        $ ZrOx75 : In-vessel Zr oxidation > 75%
    5         1         2         3         4       5       6       7        $ ZrOx50 : In-vessel Zr oxidation: 75% > ZrOx > 50%
    1         2                                                              $ ZrOx40 : In-vessel Zr oxidation: 50% > ZrOx > 40%
        H2INVES                                                              $ ZrOx30 : In-vessel Zr oxidation: 40% > ZrOx > 30%
            AND                                                              $ ZrOx21 : In-vessel Zr oxidation: 30% > ZrOx > 21%
       GETHRESH         6    1302.7     868.5   694.8   521.1   364.8   173.7 $ ZrOx10 : In-vessel Zr oxidation: 21% > ZrOx > 10%

37 What is the containment pressure during core damage?
    3     E1P>3     E1P>2     E1P>1                                          $ E1P>3 : Containment pressure greater than 3 bars
    6         1         2         3                                          $ E1P>2 : Containment pressure greater than 2 bars but less than 3 bars
    7                                                                        $ E1P>1 : Containment pressure less than 2 bars
    2        16        22
              3     *   2                                                    $Case 1: Either a level 3 containment leak or containment vented
           E1L3    E3VENT                                                    $         - containment can not pressurize
    5         9        44         1         2       5
           O2WW      N2WW     H2OWW      H2WW  EPBase
      FUN-EBASP1
       GETHRESH         3   9999.00   9999.00    1.00

    2         1        15                                                    $Case 2: Long-term ATWS (HPCS operates > 5 hr.s) - Hot pool
              3     *   2
             TC    CD-Slw
    5         9        44         1         2       5
           O2WW      N2WW     H2OWW      H2WW  EPBase
      FUN-EBASP1
       GETHRESH         3   9999.00   9999.00    1.00

    2        10        13                                                    $Case 3: RHR and containment sprays working
              4         4                                                    $         - containment not pressurized due to steam
         E1-RHR    E1-CSS
    5         9        44         1         2       5
           O2WW      N2WW     H2OWW      H2WW  EPBase
      FUN-EBASP2
       GETHRESH         3     304.0     202.6   101.3

    2        20        30                                                    $Case 4: Long-term station blackout and sprays are working
              2         4                                                    $         - containment pressure controlled by pool temperature (boil-off)
         Slw-SB     E4-CS
    5         9        44         1         2       5
           O2WW      N2WW     H2OWW      H2WW  EPBase
      FUN-EBASP3
       GETHRESH         3     304.0     202.6   101.3

    3         2        14        15                                          $Case 5: Very long term SB (approx 18 hr.s to Core Melt)
              1     *   1     *   2
             SB    E1fDep    CD-Slw
    5         9        44         1         2       5
           O2WW      N2WW     H2OWW      H2WW  EPBase
      FUN-EBASP4
       GETHRESH         3     304.0     202.6   101.3
```

```
     1        20                                                               $Case 6: Long-term station blackout and sprays are NOT working
               2
          Slw-SB
     5         9        44         1         2        5
            O2WW      N2WW     H2OWW      H2WW   EPBase
      FUN-EBASP5
        GETHRESH         3     304.0     202.6    101.3

       Otherwise                                                               $Case 7: Fast core melt (TBUX, TQUV/FTB, & TCUX)
     5         9        44         1         2        5
            O2WW      N2WW     H2OWW      H2WW   EPBase
      FUN-EBASP2
        GETHRESH         3     304.0     202.6    101.3

38 What is the level of containment leakage due to slow pressurization before VB?
     4    ESPnCL   ESP-CL2   ESP-CL3   ESP-CL4                                 $ESPnCL : Nominal containment leakage
     6         1         2         3         4                                 $ESP-CL2: Level 2 containment leakage (Leak)
     4                                                                         $ESP-CL3: Level 3 containment failure (Rupture)
     2        16        22                                                     $ESP-CL4: Level 4 containment failure (Cat. Rupture)
               3     +   2
            E1L3    E3VENT                                                     $Case 1: Containment has been vented or already had a pre-existing leak.
     1         5
          EPBase
             AND
        GETHRESH         3   9999.00   9999.00     1.00
                           Dummy -- Already failed by detonation
     2         1        15                                                     $Case 2: Long-term ATWS (HPCS runs initially), containment will fail
               3     *   2                                                     $        from overpressure
              TC    CD-Slw
     2        21        22
          PCFail     CFRan
       FUN-SLWP1
        GETHRESH         3      3.00      2.00     1.00
                           Dummy -- Already leaking from detonation
     3         2        14        15                                           $Case 3: Very long term station blackout (core damage occurs @ approx 18 hr.s)
               1     *   1     *   2
              SB    E1fDep    CD-Slw
     3         5        21        22
          EPBase    PCFail     CFRan
       FUN-SLWP2
        GETHRESH         3      3.00      2.00     1.00

       Otherwise                                                               $Case 4: Initial pressure is not high enough to threaten the containment
     1         5
          EPBase
             AND
        GETHRESH         3     -1.00    999.00   999.00
                           Parameter value triggers particular branch
39 What is the maximum hydrogen concentration in the wetwell before VB?
     6    HWW>20    HWW>16    HWW>12     HWW>8    HWW>4   NoHWW                $ HWW>20 : H2 concentration in WW > 20%      HWW>16 : 16% < H2 concen. < 20%
     6         1         2         3         4        5       6                $ HWW>12 : 12% < H2 concen. < 16%            HWW>8 : 8% < H2 concen. < 12%
```

```
7                                                                       $ HWW>4  : 4% < H2 concen. < 8%             NoHWW : H2 concen. in WW < 4%
2       23        20
         1   *     6                                                    $Case 1: Open S/RV tailpipe vacuum breaker and a Long-Term ATWS (containment
   oSRVBkr    Slw-TC                                                    $         failed from overpressure, all oxygen purged out of wetwell)
6        2         1        9         3      44      14
   In-VsH2     H2OWW     O2WW      H2WW    N2WW    NTOT
 FUN-H2WW1
 GETHRESH          5     0.20      0.16    0.12    0.08    0.04
           leakage from tailpipe vacuum breaker and containment hole
4       23        16       38        38                                 $Case 2: Open S/RV tailpipe vacuum breaker and there is a level 3 leak in
         1   *   ( 3     +  3     + 4 )                                 $         containment
   oSRVBkr      E1L3  ESP-CL3   ESP-CL4
6        2         1        9         3      44      14
   In-VsH2     H2OWW     O2WW      H2WW    N2WW    NTOT
 FUN-H2WW2
 GETHRESH          5     0.20      0.16    0.12    0.08    0.04
           leakage from tailpipe vacuum breaker and containment hole
1       20                                                              $Case 3: NO stuck open S/RV tailpipe but long-term ATWS failed containment
         6
    Slw-TC
6        2         1        9         3      44      14
   In-VsH2     H2OWW     O2WW      H2WW    N2WW    NTOT
 FUN-H2WW3
 GETHRESH          5     0.20      0.16    0.12    0.08    0.04

3       16        38       38                                           $Case 4: NO stuck open S/RV tailpipe vacuum breaker and level 3 leak in
       ( 3      +  3    + 4 )                                           $         containment
      E1L3   ESP-CL3  ESP-CL4
6        2         1        9         3      44      14
   In-VsH2     H2OWW     O2WW      H2WW    N2WW    NTOT
 FUN-H2WW4
 GETHRESH          5     0.20      0.16    0.12    0.08    0.04
           Vessel to pool but large containment hole
1       23                                                              $Case 5: Open S/RV tailpipe vacuum breaker and RPV at low pressure and
         1                                                              $         there is NOT a significant leak in containment
   oSRVBkr
6        2         1        9         3      44      14
   In-VsH2     H2OWW     O2WW      H2WW    N2WW    NTOT
 FUN-H2WW5
 GETHRESH          5     0.20      0.16    0.12    0.08    0.04
           Large leakage from tailpipe vacuum breaker
1       17                                                              $Case 6: Large suppression pool bypass with NO stuck open S/RV tailpipe
         3                                                              $         vacuum breakers
   E1-SPB3
6        2         1        9         3      44      14
   In-VsH2     H2OWW     O2WW      H2WW    N2WW    NTOT
 FUN-H2WW6
 GETHRESH          5     0.20      0.16    0.12    0.08    0.04
           Large initial suppression pool bypass
 Otherwise -- Nominal or small leakage into drywell                     $Case 7: Nominal or small suppression pool bypass with NO stuck open S/RV
6        2         1        9         3      44      14                 $         tailpipe vacuum breakers
   In-VsH2     H2OWW     O2WW      H2WW    N2WW    NTOT
```

```
      FUN-H2WW7
      GETHRESH          5      0.20      0.16    0.12    0.08    0.04
                Assume leakage back to drywell & vessel retention independent of scenario
40 To what level is the wetwell inert during core degradation?
     3     E4nWIn   E4-WIn2   E4-WIn3                                     $ E4rWIn : Wetwell is not inert
     5          1         2         3                                     $ E4-WIn2 : Wetwell inert to detonations
     3          1         3         9                                     $ E4-WIn3 : Wetwell inert to H2 combustion
           H2OWW      H2WW      O2WW
       FUN-INRT                                                           $  Calculates (1 - mole fraction of steam present initially)
       GETHRESH         3      0.65      0.45    0.00
                                Det   Combust   Inert
41 Do diffusion flames consume the hydrogen released before VB?
     2     E4-Dif    E4nDif                                               $ E4-Dif : H2 burned in range: 0% < H2 < 8%
     2          1         2                                               $ E4nDif : H2 is not burned as a diffusion flame
     6
     2         40        20                                               $Case 1: Wetwell is inert or Long-Term ATWS (No oxygen for combustion)
                3    *    6
          E4-WIn3    Slw-TC
            0.000     1.000
     2          2        21                                               $Case 2: Not a station blackout and the HIS is turned on prior to H2 generation
                2    *    1
              nSB    E2-HIS
            1.000     0.000
     1          2                                                         $Case 3: Not a station blackout, HIS NOT turned on - ignition from
                2                                                         $         ac sources - some probability ignition occurs before H2 > 8%
              nSB
            0.750     0.250
     3          2        24        27                                     $Case 4: Station blackout, ac power recovered, HIS turned on - some probability
                1    *    2    *    1                                     $         ac power recovered before H2 > 8%
               SB     E4-AC    E4-HIS
            0.120     0.880
     2          2        24                                               $Case 5: Station blackout, ac power recovered, HIS NOT turned on - some
                1    *    2                                               $         probability ac power recovered before H2 > 8% - ignition from random s
               SB     E4-AC
            0.060     0.940
      Otherwise -- Low-Pressure station blackout without recovery         $Case 6: RPV at low pressure and NO ac power - ignition from random sources
            0.000     1.000
42 What is the maximum hydrogen concentration in the drywell before VB?
     6     HDW>20    HDW>16    HDW>12     HDW>8   HDW>4   NoHDW           $ HDW>20 : H2 concentration in DW > 20%       HDW>16 : 16% < H2 concen. < 20%
     6          1         2         3         4       5       6           $ HDW>12 : 12% < H2 concen. < 16%             HDW>8 : 8% < H2 concen. < 12%
     6                                                                    $ HDW>4  : 4% < H2 concen. < 8%               NoHDW : H2 concen. in DW < 4%
     2         23        20
                1    *    6                                               $Case 1: Open S/RV tailpipe vacuum breaker and Long-Term ATWS
          oSRVBkr    SLW-TC                                               $         (Containment failed - oxygen purged out of drywell)
     5          2         3         6        10       4
          In-VsH2      H2WW    H2ODW       O2DW    H2DW
      FUN-H2DW1
      GETHRESH          5      0.20      0.16    0.12    0.08    0.04
                Small leakage from tailpipe vacuum breaker
     4         23        16        38        38
                1    * ( 3    +    3    +   4 )                           $Case 2: Open S/RV tailpipe vacuum breaker and large containment failure
          oSRVBkr      E1L3   ESP-CL3    ESP-CL4
```

```
     5         2         3         6        10       4
         In-VsH2      H2WW     H2ODW      O2DW    H2DW
       FUN-H2DW2
       GETHRESH          5      0.20      0.16    0.12    0.08    0.04
                 Small leakage from tailpipe vacuum breaker
     1        23                                                               $Case 3: Open S/RV tailpipe vacuum breaker and RPV at low pressure
               1
         oSRVBkr
     5         2         3         6        10       4
         In-VsH2      H2WW     H2ODW      O2DW    H2DW
       FUN-H2DW3
       GETHRESH          5      0.20      0.16    0.12    0.08    0.04
                 Large leakage from tailpipe vacuum i,eaker
     2        17        41                                                     $Case 4: Large suppression pool bypass with NO stuck open S/RV tailpipe
               3       * 2                                                     $        vacuum breakers and NO diffusion flames in wetwell
         E1-SPB3    E4nDif
     5         2         3         6        10       4
         In-VsH2      H2WW     H2ODW      O2DW    H2DW
       FUN-H2DW4
       GETHRESH          5      0.20      0.16    0.12    0.08    0.04
                 Large initial suppression pool bypass
     2        17        41                                                     $Case 5: Level 2 suppression pool bypass with NO stuck open S/RV tailpipe
               2       * 2                                                     $        vacuum breakers and NO diffusion flames in wetwell
         E1-SPB2    E4nDif
     5         2         3         6        10       4
         In-VsH2      H2WW     H2ODW      O2DW    H2DW
       FUN-H2DW5
       GETHRESH          5      0.20      0.16    0.12    0.08    0.04
                 Small initial suppression pool bypass
       Otherwise -- Nominal leakage into drywell only                          $Case 6: Nominal leakage into drywell with NO stuck open S/RV tailpipe
     5         2         3         6        10       4                         $        vacuum breakers
         In-VsH2      H2WW     H2ODW      O2DW    H2DW
       FUN-H2DW6
       GETHRESH          5      0.20      0.16    0.12    0.08    0.04
                 Assume leakage back to drywell & vessel retention independent of scenario
43 Do deflagrations occur in the WW prior to vessel breach?
     2   E4-WWDf   E4nWWDf                                                     $ E4-WWDf : Deflagration in wetwell before vessel breach
     2         1         2                                                     $ E4nWWDf : NO deflagration in the wetwell before vessel breach
    13
     3        41        40        20                                           $Case 1: H2 burned as a diffusion flame or wetwell inert with no containment
               1       + 3       + 6                                           $       sprays or Long-Term ATWS (No oxygen to support combustion)
          E4-Dif    E4-WIn    SLW-TC
           0.000     1.000
     3        26         4        39                                           $Case 2: The average concentration of H2 in the containment is less than
             ( 2      * 2)       * 6                                           $        4% and it is released at low pressure
          E4-LoP   E1nSORV     NoHWW
           0.000     1.000
     1        24                                                               $Case 3: ac power available (lots of ignition sources)
               2
           E4-AC
           1.000     0.000
     4        26        14         4        39                                 $Case 4: RPV at HIGH pressure and NO ac power - ignition from random sources
```

```
             ( 1     +  -4     *  1)      *  6                    $        and H2 < 4%
          E4-HiP   nE1-Dep    E1SORV     NoHWW
           0.180     0.820
    4         26        14         4        39                    $Case 5: RPV at HIGH pressure and NO ac power - ignition from random sources
             ( 1     +  -4     *  1)      *  5                    $        and 4% < H2 < 8%
          E4-HiP   nE1-Dep    E1SORV     HWW>4
           0.230     0.770
    1         39                                                  $Case 6: RPV at LOW pressure and NO ac power - ignition from random sources
               5                                                  $        and 4% < H2 < 8%
           HWW>4
           0.210     0.790
    4         26        14         4        39                    $Case 7: RPV at HIGH pressure and NO ac power - ignition from random sources
             ( 1     +  -4     *  1)      *  4                    $        and 8% < H2 < 12%
          E4-HiP   nE1-Dep    E1SORV     HWW>8
           0.280     0.720
    1         39                                                  $Case 8: RPV at LOW pressure and NO ac power - ignition from random sources
               4                                                  $        and 8% < H2 < 12%
           HWW>8
           0.280     0.720
    4         26        14         4        39                    $Case 9: RPV at HIGH pressure and NO ac power - ignition from random sources
             ( 1     +  -4     *  1)      *  3                    $        and 12% < H2 < 16%
          E4-HiP   nE1-Dep    E1SORV    HWW>12
           0.390     0.610
    1         39                                                  $Case 10: RPV at LOW pressure and NO ac power - ignition from random sources
               3                                                  $        and 12% < H2 < 16%
          HWW>12
           0.380     0.620
    5         26        14         4        39      39            $Case 11: RPV at HIGH pressure and NO ac power - ignition from random sources
             ( 1     +  -4     *  1)     *( 2   +  1)            $        and 16% < H2
          E4-HiP   nE1-Dep    E1SORV    HWW>16  HWW>20
           0.500     0.500
    2         39        39                                        $Case 12: RFV at LOW pressure and NO ac power - ignition from random sources
             ( 2     +  1)                                        $        and 16% < H2
          HWW>16    HWW>20
           0.490     0.510
       Otherwise                                                  $Case 13: Case should not be accessed
           0.000     1.000
44 Is there a detonation in the wetwell prior to vessel breach?
    2    E4-WWDt   E4nWWDt                                        $ E4-WWDt : There is a detonation in the wetwell prior to vessel breach
    4          1         2                                        $ E4nWWDt : No detonation in the wetwell prior to vessel breach
    8
    6         40        30        40        39      39      39    $Case 1: Wetwell inert to detonation or H2 < 12%
               2     *  -4     +   3     +   4   +   5   +   6
         E4-WIn2    nE4-CS   E4-WIn3     HWW>8   HWW>4   NoHWW
           0.000     1.000
    1
   20       0.00      0.00
    4         43        39        40        30                    $Case 2: 12% < H2 < 16% and containment initially inert to detonations,
               1     *   3  *  (   2   *    4)                    $        however, sprays are on which reduces steam concentration and forms
         E4-WWDf    HWW>12   E4-WIn2     E4-CS                    $        a detonable mixture in containment (High steam)
           0.220     0.780
    1
```

```
 20      5.80      0.00
  2        43        39                                       $Case 3: 12% < H2 < 16% and Low steam
            1       * 3
     E4-WWDf    HWW>12
       0.000     1.000
  1
 20      0.00      0.00
  4        43        39         40         30                 $Case 4: 16% < H2 < 20% and containment initially inert to detonations,
            1       * 2  * (     2     *     4)               $        however, sprays are on which reduces steam concentration and forms
     E4-WWDf    HWW>16   E4-WIn2      E4-CS                   $        a detonable mixture in containment (High steam)
       0.250     0.750
  1
 20 !44.2,1,1      0.00
  2        43        39                                       $Case 5: 16% < H2 < 20% and Low steam
            1       * 2
     E4-WWDf    HWW>16
       0.260     0.740
  1
 20     12.40      0.00
  4        43        39         40         30                 $Case 6: H2 > 20%  and containment initially inert to detonations,
            1       * 1  * (     2     *     4)               $        however, sprays are on which reduces steam concentration and forms
     F4-WWDf    HWW>20   E4-WIn2      E4-CS                   $        a detonable mixture in containment (High steam)
    !44,4,1   !44,4,2
  1
 20 !44,2,1,1      0.00
  2        43        39                                       $Case 7: H2 > 20% and Low steam
            1       * 1
     E4-WWDf    HWW>20
       0.450     0.550
  1
 20 !44.5,1,1      0.00
   Otnerwise  --  No combustion                               $Case 8: No combustion
       0.000     1.000
  1
 20      0.00      0.00                   $ ImpLoad: Impulse loading to drywell structures
45 What is the level of containment impulse load before vessel breach?
  7   E-Ip>60   E-Ip>50   E-ip>40   E-Ip>30 E-Ip>20 E-Ip>10 E-Ip<10     $ E-Ip>60 : Impulse > 60 KPa-S         E-Ip>50 : 60 > Impulse > 50 KPa-S
  5         1         2         3         4       5       6       7     $ E-Ip>40 : 50 > Impulse > 40 KPa-S    E-Ip>30 : 40 > Impulse > 30 KPa-S
  1        20                                                           $ E-Ip>20 : 30 > Impulse > 20 KPa-s    E-Ip>10 : 20 > Impulse > 10 KPa-S
      ImpLoad                                                           $ E-Ip<10 : Impulse < 10 KPa-S
          AND
     GETHRESH         6     60.00     50.00   40.00   30.00   20.00   10.00
                                                                        $ Parse load to verify result of preceeding question
46 With what efficiency is hydrogen burned prior to VB?
  1   H2EfBVB                                                           $ H2EfBVB : H2 burn efficiency prior to vessel breach
  4         1
 12                                                                     $Case 1: No deflagration in the wetwell before vessel breach
  1        43
            2
      E4rWWDf
        1.000
  2
```

```
18     0.000
19     0.000
 2        40       39                                  $Case 2: Wetwell steam > 45% (High Steam) and H2 ignited in Range H2 < 4%
           2     *  6
     E4-WIn2    NoHWW
       1.000
 2
18     0.079                                           $ Par 18 : H2EfVB1 - Effective efficiency of H2 combustion
19     0.275                                           $ Par 19 : H2EfVB2 - Actual efficiency of H2 combustion
 1        39
           6                                           $Case 3: Wetwell steam < 45% (Low Steam) and H2 ignited in Range H2 < 4%
       NoHWW
       1.000
 2
18     0.000
19 !46,2,2,1
 2        40       39                                  $Case 4: Wetwell steam > 45% (High steam) and H2 ignited in Range 8% > H2 > 4%
           2     *  5
     E4-WIn2    HWW>4
       1.000
 2
18      0.28
19 !46,2,2,1
 1        39                                           $Case 5: Wetwell steam < 45% (low steam) and H2 ignited in Range 8% > H2 > 4%
           5
       HWW>4
       1.000
 2
18     0.280
19 !46,2,2,1
 2        40       39                                  $Case 6: Wetwell steam > 45% (high steam) and H2 ignited in Range 12% > H2 > 8%
           2     *  4
     E4-WIn2    HWW>8
       1.000
 2
18     0.464
19     0.740
 1        39                                           $Case 7: Wetwell steam < 45% (low steam) and H2 ignited in Range 12% > H2 > 8%
           4
       HWW>8
       1.000
 2
18     0.575
19 !46,6,2,1
 2        40       39                                  $Case 8: Wetwell steam > 45% (high steam) and H2 ignited in Range 16% > H2 > 12
           2     *  3
     E4-WIn2   HWW>12
       1.000
 2
18     0.483
19     0.881
 1        39                                           $Case 9: Wetwell steam < 45% (low steam) and H2 ignited in Range 16% > H2 > 12%
```

```
               3
          HWW>12
           1.000
     2
    18     0.734
    19 !46,8,2,1
     3        40        39        39                                            $Case 10: Wetwell steam > 45% (high steam) and H2 ignited in Range  H2 > 16%
               2     * ( 2     +  1)
         E4-WIn2    HWW>16    HWW>20
           1.000
     2
    18     0.492
    19     0.935
     2        39        39                                                      $Case 11: Wetwell steam < 45% (low steam) and H2 ignited in Range  H2 > 16%
             ( 2     +  1)
          HWW>16    HWW>20
           1.000
     2
    18     0.752
    19 !46,10,2,1
       Otherwise                                                                $Case 12: Case should not be referenced
           1.000
     2
    18      0.00
    19      0.00
47 What is the peak pressure in containment from a hydrogen burn?
     6    PBrn>7    PBrn>6    PBrn>5    PBrn>4  PBrn>3  PBrn<3                  $ PBrn>7 : Peak Press > 7 bar        PBrn>6 : 7 > Peak Press > 6 bar
     6         1         2         3         4       5       6                  $ PBrn>5 : 6 > Peak Press > 5 bar    PBrn>4 : 5 > Peak Press > 4 bar
     4                                                                          $ PBrn>3 : 4 > Peak Press > 3 bar    PBrn<3 : Peak Press < 3 bar
     2        41        43
               2       * 2                                                      $Case 1: NO H2 burn
          E4nDif   E4nWWDf
     8         3         1         9         5      11      18      19      44
            H2WW     H2OWW      O2WW    EPBase    PBrn H2EfVB1 H2EfVB2    N2WW
       FUN-EPBRN1
        GETHRESH         5     709.3     608.0   506.6   405.3   304.0
                 Parse peak pressure for verification
     5        16        22        38        38      41                          $Case 2: Containment already failed or H2 burns as a diffusion flame
               3       + 2       + 3       + 4     + 1                          $        (Negligible pressure rise)
            E1L3   E3-Vent   ESP-CL3   ESP-CL4  E4-Dif
     8         3         1         9         5      11      18      19      44
            H2WW     H2OWW      O2WW    EPBase    PBrn H2EfVB1 H2EfVB2    N2WW
       FUN-EPBRN2
        GETHRESH         5     709.3     608.0   506.6   405.3   304.0
                 Parse peak pressure for verification
     1        44                                                                $Case 3: Detonation in the wetwell before vessel breach with NO large
               1                                                                $        failure in the containment (Very Fast Pressure rise)
         E4-WWDt
     6         3         1         9         5      11      18      19      44
            H2WW     H2OWW      O2WW    EPBase    PBrn H2EfVB1 H2EfVB2    N2WW
       FUN-EPBRN3
        GETHRESH         5     709.3     608.0   506.6   405.3   304.0
```

```
                 Parse peak pressure for verification
       Otherwise                                                               $Case 4: Deflagration in the wetwell before vessel breach with NO large
     8         3         1         9         5      11      18      19      44 $        failure in the containment
            H2WW     H2OWW      O2WW    FPBase    PBrn H2EfVB1 H2EfVB2    N2WW
       FUN-EPBRN4
        GETHRESH         5     709.3     608.0   506.6   405.3   304.0
                 Parse peak pressure for verification
48 What is the level of drywell leakage induced by an early detonation in containment?
     3    EnDWDt   E-DWDt2   E-DWDt3                                           $ EnDWDt : No drywell failure induced by detonation
     6         1         2         3                                           $ E-DWDt2 : Drywell leakage induced by detonation (Level 2)
     2                                                                         $ E-DWDt3 : Drywell rupture induced by detonation (Level 3)
     1        44
               1                                                               $Case 1: Detonation in wetwell before vessel breach
         E4-WWDt
     3        20        34        35
         ImpLoad    IMPDWF    IMRanD
         FUN-EDI
        GETHRESH         2      2.00      1.00
                  $ Dummy parameter values used to trigger particular branch
       Otherwise                                                               $Case 2: NO detonation in wetwell before vessel breach - NO failure
     3        20        34        35
         ImpLoad    IMPDWF    IMRanD
             AND
        GETHRESH         2      0.00     -1.00
                  $  Parameter values force Branch 1
49 What is the level of containment leakage induced by an early detonation?
     3    E4nDtF   E4-DtF2   E4-DtF3                                           $ E4nDtF : No Containment failure induced by detonation
     6         1         2         3                                           $ E4-DtF2 : Containment leakage induced by detonation (Level 2)
     3                                                                         $ E4-DtF3 : Containment rupture induced by detonation (Level 3)
     2        48        48
               2    +    3                                                     $Case 1: Detonation failed the drywell (Either Level 2 or 3)
         E-DWDt2   E-DWDt3                                                     $        This case allows coupling between drywell and containment response
     5        20        24        25        34      35
         ImpLoad     IMPCF    IMRanC    IMPDWF  IMRanD
        FUN-ECI1
        GETHRESH         2      2.00      1.00

     1        44                                                               $Case 2: Detonation in containment - No drywell failure from detonation
               1
         E4-WWDt
     3        20        24        25
         ImpLoad     IMPCF    IMRanC
        FUN-ECI2
        GETHRESH         2      2.00      1.00

       Otherwise                                                               $Case 3: No detonation in containment - No failure
     1        20
         ImpLoad
             AND
        GETHRESH         2     -1.00     -1.00
                  $  Parameter values force Branch 1
50 What is the level of containment leakage before vessel breach?              $ E5nCL : No containment failure
```

```
     4     E5nCL    E5-CL2    E5-CL3    E5-CL4                                  $ E5-CL2 : Containment failure is a leak (Level 2)
     6         1         2         3         4                                  $ E5-CL3 : Containment failed by rupture (Level 3)
     4                                                                          $ E5-CL4 : Containment failed by catastrophic rupture (Level 4)
     5        16        22        38        38      49
               3     +   2       + 3       + 4    +  3                          $Case 1: Containment either had a pre-existing rupture or was vented or
            E1L3    E3VENT   ESP-CL3   ESP-CL4 E4-DtF3                          $        was ruptured by a detonation
     1         5
          EPBase
       FUN-ECBrn1
        GETHRESH         3   9999.00   9999.00    1.00
                           Dummy -- Already failed by detonation
     3        16        38        43                                            $Case 2: Containment already leaking and NO deflagration occurred
            (  2     +   2)      * 2                                            $        - Thus, no additional leakage
            E1L2   ESP-CL2   E4nWWDf
     1         5
          EPBase
             AND
        GETHRESH         3   9999.00      0.00   -1.00
                           Dummy -- Already leaking from detonation
     3        16        49        38                                            $Case 3: Containment either had a pre-existing leak or has a leak from a
               2     +   2       + 2                                            $        detonation
            E1L2   E4-DtF2   ESP-CL2
     4         5        11        21        22
          EPBase      PBrn    PCFail     CFRan
       FUN-ECBrn2
        GETHRESH         3   9999.00      2.00    1.00
                           Dummy -- Already leaking from detonation             $Case 4: Containment intact before containment burn - No failure from detonatio
       Otherwise
     4         5        11        21        22
          EPBase      PBrn    PCFail     CFRan
       FUN-ECBrn2
        GETHRESH         3      3.00      2.00    1.00
                           Parameter value triggers particular branch
51 What is the level of drywell leakage induced by containment pressurization?
     5    EnDWDf   E-DWDf2  E-DWHDf2   E-DWDf3 E-DWHDf3                         $ EnDWDf   : No drywell failure
     6         1         2         3         4        5                         $ E-DWDf2  : Drywell failure is a leak at the DW wall (Level 2)
     5                                                                          $ E-DWHDf2 : Drywell failure is a leak at the DW head (Level 2)
     2        17        48                                                      $ E-DWDf3  : Drywell failure is a rupture at the DW wall (Level 3)
               -     +   3                                                      $ E-DWHDf3 : Drywell failure is a rupture at the DW head (Level 3)
         E1-SPB3   E-DWDt3                                                      
     1         5                                                                $Case 1: Pre-existing large leak or drywell already ruptured by a detonation
          EPBase                                                                $ Drywell already failed at wall -- prevent head failure
             AND
        GETHRESH         4   9999.00   9999.00 9999.00    0.00

     3        17        50        50                                            $Case 2: Drywell has pre-existing leak and containment ruptured
               2    (    3     +   4)                                           $        Prior drywell leakage to exclude drywell head leakage
         E1-SPB2    E5-CL3    E5-CL4                                            $        Containment rupture so burn pressure could be mitigated
     4         5        11        30        31
          EPBase      PBrn     EPDWF    DWFRan
       FUN-EDBrn1
        GETHRESH         4   9999.00      3.00    2.00   -1.00
```

```
                                                                              $Case 3: NO pre-existing drywell failure and containment is ruptured
                                                                              $        Containment rupture so burn pressure could be mitigated
    2        50        50
              3    +    4
        E5-CL3    E5-CL4
    4         5        11        30        31
        EPBase      PBrn     EPDWF    DWFRan
      FUN-EDBrn2
       GETHRESH         4      4.00      3.00      2.00    -1.00

                                                                              $Case 4: Pre-existing drywell leakage - Prior leakage to exclude head leakage
    1        17
              2
       E1-SPB2
    4         5        11        30        31
        EPBase      PBrn     EPDWF    DWFRan
      FUN-EDBrn3
       GETHRESH         4   9999.00      3.00      2.00    -1.00

                                                                              $Case 5: Burn or no burn case with no prior ruptures
      Otherwise
    4         5        11        30        31
        EPBase      PBrn     EPDWF    DWFRa)
      FUN-EDBrn4
       GETHRESH         4      4.00      3.00      2.00    -1.00
                 $ Dummy parameters select f:ilure mode
52 What is the level of suppr=ssion pool bypass following early combustion events?
                                                                              $ E5nSPB : No suppression pool bypass
    3     E5nSPB   E5-SPB2   E5-SPB3                                          $ E5-SPB2 : Suppression pool bypass level 2 (Leak)
    2         1         2         3                                           $ E5-SPB3 : Suppression pool bypass level 3 (Rupture)
    5
    4        17        48        51        51
              3    +    3    +    4    +    5                                 $Case 1: Drywell rupture from combustion or pre-existing rupture
       E1-SPB3   E-DWDt3   E-DWDf3  E-DWHDf3
         0.000     0.000     1.000                                            $Case 2: Pre-existing drywell leak and ac power is available and H2 combustion
    4        17        24        41        43                                 $        in containment - pre-existing leak exacerbated by vacuum breaker fail
              2         2    (    1    +    1)
       E1-SPB2     E4-AC    E4-Dif    E4-WWDf
         0.000     0.950     0.050                                            $Case 3: Drywell leakage from either pre-existing leak, leak from detonation
    4        17        48        51        51                                 $        or leak from pressure in containment.
              2    +    2    +    2    +    3
       E1-SPB2   E-DWDt2   E-DWDf2  E-DWHDf2
         0.000     1.000     0.000                                            $Case 4: ac power is available and H2 combustion in containment
    3        24        41        43                                           $        - vacuum breaker fails from H2 burn
              2    (    1    +    1)
         E4-AC    E4-Dif    E4-WWDf
      !52,2,2       0.000 !52,2,3                                             $Case 5: No burns in containment & no additional bypass
      Otherwise
         1.000     0.000     0.000
53 Has the upper pool dumped?                                                 $ UPDmp : Upper pool has dumped water into the suppression pool
    2      UPDmp   noUPDmp                                                    $ noUPDmp : The upper containment pool dump does NOT operate
    2         1         2
    2                                                                         $Case 1: ac power is available - Upper Pool Dump requires ac power
    1        24
              2
         E4-AC
```

```
           1.000     0.000
       Otherwise                                                               $Case 2: No AC power - cannot operate upper pool dump without ac power
           0.000     1.000
54 Is there water in the reactor cavity?
    3   E5-DFld   E5-DWet   E5-DDry                                            $ E5-DFld : Drywell is flooded (5 M of water in the pedestal)
    2         1         2         3                                            $ E5-DWet : Reactor cavity wet (200 M**3 of water)
    9                                                                          $ E5-DDry : Reactor cavity is dry
    1        51
               5                                                               $Case 1: Drywell head rupture - shield pool leaks into drywell
        E-DWHDf3
           1.000     0.000     0.000
    6        16        22        38        38      50      50                  $Case 2: No pre-existing rupture or venting and containment failure either
              -3       * 1      * -3      * -4  *  ( 3  +   4)                 $        by rupture or catastrophic rupture - combustion event failed contain
           nE1L3   E3nVENT   ESP-CL3   ESP-CL4  E5-CL3  E5-CL4
           0.990     0.010     0.000
    5        16        22        43        39      39                          $Case 3: H2 combustion in containment and containment intact except for
              -3         1       * 1      * -6    * -5                         $        possible level 2 leakage
           nE1L3   E3nVENT   E4-WWDf    nNoHWW  nHWW>4
           0.999     0.001     0.000
    8        16        22        17        41      30      39      39      24 $Case 4: No containment rupture and No large suppression pool bypass and no
              -3         1        -3         1      -4      -5      -6       1 $        containment sprays and more than 8% of H2 burns as a diffusion flame
           nE1L3   E3nVENT  nE1-SPB3    E4-Dif  nE4-CS  nHWW>4  nNoHWW   E4!AC
           0.450     0.450     0.100
    7        16        22        17        53      39      39      39          $Case 5: No containment rupture and No large suppression pool bypass and
              -3         1        -3         1   (    1 +    2   +  3 )        $        upper pool dump and more than 12% H2 without a burn
           nE1L3   E3nVENT  nE1-SPB3     UPDmp  HWW>20  HWW>16  HWW>12
           0.500     0.500     0.000
    1        20                                                                $Case 6: Long-term station blackout - Pump seal leakage
               2
          Slw-SB
           0.000     1.000     0.000
    1        53                                                                $Case 7: Upper pool has dumped
               1
           UPDmp
           0.000     1.000     0.000
    7        16        22        24        17      39      39      39          $Case 8: No containment rupture and No large suppression pool bypass and
              -3         1         1        -3   (    1 +    2   +  3)         $        No ac power, and more than 12% H2 without a burn
           nE1L3   E3nVENT     E4nAC  nE1-SPB3  HWW>20  HWW>16  HWW>12
           0.000 !54,5,1   !54,5,2
       Otherwise                                                               $Case 9: Pre-existing containment rupture or large suppression pool bypass or
           0.000     0.000     1.000                                           $        no significant H2 generation
55 What is the containment pressure before vessel breach?
    3     E5P>3     E5P>2     E5P>1                                            $ E5P>3 : Containment pressure before vessel breach > 3 bar
    6         1         2         3                                            $ E5P>2 : 3 > containment pressure > 2 bar
    5                                                                          $ E5P>1 : 2 bar > containment pressure
    1        50
              -1                                                               $Case 1: Containment has failed
           E5-CL                                                               $        Pressure set to atmospheric
    8         1         9        44         3       6      10       4       5
           H2OWW      O2WW      N2WW      H2WW   H2ODW    O2DW    H2DW  EPBASE
       FUN-IBASP1
        GETHRESH         2     304.0     202.6
```

```
     2        52          30                                                        $Case 2: NO Containment failure with a LARGE suppression pool bypass and
               3         * 4                                                        $        CS. Base Pressure changed to account for the change in total number
         E5-SPB3       E4-CS                                                        $        of moles. (Drywell and Wetwell assumed to be well mixed)
     8         1           9         44         3       6       10       4       5
           H2OWW        O2WW       N2WW      H2WW   H2ODW     O2DW    H2DW  EPBASE
       FUN-IBASP2
        GETHRESH           2      304.0     202.6

     1        52                                                                    $Case 3: NO Containment failure with a LARGE suppression pool bypass
               3                                                                    $        Base Pressure changed to account for the change in total number
         E5-SPB3                                                                    $        of moles. (Drywell and Wetwell assumed to be well mixed)
     8         1           9         44         3       6       10       4       5
           H2OWW        O2WW       N2WW      H2WW   H2ODW     O2DW    H2DW  EPBASE
       FUN-IBASP3
        GETHRESH           2      304.0     202.6

     1        30                                                                    $Case 4: NO Containment failure and NO large suppression pool bypass and
               4                                                                    $        CS. Base Pressure changed to account for the change in total number
           E4-CS                                                                    $        of moles. (Drywell and Wetwell assumed to be well mixed)
     8         1           9         44         3       6       10       4       5
           H2OWW        O2WW       N2WW      H2WW   H2ODW     O2DW    H2DW  EPBASE
       FUN-IBASP4
        GETHRESH           2      304.0     202.6

       Otherwise                                                                    $Case 5: No containment failure and NO CS - Base pressure adjusted to account
     8         1           9         44         3       6       10       4       5 $         for change in total number of moles
           H2OWW        O2WW       N2WW      H2WW   H2ODW     O2DW    H2DW  EPBASE
       FUN-IBASP5
        GETHRESH           2      304.0     202.6

56 To what level is the DW steam inert at vessel breach?                            $ E5nDIn : Drywell is not inert
     3    E5nDIn     E5-DIn2    E5-DIn3                                             $ E5-DIn2 : Drywell inert to detonations
     5         1           2          3                                             $ E5-DIn3 : Drywell inert to H2 combustion
     3         4           6         10
         H2DWELL       H2ODW    O2DWELL                                             $Case 1: Stuck open S/RV tailpipe vacuum breaker and RPV at low pressure
       FUN-DWIN1             $ Calculates dry air mole fraction in DW
        GETHRESH           3 !40,1,1   !40,1,2   !40,1,3
                                   Det     Comb.    Inert
57 Is there sufficient H2 for combustion/detonation in the DW before VB?            $ E5cDWDt : Enough H2 & O2 for a detonation ( H2 > 16% )
     3   E5cDWDt     E5cDWDf     E5nDWC                                             $ E5cDWDf : Enough H2 & O2 for a combustion ( 16% > H2 > 6% )
     5         1           2          3                                             $ E5nDWC : Not enough H2 or O2 to support combustion ( H2 < 6%)
     3         4           6         10
         H2DWELL       H2ODW    O2DWELL
       FUN-DWCBVB
        GETHRESH           3       0.16       0.06     0.00
                             H2min  -- 16%, 6% or less than 6%
58 Does an Alpha Mode Event fail both the vessel and the containment?               $ Alpha : Alpha mode event fails the RPV and containment
     2     Alpha   noAlpha                                                          $ noAlpha : There is no Alpha mode failure
     2         1           2
     2                                                                              $Case 1:  RPV at HIGH Pressure when core slump occurs
     1        26
```

```
               1
          E4-HiP
           0.001     0.999
       Otherwise                            $Case 2: RPV is a LOW pressure when core slump occurs.
           0.010     0.990
59 What fraction of the core parti ipates in core slump?
     3      HiSL     MedSL     LowSL        $ HiSL  : >50% of Core molten at core slump
     2         1         2         3        $ MedSl : Between 10% & 50% of core molten at core slump
     7                                      $ LowSL : < 10% of core molten at core slump
     1        58
               1                            $Case 1: Alpha mode failure has occurred which implies large fraction molten
           Alpha
           1.000     0.000     0.000
     2        26        28                  $Case 2: RPV at high pressure with High pressure injection & NO alpha mode
               1       * 3
          E4-HiP    E4-HPI
           0.000     0.000     1.000
     3        26         7        24        $Case 3: RPV at high pressure with CRD injection & NO alpha mode
               1  *  (  -1     *  2)
          E4-HiP   nE1fCRD     E4-AC
           0.000     0.000     1.000
     1        26                            $Case 4: RPV at HIGH pressure with no injection & NO alpha mode
               1
          E4-HiP
           1.000     0.000     0.000
     2        28        28                  $Case 5: RPV at Low pressure and there is either high or low pressure
             ( 2    +   3)                  $       injection, NO alpha mode
          E4-LPI    E4-HPI
         !59,2,1   !59,2,2   !59,2,3
     2         7        24                  $Case 6: RPV at Low pressure with only CRD injection, NO alpha mode
            ( -1     *  2)
         nE1fCRD     E4-AC
         !59,3,1   !59,3,2   !59,3,3
       Otherwise                            $Case 7: RPV at low pressure with NO injection, NO alpha mode
         !59,4,1   !59,4,2   !59,4,3
60 Is there a large in-vessel steam explosion?
     2    VesStx   nVesSTx                  $ VesStx: There is an in-vessel steam explosion
     2         1         2                  $ nVesStx: There is no in-vessel steam explosion
     3
     1        58                            $Case 1: Large steam explosion resulted in Alpha mode failure
               1
           Alpha
           1.000     0.000
     1        26                            $Case 2: RPV is at HIGH pressure and NO alpha mode failure
               1
          E4-HiP
           0.100     0.900
       Otherwise                            $Case 3: RPV is at LOW pressure and NO alpha mode failure
            0.86      0.14
61 What fraction of the core debris would be mobile at vessel breach?
     2   HiLiqVB   LoLiqVB                  $ HiLiqVB: Large amount of core debris (40%) mobile at vessel breach
     4         1         2                  $ LoLiqVB: Small amount of core debris (10%) mobile at vessel breach
```

```
    3                                                                     $ Par 46 - Feject : Fraction of core ejected at vessel breach
    4          7        24         28         28
         ( -1     *   2)     +   2      +   3                            $Case 1: Water delivered to RPV by either CRD injection or there is either
       nE1fCRD      E4-AC    E4-LPI     E4-HPI                            $        high or low pressure injection
         0.025      0.975
    1
   46    0.400      0.100
    1       26                                                            $Case 2: RPV is at high pressure and there is no injection source to the RPV
             1
        E4-HiP
         0.100      0.900
    1
   46    0.400      0.100
     Otherwise -- Low pressure with no injection                          $Case 3: RPV is at Low pressure and there is no injection source to the RPV
     !61,2,1  !61,2,2
    1
   46    0.400      0.100
62 Does a large in-vessel steam explosion fail the vessel?                $SE-Alpha : Alpha mode            SE-BtP   : RPV bottom head fails
    5  SE-Alpha    SE-BtHd SE-LgBrch SE-SmBrch SE-nFail                   $SE-LgBrch: Large Hole            SE-SmBrch: Small hole
    2         1          2         3         4        5                   $SE-nFail: Vessel does not fail from steam explosion
    3
    1        58                                                           $Case 1 : Vessel has failed by Alpha Mode Failure
              1
         Alpha
        1.0000     0.0000    0.0000    0.0000   0.0000
    1        60                                                           $Case 2: A large In-vessel steam explosion occurred but did NOT result in an
              1                                                           $        Alpha mode failure
        VesStx
        0.0000     0.2000    0.2000    0.3000   0.3000
     Otherwise                                                            $Case 3: No in-vessel steam explosion
         0.000      0.000     0.000     0.000    1.000
63 What is the mode of vessel breach?
    5    A-Fail    BH-Fail    LgBrch    SmBrch nBreach                    $Alpha: Alpha mode              BH-Fail: RPV bottom head fails at VB (32 M*M)
    2         1          2         3         4        5                   $LgBrch: Large Hole (2 M*M)     SmBrch: Small hole (0.1 M*M)
   10                                                                     $nBreach: No vessel failure
    1        58
              1                                                           $Case 1: Vessel has failed by Alpha Mode Failure
         Alpha
        1.0000     0.0000    0.0000    0.0000   0.0000
    1        62                                                           $Case 2: Vessel's bottom head failed from a large in-vessel steam explosion
              2
       SE-BtHd
        0.0000     1.0000    0.0000    0.0000   0.0000
    1        62                                                           $Case 3: In-vessel steam explosion failed the vessel with a LARGE hole.
              3
     SE-LgBrch
        0.0000     0.0000    1.0000    0.0000   0.0000
    1        62                                                           $Case 4: In-vessel steam explosion failed the vessel with a SMALL hole.
              4
     SE-SmBrch
        0.0000     0.0000    0.0000    1.0000   0.0000
    4        28         28        61        29                            $Case 5: RPV at low pressure, water is injected into RPV, and only a LARGE
```

```
        ( 2      + 3)      * :      * 2
       E4-LPI   E4-HPI   HiLiqVB   E4nCrit
       0.0000   0.1240   0.0050    0.3710  0.5000
   2       26       61
            1        1
       E4-HiP   HiLiqVB
       0.0000   0.2490   0.0050    0.7460  0.0000
   1       61
            1
      HiLiqVB
       0.0000   0.2490   0.0050    0.7460  0.0000
   3       28       28       29
        ( 2      + 3)      * 2
       E4-LPI   E4-HPI   E4nCrit
       0.0000   0.0620   0.0050    0.1880  0.7450
   1       26
            1
       E4-HiP
       0.0000   0.2490   0.0050    0.7460  0.0000
     Otherwise -- Low press., no steam explosion, o injection
       0.0000   0.2490   0.0050    0.7460  0.0000
64 Does high-pressure melt ejection occur?
   2     HPME    nHPME
   2        1        2
   5
   3       58       63       26
            1      + 5      + 2
        Alpha  nBreach   E4-LoP
        0.000    1.000
   3       63       63       61
         ( 2      + 3)      * 1
      BH-Fail   LgBrch  HiLiqVB
        0.800    0.200
   2       63       63
         ( 2      + 3)
      BH-Fail   LgBrch
     !64,2,1  !64,2,2
   1       61
            1
      HiLiqVB
     !64,2,1  !64,2,2
     Otherwise
     !64,2,1  !64,2,2
65 Does a detonation occur in the DW at vessel breach?
   2   I-DWDt   InDWDt
   4        1        2
   2
   3       56       57       63
            1        1       -5
      E5nDWIn  E5cDWDt   Breach
        1.000    0 ^00
   1
```

```
$         amount of material mobil at vessel breach - core did NOT go critical
$         after wate' injection, thus NO vessel breach is possibl:

$Case 6: RPV at high pressure, no injection, and an only a LARGE amount of
$         material molten at vessel breach


$Case 7: RPV at low pressure, no injection, and only a LARGE amount of
$         material mobile at vessel breach


$Case 8: RPV at low pressure, water injected into RPV, and only a small
$         material mobile at vessel breach


$Case 9: RPV at high pressure, no injection, and only a small amount of
$         material mobile at vessel breach


$Case 10: RPV at low pressure, is no injection, and only a small amount of
$         material mobile at vessel breach

$HPME: High-pressurr melt ejection occurs at vessel breach
$nHPME: There is no high-pressure melt ejection occurs at vessel breach

$Case 1: Alpha mode failure or NO vessel breach or RPV at LOW pressure
$         and a steam explosion did NOT fail the vessel]


$Case 2: RPV fails with a LARGE breach
$         with a LARGE amount of material mobile at vessel breach


$Case 3: RPV fails with a LARGE breach
$         with a SMALL amount of material mobile at vessel breach


$Case 4: RPV fails with a SMALL breach
$         with a LARGE amount of material mobile at vessel breach


$Case 5: RPV fails with a SMALL breach
$         with a SMALL amount of material mobile at vessel breach

$ I-DWDt : Detonation in the drywell at vessel breach
$ InDWDt : NO detonation in the :rywell a: vessel breach

$Case 1: Drywell is NOT inert to : detonation and there is sufficient H2
$         & O2 for a detonation pri.r to VB and there IS breach in the vessel
```

```
                                                         $ DW-DtILd: Impulse load from detonation in the drywell
    36     12.00      0.00                               $Case 2: No vessel breach or mixture not detonable
       Otherwise
           0.000      1.000
     1
    36     12.00      0.00                               $ DW-DtILd: Impulse load from detonation in the drywell
66 Does a deflagration occur in the DW at vessel breach?
     2    I-DWDf     InDWDf                              $ I-DWDf : Deflagration occurs in DW at vessel breach
     2         1          2                              $ InDWDf : NO deflagration in DW at vessel breach
     2
     4        56         57         63         65        $Case 1: The drywell is not inert and there is a combustible mixture in the
              -3         -3         -5          2        $        drywell and there is a breach in the vessel and the mixture did NOT
      nE5-DWIn3    nE5nDWC     Breach     InDWDt         $        detonate
           1.000      0.000
       Otherwise                                         $Case 2: No hydrogen, inert, no breach, or previous detonation
           0.000      1.000
67 Does a large ex-vessel steam explosion occur?
     2      ExSE      nExSE                              $ ExSE : A large ex-vessel steam explosion occurs
     2         1                                         $ nExSE : There is NO large ex-vessel steam explosion
     3                                                   $ Pd-SEILd (Par. 38): Impulse loading to pedestal from Stx
     4        58         63         54         28
               1        + 5     + ( 3       * 1)         $Case 1: Either the drywell is DRY and there is NO INJECTION into the vessel
           Alpha    nBreach    E5-DDry       nLPI        $        at the time of VB or the vessel failed by Alpha Mode or there was
           0.000      1.000                              $        no vessel failure
     1        64
               1                                         $Case 2: HPME occurs at VB
            HPME
           0.800      0.200
       Otherwise                                         $Case 3: VB occurs at HIGH pressure (NO HPME) or VB occurs at LOW pressure
            0.86       0.14
68 What amount of H2 is released at vessel breach?
     1      H2VB                                         $ H2VB : H2 release during blowdown at VB
     4         1                                         $ Par 7 - H2AVB : Amount of H2 released at vessel breach (kg-mols)
     7
     2        63         63                              $Case 1: Either Alpha mode vessel failure or No vessel failure
               1        + 5
          A-Fail    nBreach
           1.000
     1
     7      0.00
     2         1         28                              $Case 2: ATWS sequence, RPV at high pressure, NO high pressure injection except
               3          2                              $        CRD (TCUX) and injection recovered
              TC     E4-LPI
           1.000
     1
     7      41.0
     1         1                                         $Case 3: ATWS sequence, RPV at high pressure, NO high pressure injection (TCUX)
               3                                         $         -  NO injection recovered
              TC
           1.000
     1
     7      65.0
     3        14         24         28                   $Case 4: Core degradation occurs at high pressure, however
```

```
               -4     * ( 2     +  3)                                           $        injection is restored before vessel breach.
        nE1-DeP    E4-LPI    E4-HPI
            1.000
      1
      7      41.0
      2        28        28                                                     $Case 5: Core degradation occurs at low pressure and
              ( 2     +  3)                                                     $        injection to the RPV before vessel breach.
         E4-LPI    E4-HPI
            1.000
      1
      7      15.0
      1        26                                                               $Case 6: Core degradation & VB occur at high pressure with no water injection
                1                                                               $        before vessel breach.
           E4-HiP
            1.000
      1
      7     121.0
       Otherwise -- Low Pressure no injection recovery                          $Case 7: Core degradation & VB occur at low pressure with no water injection
            1.000                                                               $        before vessel breach.
      1
      7      48.0
69 How much hydrogen is released at vessel breach?                              $H2VB>50 : Greater than 50% of the total Zr is oxidized at VB
      4   H2VB>50   H2VB>25   H2VB>10   H2VB<10                                 $H2VB>25 : Between 25% & 50% of the total Zr is oxidized at VB
      6         1         2         3         4                                 $H2VB>10 : Between 10% & 25% of the total Zr is oxidized at VB
      2                                                                         $H2VB<10 : Less than 10% of the total Zr is oxidized at VB
      2        64        67
              ( 1     +  1)                                                     $Par 8 : FH2VB - Initialized in user function FUN-H2AVB
             HPME      EXSE
      4         2         7        46         8                                 $Case 1: HPME or an ex-vessel steam explosion has occurred
          H2INVES      H2VB    FEJECT     FH2VB
       FUN-H2AVB1
         GETHRESH         3     868.5    434.25   17.37

       Otherwise                                                                $Case 2: NO HPME and NO ex-vessel steam explosion
      4         2         7        46         8
          H2INVES      H2VB    FEJECT     FH2VB
       FUN-H2AVB2
         GETHRESH         3     868.5    434.25   17.37

70 What is the peak  drywell/wetwell  pressure difference resulting from VB?
      1    DPDWVB                                                               $ DPDWVB : Peak drywell/wetwell pressure difference at vessel breach
      4         1                                                               $ Par 13: DPDWVB - Peak drywell/wetwell pressure difference at VB
     14
      2        63        63                                                     $Case 1: Vessel either failed by Alpha mode and thus drywell pressurization is
                1     +   5                                                     $        irrelevant or vessel did not fail at all
           A-Fail   nBreach
            1.000
      1
     13      0.00
      6        26        61        63        63      54      54                 $Case 2: Vessel breach at HIGH pressure with a LARGE amount of material through
                1         1    (    2    +    3)  (   1   +   2)                $        a LARGE hole into a WET reactor cavity
           E4-HiP   HiLiqVB   BH-Fail    LgBrch E5-DFld E5-DWet                 $        - Expert Case 1-HC
```

```
        1.000
 1
13     433.00
 4         26        61        54        54                                $Case 3: Vessel breach at HIGH pressure with a LARGE amount of material through
            1         1   (     1   +    2)                                $        a SMALL hole into a WET reactor cavity
      E4-HiP   HiLiqVB   E5-DFld   E5-DWet                                 $        -Expert Case 1-hC
        1.000
 1
13     332.00
 4         26        61        63        63                                $Case 4: Vessel breach at HIGH pressure with a LARGE amount of material through
            1         1   (     2   +    3)                                $        a LARGE hole into a DRY reactor cavity
      E4-HiP   HiLiqVB   BH-Fail    LgBrch                                 $        -Expert Case 2-HC
        1.000
 1
13     392.00
 2         26        61                                                    $Case 5: Vessel breach at HIGH pressure with a LARGE amount of material through
            1         1                                                    $        a SMALL hole into a DRY reactor cavity
      E4-HiP   HiLiqVB                                                     $        -Expert Case 2-hC
        1.000
 1
13     242.00
 5         26        63        63        54      54                        $Case 6: Vessel breach at HIGH pressure with a SMALL amount of material through
            1    (    2   +     3)  (    1   +   2)                        $        a LARGE hole into a WET reactor cavity
      E4-HiP   BH-Fail    LgBrch   E5-DFld E5-DWet                         $        -Expert Case 1-Hc
        1.000
 1
13     425.00
 3         26        54        54                                          $Case 7: Vessel breach at HIGH pressure with a SMALL amount of material through
            1    (    1   +     2)                                         $        a SMALL hole into a WET reactor cavity
      E4-HiP   E5-DFld   E5-DWet                                           $        -Expert Case 1-hc
        1.000
 1
13     312.00
 3         26        63        63                                          $Case 8: Vessel breach at HIGH pressure with a SMALL amount of material through
            1    (    2   +     3)                                         $        a LARGE hole into a DRY reactor cavity
      E4-HiP   BH-Fail    LgBrch                                           $        -Expert Case 2-Hc
        1.000
 1
13     337.00
 1         26                                                              $Case 9: Vessel breach at HIGH pressure with a SMALL amount of material through
            1                                                              $        a SMALL hole into a DRY reactor cavity
      E4-HiP                                                               $        -Expert Case 2-hc
        1.000
 1
13     222.00
 5         61        63        63        54      54                        $Case 10: Vessel breach at LOW pressure with a LARGE amount of material through
            1    (    2   +     3)  (    1   +   2)                        $        a LARGE hole into a WET reactor cavity
     HiLiqVB   BH-Fail    LgBrch   E5-DFld E5-DWet                         $        - Expert Case 3-HC
        1.000
 1
13     295.00
 3         61        54        54                                          $Case 11: Vessel breach at LOW pressure with a LARGE amount of material through
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               1    (    1    +    2)                                          $        a SMALL hole into a WET reactor cavity
         HiLiqVB   E5-DFld   E5-DWet                                           $        -Expert Case 3-hC
           1.000
     1
    13    242.00
     4        63        63        54        54                                 $Case 12: Vessel breach at LOW pressure with a SMALL amount of material through
         (    2    +    3)    (    1    +    2)                                $        a LARGE hole into a WET reactor cavity
         BH-Fail    LgBrch   E5-DFld   E5-DWet                                 $        -Expert Case 3-Hc
           1.000
     1
    13    290.00
     2        54        54                                                     $Case 13: Vessel breach at LOW pressure with a SMALL amount of material through
         (    1    +    2)                                                     $        a SMALL hole into a WET reactor cavity
         E5-DFld   E5-DWet                                                     $        -Expert Case 3-hc
           1.000
     1
    13    238.00
       Otherwise                                                               $Case 14: Vessel breach at LOW pressure with a dry cavity
           1.000
     1
    13      0.00
71 What is the peak pedestal pressure at vessel breach?                        $ Ped-VBP : Peak pressure in pedestal at vessel breach
     1   Ped-VBP                                                               $ Par 13: Ped-VBP - Peak pressure in pedestal at vessel breach (Bar)
     4         1
    18                                                                         $Case 1: Vessel either failed by Alpha mode and thus drywell pressurization is
     2        63        63                                                     $        irrelevant or vessel did not fail at all
               1     +    5
          A-Fail   nBreach
           1.000
     1
    39      0.00                                                               $Case 2: Vessel breach at HIGH pressure with a LARGE amount of material through
     6        26        61        63        63       54       54                $        a LARGE hole into a WET reactor cavity
               1         1    (    2    +    3)  (   1   +    2)                $        - Expert Case 1-HC
          E4-HiP   HiLiqVB   BH-Fail    LgBrch E5-DFld E5-DWet
           1.000
     1
    39   3575.00
     4        26        61        54        54                                 $Case 3: Vessel breach at HIGH pressure with a LARGE amount of material through
               1         1    (    1    +    2)                                $        a SMALL hole into a WET reactor cavity
          E4-HiP   HiLiqVB   E5-DFld   E5-DWet                                 $        -Expert Case 1-hC
           1.000
     1
    39   2780.00
     4        26        61        63        63                                 $Case 4: Vessel breach at HIGH pressure with a LARGE amount of material through
               1         1    (    2    +    3)                                $        a LARGE hole into a DRY reactor cavity
          E4-HiP   HiLiqVB   BH-Fail    LgBrch                                 $        -Expert Case 2-HC
           1.000
     1
    39   3080.00
     2        26        61                                                     $Case 5: Vessel breach at HIGH pressure with a LARGE amount of material through
               1         1                                                     $        a SMALL hole into a DRY reactor cavity
          E4-HiP   HiLiqVB                                                     $        -Expert Case 2-hC
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       1.000
 1
39   1720.00
 5        26        63        63        54     54                          $Case 6: Vessel breach at HIGH pressure with a SMALL amount of material through
           1    (    2    +   3)    (    1   +  2)                         $        a LARGE hole into a WET reactor cavity
      E4-HiP   BH-Fail    LgBrch   E5-DFld E5-DWet                         $        -Expert Case 1-Hc
       1.000
 1
39   3245.00
 3        26        54        54                                           $Case 7: Vessel breach at HIGH pressure with a SMALL amount of material through
           1    (    1    +   2)                                           $        a SMALL hole into a WET reactor cavity
      E4-HiP   E5-DFld   E5-DWet                                           $        -Expert Case 1-hc
       1.000
 1
39   2175.00
 3        26        63        63                                           $Case 8: Vessel breach at HIGH pressure with a SMALL amount of material through
           1    (    2    +   3)                                           $        a LARGE hole into a DRY reactor cavity
      E4-HiP   BH-Fail    LgBrch                                           $        -Expert Case 2-Hc
       1.000
 1
39   2850.00
 1        26                                                               $Case 9: Vessel breach at HIGH pressure with a SMALL amount of material through
           1                                                               $        a SMALL hole into a DRY reactor cavity
      E4-HiP                                                               $        -Expert Case 2-hc
       1.000
 1
39   1430.00
 7        36        36        63        63      54      54      61         $Case 10: Vessel breach at LOW pressure with a LARGE amount of debris through
        ( -6   *   -7)    (    2    +   3)     ( 1   +   2)      1         $        a LARGE hole into a WET cavity with a LARGE amount of zirconium oxidiz
     nZrOx10  nZrOx<10   BH-Fail    LgBrch E5-DFld E5-DWet HiLiqVB         $         -Expert Case 3 OHC
       1.000
 1
39   1120.00
 5        36        36        54        54     61                          $Case 11: Vessel breach at LOW pressure with a LARGE amount of debris through
        ( -6   *   -7)    (    1    +   2)       1                         $        a SMALL hole into a WET cavity with a LARGE amount of zirconium oxidiz
     nZrOx10  nZrOx<10   E5-DFld   E5-DWet HiLiqVB                         $         -Expert Case 3 OhC
       1.000
 1
39    744.00
 5        63        63        54        54     61                          $Case 12: Vessel breach at LOW pressure with a LARGE amount of debris through
     (     2    +   3)    (    1    +   2)       1                         $        a LARGE hole into a WET cavity with a SMALL amount of zirconium oxidiz
     BH-Fail    LgBrch   E5-DFld   E5-DWet HiLiqVB                         $         -Expert Case 3 oHC
       1.000
 1
39 !71,10,1,1
 3        54        54        61                                           $Case 13: Vessel breach at LOW pressure with a LARGE amount of debris through
     (     1    +   2)         1                                           $        a SMALL hole into a WET cavity with a SMALL amount of zirconium oxidiz
     E5-DFld   E5-DWet   HiLiqVB                                           $         -Expert Case 3 ohC
       1.000
 1
39    557.00
 6        36        36        63        63      54      54                 $Case 14: Vessel breach at LOW pressure with a SMALL amount of debris through
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            ( -6   *   -7)    (    2    +   3)     ( 1   +   2)               $        a LARGE hole into a WET cavity with a LARGE amount of zirconium oxidiz
         nZrOx10  nZrOx<10   BH-Fail    LgBrch E5-DFld E5-DWet                $         -Expert Case 3 OHc
           1.000
     1
    39   1000.00
     4        36        36        54        54                                $Case 15: Vessel breach at LOW pressure with a SMALL amount of debris through
            ( -6   *   -7)      (  1    +   2)                                $        a SMALL hole into a WET cavity with a LARGE amount of zirconium oxidiz
         nZrOx10  nZrOx<10   E5-DFld   E5-DWet                                $         -Expert Case 3 Ohc
           1.000
     1
    39    605.00
     4        63        63        54        54                                $Case 16: Vessel breach at LOW pressure with a SMALL amount of debris through
          (    2    +    3)     (   1    +   2)                               $        a LARGE hole into a WET cavity with a SMALL amount of zirconium oxidiz
         BH-Fail    LgBrch   E5-DFld   E5-DWet                                $         -Expert Case 3 oHc
           1.000
     1
    39 !71,15,1,1
     2        54        54                                                    $Case 17: Vessel breach at LOW pressure with a SMALL amount of debris through
          (    1    +   2)                                                    $        a SMALL hole into a WET cavity with a SMALL amount of zirconium oxidiz
         E5-DFld   E5-DWet                                                    $         -Expert Case 3 ohc
           1.000
     1
    39    435.00
       Otherwise                                                              $Case 18: Vessel breach at LOW pressure into DRY cavity - negligible pressure
           1.000
     1
    39    100.00
72 Is the impulse loading to the drywell at VB sufficient to cause failure?
     3    InDWFI   I-DWFI2   I-DWFI3                                          $ InDWFI : Drywell does NOT fail from impulse loading at vessel breach
     6         1         2         3                                          $ I-DWFI2 : Impulse loading results in drywell leakage (Level 2)
     2                                                                        $ I-DWFI3 : Impulse loading results in drywell rupture (Level 3)
     1        65
               1                                                              $Case 1: Detonation in the drywell at vessel breach
          I-DWDt
     3        36        34        35
        DW-DtILd    IMPDWF    IMRenD
       FUN-IDI1LD
        GETHRESH         2      2.00      1.00

       Otherwise                                                              $Case 2: No impulse loading in the drywell at vessel breach
     1        36
        DW-DtILd
             AND
        GETHRESH         2      0.00     -1.00
                           $ Dummy parameters force no leakage
73 Is drywell pressurization at VB sufficient to cause failure?               $ InDWOP   : No drywell failure
     5    InDWOP   I-DWOP2  I-DWHOP2   I-DWOP3 I-DWHOP3                       $ I-DWOP2  : Drywell failure is a leak at the DW wall (Level 2)
     5         1         2         3         4       5                        $ I-DWHOP2 : Drywell failure is a leak at the DW head (Level 2)
     3        13        26        31                                          $ I-DWOP3  : Drywell failure is a rupture at the DW wall (Level 3)
          DPDWVB     IPDWF    DWFRan                                          $ I-DWHOP3 : Drywell failure is a rupture at the DW head (Level 3)
       FUN-DWFAVB          $ Function returns dummy value depending on pressure for leak or rupture
        GETHRESH         4      4.00      3.00    2.00   -1.00
```

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                     $ NoFail       Leak Md. Leak  Rupt.
74 Does the RPV pedestal fail due to pressurization at vessel breach?
     2   I-PedFP   InPedFP                                              $ I-PedFP : Pedestal fails due to pressure at vessel breach
     5         1         2                                              $ InPedFP : NO pedestal failure at vessel breach from pressure loading
     1        39
       Ped-VBP
           AND
        THRESH           1   1300.00
                      Pressure required to fail pedestal or lift RPV
75 Does the RPV pedestal fail from an ex-vessel steam explosion (impulse loading)?
     2   I-PedFI   InPedFI                                              $ I-PedFI : Pedestal fails due to impulse loading at vessel breach
     2         1         2                                              $ InPedFI : NO pedestal failure at vessel breach from impulse loading
     3
     1        74                                                        $Case 1: Pedestal has already failed from a pedestal pressurization at VB
               1
       I-PedFP
         0.000     1.000
     1        67                                                        $Case 2: Ex-vessel steam explosion has occurred in the pedestal cavity
               1
          ExSE
         0.500     0.500
     Otherwise                                                          $Case 3: No ex-vessel steam explosion
         0.000     1.000
76 Does the RPV pedestal failure induce drywell failure?
     2  I-DWFPed  InDWFPed                                              $ I-DWFPed : Drywell failure induced by pedestal failure
     2         1         2                                              $ InDWFPed : Pedestal failure does NOT induce drywell failure
     3
     5        52        58        72        73      73                  $Case 1: Drywell is already failed
               3   +     1   +     3   +     4   +   5
        E5-SPB3     Alpha   I-DWFI3   I-DWOP3 I-DWHOP3
         0.000     1.000
     2        74        75                                              $Case 2: Pedestal failed from either pressurization or ExSE.  Some probability
               1   +     1                                              $        that pedestal failure will induce drywell failure
        I-PedFP   I-PedFI
         0.175     0.825
     Otherwise                                                          $Case 3: NO pedestal failure
         0.000     1.000
77 What is the pressure in the containment at VB prior to a hydrogen burn?
     1     CP-VB                                                        $ CP-VB : Containment pressure at vessel breach prior to H2 burn
     4         1                                                        $ Par 40: CP-VB - Containment pressure at VB prior to H2 burn
     8
     4        63        63        50        50
               1   +     5    +    3    +    4                          $Case 1: Vessel either failed by Alpha mode or did NOT fail at all
        A-Fail   nBreach    E5-CL3    E5-CL4
         1.000
     1
    40      0.00
     7        52        72        73        73      54      54      26  $Case 2: Vessel Breach occurs at HIGH pressure into a WET cavity and there
        (     3   +     3   +     4   +     5)  (  1   +   2)       1  $        is a LARGE suppression pool bypass
        E5-SPB3  DW-IFVB3   I-DWOP3  I-DWHOP3 E5-DFld E5-DWet  E4-HiP
         1.000
     1
```

```
    40     50.00
     5        52        72        73        73      26                        $Case 3: Vessel Breach occurs at HIGH pressure into a DRY cavity and there
         (     3   +     3   +     4   +     5)      1                        $        is a LARGE suppression pool bypass
         E5-SPB3  DW-IFVB3   I-DWOP3  I-DWHOP3  E4-HiP
           1.000
     1
    40     40.00
     6        52        72        73        73      54      54                $Case 4: Vessel Breach occurs at LOW pressure into a WET cavity and there
         (     3   +     3   +     4   +     5)  (   1   +   2)               $        is a LARGE suppression pool bypass
         E5-SPB3  DW-IFVB3   I-DWOP3  I-DWHOP3 E5-DFld E5-DWet
           1.000
     1
    40     35.00
     4        52        72        73        73                                $Case 5: Vessel Breach occurs at LOW pressure into a DRY cavity and there
         (     3   +     3   +     4   +     5)                               $        is a LARGE suppression pool bypass
         E5-SPB3  DW-IFVB3   I-DWOP3  I-DWHOP3                                $        Negligible containment pressurization
           1.000
     1
    40      5.00
     3        64        67        61                                          $Case 6: NO large suppression pool bypass with either a high pressure melt
             ( 1     +  1)       * 1                                          $        ejection (HPME) or ex-vessel steam explosion at vessel breach which
            HPME      ExSE   HiLiqVB                                          $        involves a LARGE fraction of the core.
           1.000
     1
    40     56.75
     2        64        67                                                    $Case 7: NO large suppression pool bypass with either a high pressure melt
             ( 1     +  1)                                                    $        ejection (HPME) or ex-vessel steam explosion at vessel breach which
            HPME      ExSE                                                    $        involves a SMALL fraction of the core.
           1.000
     1
    40 !77,6,1,1
       Otherwise                                                              $Case 8: Nothing energtic enoungh at VB to cause significant containment
           1.000                                                              $         pressurization
     1
    40      0.00
78 What is the concentration of hydrogen in containment immediately after VB?
     6   IHWW>20   IHWW>16   IHWW>12    IHWW>8  IHWW>4 I-NoHWW                $ IHWW>20 : H2 concentration in WW > 20%    IHWW>16 : 16% < H2 concen. < 20%
     6         1         2         3         4       5       6                $ IHWW>12 : 12% < H2 concen. < 16%          IHWW>8  : 8% < H2 concen. < 12%
     7                                                                        $ IHWW>4  : 4% < H2 concen. < 8%            I-NoHWW : H2 concen. in WW < 4%
     2        58        63
               1    +    5                                                    $Case 1: Either ALPHA mode failure has occurred or there was NO vessel breach
           ALPHA   nBreach
     8         1         3         6         4       7       9     10      44
           H2OWW      H2WW     H2ODW      H2DW    H2VB    O2WW   O2DW    N2WW
       FUN-IH2WWO
       GETHRESH          5      0.20      0.16    0.12    0.08   0.04

     6        64        65        66        67      50      50
             ( 1   +     1   +     1   +     1)  * ( 3   +   4)               $Case 1: Either high pressure melt ejection or drywell detonation or drywell
            HPME    I-DWDt    I-DWDf      ExSE  E5-CL3  E5-CL4                $        deflagration,  or ex-vessel steam explosion - H2 consumed
     8         1         3         6         4       7       9     10      44 $        and pool bypassed
           H2OWW      H2WW     H2ODW      H2DW    H2VB    O2WW   O2DW    N2WW
```

```
       FUN-IH2WW1
       GETHRESH          5      0.20      0.16    0.12    0.08    0.04

     4        64        65        66        67                                $Case 2: High pressure melt ejection or drywell detonation or drywell
            ( 1    +     1    +     1    +   1)                               $        deflagration with NO pool bypass - H2 consumed NO pool bypass
          HPME     I-DWDt    I-DWDf      ExSE
     8         1         3         6         4       7       9      10      44
         H2OWW      H2WW     H2ODW      H2DW    H2VB    O2WW    O2DW    N2WW
       FUN-IH2WW2
       GETHRESH          5      0.20      0.16    0.12    0.08    0.04

     6        28        28        54        54      50      50                $Case 3: Water in the drywell (either injection to RPV or reactor cavity
          (    2    +    3    +    1    +    2)  * ( 3  +   4)                 $        already has water) and drywell bypassed - drywell purged by steam
        E4-LPI    E4-HPI   E5-DFld   E5-DWet  E5-CL3  E5-CL4
     8         1         3         6         4       7       9      10      44
         H2OWW      H2WW     H2ODW      H2DW    H2VB    O2WW    O2DW    N2WW
       FUN-IH2WW3
       GETHRESH          5      0.20      0.16    0.12    0.08    0.04
                 Drywell purged by steam and pool bypassed
     4        28        28        54        54                                $Case 4: Drywell wet - drywell purged by steam and NO pool bypass
          (    2    +    3    +    1    +    2)
        E4-LPI    E4-HPI   E5-DFld   E5-DWet
     8         1         3         6         4       7       9      10      44
         H2OWW      H2WW     H2ODW      H2DW    H2VB    O2WW    O2DW    N2WW
       FUN-IH2WW4
       GETHRESH          5      0.20      0.16    0.12    0.08    0.04

     2        50        50                                                    $Case 5: Drywell dry and containment failed, drywell retains some H2
           ( 3    +     4)
        E5-CL3    E5-CL4
     8         1         3         6         4       7       9      10      44
         H2OWW      H2WW     H2ODW      H2DW    H2VB    O2WW    O2DW    N2WW
       FUN-IH2WW5
       GETHRESH          5      0.20      0.16    0.12    0.08    0.04

       Otherwise                                                              $Case 6: Drywell dry and containment intact, drywell retains some H2
     8         1         3         6         4       7       9      10      44
         H2OWW      H2WW     H2ODW      H2DW    H2VB    O2WW    O2DW    N2WW
       FUN-IH2WW6
       GETHRESH          5      0.20      0.16    0.12    0.08    0.04
                 Assume leakage back to drywell & vessel retention independent of scenario
79 Is ac power not recovered following vessel breach?
     2      IfAC      I-AC                                                    $ IfAC : ac power is not recovered following vessel breach
     2         1         2                                                    $ I-AC : ac power is recovered following vessel breach
     4
     1        24                                                              $Case 1: ac power was never lost or has already been recovered
               2
         E4-AC
         0.000     1.000
     1        25                                                              $Case 2: Failure of dc power precludes AC power recovery
               1
         E4fDC
```

```
           1.000     0.000
     2         2        15                                                      $Case 3: Long-term station blackout with a FAST pour
               1         2                                                      $         - none @ 17 hr.s given none @ 14.73 hr.s
              SB    CD-Slw
           0.670     0.330
       Otherwise -- Short-term blackout w/ no recovery before VB                $ Case 4: Fast core melt - FAST pour rate from vessel (per CCI 2 hr.s AVB)
           0.551     0.449                                                      $         - none @ 5.6 hr.s given none @ 3.35 hr.s
80 Is dc power available following vessel breach?
     2      !fDC      I-DC                                                      $ !fDC : dc power is NOT available following vessel breach
     2         1         2                                                      $ I-DC : dc power IS available following vessel breach
     4
     1        25                                                                $Case 1: dc power has already been lost
               1
           E4fDC
           1.000     0.000
     1        24                                                                $Case 2: ac power is available, thus dc power is available
               2
           E4-AC
           0.000     1.000
     2         2        15                                                      $Case 3: Long-term station blackout
               1         2
              SB    CD-Slw
           0.210     0.790
       Otherwise -- Short-term blackout w/ no recovery before VB                $ Case 4: Fast core melt
           0.010     0.990
81 What is the status of containment sprays following vessel breach?
     4      IfCS      IrCS      IaCS      I-CS                                  $ IfCS : Containment sprays are failed and cannot be recovered
     2         1         2         3         4                                  $ IrCS : Sprays are recoverable when ac power is restored
     8                                                                          $ IaCS : Sprays are available
     1        30                                                                $ I-CS : Containment sprays are operating
               1
          E1fCSS                                                                $Case 1: Containment sprays were previously failed
           1.000     0.000     0.000     0.000
     6        30        79        50        50      16      22                  $Case 2: Sprays were previously recoverable and ac power has NOT been restored
               2         1       ( 4       + 3 * (  -3  +  1))                  $         detonation in the wetwell or containment failure may have failed
          E1rCSS      !fAC    E5-CL4    E5-CL3   nE1L3 E3nVENT                  $         the sprays
           0.500     0.500     0.000     0.000
     2        30        79                                                      $Case 3: Sprays were previously recoverable and ac power has NOT been restored
               2         1                                                      $         thus, the sprays are still recoverable
          E1rCSS      !fAC
           0.000     1.000     0.000     0.000
     5        30        50        50        16      22                          $Case 4: Sprays were working before vessel breach - because of detonation
               4       ( 4       + 3   * (  -3  +  1))                          $         or containment failure sprays may not be operating now
           E4-CS    E5-CL4    E5-CL3     nE1L3 E3nVENT
       !81,2,1       0.000     0.000 !81,2,2
     1        30                                                                $Case 5: Sprays were working before vessel breach
               4
           E4-CS
           0.000     0.000     0.000     1.000
     5        79        50        50        16      22                          $Case 6: ac power is available - because of a detonation in the wetwell or
               2       ( 4       + 3   * (  -3  +  1))                          $         containment failure the sprays may not be operating - also, operators
            I-AC    E5-CL4    E5-CL3     nE1L3 E3nVENT                          $         may have failed to turn on sprays even with power available
```

```
           0.500     0.000     0.450     0.050
     1        79                                                               $Case 7: ac power is available
               2
            I-AC
           0.000     0.000 !30,4,3   !30,4,4
       Otherwise                                                               $Case 8: This case should not be used
           0.000     0.000     1.000     0.000
82 To what level is the wetwell inert after vessel breach?
     3    InWWIn   I-WWIn2   I-WWIn3                                           $ InWWIn : Wetwell is not inert
     5         1         2         3                                           $ I-WWIn2 : Wetwell inert to detonations
     4         1         3         9        44
           H2OWW      H2WW      O2WW      N2WW
       FUN-WWH201
        GETHRESH         3 !40,1,1   !40,1,2   !40,1,3

83 Is there sufficient oxygen in the containment to support combustion         $ O2Det20 : Enough oxygen to support a detonation with 20% H2
     5   O2Det20   O2Det16   O2Det12      WWO2   nWWO2                         $ O2Det16 : Enough oxygen to support a detonation with 16% H2
     5         1         2         3         4       5                         $ O2Det12 : Enough oxygen to support a detonation with 12% H2
     4         1         3         9        44
           H2OWW      H2WW      O2WW      N2WW
        FUN-WWO2
        GETHRESH         4       4.0       3.0     2.0     1.0

84 Does ignition occur in the containment at vessel breach?
     2    I-CIgn    InCIgn                                                     $ I-CIgn : Ignition occurs in the containment at vessel breach
     2         1         2                                                     $ InCIgn : Ignition does not occur in the containment
     8
     3        78        82        83                                           $Case 1: Containment is either steam inert or there is insufficient O2
               6   +     3   +     5
         I-NoHWW   I-WWIn3     nWWO2
           0.000     1.000
     5        24        52        52        72      73                         $Case 2: ac power is available or leak/rupture in the drywell
               2   +     2   +     3   +    -1  +   -1                         $        Pathway for ignition sources to pass from drywell into containment
            I-AC   E5-SPB2   E5-SPB3   DW-IFVB  I-DWOP
           1.000     0.000
     4        26        67        78        78                                 $Case 3: RPV at HIGH pressure before VB or steam explosion and containment
         (     1   +     1)  (     1   +     2)                                $        H2 concentration > 16%
          E4-HiP      ExSE   IHWW>20   IHWW>16
           0.600     0.400
     3        26        67        78                                           $Case 4: RPV at HIGH pressure before VB or steam explosion and containment
         (     1   +     1)         3                                          $        H2 concentration range:  16% > H2 > 12%
          E4-HiP      ExSE   IHWW>12
           0.550     0.450
     3        26        67        78                                           $Case 5: RPV at HIGH pressure before VB or steam explosion and containment
         (     1   +     1)         4                                          $        H2 concentration range:  12% > H2 > 8%
          E4-HiP      ExSE    IHWW>8
           0.450     0.550
     3        26        67        78                                           $Case 6: RPV at HIGH pressure before VB or steam explosion and containment
         (     1   +     1)         5                                          $        H2 concentration range:  8% > H2 > 4%
          E4-HiP      ExSE    IHWW>4
           0.300     0.700
     3        26        67        78                                           $Case 7: RPV at HIGH pressure before VB or steam explosion and containment
```

```
         (     1    +    1)        6                                            $       H2 concentration range:  H2 < 4%
          E4-HiP      ExSE   I-NoHWW
           0.005     0.995
       Otherwise                                                                $Case 8 : Nothing energetic in drywell
           0.010     0.990
85 Does ignition occur in the containment following vessel breach?
     2    IgnFVB   nIgnFVB                                                      $ IgnFVB : Ignition occurs in the containment following vessel breach
     2         1         2                                                      $ nIgnFB : Ignition does not occur in the containment or it occurred at VB
     6
     5        78        82        81        83      84                          $Case 1: Containment is either steam inert or there is insufficient O2 or
               6      +  3    *  -4    +     5    +  1                          $        H2 or ignition has already occurred at vessel breach
         I-NoHWW   I-WWIr3     nI-CS     nWWO2  I-CIgn
           0.000     1.000
     1        79                                                                $Case 2: ac power is recovered following vessel breach
               2
            I-AC
           1.000     0.000
     2        78        76                                                      $Case 3: Combustible concentration > 16% - NO ac power
               1      +  2
         IHWW>20   IHWW>16
        !43,12,1  !43,12,2
     1        78                                                                $Case 4: Combustible concentration in range 16% > LGWW > 12% - NO ac power
               3
         IHWW>12
        !43,10,1  !43,10,2
     1        78                                                                $Case 5: Combustible concentration in range 12% > LGWW > 8% - NO ac power
               4
          IHWW>8
        !43,8,1   !43,8,2
        Otherwise                                                               $Case 6: Combustible concentration in range 8% > LGWW > 4% - NO ac power
        !43,6,1   !43,6,2
86 Is there a detonation in the wetwell following vessel breach?
     2    I-WWDt    InWWDt                                                      $ I-WWDt : Detonation in wetwell following vessel breach
     4         1         2                                                      $ InWWDt : NO detonation in wetwell following vessel breach
    10
     8        84         85        82        82      81      78      78      78 $Case 1. NO ignition or Containment inert or H2 in containment < 12%
                2      *   2   +  (  3     +  2)   *  -4    +  4    +  5    +  6
           InCIgn   nIgnFVB    I-WIn3   I-WWIn2  nI-CS  IHWW>8  IHWW>4  INoHWW
            0.000     1.000
     1
    20       0.00      0.00
     5         24        27        83        83      83                         $Case 2: HIS is on during VB and there is enough oxygen to support
                2     *   1   *  (  3     +   2    + 1)                         $        a detonation
            E4-AC    E4-HIS   O2Det'2   O2Det16 O2Det20
             0.01      0.99
     1
    20  !44,5,1,1      0.00
     8         52        72        73        73      39      39      39      43 $Case 3: Suppression pool bypass during VB and enough O2 to support
            (  -1    +   -1     +  -1    *  -3) *  ( -1   *  -2   *  -3   +  1) $        a detonation
           E5-SPB    I-DWFI    I-DWOP   InDWOP2 nH2WW20 nH2WW16 nH2WW12 E4-WWDf
             0.01      0.99
     1
```

```
    20 !44,5,1,1      0.00
     6         78        82        82         83       83       83             $Case 4: 12% < H2 < 16% and containment initially inert to detonations,
                3    * (   2    +    3)    * (  3     + 2    + 1)               $        however, sprays are on which reduces steam concentration and forms
          !HWW>12   I-WWIn2   I-WWIn3   O2Det12 O2Det16 O2Det20                 $        a detonable mixture in containment (High steam)
       !44,2,1   !44,2.2
     1
    20 !44,2,1,1      0.00
     4         78        83        83         83                                $Case 5: 12% > Containment H2 > 8% and Low steam
                3    *  ( 3       +  2     +  1)                                $        Low steam DDT
          IHWW>12   O2Det12   O2Det16   O2Det20
       !44,3,1   !44,3,2
     1
    20 !44,3,1,1      0.00
     5         78        82        82         83       83                       $Case 6: 16% < H2 < 20% and containment initially inert to detonations,
                2  *  (   2    +    3)    *  (  2  +   1)                       $        however, sprays are on which reduces steam concentration and forms
          IHWW>16   I-WWIn2   I-WWIn3   O2Det16 O2Det20                         $        a detonable mixture in containment (High steam)
       !44,4,1   !44,4,2
     1
    20 !44,4,1,1      0.00
     3         78        83        83                                           $Case 7: 20% > Containment H2 > 16% and Low steam
                2      (  2    +    1)                                          $       Low steam DDT
          IHWW>16   O2Det16   O2Det20
       !44,5,1   !44,5,2
     1
    20 !44,5,1,1      0.00
     4         78        82        82         83                                $Case 8: H2 > 20% and containment initially inert to detonations,
                1  *  (   2    +    3)      *  1                                $        however, sprays are on which reduces steam concentration and forms
          IHWW>20   I-WWIn2   I-WWIn3   O2Det20                                 $        a detonable mixture in containment (High steam)
       !44,6,1   !44,6,2
     1
    20 !44,6,1,1      0.00
     2         78        83                                                     $Case 9: Containment H2 > 20% and Low steam
                1         1                                                     $       Low steam DDT
          IHWW>20   O2Det20
       !44,7,1   !44,7,2
     1
    20 !44,7,1,1      0.00
       Otherwise                                                                $Case 10: No enough oxygen to support a detontion
           0 000     1.000
     1
    20      0.00      0.00
87 What is the level of containment impulse load following vessel breach?
     7   I-Ip>60   I-Ip>50   I-Ip>40   I-Ip>30 I-Ip>20 I-Ip>10 I-Ip<10          $ I-Ip>60 : Impulse > 60 KPa-S          I-Ip>50 : 60 > Impulse > 50 KPa-S
     5         1         2         3         4       5       6       7          $ I-Ip>40 : 50 > Impulse > 40 KPa-S     I-Ip>30 : 40 > Impulse > 30 KPa-S
     1        20                                                                $ I-Ip>20 : 30 > Impulse > 20 KPa-s     I-Ip>10 : 20 > Impulse > 10 KPa-S
         ImpLoad                                                                $ I-Ip<10 : Impulse < 10 KPa-S
             AND
        GETHRESH          6     60.00     50.00   40.00   30.00   20.00   10.00
                                  $ Parse containment impulse load for verification
88 With what efficiency is hydrogen burned following VB?                        $ H2Ef@VB : Efficiency at which H2 is burned following VB
     1   H2Ef@VB
     4         1
```

```
 9
 7        84        85        82        82      81       78      78        $Case 1: Wetwell steam > 45% (High Steam) and H2 ignited in Range H2 < 8%
       (   1   +    1)    * (  2     +   3   *  4) *   ( 5  +     6)
     I-CIgn     IgnFVB   I-WWIn2   I-WWIn3    I-CS  IHWW>4 I-NoHWW
       1.000
 2
18 !46,4,1,1                     $ Peak pressure from hydrogen combustion
19 !46,4,2,1                     $ Combustion efficiency
 4        84        85        78        78                                 Case 2: Wetwell steam < 45% (low steam) and H2 ignited in range H2 < 8%
       (   1   +    1)    (    5     +    6)
     I-CIgn     IgnFVB    IHWW>4   I-NoHWW
       1.000
 2
18 !46,5,1,1                     $ Peak pressure from hydrogen combustion
19 !46,5,2,1                     $ Combustion efficiency
 6        84        85        82        82      81       78                $Case 3: Wetwell steam > 45% (High Steam) and H2 ignited in Range 12% > H2 > 8%
       (   1   +    1)    * (  2     +   3   *  4)    *   4
     I-CIgn     IgnFVB   I-WWIn2   I-WVIn3    I-CS  IHWW>8
       1.000
 2
18 !46,6,1,1
19 !46,6,2,1
 3        84        85        78                                           $Case 4: Wetwell steam < 45% (Low Steam) and H2 ignited in Range 12% > H2 > 8%
       (   1   +    1)         4
     I-CIgn     IgnFVB    IHWW>8
       1.000
 2
18 !46,7,1,1
19 !46,7,2,1
 6        84        85        82        82      81       78                $Case 5: Wetwell steam > 45% (High Steam) and H2 ignited in Range 16% > H2 > 12
       (   1   +    1)    * (  2     +   3   *  4)    *   3
     I-CIgn     IgnFVB   I-WWIn2   I-WWIn3    I-CS IHWW>12
       1.000
 2
18 !46,8,1,1
19 !46,8,2,1
 3        84        85        78                                           $Case 6: Wetwell steam < 45% (Low Steam) and H2 ignited in Range 16% > H2 > 12%
       (   1   +    1)         3
     I-CIgn     IgnFVB   IHWW>12
       1.000
 2
18 !46,9,1,1
19 !46,9,2,1
 7        84        85        82        82      81       78      78        $Case 7: Wetwell steam > 45% (High Steam) and H2 ignited in Range H2 > 16%
       (   1   +    1)    * (  2     +   3      4)   * (  1   +  2)
     I-CIgn     IgnFVB   I-WWIn2   I-WWIn3    I-CS IHWW>20 IHWW>16
       1.000
 2
18 !46,10,1,1
19 !46,10,2,1
 4        84        85        78        78                                 $Case 8: Wetwell steam < 45% (Low Steam) and H2 ignited in Range H2 > 16%
       (   1   +    1)    (    1     +    2)
```

```
      I-CIgn    IgnFVB   !HWW>20   !HWW>16
       1.000
   2
  18 !46,11,1,1
  19 !46,11,2,1
    Otherwise                                                                $Case 9: No burn following vessel breach
       1.000
   2
  18      0.00
  19      0.00
89 What would be the peak pressure in containment from a hydrogen burn at VB?
   6  I-PBrn>7  I-PBrn>6  I-PBrn>5  I-PBrn>4 I-PBrn>3 I-PBrn<3              $ I-PBrn>3 : 4 > Peak Press > 3 bar    I-PBrn<3 : Peak Press < 3 bar
   6         1         2         3         4       5       6
   4
   2        84        85                                                     $Case 1: No hydrogen ignition, thus, no pressure rise
             2     *   2
      InCIgn   nIgnFVB
   8         3         1         9         5      11      18      19      44
          H2WW     H2OWW      O2WW    EPBase    PBrn H2EfVB1 H2EfVB2    N2WW
    FUN-IPBRN1
     GETHRESH          5     709.3     608.0   506.6   405.3   304.0
                Parse peak pressure for verification
   3        50        50        58                                           $Case 2: Containment already failed, negligible pressure rise
           ( 3     +   4     +   1)
        E5-CL3    E5-CL4     Alpha
   8         3         1         9         5      11      18      19      44
          H2WW     H2OWW      O2WW    EPBase    PBrn H2EfVB1 H2EfVB2    N2WW
    FUN-IPBRN2
     GETHRESH          5     709.3     608.0   506.6   405.3   304.0
                Parse peak pressure for verification
   1        86                                                               $Case 3: Detonation in the Containment
             1
        I-WWDt
   8         3         1         9         5      11      18      19      44
          H2WW     H2OWW      O2WW    EPBase    PBrn H2EfVB1 H2EfVB2    N2WW
    FUN-IPBRN3
     GETHRESH          5     709.3     608.0   506.6   405.3   304.0
                Parse peak pressure for verification
    Otherwise                                                                $Case 4: Hydrogen burn at or following vessel breach
   8         3         1         9         5      11      18      19      44
          H2WW     H2OWW      O2WW    EPBase    PBrn H2EfVB1 H2EfVB2    N2WW
    FUN-IPBRN4
     GETHRESH          5     709.3     608.0   506.6   405.3   304.0
                Parse peak pressure for verification
90 What is the level of containment pressurization at vessel breach?
   6    I-CP>7    I-CP>6    I-CP>5    I-CP>4  I-CP>3  I-CP>2                 $ I-CP>7 : Peak Press > 7 bar        I-CP>6 : 7 > Peak Press > 6 bar
   6         1         2         3         4       5       6                 $ I-CP>5 : 6 > Peak Press > 5 bar    I-CP>4 : 5 > Peak Press > 4 bar
   4                                                                         $ I-CP>3 : 4 > Peak Press > 3 bar    I-CP<3 : Peak Press < 3 bar
   3        50        50        58
             3     +   4     +   1                                           $Case 1: Large containment leak or Alpha mode failure
        E5-CL3    E5-CL4     Alpha                                           $        Containment already failed -- assign negligible pressurization
   3         5        11        41
```

```
        EPBase     PBrn  CP-VBTot
      FUN-CPCLOW
       GETHRESH        5     709.3     608.0   506.6   405.3   304.0

    1        84                                                        $Case 2:  H2 is ignited in the containment at vessel breach
              1                                                        $         Combine pressure increments from loads at VB with H2 burn
        I-CIgn
    4         5       11        40        41
        EPBase     PBrn     CP-VB  CP-VBTot
       FUN-CPC1
       GETHRESH        5     709.3     608.0   506.6   405.3   304.0

    1        85                                                        $Case 3: H2 is burned in containment following vessel breach
              1                                                        $         - Base pressure is lowered from value used for ignition at VB
         IgnFVB
    4         5       11        40        41
        EPBase     P3rn     CP-VB  CP-VBTot
       FUN-CPC2
       GETHRESH        5     709.3     608.0   506.6   405.3   304.0

      Otherwise                                                        $Case 4: No  H2 burn
    4         5       11        40        41
        EPBase     PBrn     CP-VB  CP-VBTot
       FUN-CPC3
       GETHRESH        5     709.3     608.0   506.6   405.3   304.0
                $ Parse containment pressure
91 What is the level of drywell leakage induced by a detonation in containment at VB?
    3    InDWDt   I-DWDt2   I-DWDt3                                    $ InDWDt : No drywell failure induced by detonation
    6         1         2         3                                    $ I-DWDt2 : Drywell leakage induced by detonation (Level 2)
    2                                                                  $ I-DWDt3 : Drywell rupture induced by detonation (Level 3)
    1        86
              1                                                        $Case 1: Detonation in wetwell following vessel breach
         I-WWDt
    3        20       34        35
       ImpLoad   IMPDWF    IMRanD
        FUN-EDI
       GETHRESH        2      2.00      1.00
                $ Dummy parameter values used to trigger particular branch
      Otherwise -- No detonation and thus no failure                   $Case 2: NO detonation in wetwell following vessel breach - NO failure
    3        20       34        35
       ImpLoad   IMPDWF    IMRanD
            MAX
       GETHRESH        2      0.00     -1.00
                $  Parameter values force Branch 1
92 What is the level of containment leakage induced by a detonation at VB?
    3     InDtF    I-DtF2    I-DtF3                                    $ InDtF : No Containment failure induced by detonation
    6         1         2         3                                    $ I-DtF2 : Containment leakage induced by detonation (Level 2)
    3                                                                  $ I-DtF3 : Containment rupture induced by detonation (Level 3)
    2        91        91
              2   +     3                                              $Case 1: Detonation failed the drywell (Either Level 2 or 3)
       I-DWDt2   I-DWDt3                                               $         This case allows coupling between drywell and containment response
    5        20        24        25        34        35
```

```
      ImpLoad     IMPCF     IMRanC     IMPDWF  IMRanD
     FUN-ECI1
     GETHRESH         2       2.00       1.00

   1       86                                                 $Case 2: Detonation in containment - No drywell failure from detonation
            1
       I-WWDt
   3       20        24         25
      ImpLoad     IMPCF     IMRanC
     FUN-ECI2
     GETHRESH         2       2.00       1.00

    Otherwise                                                 $Case 3: No detonation in containment - No failure
   3       20        24          .
      ImpLoad     IMPCF     IMRanC
          MAX
     GETHRESH         2       0.00      -1.00
              $  Parameter values force Branch 1
93 What is the level of containment leakage following vessel breach?    $ InCL  : No containment failure
   4     InCL     I-CL2      I-CL3      I-CL4                 $ I-CL2 : Containment failure is a leak (Level 2)
   6        1         2          3          4                 $ I-CL3 : Containment failed by rupture (Level 3)
   4                                                          $ I-CL4 : Containment failed by catastrophic rupture (Level 4)
   2       50        58
            4    +    1                                       $Case 1: Containment already failed by catastrophic ruptured or Alpha mode
       E5-CL4     Alpha
   1        5
       EPBase
          AND
     GETHRESH         3    9999.00    9999.00 9999.00
                           Dummy -- Already ruptured
   2       50        92                                       $Case 2: Containment already ruptured or ruptured from a detonation following VB
            3    +    3
       E5-CL3    I-DtF3
   1        5
       EPBase
          AND
     GETHRESH         3    9999.00    9999.00    1.00
                           Dummy -- Already failed by detonation
   2       50        92                                       $Case 3: Containment already leaking or leaking from a detonation following VB
            2    +    2
       E5-CL2    I-DtF2
   4        5        41         21         22
       EPBase  CP-VBTot     PCFail      CFRan
    FUN-ECBrn2
     GETHRESH         3    9999.00       2.00    1.00
                           Dummy -- Already leaking from detonation
    Otherwise                                                 $Case 4: Containment intact before containment burn
   4        5        41         21         22
       EPBase  CP-VBTot     PCFail      CFRan
    FUN-ECBrn2
     GETHRESH         3       3.00       2.00    1.00
                           Parameter value triggers particular branch
```

```
94 What is the level of drywell leakage induced by containment pressurization?
   5    InDWDf   I-DWDf2  I-DWHDf2   I-DWDf3 I-DWHDf3                            $ InDWDf   : No drywell failure
   6         1         2         3         4        5                            $ I-DWDf2  : Drywell failure is a leak at the DW wall (Level 2)
  10                                                                             $ I-DWHDf2 : Drywell failure is a leak at the DW head (Level 2)
   5        51        72        73        76       91                            $ I-DWDf3  : Drywell failure is a rupture at the DW wall (Level 3)
             4   +     3   +     4     +  1  +    3                              $ I-DWHDf3 : Drywell failure is a rupture at the DW head (Level 3)
       E-DWDf3   I-DWFI3   I-DWOP3 I-DWFPed I-DWDt3
   1         5                                                                   $Case 1: Drywell already ruptured
        EPBase                                                                   $        Drywell already failed at wall -- prevent head failure
           AND
      GETHRESH         4   9999.00   9999.00 9999.00     0.00

   1        51                                                                   $Case 2: Drywell head already ruptured
             5
      E-DWHDf3
   1         5
        EPBase
           AND
      GETHRESH         4   9999.00   9999.00 9999.00  9999.00

   7        85        51        72        73       91       93       93          $Case 3: Drywell wall already leaking, containment is ruptured
             1    * (  2   +     2   +     2   +  2)    (    3  +    4)          $        - Prior wall failure precludes head failure
        IgnFVB   E-DWDf2   I-DWFI2   I-DWOP2 I-DWDt2     I-CL3    I-CL4          $        - Containment ruptured so burn pressure could be mitigated
   5         5        41        30        31       40
        EPBase  CP-VBTot     EPDWF    DWFRan    CP-VB
    FUN-IDBrn1
      GETHRESH         4   9999.00      3.00     2.00    -1.00

   5        85        51        72        73       91                            $Case 4: Drywell wall already leaking - NO containment rupture
             1   *  (  2   +     2   +     2  +     2)                           $        - Prior wall failure precludes head failure
        IgnFVB   E-DWDf2   I-DWFI2   I-DWOP2 I-DWDt2
   5         5        41        30        31       40
        EPBase  CP-VBTot     EPDWF    DWFRan    CP-VB
    FUN-IDBrn2
      GETHRESH         4   9999.00      3.00     2.00    -1.00

   4        85        51        93        93                                     $Case 5: Prior drywell head leakage and containment rupture
             1       * 3   *  ( 3    +    4)                                     $        - Prior head leakage precludes no failure
        IgnFVB  E-DWHDf2     I-CL3     I-CL4                                     $        - Containment ruptured so burn pressure could be mitigated
   5         5        41        30        31       40
        EPBase  CP-VBTot     EPDWF    DWFRan    CP-VB
    FUN-IDBrn3
      GETHRESH         4   9999.00      3.00     2.00    -1.00

   2        85        51                                                         $Case 6: Prior drywell head leakage and NO containment rupture
             1     *   3                                                         $        - Prior head leakage precludes no failure
        IgnFVB  E-DWHDf2
   5         5        41        30        31       40
        EPBase  CP-VBTot     EPDWF    DWFRan    CP-VB
    FUN-IDBrn4
      GETHRESH         4   9999.00      3.00     2.00    -1.00
                   $ Dummy parameters select failure mode
```

```
     1        85                                                              $Case 7: Burn with no prior ruptures
               1
          IgnFVB
     5         5        41        30        31      40
          EPBase  CP-VBTot     EPDWF    DWFRan   CP-VB
       FUN-IDBrn5
        GETHRESH         4      4.00      3.00    2.00   -1.00
                 $ Dummy parameters select failure mode
     4        51        72        73        91                                $Case 8: No burn - Pre-existing Level 2 leakage in drywell wall
            (  2    +    2    +    2    +   2)
         E-DWDf2   I-DWFI2   I-DWOP2   I-DWDt2
     1         5
          EPBase
             AND
        GETHRESH         4   9999.00      0.00   -1.00   -1.00
                 $ Dummy parameters select failure mode
     1        51                                                              $Case 9: No burn - Pre-existing Level 2 leakage in drywell head
               3
        E-DWHDf2
     1         5
          EPBase
             AND
        GETHRESH         4   9999.00   9999.00    0.00   -1.00
                 $ Dummy parameters select failure mode
       Otherwise                                                              $Case 10: No Burn - No drywell failure
     1         5
          EPBase
             AND
        GETHRESH         4      0.00     -1.00   -1.00   -1.00
                 $ Dummy parameters select failure mode
95 What is the level of suppression pool bypass following VB?
     3     InSPB    I-SPB2    I-SPB3                                          $ InSPB : No suppression pool bypass
     2         1         2         3                                          $ I-SPB2 : Suppression pool bypass level 2 (Leak)
     5                                                                        $ I-SPB3 : Suppression pool bypass level 3 (Rupture)
     4        52        94        94        58
               3    +    4    +    5    +    1
         E5-SPB3   I-DWDf3  I-DWHDf3     Alpha                                $Case 1: Drywell rupture from combustion or pre-existing rupture
           0.000     0.000     1.000
     6        52        94        94        79      84      85                $Case 2: Pre-existing drywell leak and ac power is available and H2 combustion
          (    2    +    2    +    3)        2   (   1   +  1)                $        in containment - pre-existing leak exacerbated by vacuum breaker fail
         E5-SPB2   I-DWDf2  I-DWHDf2      I-AC  I-CIgn  IgnFVB
           0.000 !52,2,2   !52,2,3
     3        52        94        94                                          $Case 3: Pre-existing drywell leak - nothing has happened to change it
               2    +    2    +    3
         E5-SPB2   I-DWDf2  I-DWHDf2
           0.000     1.000     0.000
     3        79        84        85                                          $Case 4: ac power is available and H2 combustion in containment
               2    (    1    +    1)                                         $        - vacuum breaker fails from H2 burn
            I-AC    I-CIgn    IgnFVB
      !52,2,2        0.000 !52,2,3
       Otherwise                                                              $Case 5: No burns in containment & no additional bypass
           1.000     0.000     0.000
```

```
96 What is the containment pressure after vessel breach?
     4      IP>4      IP>3      IP>2      IP>1                                 $ ESP>3 : Containment pressure before vessel breach > 3 bar
     6         1         2         3         4                                 $ ESP>2 : 3 > containment pressure > 2 bar
     3                                                                         $ ESP>1 : 2 bar > containment pressure
     1        93
              -1                                                               $Case 1: Containment has failed
            I-CL                                                               $        Pressure set to atmospheric
     8         1         9        44         3       6      10       4       5
           H2OWW      O2WW      N2WW      H2WW   H2ODW    O2DW    H2DW  EPBASE
       FUN-LBASP1
        GETHRESH         3     405.3     304.0   202.6

     1        81                                                               $Case 2: NO Containment failure with containment sprays
               4                                                               $        - Base Pressure changed to account for the change in total number
            I-CS                                                               $          of moles
     8         1         9        44         3       6      10       4       5
           H2OWW      O2WW      N2WW      H2WW   H2ODW    O2DW    H2DW  EPBASE
       FUN-LBASP2
        GETHRESH         3     405.3     304.0   202.6

       Otherwise                                                               $Case 3: No containment failure and NO CS - Base pressure adjusted to account
     8         1         9        44         3       6      10       4       5 $        for change in total number of moles
           H2OWW      O2WW      N2WW      H2WW   H2ODW    O2DW    H2DW  EPBASE
       FUN-LBASP3
        GETHRESH         3     405.3     304.0   202.6

97 Is water not supplied to the debris late?                                   $ nLDBWat : Water NOT supplied to debris late
     3   nLDBWat  S-LDBWat  L-LDBWat                                           $ L-LDBWat : LARGE amount of water IS supplied to debris late
     2         1         2         3                                           $ S-LDBWat : SMALL amount of water (CRD flow) IS supplied to debris late
     6
     1        63                                                               $Case 1: NO vessel breach - Only way is to have large injection source into RPV
               5
         nBreach
           0.000     0.000     1.000
     2        79        12                                                     $Case 2: ac power is NOT available, however, Fire Protection system is availabl
               1         3
            IfAC    E1aFPS
           0.500     0.250     0.250
     1        79                                                               $Case 3: NO ac power and all remaining injection sources require ac power
               1
            IfAC
           1.000     0.000     0.000
     2        28        28                                                     $Case 4: Either high or low pressure injection was being supplied to RPV
          (    2      + 3)                                                     $        before vessel breach
          E4-LPI    E4-HPI
           0.333     0.333     0.334
     5         5         7         8         9      11                         $Case 5: ac power is available and at least one injection system has not failed
          (    2      + -1    +   -1     +  -1   + -1)
        E1rHPInj   nE1fCRD   nE1fCon   nE1fLPC nE1fSSW
           0.333     0.333     0.334
       Otherwise                                                               $Case 6: All injection systems have failed
           1.000     0.000     0.000
```

```
98 Is there water in the reactor cavity after VB?
     3    LDWFld    LRCWet    LRCDry
     2         1         2         3
     7
     2        54        94
               1    +    5
      E5-DFld  I-DWHDf3
        1.000     0.000     0.000
     7        54        64        67        65        66        95        79
               2    (    1    +    1    +    1    +    1)       -3         1
      E5-DWet      HPME      ExSE    I-DWDt    I-DWDf   nI-SPB3      LfAC
        1.000     0.000     0.000
     3        84        85        95
          (    1    +    1)       -3
       I-CIgn    IgnFVB   nI-SPB3
        1.000     0.000     0.000
     3        84        85        95
          (    1    +    1)        3
       I-CIgn    IgnFVB    I-SPB3
        0.900     0.100     0.000
     6        64        67        65        66        95        79
          (    1    +    1    +    1    +    1)       -3         1
         HPME      ExSE    I-DWDt    I-DWDf   nI-SPB3      LfAC
        0.900     0.100     0.000
     1        54
               2
      E5-DWet
        0.000     1.000     0.000
   Otherwise
        0.000     0.000     1.000
99 What is the nature of the core-concrete interaction?
     5       CCI    WetCCI    FldCCI    DlyCCI     noCCI
     2         1         2         3         4         5
    11
     1        63
               5
      nBreach
        0.000     0.000     0.000     0.000     1.000
     2        97        98
               1    *    3
      nLDBWat    LRCDry
        1.000     0.000     0.000     0.000     0.000
     5        98        26        28         9        24
               3    *    1    *  ( -1    +   -1    *    2)
       LRCDry    E4-HiP    E4-LPI   nE1fLPC     E4-AC
        0.000     0.000     0.200     0.000     0.800
     3        98        26        28
               3    *    2    *   -1
       LRCDry    E4-LoP    E4-LPI
        0.000     0.000     0.840     0.000     0.160
     1        98
               3
```

```
$ LDWFld : Reactor cavity flooded after vessel breach
$ LRCWet : Reactor cavity wet after vessel breach
$ LRCDry : Reactor cavity dry after vessel breach

$Case 1: Reactor cavity was previously flooded or rupture in drywell head
$       - Rupture in drywell head will drain part of shield pool into drywell

$Case 2: Drywell is already wet and NO large suppression pool bypass and NO ac
$        power and at VB either high pressure melt ejection or steam explosion
$        or H2 combustion in drywell - steam in drywell condenses and sucks
$        water back into drywell

$Case 3: H2 combustion in containment following VB and NO large suppression
$        pool bypass

$Case 4: H2 combustion in containment following VB and LARGE suppression
$        pool bypass


$Case 5: Drywell is DRY and NO large suppression pool bypass and NO ac
$        power and at VB either high pressure melt ejection or steam explosion
$        or H2 combustion in drywell - steam in drywell condenses and sucks
$        water back into drywell - Not as much steam, thus, less likely flooded

$Case 6: Reactor cavity is already wet and nothing has happened to change this


$Case 7: Reactor cavity is dry and nothing has happened to change this

$ CCI : Core-Concrete interaction begin following vessel breach in a dry cavity
$ WetCCI : CCI begins following vessel breach in a wet cavity
$ DlyCCI : CCI is delayed - Does NOT begin immediately after vessel breach
$ noCCI : NO core-concrete interactions

$Case 1: No vessel breach, thus, NO CCI.


$Case 2: Cavity is dry and there is no injection into the cavity



$Case 3: Debris is released into a dry cavity coincident with water from
$        an injection source (RPV at HIGH Pressure at VB)


$Case 4: Debris is released into a dry cavity coincident with water from
$        an injection source (RPV at LOW Pressure at VB)


$Case 5: Debris is released into a dry cavity, water from an injection source
$        is added to the cavity after debris has enter the cavity
```

```
           LRCDry
            0.500     0.000     0.500     0.000   0.000
      4        98        98        97        26                                  $Case 6: Cavity is wet and there is a replenishable source of warer or the
              ( 1   +     2    *  -1)     *   1                                  $        the cavity is flooded.  The RPV is at HIGH pressure at VB
           LDWFld    LRCWet    LDBWat    E4-HiP
            0.000     0.000     0.200     0.000   0.800
      4        98        98        97        61                                  $Case 7: Cavity is wet and there is a replenishable source of water or the
              ( 1   +     2    *  -1)     *   1                                  $        the cavity is flooded.  The RPV is at LOW pressure at VB and the
           LDWFld    LRCWet    LDBWat   HiLiqVB                                  $        debris has a LARGE amount of superheat
            0.000     0.000     0.840     0.000   0.160
      3        98        98        97                                            $Case 8: Cavity is wet and there is a replenishable source of water or the
              ( 1   +     2    *  -1)                                            $        the cavity is flooded.  The RPV is at LOW pressure at VB and the
           LDWFld    LRCWet    LDBWat                                            $        debris has a SMALL amount of superheat
            0.000     0.000     0.600     0.000   0.400
      1        26                                                                $Case 9: RPV cavity is WET with NO replenishable source of water and the
                1                                                                $        RPV was at HIGH pressure at VB
           E4-HiP
            0.000     0.200     0.000     0.800   0.000
      1        61                                                                $Case 10: RPV cavity is WET with NO replenishable source of water and the
                1                                                                $        RPV was at LOW pressure at VB and debis has a LARGE amount of
          HiLiqVB                                                                $        superheat
            0.000     0.840     0.000     0.160   0.000
        Otherwise                                                                $Case 11: RPV cavity is WET with NO replenishable source of water. RPV pressure
            0.000     0.600     0.000     0.400   0.000                          $        LOW pressure at VB and debis has a SMALL amount of superheat
100 What fraction of core not participating in HPME participates in CCI?        $HiFCCI : HIGH fraction of core participates in CCI
      2    HiFCCI    LoFCCI                                                      $LoFCCI : LOW fraction of core participates in CCI
      4         1         2                                                      $Par 45 - FCCI : Frac. of core not participating in HPME which participates in
      4
      2        63        63                                                      $Case 1: Either Alpha Mode failure or NO vessel breach
                1   +     5
           A-Fail   nBreach
            0.000     1.000
      1
     45     0.000     0.000
      2        67        61                                                      $Case 2: Ex-vessel steam explosinn with a LARGE amount of core debris mobile
                1         1                                                      $        at vessel breach
             ExSE   HiLiqVB
            0.000     1.000
      1
     45     0.900     0.600
      2        67        61                                                      $Case 3: Ex-vessel steam explosion with a SMALL amount of core debris mobile
                1         2                                                      $        at vessel breach
             ExSE   LoLiqVB
            1.000     0.000
      1
     45     0.900     0.600
        Otherwise                                                                $Case 4: NO ex-vessel steam explosion, thus, all material not participating in
            1.000     0.000                                                      $        HPME particapates in CCI.
      1
     45     1.000     0.000
101 How much H2 (& equivalent CO) and CO2 are produced during CCI?
      4    H2CCI4    H2CCI3    H2CCI2    H2CCI1                                  $H2CCI  : H2 (eq. CO) produced during CCI
```

```
      6         1         2         3         4                                 $Par 16 : LH2CC - Kg-moles H2 & equivalent CO produced during CCI
      3                                                                         $         - parameter initialized in FUN-CCI#
      3        63        63        99                                           $Par 42 : LCO2 - Kg-moles CO2 produced during CCI
                1       + 5       + 5                                           $         - parameter initialized in FUN-CCI#
           A-Fail   nBreach     noCCI
      7         2        46         8        45      16      42      17         $Case 1: Either Alpha mode failure occurred or there was NO vessel breach
          H2INVES    FEJECT     FH2VB      FCCI   LH2CC    LCO2   FZROX         $        or NO CCI
         FUN-CCI1
       GETHRESH 3    868.50    434.22     17.37

      1        64
                1
             HPME
      7         2        46         8        45      16      42      17         $Case 2: High pressure melt ejection has occurred (HPME)
          H2INVES    FEJECT     FH2VB      FCCI   LH2CC    LCO2   FZROX         $        Ejected debris (material mobile at VB) blown out of cavity from HPME
         FUN-CCI2
       GETHRESH 3    868.50    434.22     17.37

        Otherwise                                                               $Case 3: NO HPME
      7         2        46         8        45      16      42      17         $        Possible some debris blown out of cavtiy from ex-vessel steam explosio
          H2INVES    FEJECT     FH2VB      FCCI   LH2CC    LCO2   FZROX
         FUN-CCI3
       GETHRESH 3    868.50    434.22     17.37

102 What is the level of zirconium oxidation in the pedestal before CCI?
      7    ZrOx75    ZrOx50    ZrOx40    ZrOx30  ZrOx21  ZrOx10 ZrOx<10         $ ZrOx75 : Total Zr oxid. (Before CCI) > 75%
      5         1         2         3         4       5       6       7         $ ZrOx50 : Total Zr oxid. (Before CCI): 75% > ZrOx > 50%
      1        17                                                               $ ZrOx40 : Total Zr oxid. (Before CCI): 50% > ZrOx > 40%
            FZROX                                                               $ ZrOx30 : Total Zr oxid. (Before CCI): 40% > ZrOx > 30%
              AND                                                               $ ZrOx21 : Total Zr oxid. (Before CCI): 30% > ZrOx > 21%
         GETHRESH         6      0.75      0.50    0.40    0.30    0.21    0.10 $ ZrOx10 : Total Zr oxid. (Before CCI): 21% > ZrOx > 10%
                                                                                $ ZrOx<10: Total Zr oxid. (Before CCI): ZrOx < 10%
103 Is the containment not vented following VB?
      2    InVENT    I-VENT                                                     $ InVENT : Containment is NOT vented following vessel breach
      2         1         2                                                     $ I-VENT : Containment IS vented following vessel breach
      3
      3        79        93        93                                           $Case 1: Either NO ac power or containment already has LARGE leak
                1       + 3       + 4
             LfAC     I-CL3     I-CL4
            1.000     0.000
      4        99        63        81        95                                 $Case 2: NO core-concrete interaction and either  NO vessel breach or LATE
                4       ( 5       + 2    +   -3)                                $        containment sprays or NO LARGE suppression pool bypass
            noCCI   nBreach       LCS   nI-SPB3                                 $        i.e., pressure in containment has stabilized and venting not needed
            1.000     0.000                                                     $        Analysis does NOT allow errors of commission - thus no split fraction
        Otherwise                                                               $Case 3: Pressure rising in containment and ac power available
            0.900     0.100
104 Is ac power not recovered late in the accident?
      2      LfAC      L-AC                                                     $ LfAC : ac power is NOT recovered late
      2         1         2                                                     $ L-AC : ac power is recovered late
      4
      1        79                                                               $Case 1: ac power was already recovered or never lost
                2
```

```
             I-AC
            0.000     1.000
      1        80                                                               $Case 2: Failure of dc power precludes AC power recovery
                1
            E1fDC
            1.000     0.000
      2         2        15                                                     $Case 3: Long term station blackout with a FAST pour.
                1         2                                                     $        None @ 24 hr.s given none @ 17 hr.s
               SB    CD-Slw
            0.910     0.090
        Otherwise                                                               $Case 4: Fast Core Melt with HIGH pour rate from vessel
            0.230     0.770                                                     $        None @ 24 hr.s given none @ 5.6 hr.s
105 Is dc power available late in the accident?
      2      LfDC      L-DC                                                     $ LfAC : ac power is NOT recovered late
      2         1         2                                                     $ L-AC : ac power is recovered late
      4
      1        80                                                               $Case 1: ac power has already been lost
                1
            E1fDC
            1.000     0.000
      1        79                                                               $Case 2: ac power is available, thus dc power is available
                2
             I-AC
            0.000     1.000
      2         2        15                                                     $Case 3: Long-term station blackout
                1         2
               SB    CD-Slw
            0.330     0.670
        Otherwise                                                               $Case 4: Fast Core Melt
            0.060     0.940                                                     $        None @ 24 hr.s given none @ 5.6 hr.s
106 What is the late status of containment sprays?
      4      LfCS      LrCS      LaCS      L-CS                                 $ LfCS : Containment sprays are failed and cannot be recovered
      2         1         2         3         4                                 $ LrCS : Sprays are recoverable when ac power is restored
      8                                                                         $ LaCS : Sprays are available
      1        81                                                               $ L-CS : Containment sprays are operating
                1
             IfCS                                                               $Case 1: Containment sprays were previously failed
            1.000     0.000     0.000     0.000
      6        81       104        50        50      93      93                 $Case 2: Sprays were previously recoverable and ac power has NOT been restored
                2      * 1 *  (    1     + 2) *  (  3    + 4)                   $        detonation in the wetwell or containment failure following VB may
             IrCS      LfAC     E5nCL    E5-CL2   I-CL3   I-CL4                 $        have failed the sprays
        !81,2,1  !81,2,2        0.000     0.000
      2        81       104                                                     $Case 3: Sprays were previously recoverable and ac power has NOT been restored
                2         1                                                     $        thus, the sprays are still recoverable
             IrCS      LfAC
            0.000     1.000     0.000     0.000
      5        81        50        50        93      93                         $Case 4: Sprays were working previously - because of detonation
                4 *  (    1     + 2)   *  (  3   + 4)                           $        or containment failure sprays may not be operating now
             I-CS     E5nCL    E5-CL2     I-CL3   I-CL4
        !81,4,1         0.000 !81,4,3   !81,4,4
      1        81                                                               $Case 5: Sprays were working previously
                4
```

```
             I-CS
            0.000     0.000     0.000     1.000
      5       104        50        50        93      93                         $Case 6: ac power is available - because of a detonation in the wetwell or
                2 * (     1      + 2)     * ( 3    + 4)                         $        containment failure following VB, the sprays may not be operating
             L-AC     E5nCL    E5-CL2     I-CL3   I-CL4
         !81,6,1   !81,6,2   !81,6,3   !81,6,4
      1       104                                                               $Case 7: ac power is available
                2
             L-AC
            0.000     0.000 !30,4,3   !30,4,4
        Otherwise -- This case should not be used                               $Case 8: This case should not be used
            0.000     0.000     1.000     0.000
107 What is the late concentration of combustible gases in the containment?
      6   LGWW>20   LGWW>16   LGWW>12    LGWW>8  LGWW>4 L-NoGWW                 $ LGWW>20 : H2 concentration in WW > 20%      LGWW>16 : 16% < H2 concen. < 20%
      6         1         2         3         4       5       6                 $ LGWW>12 : 12% < H2 concen. < 16%             LGWW>8 : 8% < H2 concen. < 12%
      4                                                                         $ LGWW>4  : 4% < H2 concen. < 8%             L-NoGWW : H2 concen. in WW < 4%
      5        63        95        97        98     106
               -5    *   -1  * ( -1    +  -3)   *   -4                          $Case 1: Suppression pool bypass with water in the reactor cavity and NO late
           Breach     I-SPB    LDBWat   nLRCDry   nL-CS                         $        containment sprays. Steam generated from water over core debris
      8         1         3         9        16      42      44       4      10 $        inerts containment.
            H2OWW      H2WW      O2WW     LH2CC    LCO2    N2WW    H2DW    O2DW
        FUN-LGWW1
        GETHRESH          5      0.20      0.16    0.12    0.08    0.04

      2        93       103
               -1    +    2                                                     $Case 2: Containment failure or has been vented
             I-CL    I-VENT                                                     $          - containment does not pressurize and, thus, some CCI releases
      8         1         3         9        16      42      44       4      10 $            purged out of containment
            H2OWW      H2WW      O2WW     LH2CC    LCO2    N2WW    H2DW    O2DW
        FUN-LGWW2
        GETHRESH          5      0.20      0.16    0.12    0.08    0.04

      1       106
                4                                                               $Case 3: Containment NOT failed and there are containment sprays
             L-CS                                                               $          - steam content reduced in containemnt
      8         1         3         9        16      42      44       4      10
            H2OWW      H2WW      O2WW     LH2CC    LCO2    N2WW    H2DW    O2DW
        FUN-LGWW3
        GETHRESH          5      0.20      0.16    0.12    0.08    0.04

        Otherwise                                                               $Case 4: Containment is not leaking - CCI releases enter containment
      8         1         3         9        16      42      44       4      10
            H2OWW      H2WW      O2WW     LH2CC    LCO2    N2WW    H2DW    O2DW
        FUN-LGWW4
        GETHRESH          5      0.20      0.16    0.12    0.08    0.04
                   Parse the combustible gas concentration
108 To what level is the wetwell inert after vessel breach?
      3    LnWWIn    L-WWIn2   L-WWIn3                                          $ LnWWIn : Wetwell is not inert
      5         1         2         3                                           $ L-WWIn2 : Wetwell inert to detonations
      4         1         3         9        44
            H2OWW      H2WW      O2WW      N2WW
        FUN-WWH201
```

```
      GETHRESH           3 !40,1,1   !40,1,2   !40,1,3

109 Is there sufficient oxygen in the containment to support late combustion?   $ LO2Det20 : Enough oxygen to support a detonation with 20% H2
      5  LO2Det20  LO2Det16  LO2Det12     LWWO2  LnWWO2                         $ LO2Det16 : Enough oxygen to support a detonation with 16% H2
      5         1         2         3         4       5                         $ LO2Det12 : Enough oxygen to support a detonation with 12% H2
      4         1         3         9        44                                 $          - containment does not pressurize
            H2OWW      H2WW      O2WW      N2WW
         FUN-WWO2
         GETHRESH         4       4.0       3.0     2.0     1.0

110 Does ignition occur late in the containment?
      2    L-CIgn    LnCIgn                                                     $ L-CIgn : LATE ignition in the containment
      2         1         2                                                     $ LnCIgn : NO late ignition in the containment
      7
      4       107       108       106       109                                 $Case 1: Insufficient combustible material or containment inert to combustion
                6    +    3    *   -4    +    5                                 $        or not enough O2 in containment to support combustion
          L-NoGWW   I-WWIn3     nL-CS    LnWWO2
            0.000     1.000
      5        82        83        84        85     104                         $Case 2: Combustible mixture in containment following VB did NOT ignite
               -3        -5       ( 2     *  2)       1                         $        Therefore, mixture won't burn now unless ac on late
         nI-WWIn3      WWO2    InCIgn    IgnFVB    LfAC
            0.000     1.000
      1       104                                                               $Case 3: ac power available late
                2
             L-AC
            1.000     0.000
      2       107       107                                                     $Case 4: Combustible concentration > 16% - NO ac power
                1    +    2
          LGWW>20   LGWW>16
            0.510     0.490
      1       107                                                               $Case 5: Combustible concentration in range 16% > LGWW > 12% - NO ac power
                3
          LGWW>12
            0.420     0.580
      1       107                                                               $Case 6: Combustible concentration in range 12% > LGWW > 8% - NO ac power
                4
           LGWW>8
            0.330     0.670
        Otherwise                                                               $Case 7: Combustible concentration in range 8% > LGWW > 4% - NO ac power
            0.280     0.720
111 Is there a detonation in the wetwell following vessel breach?
      2    L-WWDt    LnWWDt                                                     $ L-WWDt : Late detonation in wetwell
      4         1         2                                                     $ LnWWDt : NO late detonation in wetwell
      9
      8       110       108       108       106     108     107     107     107 $Case 1: NO ignition or Containment inert or H2 in containment < 12%
                2     + ( 2   +    3)    *   -4     + 3   +   4     + 5   +   6
           LnCIgn   L-WWIn2   L-WWIn3     nL-CS  L-WWIn  LGWW>8  LGWW>4 L-NoGWW
            0.000     1.000
      1
     20      0.00      0.00
      2        27        79                                                     $Case 2: ac power is ON after vessel breach and the HIS is ON
                1    *    2
```

```
          E4-HIS      I-AC
           0.000     1.000
     1
    20      0.00      0.00
     6       107       108       108       109     109     109                  $Case 3: 12% < H2 < 16% and containment initially inert to detonations,
               3 * (     2   +    3)   * (   3   +  2    +  1)                  $        however, sprays are on which reduces steam concentration and forms
         LGWW>12   L-WWIn2   L-WWIn3  LO2Det12 LO2Dt16 LO2Dt20                  $        a detonable mixture in containment (High steam)
           0.220     0.780
     1
    20       5.8      0.00
     4       107       109       109       109                                  $Case 4: 12% < H2 < 16% and Low steam
               3      (  3     +   2     +  1)                                  $        Low steam DDT
         LGWW>12  LO2Det12   LO2Dt16   LO2Dt20
           0.000     1.000
     1
    20      0.00      0.00
     5       107       108       108       109     109                          $Case 5: 16% < H2 < 20% and containment initially inert to detonations,
               2 * (     2   +    3)   * (   2  +   1)                          $        however, sprays are on which reduces steam concentration and forms
         LGWW>16   L-WWIn2   L-WWIn3   LO2Dt16 LO2Dt20                          $        a detonable mixture in containment (High steam)
           0.250     0.750
     1
    20       5.8      0.00
     3       107       109       109                                            $Case 6: 20% > Containment H2 > 16% and Low steam
               2      (  2    +   1)                                            $       Low steam DDT
         LGWW>16   LO2Dt16   LO2Dt20
           0.260     0.740
     1
    20      12.4      0.00
     4       107       138       108       109                                  $Case 7: H2 > 20% and containment initially inert to detonations,
               1 * (     2   +    3)      *  1                                  $        however, sprays are on which reduces steam concentration and forms
         LGWW>20   L-WWIn2   L-WWIn3  LO2Det20                                  $        a detonable mixture in containment (High steam)
           0.250     0.750
     1
    20       5.8      0.00
     2       107       109                                                      $Case 8: Containment H2 > 20% and Low steam
               1         1                                                      $       Low steam DDT
         LGWW>20  LO2Det20
           0.450     0.550
     1
    20      12.4      0.00
       Otherwise                                                                $Case 9: Not enough oxygen to support a detonation
           0.000     1.000
     1
    20      0.00      0.00
112 What is the late level of containment impulse load?
     7   L-Ip>60   L-Ip>50   L-Ip>40    L-Ip>30 L-Ip>20 L-Ip>10 L-Ip<10         $ L-Ip>60 : Impulse > 60 KPa-S         L-Ip>50 : 60 > Impulse > 50 KPa-S
     5         1         2         3          4       5       6       7         $ L-Ip>40 : 50 > Impulse > 40 KPa-S    L-Ip>30 : 40 > Impulse > 30 KPa-S
     1        20                                                                $ L-Ip>20 : 30 > Impulse > 20 KPa-s    L-Ip>10 : 20 > Impulse > 10 KPa-S
         ImpLoad                                                                $ L-Ip<10 : Impulse < 10 KPa-S
             AND
        GETHRESH         6     60.00     50.00   40.00   30.00   20.00   10.00
                            $ Parse containment impulse load for verification
```

```
113 What is the late gas combustion efficiency?
      1  H2EfaVB                                                               $ H2EfaVB : Efficiency at which H2 is burned following VB
      4        1
      9
      6        110       108       108       106     107     107                $Case 1: Wetwell st^am > 45% (High Steam) and H2 ignited in Range H2 < 8%
               1   *   ( 2    +   3)   *     4   (   5 +    6)
          L-CIgn   L-WWIn2   L-WWIn3      L-CS  LGWW>4 L-NoGWW
           1.000
      2
     18      0.280                   $ Peak pressure from hydrogen combustion
     19      0.275                   $ Combustion efficiency
      3        110       107       107                                           Case 2: Wetwell steam < 45% (low steam) and H2 ignited in range H2 < 8%
               1   (     5    +   6)
          L-CIgn    LGWW>4   L-NoGWW
           1.000
      2
     18      0.280                   $ Peak pressure from hydrogen combustion
     19      0.275                   $ Combustion efficiency
      5        110       108       108       106     107                        $Case 3: Wetwell steam > 45% (High Steam) and H2 ignited in Range 12% > H2 > 8%
               1   *   ( 2    +   3)   *     4   * 4
          L-CIgn   L-WWIn2   L-WWIn3      L-CS  LGWW>8
           1.000
      2
     18      0.464
     19      0.740
      2        110       107                                                     $Case 4: Wetwell steam < 45% (Low Steam) and H2 ignited in Range 12% > H2 > 8%
               1         4
          L-CIgn    LGWW>8
           1.000
      2
     18      0.575
     19      0.740
      5        110       108       108       106     107                        $Case 5: Wetwell steam > 45% (High Steam) and H2 ignited in Range 16% > H2 > 12
               1   *   ( 2    +   3)   *     4   * 3
          L-CIgn   L-WWIn2   L-WWIn3      L-CS LGWW>12
           1.000
      2
     18      0.483
     19      0.881
      2        110       107                                                     $Case 6: Wetwell steam < 45% (Low Steam) and H2 ignited in Range 16% > H2 > 12%
               1         3
          L-CIgn   LGWW>12
           1.000
      2
     18      0.734
     19      0.881
      6        110       108       108       106     107     107                $Case 7: Wetwell steam > 45% (High Steam) and H2 ignited in Range H2 > 16%
               1   *   ( 2    +   3)   *     4   * ( 1 +    2)
          L-CIgn   L-WWIn2   L-WWIn3      L-CS LGWW>20 LGWW>16
           1.000
      2
     18      0.492
```

```
     19     0.935                                                                $Case 8: Wetwell steam < 45% (Low Steam) and H2 ignited in Range H2 > 16%
      3       110       107       107
                1    (    1    +    2)
           L-CIgn   LGWW>20   LGWW>16
            1.000
      2
     18     0.752
     19     0.935                                                                $Case 9: No LATE burn
        Otherwise
            1.000
      2
     18      0.00
     19      0.00
114 what is the peak pressure in containment from a late hydrogen burn?
      6  L-PBrn>7  L-PBrn>6  L-PBrn>5  L-PBrn>4 L-PBrn>3 L-PBrn>2
      6         1         2         3         4       5       6
      4                                                                          $Case 1: No late H2 ignition
      1       110
                2
           LnCIgn
      8         3         1         9         5      11      18      19      44
             H2WW     H2OWW      O2WW    EPBase    PBrn H2EfVB1 H2EfVB2    N2WW
        FUN-IPBRN1
         GETHRESH         5     709.3     608.0   506.6   405.3   304.0
                  Parse peak pressure for verification
      4        93        93        27        79                                  $Case 2: Containment already failed OR ac power and CIS are both working
                3       + 4       + 1       * 2                                  $         after vessel breach
            I-CL3     I-CL4    E4-HIS      I-AC
      8         3         1         9         5      11      18      19      44
             H2WW     H2OWW      O2WW    EPBase    PBrn H2EfVB1 H2EfVB2    N2WW
        FUN-IPBRN2
         GETHRESH         5     709.3     608.0   506.6   405.3   304.0
                  Parse peak pressure for verification                           $Case 3: Detonation in Containment
      1       111
                1
           L-WWDt
      8         3         1         9         5      11      18      19      44
             H2WW     H2OWW      O2WW    EPBase    PBrn H2EfVB1 H2EfVB2    N2WW
        FUN-IPBRN3
         GETHRESH         5     709.3     608.0   506.6   405.3   304.0
                  Parse peak pressure for verification
        Otherwise                                                                $Case 4: Late H2 burn
      8         3         1         9         5      11      18      19      44
             H2WW     H2OWW      O2WW    EPBase    PBrn H2EfVB1 H2EfVB2    N2WW
        FUN-IPBRN4
         GETHRESH         5     709.3     608.0   506.6   405.3   304.0
                  Parse peak pressure for verification
115 What is the level of drywell leakage induced by a late detonation in containment?
      3    LnDWDt   L-DWDt2   L-DWDt3                                            $ LnDWDt : No drywell failure induced by detonation
      6         1         2         3                                            $ L-DWDt2 : Drywell leakage induced by detonation (Level 2)
      2                                                                          $ L-DWDt3 : Drywell rupture induced by detonation (Level 3)
      1       111
```

```
                1                                                               $Case 1: Late detonation in wetwell
           L-WWDt
      3        20        34        35
          ImpLoad    IMPDWF    IMRanD
          FUN-ED1
         GETHRESH         2      2.00      1.00
                  $ Dummy parameter values uscd to trigger particular branch
        Otherwise -- No detonation and thus no failure                          $Case 2: NO late detonation in wetwell - NO failure
      3        20        34        35
          ImpLoad    IMPDWF    IMRanD
              MAX
         GETHRESH         2      0.00     -1.00
                  $ Parameter values force Branch 1
116 What is the level of containment leakage induced by a late detonation?
      3     LnDtF    L-DtF2    L-DtF3                                           $ LnDtF : No Containment failure induced by detonation
      6         1         2         3                                           $ L-DtF2 : Containment leakage induced by detonation (Level 2)
      3                                                                         $ L-DtF3 : Containment rupture induced by detonation (Level 3)
      2       115       115
                2    +    3                                                     $Case 1: Late detonation failed the drywell (Either Level 2 or 3)
          L-DWDt2   L-DWDt3                                                     $        This case allows coupling between drywell and containment response
      5        20        24        25        34      35
          ImpLoad     IMPCF    IMRanC    IMPDWF  IMRanD
         FUN-ECI1
         GETHRESH         2      2.00      1.00

      1       111                                                               $Case 2: Late detonation in containment - No drywell failure from detonation
                1
           L-WWDt
      3        20        24        25
          ImpLoad     IMPCF    IMRanC
         FUN-ECI2
         GETHRESH         2      2.00      1.00

        Otherwise                                                               $Case 3: No late detonation in containment - No failure
      3        20        24        25
          ImpLoad     IMPCF    IMRanC
              MAX
         GETHRESH         2      0.00     -1.00
                  $ Parameter values force Branch 1
117 What is the level of containment leakage induced by late combustion events? $ LnCL : No containment failure
      4     LnCL     L-CL2     L-CL3     L-CL4                                  $ L-CL2 : Containment failure is a leak (Level 2)
      6         1         2         3         4                                 $ L-CL3 : Containment failed by rupture (Level 3)
      4                                                                         $ L-CL4 : Containment failed by catastrophic rupture (Level 4)
      1        93
                4                                                               $Case 1: Containment already failed by catastrophic rupture
           I-CL4
      2         5        11
          EPBase     PBrr
       FUN-LCPLOW
         GETHRESH        3  9999.00   9999.00 9999.00
                           Dummy -- Already ruptured
      3        93       103       116                                           $Case 2: Containment already ruptured or ruptured from a late detonation or
```

```
          3     +    2     +    3                                       $        vented late
      I-CL3    I-VENT     L-DtF3
   2      5        11
     EPBase      PBrn
   FUN-LCPLOW
    GETHRESH          3   9999.00   9999.00    1.00
                         Dummy -- Already failed
   2     93       116                                                   $Case 3: Containment already leaking or leaking from a late detonation
          2     +   2
      I-CL2     L-DtF2
   4      5        11        21        22
     EPBase      PBrn    PCFail      CFRan
   FUN-ECBrn2
    GETHRESH          3   9999.00      2.00    1.00
                         Dummy -- Already leaking from detonation
   Otherwise                                                            $Case 4: Containment intact before containment burn
   4      5        11        21        22
     EPBase      PBrn    PCFail      CFRan
   FUN-ECBrn2
    GETHRESH          3      3.00      2.00    1.00
                         Parameter value triggers particular branch
118 What is the level of drywell leakage induced by late combustion?
   5    LnDWDf   L-DWDf2  L-DWHDf2   L-DWDf3 L-DWHDf3                   $ LnDWDf   : No drywell failure
   6        1         2         3         4       5                     $ L-DWDf2  : Drywell failure is a leak at the DW wall (Level 2)
   7                                                                    $ L-DWHDf2 : Drywell failure is a leak at the DW head (Level 2)
   2     94       115                                                   $ L-DWDf3  : Drywell failure is a rupture at the DW wall (Level 3)
          4     +   3                                                   $ L-DWHDf3 : Drywell failure is a rupture at the DW head (Level 3)
    I-DWDf3    L-DWDt3
   1      5                                                             $Case 1: Drywell already ruptured
     EPBase                                                             $        Drywell already failed at wall -- prevent head failure
        AND
    GETHRESH          4   9999.00   9999.00 9999.00    0.00

   1     94                                                             $Case 2: Drywell head already ruptured
          5
    I-DWHDf3
   1      5
     EPBase
        AND
    GETHRESH          4   9999.00   9999.00 9999.00 9999.00
                 $ Dummy case, head rupture is retained
   4     94       115       117       117                               $Case 3: Drywell wall already leaking, containment is ruptured
     (    2     +   2)    (   3     +   4)                              $        - Prior wall failure precludes head failure
    I-DWDf2  LI-DWDt2     L-CL3     L-CL4                               $        - Containment ruptured so burn pressure could be mitigated
   4      5        11        30        31
     EPBase      PBrn     EPDWF    DWFRan
   FUN-LDBrn1
    GETHRESH          4   9999.00      3.00    2.00   -1.00

   2     94       115                                                   $Case 4: Drywell wall already leaking - NO containment rupture
          2     +   2                                                   $        - Prior wall failure precludes head failure
    I-DWDf2  LI-DWDt2
```

```
   4         5        11        30        31
       EPBase      PBrn     EPDWF    DWFRan
     FUN-LDBrn2
      GETHRESH          4   9999.00      3.00     2.00    -1.00

   3        94       117       117                                        $Case 5: Prior drywell head leakage and containment rupture
             3      (  3      +   4)                                      $         - Prior head leakage precludes no failure
      I-DWHDf2     L-CL3     L-CL4                                        $         - Containment ruptured so burn pressure could be mitigated
   4         5        11        30        31
       EPBase      PBrn     EPDWF    DWFRan
     FUN-LDBrn3
      GETHRESH          4   9999.00      3.00     2.30    -1.00

   1        94                                                            $Case 6: Prior drywell head leakage and NO containment rupture
             3                                                            $         - Prior head leakage precludes no failure
      I-DWHDf2
   4         5        11        30        31
       EPBase      PBrn     EPDWF    DWFRan
     FUN-LDBrn4
      GETHRESH          4   9999.00      3.00     2.00    -1.00
                  $ Dummy parameters select failure mode
     Otherwise                                                            $Case 7: Burn or nc burn cases with no prior ruptures
   4         5        11        30        31
       EPBase      PBrn     EPDWF    DWFRan
     FUN-LDBrn5
      GETHRESH          4      4.00      3.00     2.00    -1.00
                  $ Dummy parameters select failure mode
119 Is the containment not vented late?
   2    LnVENT    L-VENT                                                  $ LnVENT : Containment is NOT vented LATE
   2         1         2                                                  $ I-VENT : Containment IS vented following LATE
   4
   3       104       117       117                                        $Case 1: Either NO ac power or containment already has LARGE leak
             1  +  (   3     +    4)
          LfAC     L-CL3     L-CL4
         1.000     0.000
   4        99        63        81        95                              $Case 2: NO core-concrete interaction and either  NO vessel breach or INTERMEDI
             4     (   5     +   2   +   -3)                              $         containment sprays or NO LARGE suppression pool bypass
         noCCI   nBreach      I-CS   nI-SPB3                              $         - opportunity existed earlier
         1.000     0.000
   5        99        63       106       118       118                    $Case 3: NO core-concrete interaction and either  NO vessel breach or LATE
             4     (   5     +   4   + ( -4        -5))                   $         containment sprays or NO LATE LARGE suppression pool bypass
         noCCI   nBreach      L-CS nL-DWDf3 nL-DWHDf3
    !103,2,1  !103,2,2
     Otherwise                                                            $Case 4: Pressure rising in containment and ac power available
    !103,3,1  !103,3,2
120 How much concrete must be eroded to cause pedestal failure?
   1  ConErPed                                                            $ ConErPed: Depth of concrete eroded radially to fail pedes*al (m)
   3         1
         1.000
   1
  43      0.40          $ ConErPed: Depth of concrete eroded radially to fail pedestal (m)
121 At what time does pedestal failure occur?                             $ PedFaVB : Pedestal fails at vessel breach
```

```
6   PedF@VB   PedF@10    PedF@6    PefF@3    PedF@1    NoPedF           $ PedF@10 : Pedestal fails 10 hours from VB
6         1         2         3         4         5         6           $ PedF@6 : Pedestal fails 6 hours from VB
9                                                                       $ PefF@3 : Pedestal fails 3 hours from VB
4        63        63        99        99                               $ PefF@1 : Pedestal fails 1 hours from VB
          1       + 5         4       + 5                               $ NoPedF : No pedestal failure
     A-Fail   nBreach    DlyCCI     noCCI
1        43                                                             $Case 1: NO core-concrete interactions - NO pedestal erosion OR delayed
   ConErPed                                                             $        CCI which would be very late pedestal erosion or NO vessel
        AND                                                             $        breach (NO CCI) or Alpha mode failure in which case pedestal
   GETHRESH         5    9999.0    9999.0    9999.0    9999.0    9999.0 $        failure is no longer a concern
                      $ Dummy parameters force Branch 6
2        75        74                                                   $Case 2: Pedestal already failed from impulse or pressurization at VB
          1       + 1
    I-PedFI   I-PedFP
1        43
   ConErPed
        AND
   GETHRESH         5      0.00     -1.00     -1.00     -1.00     -1.00
                      $ Dummy parameters force Branch 1
4       102       102        61        99                               $Case 3: Water and High metal, and high superheat
         -1      * -2       * 1      *  2                               $        Group 1 for MCCI Experts
    nZrOx75   nZrOx50   HiLiqVB    WetCCI
1        43
   ConErPed
        AND
   GETHRESH         5   9999.00      0.83      0.55      0.32      0.19

4       102       102        61        99                               $Case 4: Water and Low metal, and Low superheat
         -1      * -2       * 2      *  2                               $        Group 3 for MCCI Experts
    nZrOx75   nZrOx50   LoLiqVB    WetCCI
1        43
   ConErPed
        AND
   GETHRESH         5   9999.00      0.79      0.52      0.29      0.16

1        99                                                             $Case 5: Remaining case with water
          2                                                             $        Group 2 for MCCI Experts
     WetCCI
1        43
   ConErPed
        AND
   GETHRESH         5   9999.00      0.74      0.49      0.26      0.14

5       102       102        61        63        63                     $Case 6: NO Water and High metal, and High flow
         -1      * -2       * 1  * (    2    +   3)                     $        Group 6 for MCCI Experts
    nZrOx75   nZrOx50   HiLiqVB   BH-Fail    LgBrch
1        43
   ConErPed
        AND
   GETHRESH         5   9999.00      0.83      0.66      0.40      0.20

3        61        63        63                                         $Case 7: NO Water and Low metal, and High flow
```

```
               1 *  (     2   +    3)                                           $        Group 7 for MCCI Experts
          HiLiqVB   BH-Fail    LgBrch
      1        43
         ConErPed
              AND
         GETHRESH         5   9999.00      0.92    0.73    0.47    0.26

      4       102       102        63        63                                 $Case 8: NO Water and High metal, and Medium flow
               -1     *  -2  *  (   2    +   3)                                 $        Group 5 for MCCI Experts
          nZrOx75   nZrOx50   BH-Fail    LgBrch
      1        43
         ConErPed
              AND
         GETHRESH         5   9999.00      0.92    0.71    0.47    0.26

        Otherwise -- Group 4 for MCCI experts                                   $Case 9: NO Water and Low metal, and Medium flow or Low flow
      1        43                                                               $        Group 4 for MCCI Experts
         ConErPed
              AND
         GETHRESH         5   9999.00      0.82    0.62    0.40    0.20

122 What is the level of late suppression pool bypass?
      3     LnSPB    L-SPB2    L-SPB3                                           $ LnSPB : No suppression pool bypass
      2         1         2         3                                           $ L-SPB2 : Suppression pool bypass level 2 (Leak)
      7                                                                         $ L-SPB3 : Suppression pool bypass level 3 (Rupture)
      3        95       118       118
                3     +   4    +    5
           I-SPB3   L-DWDf3  L-DWHDf3                                           $Case 1: Drywell rupture from combustion or pre-existing rupture
            0.000     0.000     1.000
      5        95       118       118       121     121                         $Case 2: Pre-existing drywell leak and Late pedestal failure
           (    2     +   2    +   3)        -1      -6                         $        - Pedestal failure causes rupture with preexisting leak
           L-SPB2   L-DWDf2  L-DWHDf2  nPedF@VB  L-PedF
            0.000 !76,2,2   !76,2,1
      5        95       118       118       104     110                         $Case 3: Pre-existing drywell leak and ac power is available and H2 combustion
           (    2     +   2    +   3)         2       1                         $        in containment - pre-existing leak exacerbated by vacuum breaker failu
           L-SPB2   L-DWDf2  L-DWHDf2      L-AC  L-CIgn
            0.000 !52,2,2   !52,2,3
      3        95       118       118                                           $Case 4: Pre-existing drywell leak - nothing has happened to change it
                2     +   2    +    3
           L-SPB2   L-DWDf2  L-DWHDf2
            0.000     1.000     0.000
      2       121       121                                                     $Case 5: Drywell failure caused by Late pedestal failure
               -1        -6
         nPedF@VB    L-PedF
        !76,2,2       0.000 !76,2,1
      2       104       110                                                     $Case 6: ac power is available and H2 combustion in containment
                2         1                                                     $        - vacuum breaker fails from H2 burn
             L-AC    L-CIgn
        !52,2,2       0.000 !52,2,3
        Otherwise                                                               $Case 7: No burns in containment & no additional bypass
            1.000     0.000     0.000
123 What is the late containment pressure due to non-condensibles or steam?
```

```
      2   LT-Pres  nLT-Pres                                                     $ LT-Pres  : Late containment pressure
      4         1         2                                                     $ nLT-Pres : Late pressure negligible
      4                                                                         $ Par 47 - LT-Pres : Late containment pressure from non-condensibles or steam
      2       117       119
               -1     +   2                                                     $Case 1: Containment either already failed or vented - containment will not
             L-CL    L-VENT                                                     $        pressurize from non-condensibles or steam
            0.000     1.000
      1
     47     0.000     0.000
      5        99        63       106       118       118                       $Case 2: NO core-concrete interactions and either NO vessel breach or LATE
                4     (   5    +    4   +  ( -4       -5))                      $        containment sprays or NO LATE suppression pool bypass
            noCCI   nBreach      L-CS  nL-DWDf3 nL-DWHDf3                       $        RHR may not be initiated
            0.000     1.000
      1
     47     400.0     0.000
      5        63        95        97        98       106                       $Case 3: Large amount of steam is being generated by water over core debris
               -5    *    3    * ( -1     +  1)    *   -4                       $        (cavity either flooded or injection source) and the suppression
           Breach    I-SPB3    LDBWat    LDWFld     nL-CS                       $        pool is bypassed with no late containment sprays
            1.000     0.000
      1
     47 !19,1,1,1     0.000
        Otherwise                                                               $Case 4: No means of pressure relief
            1.000     0.000
      1
     47 !123,2,1,1    0.000
124 Does containment failure occur late due to non-condensibles or steam?
      4     LPnCL    LP-CL2    LP-CL3    LP-CL4                                 $ LPnCL  : No containment failure from late non-condensibles or steam
      5         1         2         3         4                                 $ LP-CL2 : Containment failure is a leak (Level 2)
      4         5        47        21        22                                 $ LP-CL3 : Containment failed by rupture (Level 3)
           EPBASE   LT-PRES    pCFail     CFRan                                 $ LP-CL4 : Containment failed by catastrophic rupture (Level 4)
    FUN-LTPRES
    GETHRESH                3      3.00      2.00      1.00

125 What is the long-term level of containment leakage?                         $ LTnCL  : No LONG-TERM containment failure
      4     LTnCL    LT-CL2    LT-CL3    LT-CL4                                 $ LT-CL2 : Containment failure is a leak (Level 2)
      2         1         2         3         4                                 $ LT-CL3 : Containment failed by rupture (Level 3)
      4                                                                         $ LT-CL4 : Containment failed by catastrophic rupture (Level 4)
      2       117       124
                4     +   4                                                     $Case 1: Containment already failed by catastrophic rupture
            L-CL4    LP-CL4
            0.000     0.000     0.000     1.000
      3       117       124       119                                           $Case 2: Containment already ruptured or vented late
                3     +   3    +    2
            L-CL3    LP-CL3    L-VENT
            0.000     0.000     1.000     0.000
      2       117       124                                                     $Case 3: Containment already leaking
                2     +   2
            L-CL2    LP-CL2
            0.000     1.000     0.000     0.000
        Otherwise                                                               $Case 4: NO containment failure
            1.000     0.000     0.000     0.000
```

B.2 EVNTRE Binning Input File

The file listed below, **ggbin.dat**, is used in EVNTRE to bin the APET end states into accident progression bins.

```
GRAND GULF BINNING INPUT  ** Version 7 **
 13     ASeq      ZrOxid    VB        DCH-SE    SPB-L   CLEAK-L SPRAYS
        MCCI      SRVBKr    CF-BVB    CF-VB     DF-BVB  DF-VB
  6   6 Fst-SB       Slw-SB    Fst-T2    Slw-T2  Fst-TC  Slw-TC
  1   1        20
                1
           Fst-SB
  1   2        20
                2
           Slw-SB
  1   3        20
                3
           Fst-T2
  1   4        20
                4
           Slw-T2
  1   5        20
                5
           Fst-TC
  1   6        20
                6
           Slw-TC
  2   2    HiZrOx    LoZrOx
  2   1        36        36
               -6    *   -7
          nZrOx10  nZrOx<10
  2   2        36        36
                6     +   7
           ZrOx10   ZrOx<10
  5   5  HiP-nLPI  LoP-nLPI   HiP-LPI   LoP-LPI       nVB
  1   5        63
                5
          nBreach
  3   1        26        97        97
                1    (    1    +    2)
           E4-HiP   nLDBWat  S-LDBWat
  2   2        97        97
           (    1    +    2)
          nLDBWat  S-LDBWat
  1   3        26
                1
           E4-HiP
  1   4        26
                2
           E4-LoP
  5   5     HiDCH     LoDCH    HiEXSE    LoEXSE nDCH-SE
  2   1        64        61
                1         1
             HPME   HiLiqVB
  1   2        64
                1
             HPME
  2   3        67        61
                1         1
             ExSE   HiLiqVB
  1   4        67
                1
             ExSE
```

```
2   5       64        67
             2         2
         nHPME     nExSE
8   8  SPBE0L0   SPBE0L3   SPBE0L2   SPBE0L3 SPBE2L2 SPBE2L3 SPBE2L3 SPBE3L3
1   1      122
             1
         LnSPB
2   2       52        95
             1         3
        E5nSPB    I-SPB3
3   3       52        95       122
             1         1         2
        E5nSPB     InSPB    L-SPB2
3   4       52        95       122
             1         1         3
        E5nSPB     InSPB    L-SPB3
5   5       95       122        52        95     122
           ( 2      * 2)     + (1       * 2    * 2)
        I-SPB2    L-SPB2    E5nSPB    I-SPB2  L-SPB2
2   6       52        95
             2      *  3
        E5-SPB2   I-SPB3
2   7       95       122
             2      *  3
        I-SPB2    L-SPB3
1   8       52
             3
        E5-SPB3
9   9    CE-Lk    CE-Rpt   CE-VENT    CVB-Lk CVB-Rpt   CL-Lk  CL-Rpt
       CL-VENT    CnFail
2   1       50        93
             2      *  2
        E5-CL2     I-CL2
1   3       22
             2
       E3-VENT
2   2       50        50
             3      +  4
        E5-CL3    E5-CL4
1   4       93
             2
         I-CL2
2   5       93        93
             3      +  4
         I-CL3     I-CL4
1   6      125
             2
        LT-CL2
2   8      103       119
             2      +  2
        I-Vent    L-Vent
2   7      125       125
             3      +  4
        LT-CL3    LT-CL4
1   9      125
             1
         LTnCL
4   4     noCS    ECSnoL       LCS       ECS
6   1       30        81       106        30      81     106
         (  -4    *   -4    *  -4)   + ( -4   *   -4   *  4)
        nE4-CS     nI-CS     nL-CS    nE4-CS   nI-CS    L-CS
3   2       30        81       106
             4        -4        -4
         E4-CS     nI-CS     nL-CS
6   3       30        81       106        30      81     106
         (  -4    *    4    *  -4)   + ( -4   *    4   *  4)
        nE4-CS      I-CS     nL-CS    nE4-CS    I-CS    L-CS
6   4       30        81       106        30      81     106
```

```
          (  4      *   4     *  -4)    + ( 4    *   4    *  4)
          E4-CS      1-CS     nL-CS     E4-CS    1-CS    L-CS
 5   5   DryCCI    WetCCI    FLDCCI    DlyCCI   noCCI
 1   1       99
              1
            CCI
 1   2       99
              2
         WetCCI
 1   3       99
              3
         FldCCI
 1   4       99
              4
         DlyCCI
 1   5       99
              5
          noCCI
 2   2  cSRVBkr   cSRVBkr
 1   1       23
              1
        cSRVBkr
 1   2       23
              2
        cSRVBkr
 8   8   E-VENT     CR-SP    CR-DET    CR-DEF   CL-SP  CL-DET  CL-DEF  nCFail
 1   1       22
              2
         E3VENT
 3   2       16        38        38
              3    +    3    +    4
          E1-L3   ESP-CL3   ESP-CL4
 1   3       49
              3
        E4-DtF3
 2   4       50        50
              3    +    4
        E5-CL3    E5-CL4
 2   5       16        38
              2    +    2
          E1-L2   ESP-CL2
 1   6       49
              2
        E4-DtF2
 1   7       50
              2
         E5-CL2
 1   8       50
              1
          E5nCL
 8   8    ERupt     ALPHA    IR-Det    IR-Def  E-Leak  IL-Det  IL-Def nICFail
 2   1       50        50
              3    +    4
         E5-CL3    E5-CL4
 1   2       58
              1
          ALPHA
 1   3       92
              3
         I-DtF3
 2   4       93        93
              3    +    4
          I-CL3     I-CL4
 1   5       50
              2
         E5-CL2
 1   6       92
              2
```

```
            I-DtF2
 1   7          93
                 2
            I-CL2
 1   8          93
                 1
              InCL
 5   5      DR-Det     DR-Def     DL-Det     DL-Def  nDFail
 1   1          48
                 3
          E-DWDt3
 1   2          52
                 3
           E5-SPB3
 2   3          48          17
                 2       *  -2
          E-DWDt2    E1-SPB2
 1   4          52
                 2
           E5-SPB2
 1   5          52
                 1
           E5-SPB1
12  12      EDWRpt      ALPHA     R-DWOP     R-PedP R-PedSE  DR-Det  DR-Def
             EDWLk     L-DWOP     DL-Det     DL-Def   n1DWF
 1   1          52
                 3
           E5-SPB3
 1   2          58
                 1
             ALPHA
 2   3          73          73
                 4       +   5
           I-DWOP3  I-DWHOP3
 2   4          76          74
                 1       *   1
          I-DWFPed    I-PedFP
 1   5          76
                 1
          I-DWFPed
 2   6          91          72
                 3       +   3
           I-DWDt3    I-DWF13
 1   7          95
                 3
            I-SPB3
 1   8          52
                 2
           E5-SPB2
 2   9          73          73
                 2       +   3
           I-DWOP2  I-DWHOP2
 2  10          91          72
                 2       +   2
           I-DWDt2    I-DWF12
 1  11          95
                 2
            I-SPB2
 1  12          95
                 1
             InSPB
```

B.3 Frequency Output File From EVNTRE

The realized split fractions calculated by EVNTRE for PDS 1 are contained in **gl_freq.out**, shown below. The files for the other plant damage states are similar (the split fractions are different, of course).

```
1          TREE ID:       GRAND GULF APET, REV. 7 - 1 MAR 89 LHS R15 - PDSG1       SARRP
    # OF QUESTIONS:  125
      OBSERVATIONS:   250
        FOR SERIES:  GRAND GULF POINTER
       SEQUENCE ID:          cen

 ********  QUESTION:    1  What is the initiating event?
 Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                          250
           BRANCHES:           TLOSP     T2        TC
                                 1        2         3
    REALIZED SPLIT:          1.000E+00 0.000E+00 0.000E+00

 ********  QUESTION:    2  Is there a Station Blackout (Diesel Generators fail)?
 Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                          250
           BRANCHES:           SB        nSB
                                 1        2
    REALIZED SPLIT:          1.000E+00 0.000E+00

 ********  QUESTION:    3  Is dc Power not available?
 Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                          250
           BRANCHES:           E1fDC     E1-DC
                                 1        2
    REALIZED SPLIT:          0.000E+00 1.000E+00

 ********  QUESTION:    4  Do one or more S/RVs fail to reclose?
 Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                          500
           BRANCHES:           E1SORV    E1nSORV
                                 1        2
    REALIZED SPLIT:          5.203E-02 9.480E-01

 ********  QUESTION:    5  Does HPCS fail to inject?
 Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                          500
           BRANCHES:           E1fHPInj  E1rHPInj  E1-HPInj
                                 1        2         3
    REALIZED SPLI            0.000E+00 1.000E+00 0.000E+00

 ********  QUESTION:    6  Does RCIC fail to inject initially?
 Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                          500
           BRANCHES:           E1fRCIC   E1-RCIC
                                 1        2
    REALIZED SPLIT:          1.000E+00 0.000E+00

 ********  QUESTION:    7  Does the CRD hydraulic system fail to inject?
 Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                          500
           BRANCHES:           E1fCRD    E1rCRD    E1-CRD
                                 1        2         3
    REALIZED SPLIT:          1.000E+00 0.000E+00 0.000E+00

 ********  QUESTION:    8  Does the condensate system fail?
 Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                          500
           BRANCHES:           E1fCond   E1rCond   E1aCond
                                 1        2         3
```

```
    REALIZED SPLIT:          0.000E+00 1.000E+00 0.000E+00


********  QUESTION:    9  Do the LPCS and LPCI systems fail?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                              500
          BRANCHES:           E1fLPC    E1rLPC    E1aLPC    E1-LPC
                               1         2         3         4
    REALIZED SPLIT:          0.000E+00 1.000E+00 0.000E+00 0.000E+00


********  QUESTION:   10  Does RHR fail (heat exchangers not available)?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                              500
          BRANCHES:           E1fRHR    E1rRHR    E1aRHR    E1-RHR
                               1         2         3         4
    REALIZED SPLIT:          0.000E+00 1.000E+00 0.000E+00 0.000E+00


********  QUESTION:   11  Does the service water system or cross-tie to LPCI fail?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                              500
          BRANCHES:           E1fSSW    E1rSSW    E1aSSW
                               1         2         3
    REALIZED SPLIT:          1.000E+00 0.000E+00 0.000E+00


********  QUESTION:   12  Does the fire protection system cross-tie to LPCI fail?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                              500
          BRANCHES:           E1fFWS    E1ofFWS   E1aFWS
                               1         2         3
    REALIZED SPLIT:          0.000E+00 0.000E+00 1.000E+00


********  QUESTION:   13  Are the containment (wetwell) sprays failed?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                              500
          BRANCHES:           E1fCSS    E1rCSS    E1aCSS    E1-CSS
                               1         2         3         4
    REALIZED SPLIT:          0.000E+00 1.000E+00 0.000E+00 0.000E+00


********  QUESTION:   14  What is the status of vessel depressurization?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                              500
          BRANCHES:           E1fDep    E1ofDep   E1nDep    E1-Dep
                               1         2         3         4
    REALIZED SPLIT:          0.000E+00 0.000E+00 1.000E+00 0.000E+00


********  QUESTION:   15  When does core damage occur?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                              500
          BRANCHES:           CD-Fst    CD-Slw
                               1         2
    REALIZED SPLIT:          1.000E+00 0.000E+00


********  QUESTION:   16  What is the level of pre-existing leakage or isolation failure?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                             1000
          BRANCHES:           E1nL      E1L2      E1L3
                               1         2         3
    REALIZED SPLIT:          9.935E-01 6.5[illegible]E-03 0.000E+00


********  QUESTION:   17  What is the level of pre-existing suppression pool bypass?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB.                             1500
          BRANCHES:           E1nSPB    E1-SPB2   E1-SPB3
                               1         2         3
    REALIZED SPLIT:          9.996E-01 3.974E-04 0.000E+00


********  QUESTION:   18  What is the structural capacity of the containment?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB. INPUT PARM.                 1500
```

```
           BRANCHES:           Contain
                                  1
    REALIZED SPLIT:           1.000E+00


******** QUESTION:   19  What is the structural capacity of the drywell?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB. INPUT PARM.              1500
           BRANCHES:           Drywell
                                  1
    REALIZED SPLIT:           1.000E+00


******** QUESTION:   20  What type of sequence is this (summary of plant damage)?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                            1500
           BRANCHES:           Fst-SB    Slw-SB    Fst-T2    Slw-T2    Fst-TC    Slw-TC
                                  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     1.000E+00
       DEPENDENCIES:    2        15

      REQ. BRANCHES:    1    *    1

        DESCRIPTION:  SB        CD-Fst

 CASE/BRANCH SPLIT:           1.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:    2     0.000E+00
       DEPENDENCIES:    2

      REQ. BRANCHES:    1

        DESCRIPTION:  SB

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:    3     0.000E+00
       DEPENDENCIES:    1        15

      REQ. BRANCHES:    2    *    1

        DESCRIPTION:  T2        CD-Fst

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:    4     0.000E+00
       DEPENDENCIES:    1

      REQ. BRANCHES:    2

        DESCRIPTION:  T2

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:    5     0.000E+00
       DEPENDENCIES:    1        15

      REQ. BRANCHES:    3    *    1

        DESCRIPTION:  TC        CD-Fst

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:    6     0.000E+00
        DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
```

```
********  QUESTION:   21  Do the operators turn on the HIS before core degradation?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                                 2750
          BRANCHES:           E2-HIS    E2nHIS
                                1         2
     REALIZED SPLIT:          5.000E-01 5.000E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      0.000E+00
      DEPENDENCIES:    2

     REQ. BRANCHES:    2

       DESCRIPTION:  nSB

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2      1.000E+00
       DESCRIPTION:          Otherwise   --    Station Blackout
 CASE/BRANCH SPLIT:           5.000E-01 5.000E-01


********  QUESTION:   22  Is the containment not vented before core degradation?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                                 2750
          BRANCHES:           E3nVENT   E3VENT
                                1         2
     REALIZED SPLIT:          1.000E+00 0.000E+00

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      0.000E+00
      DEPENDENCIES:    1         15        21

     REQ. BRANCHES:    3    *    2    *    2

       DESCRIPTION:  TC        CD-Slw    E2nHIS

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2      0.000E+00
      DEPENDENCIES:    1         15

     REQ. BRANCHES:    3    *    2

       DESCRIPTION:  TC        CD-Slw

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    3      0.000E+00
      DEPENDENCIES:    1          6        15

     REQ. BRANCHES:    3    *    2    *    1

       DESCRIPTION:  TC        E1-RCIC   CD-Fst

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    4      0.000E+00
      DEPENDENCIES:    2

     REQ. BRANCHES:    2

       DESCRIPTION:  nSB

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00
```

```
CASE NUMBER/SPLIT:    5     1.000E+00
      DESCRIPTION:          Otherwise
CASE/BRANCH SPLIT:          1.000E+00 0.000E+00


********  QUESTION:   23  Does (do) any S/RV tailpipe vacuum breaker(s) stick wide open?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                             4206
         BRANCHES:            oSRVBkr   cSRVBkr
                               1         2
   REALIZED SPLIT:          2.417E-01 7.583E-01

                   SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     5.202E-02
     DEPENDENCIES:    4

    REQ. BRANCHES:    1

      DESCRIPTION:  E1SORV

CASE/BRANCH SPLIT:          0.000E+00 5.202E-02

CASE NUMBER/SPLIT:    2     9.480E-01
     DEPENDENCIES:   20         20         14

    REQ. BRANCHES: (  1    +    3)   *   /4

      DESCRIPTION:  Fst-SB    Fst-T2   /E1-Dep

CASE/BRANCH SPLIT:          2.417E-01 7.063E-01

CASE NUMBER/SPLIT:    3     0.000E+00
     DEPENDENCIES:   20         20         20         14

    REQ. BRANCHES: (  2    +    4    +    6)   *   /4

      DESCRIPTION:  Slw-SB    Slw-T2    Slw-TC   /E1-Dep

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    4     0.000E+00
     DEPENDENCIES:   20

    REQ. BRANCHES:    5

      DESCRIPTION:  Fst-TC

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    5     0.000E+00
      DESCRIPTION:          Otherwise
CASE/BRANCH SPLIT:          0.000E+00 0.000E+00


********  QUESTION:   24  Does ac power remain lost during core degradation?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                          7792
         BRANCHES:            E4fAC     E4-AC
                               1         2
   REALIZED SPLIT:          3.752E-01 6.248E-01

                   SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     0.000E+00
     DEPENDENCIES:    3

    REQ. BRANCHES:    1

      DESCRIPTION:  E1fDC
```

```
CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    2     0.000E+00
     DEPENDENCIES:    2        15

    REQ. BRANCHES:    1    *    2

      DESCRIPTION:  SB        CD-S1w

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    3     1.000E+00
     DEPENDENCIES:    2

    REQ. BRANCHES:    1

      DESCRIPTION:  SB

CASE/BRANCH SPLIT:          3.752E-01 6.248E-01

CASE NUMBER/SPLIT:    4     0.000E+00
      DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          0.000E+00 0.000E+00


********  QUESTION:   25  Is dc power available during core degradation?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                             7792
          BRANCHES:            E4fDC     E4-DC
                                 1          2
   REALIZED SPLIT:          0.000E+00 1.000E+00

                   SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     0.000E+00
     DEPENDENCIES:    3

    REQ. BRANCHES:    1

      DESCRIPTION:  E1fDC

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    2     6.248E-01
     DEPENDENCIES:   24

    REQ. BRANCHES:    2

      DESCRIPTION:  E4-AC

CASE/BRANCH SPLIT:          0.000E+00 6.248E-01

CASE NUMBER/SPLIT:    3     0.000E+00
     DEPENDENCIES:    2        15

    REQ. BRANCHES:    1    *    2

      DESCRIPTION:  SB        CD-S1w

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    4     3.752E-01
      DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          0.000E+00 3.752E-01

********  QUESTION:   26  What is the RPV pressure during core degradation?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                            12792
```

```
         BRANCHES:          E4-HiP   E4-LoP
                              1        2
   REALIZED SPLIT:          2.465E-01 7.535E-01

                   SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     0.000E+00
     DEPENDENCIES:   14        25

    REQ. BRANCHES:    4    *    2

      DESCRIPTION:  E1-Dep    E4 'C

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    2     5.201E-02
     DEPENDENCIES:    4

    REQ. BRANCHES:    1

      DESCRIPTION:  E1SORV

CASE/BRANCH SPLIT:          0.000E+00 5.201E-02

CASE NUMBER/SPLIT:    3     0.000E+00
     DEPENDENCIES:   14        25

    REQ. BRANCHES:    1    +    1

      DESCRIPTION:  E1fDep    E4fDC

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    4     9.480E-01
     DEPENDENCIES:    2        14

    REQ. BRANCHES:    1    *    3

      DESCRIPTION:  SB        E1nDep

CASE/BRANCH SPLIT:          2.465E-01 7.015E-01

CASE NUMBER/SPLIT:    5     0.000E+00
     DEPENDENCIES:   21         1         1         15         22         15

    REQ. BRANCHES:    1    *(   2    +    3    *(   2    *    2    +    1))

      DESCRIPTION:  E2-HIS    T2        TC        CD-Slw    E3VENT    CD-Fst

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    6     0.000E+00
      DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          0.000E+00 0.000E+00


******** QUESTION:   27  What is the status of the HIS before vessel breach?
Q-TYPE/TIMES ASKED:      DEP. INPUT PROB.                              14890
         BRANCHES:          E4-HIS   E4nHIS
                              1        2
   REALIZED SPLIT:          2.125E-01 7.875E-01

                   SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     5.000E-01
     DEPENDENCIES:   21

    REQ. BRANCHES:    2
```

```
      DESCRIPTION:  E2nHIS

CASE/BRANCH SPLIT:          0.000E+00 5.000E-01

CASE NUMBER/SPLIT:    2     0.000E+00
     DEPENDENCIES:    2

    REQ. BRANCHES:    2

      DESCRIPTION:  nSB

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    3     1.876E-01
     DEPENDENCIES:   24

    REQ. BRANCHES:    1

      DESCRIPTION:  E4fAC

CASE/BRANCH SPLIT:          1.876E-01 0.000E+00

CASE NUMBER/SPLIT:    4     7.699E-02
     DEPENDENCIES:   20        26        14        25

    REQ. BRANCHES:    1    *    1    *    3    *    2

      DESCRIPTION:  Fst-SB    E4-HiP    E1nDep    E4-DC

CASE/BRANCH SPLIT:          9.851E-03 6.714E-02

CASE NUMBER/SPLIT:    5     2.354E-01
     DEPENDENCIES:   20        26

    REQ. BRANCHES:    1    *    2

      DESCRIPTION:  Fst-SB    E4-LoP

CASE/BRANCH SPLIT:          1.505E-02 2.203E-01

CASE NUMBER/SPLIT:    6     0.000E+00
     DEPENDENCIES:   20

    REQ. BRANCHES:    2

      DESCRIPTION:  Slw-SB

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    7     0.000E+00
      DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

********  QUESTION:   28  Is RPV injection restored during core degradation?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                          17334
          BRANCHES:            E4nLPI    E4-LPI    E4-HPI
                                 1         2         3
    REALIZED SPLIT:          1.286E-01 2.466E-01 6.248E-01

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     6.248E-01
     DEPENDENCIES:    5        24

    REQ. BRANCHES:    2    *    2
```

```
      DESCRIPTION:  E1rHPInj  E4-AC

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 6.248E-01

CASE NUMBER/SPLIT:     2      9.248E-02
     DEPENDENCIES:    26

   REQ. BRANCHES:      1

      DESCRIPTION:  E4-HIP

CASE/BRANCH SPLIT:            9.248E-02 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:     3      0.000E+00
     DEPENDENCIES:     9          24

   REQ. BRANCHES:    /1    *     2

      DESCRIPTION: /E1fLPC     E4-AC

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:     4      0.000E+00
     DEPENDENCIES:     8          24          20          27

   REQ. BRANCHES:    /1    *     2     *    /1     *     2

      DESCRIPTION: /E1fCond    E4-AC     /Fst-SB     E4nHIS

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:     5      0.000E+00
     DEPENDENCIES:     8          24          20

   REQ. BRANCHES:    /1    *     2     *    /1

      DESCRIPTION: /E1fCond    E4-AC     /Fst-SB

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:     6      0.000E+00
     DEPENDENCIES:     8          24          27

   REQ. BRANC. S:    /1    *     2     *     2

      DESCRIPTION: /E1fCond    E4-AC      E4nHIS

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:     7      0.000E+00
     DEPENDENCIES:     8          24

   REQ. BRANCHES:    /1    *     2

      DESCRIPTION: /E1fCond    E4-AC

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:     8      2.827E-01
     DEPENDENCIES:    12          20          24          27          24

   REQ. BRANCHES:      3    *     1    *(    2     *     2     +     1)

      DESCRIPTION:  E1aFWS     Fst-SB     E4-AC      E4nHIS     E4fAC

CASE/BRANCH SPLIT:            3.616E-02 2.466E-01 0.000E+00

CASE NUMBER/SPLIT:     9      0.000E+00
```

```
      DEPENDENCIES:  12        20

     REQ. BRANCHES:   3    *    1

       DESCRIPTION:  E1aFWS    Fst-SB

 CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:  10     0.000E+00
       DESCRIPTION:        Otherwise
 CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00


******** QUESTION:   29  Is the core in a critical configuration following injection recovery?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                                    22629
          BRANCHES:             E4-Crit   E4nCrit
                                  1         2
    REALIZED SPLIT:            8.661E-03 9.913E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:   1     0.000E+00
      DEPENDENCIES:   1        28

     REQ. BRANCHES:   3    *    2

       DESCRIPTION:  TC        E4-LPI

 CASE/BRANCH SPLIT:            0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:   2     8.714E-01
      DEPENDENCIES:  28        28

     REQ. BRANCHES:   2    *    3

       DESCRIPTION:  E4-LPI    E4-HPI

 CASE/BRANCH SPLIT:            8.661E-03 8.627E-01

 CASE NUMBER/SPLIT:   3     1.286E-01
       DESCRIPTION:        Otherwise
 CASE/BRANCH SPLIT:            0.000E+00 1.286E-01


******** QUESTION:   30  What is the status of containment sprays?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                                    22629
          BRANCHES:             E4fCS     E4rCS     E4aCS     E4-CS
                                  1         2         3         4
    REALIZED SPLIT:            0.000E+00 3.752E-01 6.248E-01 0.000E+00

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:   1     0.000E+00
      DEPENDENCIES:  13

     REQ. BRANCHES:   1

       DESCRIPTION:  E1fCSS

 CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:   2     3.752E-01
      DEPENDENCIES:  13        24

     REQ. BRANCHES:   2    *    1

       DESCRIPTION:  E1rCSS    E4fAC
```

```
CASE/BRANCH SPLIT:          0.000E+00 3.752E-01 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    3     0.000E+00
     DEPENDENCIES:    1        15

    REQ. BRANCHES:    3    *    2

      DESCRIPTION:  TC        CD-S1w

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    4     0.000E+00
     DEPENDENCIES:   20        24

    REQ. BRANCHES:    2    *    2

      DESCRIPTION:  S1w-SB    E4-AC

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    5     6.248E-01
      DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 6.248E-01 0.000E+00


********  QUESTION:   31  What amount of Oxygen is in the wetwell during core degradation?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB. INPUT PARM.             22629
          BRANCHES:           O2WW
                                1
    REALIZED SPLIT:         1.000E+00


********  QUESTION:   32  What amount of Oxygen is in the drywell during core degradation?
Q-TYPE/TIMES ASKED:       INDEP. INPUT PROB. INPUT PARM.             22629
          BRANCHES:           O2DW
                                1
    REALIZED SPLIT:         1.000E+00


********  QUESTION:   33  What amount of steam is present in the containment at core damage?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB. INPUT PARM.               22629
          BRANCHES:           H2OWW
                                1
    REALIZED SPLIT:         1.000E+00

                      SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     0.000E+00
     DEPENDENCIES:   16        22

    REQ. BRANCHES:    3    +    2

      DESCRIPTION:  E1L3      E3VENT

CASE/BRANCH SPLIT:          0.000E+00

CASE NUMBER/SPLIT:    2     0.000E+00
     DEPENDENCIES:    1        15

    REQ. BRANCHES:    3    *    2

      DESCRIPTION:  TC        CD-S1w

CASE/BRANCH SPLIT:          0.000E+00

CASE NUMBER/SPLIT:    3     0.000E+00
     DEPENDENCIES:   10        13
```

```
     REQ. BRANCHES:    4    *    4

       DESCRIPTION:  E1-RHR    E1-CSS

CASE/BRANCH SPLIT:            0.000E+00

CASE NUMBER/SPLIT:    4     0.000E+00
     DEPENDENCIES:    2         14         15

     REQ. BRANCHES:    1    *    1    *    2

       DESCRIPTION:  SB         ElfDep    CD-Slw

CASE/BRANCH SPLIT:            0.000E+00

CASE NUMBER/SPLIT:    5     0.000E+00
     DEPENDENCIES:   20

     REQ. BRANCHES:    2

       DESCRIPTION:  Slw-SB

CASE/BRANCH SPLIT:            0.000E+00

CASE NUMBER/SPLIT:    6     1.000E+00
      DESCRIPTION:          Otherwise
CASE/BRANCH SPLIT:          1.000E+00


********  QUESTION:   34  What amount of steam is present in the drywell at core damage?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB. INPUT PARM.                 22629
          BRANCHES:             H2ODW
                                  1
    REALIZED SPLIT:          1.000E+00

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     2.416E-01
     DEPENDENCIES:   23

     REQ. BRANCHES:    1

       DESCRIPTION:  oSRVBkr

CASE/BRANCH SPLIT:            2.416E-01

CASE NUMBER/SPLIT:    2     0.000E+00
     DEPENDENCIES:    1         15

     REQ. BRANCHES:    3    *    2

       DESCRIPTION:  TC         CD-Slw

CASE/BRANCH SPLIT:            0.000E+00

CASE NUMBER/SPLIT:    3     0.000E+00
     DEPENDENCIES:   10         13

     REQ. BRANCHES:    4    *    4

       DESCRIPTION:  E1-RHR    E1-CSS

CASE/BRANCH SPLIT:            0.000E+00

CASE NUMBER/SPLIT:    4     0.000E+00
     DEPENDENCIES:    2         14         15

     REQ. BRANCHES:    1    *    1    *    2
```

```
        DESCRIPTION:  SB        ElfDep    CD-Slw

 CA' 'BRANCH SPLIT:             0.000E+00

 C      MBER/SPLIT:    5        0.000E+00
        /ENDENCIES:   20

      REQ. BRANCHES:    2

        DESCRIPTION:  Slw-SB

  CASE/BRANCH SPLIT:            0.000E+00

  CASE NUMBER/SPLIT:    6       7.584E-01
        DESCRIPTION:           Otherwise
  CASE/BRANCH SPLIT:            7.584E-01


 ********  QUESTION:   35  Total amount of hydrogen released in-vessel during core degradation?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB. INPUT PARM.                 22629
           BRANCHES:            In-VsH2
                                   1
     REALIZED SPLIT:            1.000E+00

                     SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1       0.000E+00
       DEPENDENCIES:    1          28

      REQ. BRANCHES:    3    *     2

        DESCRIPTION:  TC        E4-LPI

  CASE/BRANCH SPLIT:            0.000E+00

  CASE NUMBER/SPLIT:    2       0.000E+00
       DEPENDENCIES:    1

      REQ. BRANCHES:    3

        DESCRIPTION:  TC

  CASE/BRANCH SPLIT:            0.000E+00

  CASE NUMBER/SPLIT:    3       8.714E-01
       DEPENDENCIES:   14          28         28

      REQ. BRANCHES:   /4    *(    2    +     3)

        DESCRIPTION: /E1-Dep    E4-LPI    E4-HPI

  CASE/BRANCH SPLIT:            8.714E-01

  CASE NUMBER/SPLIT:    4       0.000E+00
       DEPENDENCIES:   28          28

      REQ. BRANCHES: (  2     +     3)

        DESCRIPTION:  E4-LPI    E4-HPI

  CASE/BRANCH SPLIT:            0.000E+00

  CASE NUMBER/SPLIT:    5       9.248E-02
       DEPENDENCIES:   26

      REQ. BRANCHES:    1
```

```
      DESCRIPTION:  E4-HIP

 CASE/BRANCH SPLIT:            9.248E-02

 CASE NUMBER/SPLIT:    6     3.617E-02
      DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:            3.617E-02


********  QUESTION:    36  What is the level of In-Vessel zirconium oxidation?
Q-TYPE/TIMES ASKED:        INDEP. CALC. PROB.                           22629
          BRANCHES:            ZrOx75    ZrOx50    ZrOx40    ZrOx30    ZrOx21    ZrOx10    ZrOx<10
                                 1         2         3         4         5         6         7
   REALIZED SPLIT:             0.000E+00 3.546E-02 1.134E-01 1.448E-01 1.455E-01 2.043E-01 3.566E-01


********  QUESTION:    37  What is the containment pressure during core damage?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                             22629
          BRANCHES:            E1P>3     E1P>2     E1P>1
                                 1         2         3
   REALIZED SPLIT:             0.000E+00 0.000E+00 1.000E+00

                       SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     0.000E+00
     DEPENDENCIES:    16         22

    REQ. BRANCHES:     3    +    2

      DESCRIPTION:  E1L3       E3VENT

 CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2     0.000E+00
     DEPENDENCIES:     1         15

    REQ. BRANCHES:     3    *    2

      DESCRIPTION:  TC         CD-Slw

 CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    3     0.000E+00
     DEPENDENCIES:    10         13

    REQ. BRANCHES:     4    *    4

      DESCRIPTION:  E1-RHR     E1-CSS

 CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    4     0.000E+00
     DEPENDENCIES:    20         30

    REQ. BRANCHES:     2    *    4

      DESCRIPTION:  Slw-SB     E4-CS

 CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    5     0.000E+00
     DEPENDENCIES:     2         14        15

    REQ. BRANCHES:     1    *    1    *    2

      DESCRIPTION:  SB         E1fDep    CD-Slw

 CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00
```

```
 CASE NUMBER/SPLIT:    6     0.000E+00
      DEPENDENCIES:   20

     REQ. BRANCHES:    2

       DESCRIPTION:  Slw-SB

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    7     1.000E+00
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 1.000E+00


******** QUESTION:   38  What is the level of containment leakage due to slow pressurization before VB?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                                22629
          BRANCHES:            ESPnCL    ESP-CL2   ESP-CL3   ESP-CL4
                                 1          2         3         4
    REALIZED SPLIT:          1.000E+00 0.000E+00 0.000E+00 0.000E+00

                     SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     0.000E+00
      DEPENDENCIES:   16        22

     REQ. BRANCHES:    3   +    2

       DESCRIPTION:  E1L3      E3VENT

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2     0.000E+00
      DEPENDENCIES:    1        15

     REQ. BRANCHES:    3   *    2

       DESCRIPTION:  TC        CD-Slw

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    3     0.000E+00
      DEPENDENCIES:    2        14        15

     REQ. BRANCHES:    1   *    1    *    2

       DESCRIPTION:  SB        ElfDep    CD-Slw

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    4     1.000E+00
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          1.000E+00 0.000E+00 0.000E+00 0.000E+00


******** QUESTION:   39  What is the maximum hydrogen concentration in the wetwell before VB?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                              22629
          BRANCHES:            HWW>20    HWW>16    HWW>12    HWW>8     HWW>4     NoHWW
                                 1          2         3         4         5         6
    REALIZED SPLIT:          4.051E-01 9.151E-02 9.311E-02 9.812E-02 8.479E-02 2.274E-01

                     SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     0.000E+00
      DEPENDENCIES:   23        20

     REQ. BRANCHES:    1   *    6
```

```
        DESCRIPTION:  oSRVBkr   Slw-TC

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:     2     0.000E+00
      DEPENDENCIES:   23        16        38        38

     REQ. BRANCHES:     1    *(   3    +    3    +    4)

        DESCRIPTION:  oSRVBkr   E1L3      ESP-CL3   ESP-CL4

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:     3     0.000E+00
      DEPENDENCIES:   20

     REQ. BRANCHES:     6

        DESCRIPTION:  Slw-TC

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:     4     0.000E+00
      DEPENDENCIES:   16        38        38

     REQ. BRANCHES: (   3    +    3    +    4)

        DESCRIPTION:  E1L3      ESP-CL3   ESP-CL4

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:     5     2.416E-01
      DEPENDENCIES:   23

     REQ. BRANCHES:     1

        DESCRIPTION:  oSRVBkr

 CASE/BRANCH SPLIT:          9.549E-02 2.185E-02 2.359E-02 2.539E-02 1.739E-02 5.794E-02

 CASE NUMBER/SPLIT:     6     0.000E+00
      DEPENDENCIES:   17

     REQ. BRANCHES:     3

        DESCRIPTION:  E1-SPB3

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:     7     7.584E-01
       DESCRIPTION:          Otherwise -- Nominal or small leakage into drywell
 CASE/BRANCH SPLIT:          3.096E-01 6.966E-02 6.953E-02 7.273E-02 6.740E-02 1.695E-01


********  QUESTION:    40  To what level is the wetwell inert during core degradation?
Q-TYPE/TIMES ASKED:        INDEP. CALC. PROB.                                22629
          BRANCHES:            E4nWIn    E4-WIn2   E4-WIn3
                                 1         2         3
    REALIZED SPLIT:            1.000E+00 0.000E+00 0.000E+00


********  QUESTION:    41  Do diffusion flames consume the hydrogen released before VB?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                                  29846
          BRANCHES:            E4-Dif    E4nDif
                                 1         2
    REALIZED SPLIT:            3.900E-02 9.610E-01

                         SUMMARY BY CASE
```

```
 CASE NUMBER/SPLIT:    1      0.000E+00
      DEPENDENCIES:   40        20

     REQ. BRANCHES:    3   +    6

       DESCRIPTION:  E4-WIn3   Slw-TC

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2      0.000E+00
      DEPENDENCIES:    2        21

     REQ. BRANCHES:    2   *    1

       DESCRIPTION:  nSB       E2-HIS

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    3      0.000E+00
      DEPENDENCIES:    2

     REQ. BRANCHES:    2

       DESCRIPTION:  nSB

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    4      2.487E-02
      DEPENDENCIES:    2        24        27

     REQ. BRANCHES:    1   *    2   *    1

       DESCRIPTION:  SB        E4-AC     E4-HIS

 CASE/BRANCH SPLIT:           2.966E-03 2.190E-02

 CASE NUMBER/SPLIT:    5      5.999E-01
      DEPENDENCIES:    2        24

     REQ. BRANCHES:    1   *    2

       DESCRIPTION:  SB        E4-AC

 CASE/BRANCH SPLIT:           3.603E-02 5.639E-01

 CASE NUMBER/SPLIT:    6      3.752E-01
       DESCRIPTION:          Otherwise -- Low Pressure station blackout without recovery
 CASE/BRANCH SPLIT:           0.000E+00 3.752E-01


******** QUESTION:   42  What is the maximum hydrogen concentration in the drywell before VB?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                              29846
          BRANCHES:           HDW>20    HDW>16    HDW>12    HDW         HDW>4     NoHDW
                                1         2         3         4           5         6
    REALIZED SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.000E+00

                     SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      0.000E+00
      DEPENDENCIES:   23        20

     REQ. BRANCHES:    1   *    6

       DESCRIPTION:  oSRVBkr   Slw-TC

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
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CASE NUMBER/SPLIT:    2      0.000E+00
     DEPENDENCIES:   23         16         38         38

   REQ. BRANCHES:    1     *(    3     +     3     +     4)

      DESCRIPTION:  oSRVBkr   E1L3      ESP-CL3   ESP-CL4

CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    3      2.416E-01
     DEPENDENCIES:   23

   REQ. BRANCHES:    1

      DESCRIPTION:  oSRVBkr

CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.416E-01

CASE NUMBER/SPLIT:    4      0.000E+00
     DEPENDENCIES:   17         41

   REQ. BRANCHES:    3     *     2

      DESCRIPTION:  E1-SPB3   E4nDif

CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    5      2.494E-04
     DEPENDENCIES:   17         41

   REQ. BRANCHES:    2     *     2

      DESCRIPTION:  E1-SPB2   E4nDif

CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.494E-04

CASE NUMBER/SPLIT:    6      7.581E-01
      DESCRIPTION:           Otherwise -- Nominal leakage into drywell only
CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 7.581E-01


********  QUESTION:   43  Do deflagrations occur in the WW prior to vessel breach?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                              36564
         BRANCHES:           E4-WWDf   E4nWWDf
                               1          2
   REALIZED SPLIT:           6.129E-01 3.871E-01

                     SUMMARY BY CASE

CASE NUMBER/SPLIT:    1      3.900E-02
     DEPENDENCIES:   41         40         20

   REQ. BRANCHES:    1     +     3     +     6

      DESCRIPTION:  E4-Dif    E4-WIn3   Slw-TC

CASE/BRANCH SPLIT:           0.000E+00 3.900E-02

CASE NUMBER/SPLIT:    2      1.670E-01
     DEPENDENCIES:   25          4         39

   REQ. BRANCHES: (  2     *     2)    *     6

      DESCRIPTION:  E4-LoP    E1nSORV   NoHWW

CASE/BRANCH SPLIT:           0.000E+00 1.670E-01

CASE NUMBER/SPLIT:    3      4.784E-01
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      DEPENDENCIES:   24

     REQ. BRANCHES:    2

       DESCRIPTION:  E4-AC

CASE/BRANCH SPLIT:            4.784E-01 0.000E+00

CASE NUMBER/SPLIT:    4      4.881E-03
     DEPENDENCIES:   26          14          4        39

     REQ. BRANCHES: (  1     +   /4     *     1)    *    6

       DESCRIPTION:  E4-HiP    /E1-Dep     E1SORV    NoHWW

CASE/BRANCH SPLIT:            1.053E-03 3.828E-03

CASE NUMBER/SPLIT:    5      6.234E-03
     DEPENDENCIES:   26          14          4        39

     REQ. BRANCHES: (  1     +   /4     *     1)    *    5

       DESCRIPTIUN:  E4-HiP    /E1-Dep     E1SORV    HWW>4

CASE/BRANCH SPLIT:            1.323E-03 4.911E-03

CASE NUMBER/SPLIT:    6      2.137E-02
     DEPENDENCIES:   39

     REQ. BRANCHES:    5

       DESCRIPTION:  HWW>4

CASE/BRANCH SPLIT:            3.813E-03 1.756E-02

CASE NUMBER/SPLIT:    7      [illegible]
     DEPENDENCIES:   26          14          4        39

     REQ. BRANCHES: (  1     +   /4     *     1)    *    4

       DESCRIPTION:  E4-HiP    /E1-Dep     E1SORV    HWW>8

CASE/BRANCH SPLIT:            3.036E-03 8.210E-03

CASE NUMBER/SPLIT:    8      2.573E-02
     DEPENDENCIES:   39

     REQ. BRANCHES:    4

       DESCRIPTION:  HWW>8

CASE/BRANCH SPLIT:            7.809E-03 1.792E-02

CASE NUMBER/SPLIT:    9      1.222E-02
     DEPENDENCIES:   26          14          4        39

     REQ. BRANCHES: (  1     +   /4     *     1)    *    3

       DESCRIPTION:  E4-HiP    /E1-Dep     E1SORV    HWW>12

CASE/BRANCH SPLIT:            4.771E-03 7.445E-03

CASE NUMBER/SPLIT:   10      2.489E-02
     DEPENDENCIES:   39

     REQ. BRANCHES:    3

       DESCRIPTION:  HWW>12
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CASE/BRANCH SPLIT:          1.022E-02 1.467E-02

CASE NUMBER/SPLIT:   11     7.741E-02
     DEPENDENCIES:   26        14         4         39         39

    REQ. BRANCHES: (  1    +   /4    *    1)   *(   2    +    1)

      DESCRIPTION:  E4-HiP   /E1-Dep    E1SORV    HWW>16    HWW>20

CASE/BRANCH SPLIT:          3.861E-02 3.879E-02

CASE NUMBER/SPLIT:   12     1.316E-01
     DEPENDENCIES:   39        39

    REQ. BRANCHES: (  2    +    1)

      DESCRIPTION:  HWW>16    HWW>20

CASE/BRANCH SPLIT:          6.387E-02 6.768E-02

CASE NUMBER/SPLIT:   13     0.000E+00
      DESCRIPTION:          Otherwise
CASE/BRANCH SPLIT:          0.000E+00 0.000E+00


********  QUESTION:   44  Is there a detonation in the wetwell prior to vessel breach?
Q-TYPE/TIMES ASKED:       DEF. INPUT PROB. INPUT PARM.                  44444
          BRANCHES:             E4-WWDt   E4nWWDt
                                   1         2
    REALIZED SPLIT:          1.535E-01 8.465E-01

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     4.103E-01
     DEPENDENCIES:   40        30         40         39         39         39

    REQ. BRANCHES:    2    *   /4    +    3    +    4    +    5    +    6

      DESCRIPTION:  E4-WIn2  /E4-CS     E4-WIn3   HWW>8     HWW>4      NoHWW

CASE/BRANCH SPLIT:          0.000E+00 4.103E-01

CASE NUMBER/SPLIT:    2     0.000E+00
     DEPENDENCIES:   43        39         40         30

    REQ. BRANCHES:    1    *    3    *(   2    *    4)

      DESCRIPTION:  E4-WWDf   HWW>12    E4-WIn2   E4-CS

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    3     6.774E-02
     DEPENDENCIES:   43        39

    REQ. BRANCHES:    1    *    3

      DESCRIPTION:  E4-WWDf   HWW>12

CASE/BRANCH SPLIT:          0.000E+00 6.774E-02

CASE NUMBER/SPLIT:    4     0.000E+00
     DEPENDENCIES:   43        39         40         30

    REQ. BRANCHES:    1    *    2    *(   2    *    4)

      DESCRIPTION:  E4-WWDf   HWW>16    E4-WIn2   E4-CS
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CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    5     6.640E-02
     DEPENDENCIES:   43        39

    REQ. BRANCHES:    1    *    2

      DESCRIPTION:  E4-WWDf   HWW>16

CASE/BRANCH SPLIT:          1.692E-02 4.948E-02

CASE NUMBER/SPLIT:    6     0.000E+00
     DEPENDENCIES:   43        39         40         30

    REQ. BRANCHES:    1    *    1    *(   2    *    4)

      DESCRIPTION:  E4-WWDf   HWW>20    E4-WIn2   E4-CS

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    7     3.056E-01
     DEPENDENCIES:   43        39

    REQ. BRANCHES:    1    *    1

      DESCRIPTION:  E4-WWDf   HWW>20

CASE/BRANCH SPLIT:          1.366E-01 1.690E-01

CASE NUMBER/SPLIT:    8     1.499E-01
      DESCRIPTION:         Otherwise  --  No combustion
CASE/BRANCH SPLIT:          0.000E+00 1.499E-01


********  QUESTION:   45  What is the level of containment impulse load before vessel breach?
Q-TYPE/TIMES ASKED:       INDEP. CALC. PROB.                          44444
          BRANCHES:           E-Ip>60   E-Ip>50   E-Ip>40   E-Ip>30   E-Ip>20   E-Ip>10   E-Ip<10
                                 1         2         3         4         5         6         7
    REALIZED SPLIT:         8.328E-05 1.811E-03 3.286E-03 4.625E-03 1.852E-02 5.276E-02 9.189E-01


********  QUESTION:   46  With what efficiency is hydrogen burned prior to VB?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB. INPUT PARM.                44444
          BRANCHES:           H2EfBVB
                                 1
    REALIZED SPLIT:         1.000E+00

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     3.871E-01
     DEPENDENCIES:   43

    REQ. BRANCHES:    2

      DESCRIPTION:  E4nWWDf

CASE/BRANCH SPLIT:          3.871E-01

CASE NUMBER/SPLIT:    2     0.000E+00
     DEPENDENCIES:   40        39

    REQ. BRANCHES:    2    *    6

      DESCRIPTION:  E4-WIn2   NoHWW

CASE/BRANCH SPLIT:          0.000E+00

CASE NUMBER/SPLIT:    3     4.644E-02
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```
      DEPENDENCIES:   39

     REQ. BRANCHES:    6

       DESCRIPTION:  NoHWW

 CASE/BRANCH SPLIT:             4.644E-02

 CASE NUMBER/SPLIT:    4      0.000E+00
      DEPENDENCIES:   40          39

     REQ. BRANCHES:    2     *     5

       DESCRIPTION:  E4-WIn2   HWW>4

 CASE/BRANCH SPLIT:             0.000E+00

 CASE NUMBER/SPLIT:    5      5.881E-02
      DEPENDENCIES:   39

     REQ. BRANCHES:    5

       DESCRIPTION:  HWW>4

 CASE/BRANCH SPLIT:             5.881E-02

 CASE NUMBER/SPLIT:    6      0.000E+00
      DEPENDENCIES:   40          39

     REQ. BRANCHES:    2     *     4

       DESCRIPTION:  E4-WIn2   HWW>8

 CASE/BRANCH SPLIT:             0.000E+00

 CASE NUMBER/SPLIT:    7      6.792E-02
      DEPENDENCIES:   39

     REQ. BRANCHES:    4

       DESCRIPTION:  HWW>8

 CASE/BRANCH SPLIT:             6.792E-02

 CASE NUMBER/SPLIT:    8      0.000E+00
      DEPENDENCIES:   40          39

     REQ. BRANCHES:    2     *     3

       DESCRIPTION:  E4-WIn2   HWW>12

 CASE/BRANCH SPLIT:             0.000E+00

 CASE NUMBER/SPLIT:    9      6.774E-02
      DEPENDENCIES:   39

     REQ. BRANCHES:    3

       DESCRIPTION:  HWW>12

 CASE/BRANCH SPLIT:             6.774E-02

 CASE NUMBER/SPLIT:   10      0.000E+00
      DEPENDENCIES:   40          39          39

     REQ. BRANCHES:    2     *(   2     +     1)

       DESCRIPTION:  E4-WIn2   HWW>16     HWW>20
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```
 CASE/BRANCH SPLIT:          0.000E+00

 CASE NUMBER/SPLIT:   11     3.720E-01
      DEPENDENCIES:   39        39

     REQ. BRANCHES: (  2    +    1)

       DESCRIPTION:  HWW>16    HWW>20

 CASE/BRANCH SPLIT:          3.720E-01

 CASE NUMBER/SPLIT:   12     0.000E+00
       DESCRIPTION:        Otherwise
 CASE/BRANCH SPLIT:          0.000E+00


******** QUESTION:   47  What is the peak pressure in containment from a hydrogen burn?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                              44444
          BRANCHES:            PBrn>7    PBrn>6    PBrn>5    PBrn>4    PBrn>3    PBrn<3
                                 1         2         3         4         5         6
   REALIZED SPLIT:           2.458E-02 2.843E-02 4.510E-02 7.687E-02 5.686E-02 7.682E-01

                     SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     3.481E-01
      DEPENDENCIES:   41        43

     REQ. BRANCHES:    2    *    2

       DESCRIPTION:  E4nDif    E4nWWDf

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.481E-01

 CASE NUMBER/SPLIT:    2     3.900E-02
      DEPENDENCIES:   16        22         38         38         41

     REQ. BRANCHES:    3    +    2    +    3    +    4    +    1

       DESCRIPTION:  E1L3      E3VENT    ESP-CL3   ESP-CL4   E4-Dif

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.900E-02

 CASE NUMBER/SPLIT:    3     1.535E-01
      DEPENDENCIES:   44

     REQ. BRANCHES:    1

       DESCRIPTION:  E4-WWDt

 CASE/BRANCH SPLIT:          1.132E-02 1.165E-02 1.421E-02 2.832E-02 6.145E-03 8.187E-02

 CASE NUMBER/SPLIT:    4     4.594E-01
       DESCRIPTION:        Otherwise
 CASE/BRANCH SPLIT:          1.326E-02 1.678E-02 3.089E-02 4.854E-02 5.072E-02 2.992E-01


******** QUESTION:   48  What is the level of drywell leakage induced by an early detonation in containment?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                              44444
          BRANCHES:            EnDWDt    E-DWDt2   E-DWDt3
                                 1         2         3
   REALIZED SPLIT:           9.826E-01 1.413E-02 3.318E-03

                     SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     1.535E-01
      DEPENDENCIES:   44
```

```
     REQ. BRANCHES:    1

       DESCRIPTION:  E4-WWDt

  CASE/BRANCH SPLIT:          1.361E-01 1.413E-02 3.318E-03

  CASE NUMBER/SPLIT:    2     8.465E-01
        DESCRIPTION:         Otherwise
  CASE/BRANCH SPLIT:          8.465E-01 0.000E+00 0.000E+00


******** QUESTION:    49  What is the level of containment leakage induced by an early detonation?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                                   44444
          BRANCHES:            E4nDtF    E4-DtF2   E4-DtF3
                                 1          2         3
    REALIZED SPLIT:           9.460E-01 3.384E-02 2.011E-02

                     SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     1.745E-02
       DEPENDENCIES:   48         48

     REQ. BRANCHES:    2    +    3

       DESCRIPTION:  E-DWDt2   E-DWDt3

  CASE/BRANCH SPLIT:          0.000E+00 7.537E-03 9.910E-03

  CASE NUMBER/SPLIT:    2     1.361E-01
       DEPENDENCIES:   44

     REQ. BRANCHES:    1

       DESCRIPTION:  E4-WWDt

  CASE/BRANCH SPLIT:          9.956E-02 2.630E-02 1.020E-02

  CASE NUMBER/SPLIT:    3     8.465E-01
        DESCRIPTION:         Otherwise
  CASE/BRANCH SPLIT:          8.465E-01 0.000E+00 0.000E+00


******** QUESTION:    50  What is the level of containment leakage before vessel breach?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                                   44444
          BRANCHES:            E5nCL     E5-CL2    E5-CL3    E5-CL4
                                 1          2         3         4
    REALIZED SPLIT:           7.706E-01 5.978E-02 1.696E-01 0.000E+00

                     SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     2.011E-02
       DEPENDENCIES:   16         22         38         38         49

     REQ. BRANCHES:    3    +    2    +    3    +    4    +    3

       DESCRIPTION:  E1L3      E3VENT    ESP-CL3   ESP-CL4   E4-DtF3

  CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 2.011E-02 0.000E+00

  CASE NUMBER/SPLIT:    2     2.444E-03
       DEPENDENCIES:   16         38         43

     REQ. BRANCHES: (  2    +    2)   *    2

       DESCRIPTION:  E1L2      ESP-CL2   E4nWWDf

  CASE/BRANCH SPLIT:          0.000E+00 2.444E-03 0.000E+00 0.000E+00
```

```
  CASE NUMBER/SPLIT:     3     3.740E-02
       DEPENDENCIES:    16         49          38

      REQ. BRANCHES:     2    +    2    +    2

        DESCRIPTION:  E1L2      E4-DtF2   ESP-CL2

  CASE/BRANCH SPLIT:           0.000E+00 2.287E-02 1.453E-02 0.000E+00

  CASE NUMBER/SPLIT:     4     9.400E-01
        DESCRIPTION:          Otherwise
  CASE/BRANCH SPLIT:           7.706E-01 3.447E-02 1.349E-01 0.000E+00


******** QUESTION:    51  What is the level of drywell leakage induced by containment pressurization?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                               44444
          BRANCHES:             EnDWDf    E-DWDf2   E-DWHDf2  E-DWDf3   E-DWHDf3
                                  1         2         3         4         5
    REALIZED SPLIT:            9.045E-01 5.895E-02 0.000E+00 3.652E-02 0.000E+00

                      SUMMARY BY CASE

  CASE NUMBER/SPLIT:     1     3.318E-03
       DEPENDENCIES:    17         48

      REQ. BRANCHES:     3    +    3

        DESCRIPTION:  E1-SPB3   E-DWDt3

  CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 3.318E-03 0.000E+00

  CASE NUMBER/SPLIT:     2     4.407E-05
       DEPENDENCIES:    17         50          50

      REQ. BRANCHES:     2    *(   3    +    4)

        DESCRIPTION:  E1-SPB2   E5-CL3    E5-CL4

  CASE/BRANCH SPLIT:           0.000E+00 3.502E-05 0.000E+00 9.049E-06 0.000E+00

  CASE NUMBER/SPLIT:     3     1.662E-01
       DEPENDENCIES:    50         50

      REQ. BRANCHES:     3    +    4

        DESCRIPTION:  E5-CL3    E5-CL4

  CASE/BRANCH SPLIT:           8.394E-02 4.907E-02 0.000E+00 3.320E-02 0.000E+00

  CASE NUMBER/SPLIT:     4     2.216E-04
       DEPENDENCIES:    17

      REQ. BRANCHES:     2

        DESCRIPTION:  E1-SPB2

  CASE/BRANCH SPLIT:           0.000E+00 2.216E-04 0.000E+00 0.000E+00 0.000E+00

  CASE NUMBER/SPLIT:     5     8.302E-01
        DESCRIPTION:          Otherwise
  CASE/BRANCH SPLIT:           8.206E-01 9.621E-03 0.000E+00 0.000E+00 0.000E+00


******** QUESTION:    52  What is the level of suppression pool bypass following early combustion events
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                               44444
          BRANCHES:             E5nSPB    E5-SPB2   E5-SPB3
                                  1         2         3
    REALIZED SPLIT:            8.692E-01 7.000E-02 6.079E-02
```

```
                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    1      3.652E-02
     DEPENDENCIES:   17         48         51         51

    REQ. BRANCHES:    3    +    3    +    4    +    5

      DESCRIPTION:  E1-SPB3   E-DWDt3   E-DWDf3   E-DWHDf3

CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 3.652E-02

CASE NUMBER/SPLIT:    2      1.389E-04
     DEPENDENCIES:   17         24         41         43

    REQ. BRANCHES:    2    *    2    *(   1    +    1)

      DESCRIPTION:  E1-SPB2   E4-AC     E4-Dif    E4-WWDf

CASE/BRANCH SPLIT:           0.000E+00 1.305E-04 8.417E-06

CASE NUMBER/SPLIT:    3      6.987E-02
     DEPENDENCIES:   17         48         51         51

    REQ. BRANCHES:    2    +    2    +    2    +    3

      DESCRIPTION:  E1-SPB2   E-DWDt2   E-DWDf2   E-DWHDf2

CASE/BRANCH SPLIT:           0.000E+00 6.987E-02 0.000E+00

CASE NUMBER/SPLIT:    4      4.403E-01
     DEPENDENCIES:   24         41         43

    REQ. BRANCHES:    2    *(   1    +    1)

      DESCRIPTION:  E4-AC     E4-Dif    E4-WWDf

CASE/BRANCH SPLIT:           4.160E-01 0.000E+00 2.426E-02

CASE NUMBER/SPLIT.    5      4.532E-01
      DESCRIPTION:          Otherwise
CASE/BRANCH SPLIT:           4.532E-01 0.000E+00 0.000E+00


********  QUESTION:   53  Has the upper pool dumped?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                        44444
          BRANCHES:            UPDmp     noUPDmp
                                 1          2
    REALIZED SPLIT:           6.248E-01 3.752E-01

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    1      6.248E-01
     DEPENDENCIES:   24

    REQ. BRANCHES:    2

      DESCRIPTION:  E4-AC

CASE/BRANCH SPLIT:           6.248E-01 0.000E+00

CASE NUMBER/SPLIT:    2      3.752E-01
      DESCRIPTION:          Otherwise
CASE/BRANCH SPLIT:           0.000E+00 3.752E-01


********  QUESTION:   54  Is there water in the reactor cavity?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                        49060
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         BRANCHES:            E5-DFld  E5-DWet  E5-DDry
                                 1        2        3
   REALIZED SPLIT:            5.167E-01 3.009E-01 1.824E-01

                 SUMMARY BY CASE

CASE NUMBER/SPLIT:    1      0.000E+00
     DEPENDENCIES:   51

    REQ. BRANCHES:    5

      DESCRIPTION:  E-DWHDf3

CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    2      1.695E-01
     DEPENDENCIES:   16        22        38        38        50        50

    REQ. BRANCHES:   /3    *    1    *   /3    *   /4    *(   3    +    4)

      DESCRIPTION: /E1L3       E3nVENT  /ESP-CL3  /ESP-CL4   E5-CL3    E5-CL4

CASE/BRANCH SPLIT:           1.679E-01 1.654E-03 0.000E+00

CASE NUMBER/SPLIT:    3      3.381E-01
     DEPENDENCIES:   16        22        43        39        39

    REQ. BRANCHES:   /3    *    1    *    1    *   /6    *   /5

      DESCRIPTION: /E1L3       E3nVENT   E4-WWDf  /NoHWW     /HWW>4

CASE/BRANCH SPLIT:           3.378E-01 2.854E-04 0.000E+00

CASE NUMBER/SPLIT:    4      0.000E+00
     DEPENDENCIES:   16        22        17        41        30        39        39        24

    REQ. BRANCHES:   /3    *    1    *   /3    *    1    *   /4    *   /5    *   /6    *    1

      DESCRIPTION: /E1L3       E3nVENT  /E1-SPB3   E4-Dif    /E4-CS    /HWW>4    /NoHWW     E4fAC

CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    5      2.130E-02
     DEPENDENCIES:   16        22        17        53        39        39        39

    REQ. BRANCHES:   /3    *    1    *   /3    *    1    *(   1    +    2    +    3)

      DESCRIPTION: /E1L3       E3nVENT  /E1-SPB3   UPDmp     HWW>20    HWW>16    HWW>12

CASE/BRANCH SPLIT:           1.103E-02 1.027E-02 0.000E+00

CASE NUMBER/SPLIT:    6      0.000E+00
     DEPENDENCIES:   20

    REQ. BRANCHES:    2

      DESCRIPTION:  S1w-SB

CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    7      2.242E-01
     DEPENDENCIES:   53

    REQ. BRANCHES:    1

      DESCRIPTION:  UPDmp

CASE/BRANCH SPLIT:           0.000E+00 2.242E-01 0.000E+00
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 CASE NUMBER/SPLIT:    8     1.286E-01
      DEPENDENCIES:   16         22        24        17        39        39        39

     REQ. BRANCHES:   /3    *    1    *    1    *   /3    *(   1    +    2    +    3)

       DESCRIPTION: /E1L3      E3nVENT   E4fAC    /E1-SPB3  HWW>20    HWW>16    HWW>12

 CASE/BRANCH SPLIT:          0.000E+00 6.449E-02 6.412E-02

 CASE NUMBER/SPLIT:    9     1.183E-01
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 1.183E-01


********  QUESTION:   55  What is the containment pressure before vessel breach?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                            49060
          BRANCHES:           E5P>3     E5P>2     E5P>1
                               1         2         3
    REALIZED SPLIT:          0.000E+00 0.000E+00 1.000E+00

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     2.293E-01
      DEPENDENCIES:   50

     REQ. BRANCHES:   /1

       DESCRIPTION: /E5nCL

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 2.293E-01

 CASE NUMBER/SPLIT:    2     0.000E+00
      DEPENDENCIES:   52         30

     REQ. BRANCHES:    3    *    4

       DESCRIPTION:  E5-SPB3   E4-CS

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    3     1.905E-02
      DEPENDENCIES:   52

     REQ. BRANCHES:    3

       DESCRIPTION:  E5-SPB3

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 1.905E-02

 CASE NUMBER/SPLIT:    4     0.000E+00
      DEPENDENCIES:   30

     REQ. BRANCHES:    4

       DESCRIPTION:  E4-CS

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    5     7.516E-01
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 7.516E-01


********  QUESTION:   56  To what level is the DW steam inert at vessel breach?
Q-TYPE/TIMES ASKED:       INDEP. CALC. PROB.                          49060
          BRANCHES:           E5nDIn    E5-DIn2   E5-DIn3
                               1         2         3
```

```
   REALIZED SPLIT:          9.217E-01 7.304E-02 5.305E-03

******** QUESTION:   57  Is there sufficient H2 for combustion/detonation in the DW before VB?
Q-TYPE/TIMES ASKED:      INDEP. CALC. PROB.                                   49060
          BRANCHES:           E5cDWDt   E5cDWDf   E5nDWC
                                 1         2         3
   REALIZED SPLIT:          5.891E-04 3.445E-03 9.960E-01

******** QUESTION:   58  Does an Alpha Mode Event fail both the vessel and the containment?
Q-TYPE/TIMES ASKED:      DEP. INPUT PROB.                                     52427
          BRANCHES:           Alpha     noAlpha
                                1         2
   REALIZED SPLIT:          7.901E-03 9.921E-01

                   SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     2.464E-01
      DEPENDENCIES:   26

     REQ. BRANCHES:    1

       DESCRIPTION:  E4-HiP

 CASE/BRANCH SPLIT:          2.368E-04 2.462E-01

 CASE NUMBER/SPLIT:    2     7.536E-01
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          7.664E-03 7.459E-01

******** QUESTION:   59  What fraction of the core participates in core slump?
Q-TYPE/TIMES ASKED:      DEP. INPUT PROB.                                     52427
          BRANCHES:           HiSL      MedSL     LowSL
                                1         2         3
   REALIZED SPLIT:          1.360E-01 0.000E+00 8.640E-01

                   SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     7.901E-03
      DEPENDENCIES:   58

     REQ. BRANCHES:    1

       DESCRIPTION:  Alpha

 CASE/BRANCH SPLIT:          7.901E-03 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2     1.538E-01
      DEPENDENCIES:   26        28

     REQ. BRANCHES:    1    *    3

       DESCRIPTION:  E4-HiP    E4-HPI

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 1.538E-01

 CASE NUMBER/SPLIT:    3     0.000E+00
      DEPENDENCIES:   26         7        24

     REQ. BRANCHES:    1    *(  /1    *    2)

       DESCRIPTION:  E4-HiP   /E1fCRD    E4-AC

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    4     9.237E-02
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```
      DEPENDENCIES:   26

     REQ. BRANCHES:    1

       DESCRIPTION:  E4-HiP

 CASE/BRANCH SPLIT:           9.237E-02 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    5      7.101E-01
      DEPENDENCIES:   28        28

     REQ. BRANCHES: (  2    +    3)

       DESCRIPTION:  E4-LPI    E4-HPI

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 7.101E-01

 CASE NUMBER/SPLIT:    6      0.000E+00
      DEPENDENCIES:    7        24

     REQ. BRANCHES: ( /1    *    2)

       DESCRIPTION: /E1fCRD    E4-AC

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    7      3.575E-02
       DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:           3.575E-02 0.000E+00 0.000E+00

********  QUESTION:   60  Is there a large in-vessel steam explosion?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                           80884
          BRANCHES:           VesStx    nVesSTx
                                1         2
    REALIZED SPLIT:           6.741E-01 3.259E-01

                     SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      7.903E-03
      DEPENDENCIES:   58

     REQ. BRANCHES:    1

       DESCRIPTION:  Alpha

 CASE/BRANCH SPLIT:           7.903E-03 0.000E+00

 CASE NUMBER/SPLIT:    2      2.462E-01
      DEPENDENCIES:   26

     REQ. BRANCHES:    1

       DESCRIPTION:  E4-HiP

 CASE/BRANCH SPLIT:           2.453E-02 2.216E-01

 CASE NUMBER/SPLIT:    3      7.459E-01
       DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:           6.417E-01 1.042E-01

********  QUESTION:   61  What fraction of the core debris would be mobile at vessel breach?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB. INPUT PARM.               80884
          BRANCHES:           HiLiqVB   LoLiqVB
                                1         2
    REALIZED SPLIT:           3.390E-02 9.661E-01
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```
                    SUMMARY BY CASE

CASE NUMBER/SPLIT:     1      8.714E-01
     DEPENDENCIES:     7        24        28        28

    REQ. BRANCHES: ( /1    *    2)   +    2    +    3

      DESCRIPTION: /E1fCRD    E4-AC     E4-LPI    E4-HPI

CASE/BRANCH SPLIT:            2.080E-02 8.506E-01

CASE NUMBER/SPLIT:     2      9.245E-02
     DEPENDENCIES:    26

    REQ. BRANCHES:     1

      DESCRIPTION:  E4-HiP

CASE/BRANCH SPLIT:            9.421E-03 8.303E-02

CASE NUMBER/SPLIT:     3      3.610E-02
      DESCRIPTION:           Otherwise -- Low pressure with no injection
CASE/BRANCH SPLIT:            3.680E-03 3.242E-02


********  QUESTION:    62  Does a large in-vessel steam explosion fail the vessel?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                              80884
          BRANCHES:            SE-Alpha  SE-BtHd   SE-LgBrch SE-SmBrch SE-nFail
                                   1         2          3         4         5
    REALIZED SPLIT:            7.903E-03 1.340E-01 1.340E-01 2.008E-01 5.233E-01

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:     1      7.903E-03
     DEPENDENCIES:    58

    REQ. BRANCHES:     1

      DESCRIPTION:  Alpha

CASE/BRANCH SPLIT:            7.903E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:     2      6.662E-01
     DEPENDENCIES:    60

    REQ. BRANCHES:     1

      DESCRIPTION:  VesStx

CASE/BRANCH SPLIT:            0.000E+00 1.340E-01 1.340E-01 2.008E-01 1.974E-01

CASE NUMBER/SPLIT:     3      3.259E-01
      DESCRIPTION:           Otherwise
CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.259E-01

********  QUESTION:    63  What is the mode of vessel breach?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                              80884
          BRANCHES:             A-Fail    BH-Fail   LgBrch    SmBrch    nBreach
                                   1         2         3         4         5
    REALIZED SPLIT:            7.903E-03 1.855E-01 1.384E-01 3.430E-01 3.251E-01

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:     1      7.903E-03
     DEPENDENCIES:    58

    REQ. BRANCHES:     1
```

```
      DESCRIPTION:  Alpha

CASE/BRANCH SPLIT:          7.903E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    2     1.340E-01
     DEPENDENCIES:   62

    REQ. BRANCHES:    2

      DESCRIPTION:  SE-BtHd

CASE/BRANCH SPLIT:          0.000E+00 1.340E-01 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    3     1.340E-01
     DEPENDENCIES:   62

    REQ. BRANCHES:    3

      DESCRIPTION:  SE-LgBrch

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 1.340E-01 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    4     2.008E-01
     DEPENDENCIES:   62

    REQ. BRANCHES:    4

      DESCRIPTION:  SE-SmBrch

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 2.008E-01 0.000E+00

CASE NUMBER/SPLIT:    5     5.608E-03
     DEPENDENCIES:   28         28         61         29

    REQ. BRANCHES: (  2    +    3)    *    1    *    2

      DESCRIPTION:  E4-LPI    E4-HPI    HiLiqVB   E4nCrit

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 2.818E-03 2.790E-03

CASE NUMBER/SPLIT:    6     8.733E-03
     DEPENDENCIES:   26         61

    REQ. BRANCHES:    1    *    1

      DESCRIPTION:  E4-HiP    HiLiqVB

CASE/BRANCH SPLIT:          0.000E+00 2.103E-03 0.000E+00 6.629E-03 0.000E+00

CASE NUMBER/SPLIT:    7     1.273E-03
     DEPENDENCIES:   61

    REQ. BRANCHES:    1

      DESCRIPTION:  HiLiqVB

CASE/BRANCH SPLIT:          0.000E+00 2.396E-04 0.000E+00 1.033E-03 0.000E+00

CASE NUMBER/SPLIT:    8     4.138E-01
     DEPENDENCIES:   28         28         29

    REQ. BRANCHES: (  2    +    3)    *    2

      DESCRIPTION:  E4-LPI    E4-HPI    E4nCrit

CASE/BRANCH SPLIT:          0.000E+00 2.426E-02 4.247E-03 6.294E-02 3.223E-01
```

```
CASE NUMBER/SPLIT:    9     7.853E-02
     DEPENDENCIES:   26

     REQ. BRANCHES:    1

       DESCRIPTION:  E4-HiP

CASE/BRANCH SPLIT:          0.000E+00 2.106E-02 0.000E+00 5.747E-02 0.000E+00

CASE NUMBER/SPLIT:   10     1.536E-02
       DESCRIPTION:        Otherwise -- Low press., no steam explosion, no injection
CASE/BRANCH SPLIT:          0.000E+00 3.921E-03 1.351E-04 1.130E-02 0.000E+00


******** QUESTION:   64  Does high pressure melt ejection occur?
Q-TYPE/TIMES ASKED:      DEP. INPUT PROB.                           80884
          BRANCHES:            HPME      nHPME
                                1          2
   REALIZED SPLIT:          1.130E-01 8.870E-01

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     8.592E-01
     DEPENDENCIES:   58         63         26

     REQ. BRANCHES:    1    +     5    +    2

       DESCRIPTION:  Alpha     nBreach   E4-LoP

CASE/BRANCH SPLIT:          0.000E+00 8.592E-01

CASE NUMBER/SPLIT:    2     2.412E-03
     DEPENDENCIES:   63         63         61

     REQ. BRANCHES: (  2    +     3)    *    1

       DESCRIPTION:  BH-Fail   LgBrch    HiLiqVB

CASE/BRANCH SPLIT:          2.069E-03 3.431E-04

CASE NUMBER/SPLIT:    3     4.016E-02
     DEPENDENCIES:   63         63

     REQ. BRANCHES: (  2    +     3)

       DESCRIPTION:  BH-Fail   LgBrch

CASE/BRANCH SPLIT:          3.368E-02 6.483E-03

CASE NUMBER/SPLIT:    4     9.030E-03
     DEPENDENCIES:   61

     REQ. BRANCHES:    1

       DESCRIPTION:  HiLiqVB

CASE/BRANCH SPLIT:          7.959E-03 1.071E-03

CASE NUMBER/SPLIT:    5     8.916E-02
       DESCRIPTION:        Otherwise
CASE/BRANCH SPLIT:          6.928E-02 1.988E-02


******** QUESTION:   65  Does a detonation occur in the DW at vessel breach?
Q-TYPE/TIMES ASKED:      DEP. INPUT PROB. INPUT PARM.               80884
          BRANCHES:            I-DWDt    InDWDt
                                1          2
   REALIZED SPLIT:          4.984E-04 9.995E-01
```

```
                         SUMMARY BY CASE

   CASE NUMBER/SPLIT:    1      4.984E-04
        DEPENDENCIES:   56          57         63

       REQ. BRANCHES:    1   *    1    *   /5

         DESCRIPTION:  E5nDIn    E5cDWDt  /nBreach

   CASE/BRANCH SPLIT:           4.984E-04 0.000E+00

   CASE NUMBER/SPLIT:    2      9.995E-01
         DESCRIPTION:          Otherwise
   CASE/BRANCH SPLIT:           0.000E+00 9.995E-01


******** QUESTION:   66  Does a deflagration occur in the DW at vessel breach?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                                80884
          BRANCHES:              I-DWDf     InDWDf
                                   1          2
    REALIZED SPLIT:             2.844E-04 9.997E-01

                         SUMMARY BY CASE

   CASE NUMBER/SPLIT:    1      2.844E-04
        DEPENDENCIES:   56          57         63         65

       REQ. BRANCHES:   /3   *   /3    *   /5    *    2

         DESCRIPTION: /E5-DIn3  /E5nDWC   /nBreach   InDWDt

   CASE/BRANCH SPLIT:           2.844E-04 0.000E+00

   CASE NUMBER/SPLIT:    2      9.997E-01
         DESCRIPTION:          Otherwise
   CASE/BRANCH SPLIT:           0.000E+00 9.997E-01


******** QUESTION:   67  Does a large ex-vessel steam explosion occur?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                               109901
          BRANCHES:              ExSE      nExSE
                                   1          2
    REALIZED SPLIT:             5.303E-01 4.696E-01

                         SUMMARY BY CASE

   CASE NUMBER/SPLIT:    1      3.777E-01
        DEPENDENCIES:   58          63         54         28

       REQ. BRANCHES:    1   +    5    +(   3    *     1)

         DESCRIPTION:  Alpha      nBreach   E5-DDry   E4nLPI

   CASE/BRANCH SPLIT:           0.000E+00 3.777E-01

   CASE NUMBER/SPLIT:    2      8.568E-02
        DEPENDENCIES:   64

       REQ. BRANCHES:    1

         DESCRIPTION:  HPME

   CASE/BRANCH SPLIT:           6.861E-02 1.707E-02

   CASE NUMBER/SPLIT:    3      5.366E-01
         DESCRIPTION:          Otherwise
   CASE/BRANCH SPLIT:           4.617E-01 7.489E-02
```

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******** QUESTION:   68  What amount of H2 is released at vessel breach?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB. INPUT PARM.              109901
        BRANCHES:            H2VB
                               1
    REALIZED SPLIT:          1.000E+00

                    SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1      3.332E-01
       DEPENDENCIES:   63         63

      REQ. BRANCHES:    1    +     5

        DESCRIPTION:  A-Fail    nBreach

  CASE/BRANCH SPLIT:           3.332E-01

  CASE NUMBER/SPLIT:    2      0.000E+00
       DEPENDENCIES:    1        28

      REQ. BRANCHES:    3    *     2

        DESCRIPTION:  TC        E4-LPI

  CASE/BRANCH SPLIT:           0.000E+00

  CASE NUMBER/SPLIT.    3      0.000E+00
       DEPENDENCIES:    1

      REQ. BRANCHES:    3

        DESCRIPTION:  TC

  CASE/BRANCH SPLIT:           0.000E+00

  CASE NUMBER/SPLIT:    4      5.388E-01
       DEPENDENCIES:   14        28         28

      REQ. BRANCHES:   /4    *(   2    +    3)

        DESCRIPTION: /E1-Dep    E4-LPI    E4-HPI

  CASE/BRANCH SPLIT:           5.388E-01

  CASE NUMBER/SPLIT:    5      0.000E+00
       DEPENDENCIES:   28        28

      REQ. BRANCHES: (  2    +     3)

        DESCRIPTION:  E4-LPI    E4-HPI

  CASE/BRANCH SPLIT:           0.000E+00

  CASE NUMBER/SPLIT:    6      9.235E-02
       DEPENDENCIES:   26

      REQ. BRANCHES:    1

        DESCRIPTION:  E4-HiP

  CASE/BRANCH SPLIT:           9.235E-02

  CASE NUMBER/SPLIT:    7      3.568E-02
        DESCRIPTION:          Otherwise -- Low Pressure no injection recovery
  CASE/BRANCH SPLIT:           3.568E-02
```

```
******** QUESTION:   69  How much hydrogen is released at vessel breach?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                                109901
          BRANCHES:           H2VB>50   H2VB>25   H2VB>10   H2VB<10
                                 1         2         3         4
    REALIZED SPLIT:          0.000E+00 4.053E-02 6.047E-01 3.548E-01

                     SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     5.746E-01
       DEPENDENCIES:   64         67

     REQ. BRANCHES: (  1    +     1)

       DESCRIPTION:  HPME       ExSE

  CASE/BRANCH SPLIT:         0.000E+00 3.747E-02 5.372E-01 0.000E+00

  CASE NUMBER/SPLIT:    2     4.253E-01
        DESCRIPTION:        Otherwise
  CASE/BRANCH SPLIT:         0.000E+00 3.053E-03 6.748E-02 3.548E-01


******** QUESTION:   70  What is the peak drywell/wetwell pressure difference resulting from VB?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB. INPUT PARM.                 109901
          BRANCHES:          DPDWVB
                                1
    REALIZED SPLIT:          1.000E+00

                     SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     3.332E-01
       DEPENDENCIES:   63         63

     REQ. BRANCHES:    1    +     5

       DESCRIPTION:  A-Fail     nBreach

  CASE/BRANCH SPLIT:          3.332E-01

  CASE NUMBER/SPLIT:    2     9.915E-04
       DEPENDENCIES:   26         61          63          63          54          54

     REQ. BRANCHES:    1    *     1    *(    2    +     3)   *(    1    +     2)

       DESCRIPTION:  E4-HiP     HiLiqVB   BH-Fail    LgBrch     E5-DFld   E5-DWet

  CASE/BRANCH SPLIT:          9.915E-04

  CASE NUMBER/SPLIT:    3     6.462E-03
       DEPENDENCIES:   26         61          54          54

     REQ. BRANCHES:    1    *     1    *(    1    +     2)

       DESCRIPTION:  E4-HiP     HiLiqVB   E5-DFld    E5-DWet

  CASE/BRANCH SPLIT:          6.462E-03

  CASE NUMBER/SPLIT:    4     1.421E-03
       DEPENDENCIES:   26         61          63          63

     REQ. BRANCHES:    1    *     1    *(    2    +     3)

       DESCRIPTION:  E4-HiP     HiLiqVB   BH-Fail    LgBrch

  CASE/BRANCH SPLIT:          1.421E-03

  CASE NUMBER/SPLIT:    5     2.566E-03
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    DEPENDENCIES:  26        61

   REQ. BRANCHES:   1    *    1

     DESCRIPTION:  E4-HiP    HiLiqVB

CASE/BRANCH SPLIT:           2.566E-03

CASE NUMBER/SPLIT:   6     3.166E-02
     DEPENDENCIES:  26        63        63        54        54

   REQ. BRANCHES:   1    *(   2    +    3)   *(   1    +    2)

     DESCRIPTION:  E4-HiP    BH-Fail   LgBrch    E5-DFld   E5-DWet

CASE/BRANCH SPLIT:           3.166E-02

CASE NUMBER/SPLIT:   7     6.885E-02
     DEPENDENCIES:  26        54        54

   REQ. BRANCHES:   1    *(   1    +    2)

     DESCRIPTION:  E4-HiP    E5-DFld   E5-DWet

CASE/BRANCH SPLIT:           6.885E-02

CASE NUMBER/SPLIT:   8     8.465E-03
     DEPENDENCIES:  26        63        63

   REQ. BRANCHES:   1    *(   2    +    3)

     DESCRIPTION:  E4-HiP    BH-Fail   LgBrch

CASE/BRANCH SPLIT:           8.465E-03

CASE NUMBER/SPLIT:   9     2.026E-02
     DEPENDENCIES:  26

   REQ. BRANCHES:   1

     DESCRIPTION:  E4-HiP

CASE/BRANCH SPLIT:           2.026E-02

CASE NUMBER/SPLIT:  10     4.529E-03
     DEPENDENCIES:  61        63        63        54        54

   REQ. BRANCHES:   1    *(   2    +    3)   *(   1    +    2)

     DESCRIPTION:  HiLiqVB   BH-Fail   LgBrch    E5-DFld   E5-DWet

CASE/BRANCH SPLIT:           4.529E-03

CASE NUMBER/SPLIT:  11     9.826E-03
     DEPENDENCIES:  61        54        54

   REQ. BRANCHES:   1    *(   1    +    2)

     DESCRIPTION:  HiLiqVB   E5-DFld   E5-DWet

CASE/BRANCH SPLIT:           9.826E-03

CASE NUMBER/SPLIT:  12     2.230E-01
     DEPENDENCIES:  63        63        54        54

   REQ. BRANCHES: (  2    +    3)   *(   1    +    2)

     DESCRIPTION:  BH-Fail   LgBrch    E5-DFld   E5-DWet
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CASE/BRANCH SPLIT:          2.230E-01

CASE NUMBER/SPLIT:   13     1.840E-01
     DEPENDENCIES:   54        54

    REQ. BRANCHES: (  1    +    2)

      DESCRIPTION:  E5-DFld   E5-DWet

CASE/BRANCH SPLIT:          1.840E-01

CASE NUMBER/SPLIT:   14     1.048E-01
      DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          1.048E-01


********  QUESTION:   71  What is the peak pedestal pressure at vessel breach?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB. INPUT PARM.            109901
          BRANCHES:           Ped-VBP
                                 1
   REALIZED SPLIT:          1.000E+00

                   SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     3.332E-01
     DEPENDENCIES:   63        63

    REQ. BRANCHES:    1    +    5

      DESCRIPTION:  A-Fail    nBreach

CASE/BRANCH SPLIT:          3.332E-01

CASE NUMBER/SPLIT:    2     9.915E-04
     DEPENDENCIES:   26        61         63         63         54         54

    REQ. BRANCHES:    1    *    1    *(   2    +    3)   *(   1    +    2)

      DESCRIPTION:  E4-HiP    HiLiqVB   BH-Fail    LgBrch    E5-DFld    E5-DWet

CASE/BRANCH SPLIT:          9.915E-04

CASE NUMBER/SPLIT:    3     6.462E-03
     DEPENDENCIES:   26        61         54         54

    REQ. BRANCHES:    1    *    1    *(   1    +    2)

      DESCRIPTION:  E4-HiP    HiLiqVB   E5-DFld   E5-DWet

CASE/BRANCH SPLIT.          6.462E-03

CASE NUMBER/SPLIT:    4     1.421E-03
     DEPENDENCIES:   26        61         63         63

    REQ. BRANCHES:    1    *    1    *(   2    +    3)

      DESCRIPTION:  E4-HiP    HiLiqVB   BH-Fail    LgBrch

CASE/BRANCH SPLIT:          1.421E-03

CASE NUMBER/SPLIT:    5     2.566E-03
     DEPENDENCIES:   26        61

    REQ. BRANCHES:    1    *    1

      DESCRIPTION:  E4-HiP    HiLiqVB
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CASE/BRANCH SPLIT:          2.566E-03

CASE NUMBER/SPLIT:    6     3.166E-02
     DEPENDENCIES:   26         63         63         54         54

    REQ. BRANCHES:    1    *(   2    +     3)   *(    1    +     2)

      DESCRIPTION:  E4-HiP    BH-Fail   LgBrch    E5-DFld   E5-DWet

CASE/BRANCH SPLIT:          3.166E-02

CASE NUMBER/SPLIT:    7     6.885E-02
     DEPENDENCIES:   26         54         54

    REQ. BRANCHES:    1    *(   1    +     2)

      DESCRIPTION:  E4-HiP    E5-DFld   E5-DWet

CASE/BRANCH SPLIT:          6.885E-02

CASE NUMBER/SPLIT:    8     8.465E-03
     DEPENDENCIES:   26         63         63

    REQ. BRANCHES:    1    *(   2    +     3)

      DESCRIPTION:  E4-HiP    BH-Fail   LgBrch

CASE/BRANCH SPLIT:          8.465E-03

CASE NUMBER/SPLIT:    9     2.026E-02
     DEPENDENCIES:   26

    REQ. BRANCHES:    1

      DESCRIPTION:  E4-HiP

CASE/BRANCH SPLIT:          2.026E-02

CASE NUMBER/SPLIT:   10     2.708E-03
     DEPENDENCIES:   36         36         63         63         54         54         61

    REQ. BRANCHES: ( /6    *   /7)   *(   2    +     3)   *(   1    +     2)   *     1

      DESCRIPTION: /ZrOx10    /ZrOx<10   BH-Fail    LgBrch    E5-DFld   E5-DWet   HiLiqVB

CASE/BRANCH SPLIT:          2.708E-03

CASE NUMBER/SPLIT:   11     4.073E-03
     DEPENDENCIES:   36         36         54         54         61

    REQ. BRANCHES: ( /6    *   /7)   *(   1    +     2)   *     1

      DESCRIPTION: /ZrOx10    /ZrOx<10   E5-DFld   E5-DWet   HiLiqVB

CASE/BRANCH SPLIT:          4.073E-03

CASE NUMBER/SPLIT:   12     1.821E-03
     DEPENDENCIES:   63         63         54         54         61

    REQ. BRANCHES: (  2    +     3)   *(   1    +     2)   *     1

      DESCRIPTION:  BH-Fail   LgBrch    E5-DFld   E5-DWet   HiLiqVB

CASE/BRANCH SPLIT:          1.821E-03

CASE NUMBER/SPLIT:   13     5.754E-03
     DEPENDENCIES:   54         54         61
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      REQ. BRANCHES: (  1     +     2)    *     1

         DESCRIPTION:  E5-DFld   E5-DWet   HiLiqVB

 CASE/BRANCH SPLIT:             5.754E-03

 CASE NUMBER/SPLIT:   14      1.039E-01
      DEPENDENCIES:   36         36         63         63         54         54

      REQ. BRANCHES: ( /6     *    /7)   *(    2     +     3)   *(    1     +     2)

         DESCRIPTION: /ZrOx10    /ZrOx<10   BH-Fail   LgBrch    E5-DFld   E5-DWet

 CASE/BRANCH SPLIT:             1.039E-01

 CASE NUMBER/SPLIT:   15      9.235E-02
      DEPENDENCIES:   36         36         54         54

      REQ. BRANCHES: ( /6     *    /7)   *(    1     +     2)

         DESCRIPTION: /ZrOx10    /ZrOx<10   E5-DFld   E5-DWet

 CASE/BRANCH SPLIT:             9.235E-02

 CASE NUMBER/SPLIT:   16      1.191E-01
      DEPENDENCIES:   63         63         54         54

      REQ. BRANCHES: (  2     +     3)   *(    1     +     2)

         DESCRIPTION:  BH-Fail   LgBrch    E5-DFld   E5-DWet

 CASE/BRANCH SPLIT:             1.191E-01

 CASE NUMBER/SPLIT:   17      9.161E-02
      DEPENDENCIES:   54         54

      REQ. BRANCHES: (  1     +     2)

         DESCRIPTION:  E5-DFld   E5-DWet

 CASE/BRANCH SPLIT:             9.161E-02

 CASE NUMBER/SPLIT:   18      1.048E-01
       DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:             1.048E-01


******** QUESTION:   72  Is the impulse loading to the drywell at VB sufficient to cause failure?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                             109901
          BRANCHES:             InDWFI    I-DWFI2   I-DWFI3
                                   1         2         3
    REALIZED SPLIT:            9.999E-01 9.723E-05 0.000E+00

                       SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      4.978E-04
      DEPENDENCIES:   65

      REQ. BRANCHES:    1

         DESCRIPTION:  I-DWDt

 CASE/BRANCH SPLIT:            4.006E-04 9.723E-05 0.000E+00

 CASE NUMBER/SPLIT:    2      9.995E-01
       DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:            9.995E-01 0.000E+00 0.000E+00
```

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******** QUESTION:   73  Is drywell pressurization at VB sufficient to cause failure?
Q-TYPE/TIMES ASKED:      INDEP. CALC. PROB.                              109901
          BRANCHES:          InDWOP     I-DWOP2   I-DWHOP2  I-DWOP3   I-DWHOP3
                               1          2          3         4         5
    REALIZED SPLIT:         9.105E-01 2.746E-02 0.000E+00 6.198E-02 0.000E+00

******** QUESTION:   74  Does the RPV pedestal fail due to pressurization at vessel breach?
Q-TYPE/TIMES ASKED:      INDEP. CALC. PROB.                              109901
          BRANCHES:          I-PedFP   InPedFP
                               1          2
    REALIZED SPLIT:         1.689E-01 8.311E-01

******** QUESTION:   75  Does the RPV pedestal fail from an ex-vessel steam explosion (impulse loading)
Q-TYPE/TIMES ASKED:      DEP. INPUT PROB.                                129120
          BRANCHES:          I-PedFI   InPedFI
                               1          2
    REALIZED SPLIT:         2.016E-01 7.983E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      1.689E-01
      DEPENDENCIES:   74

     REQ. BRANCHES:    1

       DESCRIPTION:  I-PedFP

 CASE/BRANCH SPLIT:           0.000E+00 1.689E-01

 CASE NUMBER/SPLIT:    2      4.050E-01
      DEPENDENCIES:   67

     REQ. BRANCHES:    1

       DESCRIPTION:  ExSE

 CASE/BRANCH SPLIT:           2.016E-01 2.034E-01

 CASE NUMBER/SPLIT:    3      4.260E-01
       DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:           0.000E+00 4.260E-01

******** QUESTION:   76  Does the RPV pedestal failure induce drywell failure?
Q-TYPE/TIMES ASKED:      DEP. INPUT PROB.                                129120
          BRANCHES:          I-DWFPed  InDWFPed
                               1          2
    REALIZED SPLIT:         5.398E-02 9.460E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      1.243E-01
      DEPENDENCIES:   52         58         72         73         73

     REQ. BRANCHES:    3    +    1    +    3    +    4    +    5

       DESCRIPTION:  E5-SPB3   Alpha     I-DWFI3   I-DWOP3   I-DWHOP3

 CASE/BRANCH SPLIT:           0.000E+00 1.243E-01

 CASE NUMBER/SPLIT:    2      3.171E-01
      DEPENDENCIES:   74         75

     REQ. BRANCHES:    1    +    1
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       DESCRIPTION:  I-PedFP   I-PedFI

CASE/BRANCH SPLIT:            5.398E-02 2.631E-01

CASE NUMBER/SPLIT:    3      5.586E-01
      DESCRIPTION:          Otherwise
CASE/BRANCH SPLIT:            0.000E+00 5.586E-01


********  QUESTION:   77  What is the pressure in the containment at VB prior to a hydrogen burn?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB. INPUT PARM.             129120
          BRANCHES:           CP-VB
                                1
    REALIZED SPLIT:           1.000E+00

                     SUMMARY BY CASE

CASE NUMBER/SPLIT:    1      4.472E-01
     DEPENDENCIES:   63        63        50        50

    REQ. BRANCHES:    1   +    5    +    3   +    4

      DESCRIPTION:  A-Fail    nBreach   E5-CL3    E5-CL4

CASE/BRANCH SPLIT:           4.472E-01

CASE NUMBER/SPLIT:    2      1.095E-02
     DEPENDENCIES:   52        72        73        73        54        54        26

    REQ. BRANCHES: (  3    +    3    +    4    +    5)   *(   1    +    2)    *    1

      DESCRIPTION:  E5-SPB3   I-DWFI3   I-DWOP3   I-DWHOP3  E5-DFld   E5-DWet   E4-HiP

CASE/BRANCH SPLIT:           1.095E-02

CASE NUMBER/SPLIT:    3      7.790E-04
     DEPENDENCIES:   52        72        73        73        26

    REQ. BRANCHES: (  3    +    3    +    4    +    5)    *    1

      DESCRIPTION:  E5-SPB3   I-DWFI3   I-DWOP3   I-DWHOP3  E4-HiP

CASE/BRANCH SPLIT:           7.790E-04

CASE NUMBER/SPLIT:    4      4.554E-02
     DEPENDENCIES:   52        72        73        73        54        54

    REQ. BRANCHES: (  3    +    3    +    4    +    5)   *(   1    +    2)

      DESCRIPTION:  E5-SPB3   I-DWFI3   I-DWOP3   I-DWHOP3  E5-DFld   E5-DWet

CASE/BRANCH SPLIT:           4.554E-02

CASE NUMBER/SPLIT:    5      0.000E+00
     DEPENDENCIES:   52        72        73        73

    REQ. BRANCHES: (  3    +    3    +    4    +    5)

      DESCRIPTION:  E5-SPB3   I-DWFI3   I-DWOP3   I-DWHOP3

CASE/BRANCH SPLIT:           0.000E+00

CASE NUMBER/SPLIT:    6      2.331E-02
     DEPENDENCIES:   64        67        61

    REQ. BRANCHES: (  1    +    1)    *    1

      DESCRIPTION:  HPME      ExSE      HiLiqVB
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CASE/BRANCH SPLIT:          2.331E-02

CASE NUMBER/SPLIT:    7     3.992E-01
     DEPENDENCIES:   64          67

    REQ. BRANCHES: (  1    +    1)

      DESCRIPTION:  HPME       ExSE

CASE/BRANCH SPLIT:          3.992E-01

CASE NUMBER/SPLIT:    8     7.298E-02
      DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          7.298E-02


********  QUESTION:   78  What is the concentration of hydrogen in containment immediately after VB?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                          129120
          BRANCHES:             IHWW>20   IHWW>16   IHWW>12   IHWW>8    IHWW>4    I-NoHWW
                                 1         2         3         4         5         6
    REALIZED SPLIT:            1.488E-01 3.598E-02 6.082E-02 2.424E-01 2.676E-01 2.443E-01

                     SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     3.332E-01
      DEPENDENCIES:   58          63

     REQ. BRANCHES:    1     +     5

       DESCRIPTION:  Alpha      nBreach

 CASE/BRANCH SPLIT:            2.367E-02 7.766E-03 8.191E-03 1.653E-02 5.087E-02 2.262E-01

 CASE NUMBER/SPLIT:    2     1.013E-01
      DEPENDENCIES:   64          65         66         67         50         50

     REQ. BRANCHES: (  1    +    1    +    1    +    1)   *(   3    +    4)

       DESCRIPTION:  HPME       I-DWDt    I-DWDf     ExSE       E5-CL3     E5-CL4

 CASE/BRANCH SPLIT:            1.561E-03 1.393E-03 3.259E-03 2.747E-02 6.759E-02 0.000E+00

 CASE NUMBER/SPLIT:    3     4.734E-01
      DEPENDENCIES:   64          65         66         67

     REQ. BRANCHES: (  1    +    1    +    1    +    1)

       DESCRIPTION:  HPME       I-DWDt    I-DWDf     ExSE

 CASE/BRANCH SPLIT:            1.066E-01 2.200E-02 4.163E-02 1.901E-01 1.130E-01 0.000E+00

 CASE NUMBER/SPLIT:    4     1.267E-02
      DEPENDENCIES:   28          28         54         54         50         50

     REQ. BRANCHES: (  2    +    3    +    1    +    2)   *(   3    +    4)

       DESCRIPTION:  E4-LPI     E4-HPI    E5-DFld    E5-DWet    E5-CL3     E5-CL4

 CASE/BRANCH S                 3.240E-05 4.853E-05 9.827E-05 2.898E-04 3.189E-03 9.016E-03

 CASE NUMBER/SPLIT:    5     6.214E-02
      DEPENDENCIES:   28          28         54         54

          BRANCHES: (  2    +    3    +    1    +    2)

       DESCRIPTION:  E4-LPI     E4-HPI    E5-DFld    E5-DWet
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 CASE/BRANCH SPLIT:           6.471E-03 1.911E-03 3.686E-03 8.034E-03 3.297E-02 9.074E-03

 CASE NUMBER/SPLIT:    6      0.000E+00
      DEPENDENCIES:   50         50

    REQ. BRANCHES: (  3    +    4)

      DESCRIPTION:  E5-CL3    E5-CL4

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    7      1.728E-02
      DESCRIPTION:           Otherwise
 CASE/BRANCH SPLIT:           1.046E-02 2.855E-03 3.959E-03 2.456E-06 0.000E+00 0.000E+00


********  QUESTION:   79  Is ac power not recovered following vessel breach?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                              170124
          BRANCHES:           IfAC      I-AC
                                1         2
   REALIZED SPLIT:           2.351E-01 7.648E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      6.253E-01
      DEPENDENCIES:   24

    REQ. BRANCHES:    2

      DESCRIPTION:  E4-AC

 CASE/BRANCH SPLIT:           0.000E+00 6.253E-01

 CASE NUMBER/SPLIT:    2      0.000E+00
      DEPENDENCIES:   25

    REQ. BRANCHES:    1

      DESCRIPTION:  E4fDC

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    3      0.000E+00
      DEPENDENCIES:    2         15

    REQ. BRANCHES:    1    *    2

      DESCRIPTION:  SB         CD-Slw

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    4      3.747E-01
      DESCRIPTION:           Otherwise -- Short term blackout w/ no recovery before VB
 CASE/BRANCH SPLIT:           2.351E-01 1.396E-01


********  QUESTION:   80  Is dc power available following vessel breach?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                              187326
          BRANCHES:           IfDC      I-DC
                                1         2
   REALIZED SPLIT:           3.191E-03 9.967E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      0.000E+00
      DEPENDENCIES:   25

    REQ. BRANCHES:    1
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       DESCRIPTION:  E4fDC

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    2     6.256E-01
     DEPENDENCIES:   24

   REQ. BRANCHES:    2

       DESCRIPTION:  E4-AC

CASE/BRANCH SPLIT:          0.000E+00 6.256E-01

CASE NUMBER/SPLIT:    3     0.000E+00
     DEPENDENCIES:    2        15

   REQ. BRANCHES:    1    *    2

       DESCRIPTION:  SB        CD-Slw

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    4     3.743E-01
      DESCRIPTION:         Otherwise -- Short term blackout w/ no recovery before VB
CASE/BRANCH SPLIT:          3.191E-03 3.711E-01

********  QUESTION:   81  What is the status of containment sprays following vessel breach?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                              204304
          BRANCHES:            IfCS      IrCS      IaCS      I-CS
                                 1         2         3         4
    REALIZED SPLIT:           6.573E-02 2.202E-01 6.493E-02 6.291E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     0.000E+00
      DEPENDENCIES:   30

     REQ. BRANCHES:    1

       DESCRIPTION:  E4fCS

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2     2.868E-02
      DEPENDENCIES:   30        79        50        50        16        22

     REQ. BRANCHES:    2    *    1    *(   4    +    3    *(  /3    +    1))

       DESCRIPTION:  E4rCS     IfAC      E5-CL4    E5-CL3    /E1L3     E3nVENT

 CASE/BRANCH SPLIT:          1.484E-02 1.385E-02 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    3     2.064E-01
      DEPENDENCIES:   30        79

     REQ. BRANCHES:    2    *    1

       DESCRIPTION:  E4rCS     IfAC

 CASE/BRANCH SPLIT:          0.000E+00 2.064E-01 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    4     0.000E+00
      DEPENDENCIES:   30        50        50        16        22

     REQ. BRANCHES:    4    *(   4    +    3    *(  /3    +    1))
```

```
      DESCRIPTION:  E4-C5      E5-CL4    E5-CL3    /E1L3      E3nVENT

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    5       0.000E+00
     DEPENDENCIES:   30

    REQ. BRANCHES:    4

      DESCRIPTION:  E4-C5

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    6       [illegible]
     DEPENDENCIES:   79         56         50         16         22

    REQ. BRANCHES:    2     *(   4    +    3    *(  /3    +    1))

      DESCRIPTION:  I-AC       E5-CL4    E5-CL3    /E1L3      E3nVENT

CASE/BRANCH SPLIT:            7.089E-02 0.000E+00 5.915E-02 1.069E-02

CASE NUMBER/SPLIT:    7       6.242E-01
     DEPENDENCIES:   79

    REQ. BRANCHES:    2

      DESCRIPTION:  I-AC

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 [illegible] 6.184E-01

CASE NUMBER/SPLIT:    8       0.000E+00
      DESCRIPTION:           Otherwise
CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00 0.000E+00


********  QUESTION:   82  To what level is the wetwell inert after vessel breach?
Q-TYPE/TIMES ASKED:       INDEP. CALC. PROB.                       204304
          BRANCHES:          InWWIn    I-WWIn2   I-WWIn3
                               1         2         3
   REALIZED SPLIT:            9.723E-01 2.775E-02 0.000E+00


********  QUESTION:   83  Is there sufficient oxygen in the containment to support combustion
Q-TYPE/TIMES ASKED:       INDEP. CALC. PROB.                       204304
          BRANCHES:          O2Det20   O2Det16   O2Det12   WWO2      nWWO2
                               1         2         3         4         5
   REALIZED SPLIT:            6.036E-01 7.096E-02 6.818E-02 4.143E-02 2.158E-01


********  QUESTION:   84  Does ignition occur in the containment at vessel breach?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                         234274
          BRANCHES:          I-CIgn    InCIgn
                               1         2
   REALIZED SPLIT:            4.428E-01 5.571E-01

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    1       4.059E-01
     DEPENDENCIES:   78         82         83

    REQ. BRANCHES:    6    +    3    +    5

      DESCRIPTION:  I-NoHWW   I-WWIn3   nWWO2

CASE/BRANCH SPLIT:            0.000E+00 4.059E-01

CASE NUMBER/SPLIT:    2       3.441E-01
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```
      DEPENDENCIES:   24        52        52        72        73

     REQ. BRANCHES:    2    +    2    +    3    +   /1    +   /1

       DESCRIPTION:  E4-AC     E5-SPB2   E5-SPB3  /InDWFI   /InDWDP

 CASE/BRANCH SPLIT:           3.441E-01 0.000E+00

 CASE NUMBER/SPLIT:    3      9.745E-02
      DEPENDENCIES:   26        67        78        78

     REQ. BRANCHES: (  1    +    1)   *(   1    +    2)

       DESCRIPTION:  E4-HiP    ExSE      IHWW>20   IHWW>16

 CASE/BRANCH SPLIT:           6.054E-02 3.690E-02

 CASE PUMBER/SPLIT:    4      1.677E-02
      DEPENDENCIES:   26        67        78

     REQ. BRANCHES: (  1    +    1)    *    3

       DESCRIPTION:  E4-HiP    ExSE      IHWW>12

 CASE/BRANCH SPLI*:           1.013E-02 6.636E-03

 CASE NUMBER/SPLIT:    5      4.576E-02
      DEPENDENCIES:   26        67        78

     REQ. BRANCHES: (  1    +    1)    *    4

       DESCRIPTION:  E4-HiP    ExSE      IHWW>8

 CASE/BRANCH SPLIT:           1.969E-02 2.606E-02

 CASE NUMBER/SPLIT:    6      2.425E-02
      DEPENDENCIES:   26        67        78

     REQ. BRANCHES: (  1    +    1)    *    5

       DESCRIPTION:  E4-HiP    ExSE      IHWW>4

 CASE/BRANCH SPLIT:           7.796E-03 1.646E-02

 CASE NUMBER/SPLIT:    7      0.000E+00
      DEPENDENCIES:   26        67        78

     REQ. BRANLHES: (  1    +    1)    *    6

       DESCRIPTION:  E4-HiP    ExSE      I-NoHWW

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    8      6.572E-02
       DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:           5.518E-04 6.517E-02


******** QUESTION:    85  Does ignition occur in the containment following vessel breach?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                                249742
          BRANCHES:            IgnFVB    nIgnFVB
                                  1         2
    REALIZED SPLIT:          8.833E-02 9.116E-01

                        SUMMARY BY CASE

 CATE NUMBER/SPLIT:    1     8.490E-01
      DEPENDENCIES:   78        82        81        83        84
```

```
     REQ. BRANCHES:   6    +    3    *   /4     +    5    +    1

       DESCRIPTION:  I-NoHWW   I-WWIn3  /I-CS      IWWD2     I-CIgn

 CASE/BRANCH SPLIT:           0.000E+00 8.490E-01

 CASE NUMBER/SPLIT:   2     5.635E-02
      DEPENDENCIES:  78

     REQ. BRANCHES:   2

       DESCRIPTION:  I-AC

 CASE/BRANCH SPLIT:           5.635E-02 0.000E+00

 CASE NUMBER/SPLIT:   3     4.375E-02
      DEPENDENC'ES:  78         78

     REQ. BRANCHES:   1    +    2

       DESCRIPTION:  IHWW>20   IHWW>16

 CASE/GRANCH SPLIT:           1.699E-02 2.676E-02

 CASE NUMBER/SPLIT:   4     1.051E-02
      DEPENDENCIES:  78

     REQ. BRANCHES:   3

       DESCRIPTION:  IHWW>12

 CASE/BPANCH SPLIT:           3.848E-03 6.660E-03

 CASE NUMBER/SPLIT:   5     2.163E-02
      DEPENDENCIES:  78

     REQ. BRANCHES:   4

       DESCRIPTION:  IHWW>8

 CASE/BRANCH SPLIT:           6.017E-03 1.561E-02

 CASE NUMBER/SPLIT:   6     1.872E-02
       DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:           5.126E-03 1.359E-02


********  QUESTION:   86  Is there a detonation in the wetwell following vessel breach?
Q-TYPE/TIMES ASKED:       DEP. INPU7 PROB. INPUT PARM.              279691
          BRANCHES:           I-WWDt    InWWDt
                               1         2
    REALIZED SPLIT:          6.010E-02 9.398E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:   1     8.273E-01
      DEPENDENCIES:  84         85        82        82        81        78        78        78

     REQ. BRANCHES:   2    *    2    +(   3    +    2)   *   /4     +    4    +    5    +    6

       DESCRIPTION:  InCIgn    nIgnFVB   I-WWIn3   I-WWIn2  /I-CS      IHWW>8    IHWW>4    I-NoHWW

 CASE/BRANCH SPLIT:           0.000E+00 8.273E-01

 CASE NUMBER/SPLIT:   2     2.043E-03
      DEPENDENCIES:  24         27        83        83        83
```

```
    REQ. BRANCHES:   2    *    1    *(   3    +    2    +    1)

      DESCRIPTION:  E4-AC     E4-HIS    O2Det12   O2Det16   O2Det20

CASE/BRANCH SPLIT:          5.039E-06 2.038E-02

CASE NUMBER/SPLIT:   3      6.068E-03
     DEPENDENCIES:  52         72         73         73         39         39         39         43

    REQ. BRANCHES: ( /1    +   /1    +   /1    *   /3)   *(  /1    *   /2    *   /3    +    1)

      DESCRIPTION: /E5nSPB   /InDWF1   /InDWOP   /1-DWHOP2 /HWW>20   /HWW>16   /HWW>12    E4-WWDf

CASE/BRANCH SPLIT:          4.739E-05 6.020E-03

CASE NUMBER/SPLIT:   4      0.000E+00
     DEPENDENCIES:  78         82         82         83         83         83

    REQ. BRANCHES:   3    *(   2    +    3)   *(   3    +    2    +    1)

      DESCRIPTION:  IHWW>12   I-WWIn2   I-WWIn3   O2Det12   O2Det16   O2Det20

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:   5      2.602E-02
     DEPENDENCIES:  75         83         83         83

    REQ. BRANCHES:   3    *(   3    +    2    +    1)

      DESCRIPTION:  IHWW>12   O2Det12   O2Det16   O2Det20

CASE/BRANCH SPLIT:          0.000E+00 2.602E-02

CASE NUMBER/SPLIT:   6      0.000E+00
     DEPENDENCIES:  78         82         82         83         83

    REQ. BRANCHES:   2    *(   2    +    3)   *(   2    +    1)

      DESCRIPTION:  IHWW>16   I-WWIn2   I-WWIn3   O2Det16   O2Det20

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:   7      1.881E-02
     DEPENDENCIES:  78         83         83

    REQ. BRANCHES:   2    *(   2    +    1)

      DESCRIPTION:  IHWW>16   O2Det16   O2Det20

CASE/BRANCH SPLIT:          5.667E-03 1.314E-02

CASE NUMBER/SPLIT:   8      0.000E+00
     DEPENDENCIES:  78         82         82         83

    REQ. BRANCHES:   1    *(   2    +              *    1

      DESCRIPTION:  IHWW>20   I-WWIn2   I-WWIn3   O2Det20

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:   9      1.188E-01
     DEPENDENCIES:  78         83

    REQ. BRANCHES:   1    *    1

      DESCRIPTION:  IHWW>20   O2Det20

CASE/BRANCH SPLIT:          5.438E-02 6.440E-02
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 CASE NUMBER/SPLIT:   10     9.199E-04
      DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:          0.000E+00 9.199E-04

********  QUESTION:   87  What is the level of containment impulse load following vessel breach?
Q-TYPE/TIMES ASKED:       INDEP. CALC. PROB.                          279681
          BRANCHES:             1-Ip>60   1-Ip>50   1-Ip>40   1-Ip>30   1-Ip>20   1-Ip>10   1-Ip<10
                                   1         2         3         4         5         6         7
   REALIZED SPLIT:            6.396E-05 8.561E-04 1.114E-03 2.231E-03 6.540E-03 2.056E-02 9.686E-01

********  QUESTION:   88  With what efficiency is hydrogen burned following VB?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB. INPUT PARM.                279681
          BRANCHES:             H2Ef@VB
                                   1
   REALIZED SPLIT:              9.999E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      0.000E+00
      DEPENDENCIES:   84        85        82        82        81        78        78

     REQ. BRANCHES: (  1    +    1)   *(   2    +    3    *    4)   *(   5    +    6)

       DESCRIPTION:  1-CIgn    IgnFVB    1-WWIn2   1-WWIn3   1-CS      IHWW>4    1-NoHWW

 CASE/BRANCH SPLIT:           0.000E+00

 CASE NUMBER/SPLIT:    2      1.732E-01
      DEPENDENCIES:   84        85        78        78

     REQ. BRANCHES: (  1    +    1)   *(   5    +    6)

       DESCRIPTION:  1-CIgn    IgnFVB    IHWW>4    1-NoHWW

 CASE/BRANCH SPLIT:           1.732E-01

 CASE NUMBER/SPLIT:    3      0.000E+00
      DEPENDENCIES:   84        85        82        82        81        78

     REQ. BRANCHES: (  1    +    1)   *(   2    +    3    *    4)   *    4

       DESCRIPTION:  1-CIgn    IgnFVB    1-WWIn2   1-WWIn3   1-CS      IHWW>8

 CASE/BRANCH SPLIT:           0.000E+00

 CASE NUMBER/SPLIT:    4      1.851E-01
      DEPENDENCIES:   84        85        78

     REQ. BRANCHES: (  1    +    1)   *    4

       DESCRIPTION:  1-CIgn    IgnFVB    IHWW>8

 CASE/BRANCH SPLIT:           1.851E-01

 CASE NUMBER/SPLIT:    5      0.000E+00
      DEPENDENCIES:   84        85        82        82        81        78

     REQ. BRANCHES: (  1    +    1)   *(   2    +    3    *    4)   *    3

       DESCRIPTION:  1-CIgn    IgnFVB    1-WWIn2   1-WWIn3   1-CS      IHWW>12

 CASE/BRANCH SPLIT:           0.000E+00

 CASE NUMBER/SPLIT:    6      2.825E-02
      DEPENDENCIES:   84        85        78
```

```
     REQ. BRANCHES: ( 1    +    1)   *    3

        DESCRIPTION:  I-CIgn    IgnFVB    IHWW>12

 CASE/BRANCH SPLIT:            2.825E-02

 CASE NUMBER/SPLIT:    7     0.000E+00
      DEPENDENCIES:   84         85        82         82         81         78         78

     REQ. BRANCHES: ( 1    +    1)   *(   2    +    3    *    4)   *(   1    +    2)

        DESCRIPTION:  I-CIgn    IgnFVB    I-WWIn2   I-WWIn3   I-CS       IHWW>20   IHWW>16

 CASE/BRANCH SPLIT:            0.000E+00

 CASE NUMBER/SPLIT:    8     1.444E-01
      DEPENDENCIES:   84         85        78         78

     REQ. BRANCHES: ( 1    +    1)   *(   1    +    2)

        DESCRIPTION:  I-CIgn    IgnFVB    IHWW>20   IHWW>16

 CASE/BRANCH SPLIT:            1.444E-01

 CASE NUMBER/SPLIT:    9     4.690E-01
       DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:            4.690E-01

********  QUESTION:   89  What would be the peak pressure in containment from a hydrogen burn at VB?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                            279691
          BRANCHES:             I-PBrn>7  I-PBrn>6  I-PBrn>5  I-PBrn>4  I-PBrn>3  I-PBrn<3
                                    1         2         3         4         5         6
    REALIZED SPLIT:            3.396E-02 1.700E-02 2.157E-02 1.307E-02 2.225E-02 8.860E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     4.690E-01
      DEPENDENCIES:   84         85

     REQ. BRANCHES:    2    *    2

        DESCRIPTION:  InCIgn    nIgnFVB

 CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.690E-01

 CASE NUMBER/SPLIT:    2     8.592E-02
      DEPENDENCIES:   50         50        58

     REQ. BRANCHES: ( 3    +    4    +    1)

        DESCRIPTION:  E5-CL3    E5-CL4    Alpha

 CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 8.592E-02

 CASE NUMBER/SPLIT:    3     5.941E-02
      DEPENDENCIES:   86

     REQ. BRANCHES:    1

        DESCRIPTION:  I-WWDt

 CASE/BRANCH SPLIT:            1.445E-02 7.633E-03 9.093E-03 3.638E-03 2.151E-03 2.245E-02

 CASE NUMBER/SPLIT:    4     3.856E-01
       DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:            1.952E-02 9.366E-03 1.248E-02 1.543E-02 2.010E-02 3.087E-01
```

```
********  QUESTION:   90  What is the level of containment pressurization at vessel breach?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                             279691
          BRANCHES:             I-CP>7     I-CP>6     I-CP>5     I-CP>4     I-CP>3     I-CP>2
                                 1          2          3          4          5          6
    REALIZED SPLIT:           4.227E-02 1.813E-02 1.799E-02 2.068E-02 3.854E-02 8.623E-01

                     SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     1.740E-01
       DEPENDENCIES:   50        50        58

      REQ. BRANCHES:    3    +    4    +    1

        DESCRIPTION:  E5-CL3    E5-CL4    Alpha

  CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.740E-01

  CASE NUMBER/SPLIT:    2     3.619E-01
       DEPENDENCIES:   84

      REQ. BRANCHES:    1

        DESCRIPTION:  I-CIgn

  CASE/BRANCH SPLIT:          3.375E-02 1.348E-02 1.240E-02 1.327E-02 3.005E-02 2.589E-01

  CASE NUMBER/SPLIT:    3     8.308E-02
       DEPENDENCIES:   85

      REQ. BRANCHES:    1

        DESCRIPTION:  IgnFVB

  CASE/BRANCH SPLIT:          8.519E-03 4.645E-03 5.591E-03 7.401E-03 8.491E-03 4.843E-02

  CASE NUMBER/SPLIT:    4     3.809E-01
        DESCRIPTION:         Otherwise
  CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.809E-01

********  QUESTION:   91  What is the level of drywell leakage induced by a detonation in containment
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                             279691
          BRANCHES:             InDWDt     I-DWDt2   I-DWDt3
                                 1          2          3
    REALIZED SPLIT:           9.895E-01 7.392E-03 3.055E-03

                     SUMMARY BY CASE

  CASE NUMBER/SPLIT:    1     6.010E-02
       DEPENDENCIES:   86

      REQ. BRANCHES:    1

        DESCRIPTION:  I-WWDt

  CASE/BRANCH SPLIT:          4.965E-02 7.392E-03 3.055E-03

  CASE NUMBER/SPLIT:    2     9.399E-01
        DESCRIPTION:         Otherwise -- No detonation and thus no failure
  CASE/BRANCH SPLIT:          9.399E-01 0.000E+00 0.000E+00

********  QUESTION:   92  What is the level of containment leakage induced by a detonation at VB?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                             279691
          BRANCHES:             InDtF      I-DtF2     I-DtF3
                                 1          2          3
```

```
   REALIZED SPLIT:          9.757E-01 1.423E-02 1.003E-02

                       SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     1.045E-02
      DEPENDENCIES:   91        91

     REQ. BRANCHES:    2    +    3

       DESCRIPTION:  I-DWDt2   I-DWDt3

 CASE/BRANCH SPLIT:          0.000E+00 4.780E-03 5.666E-03

 CASE NUMBER/SPLIT:    2     4.965E-02
      DEPENDENCIES:   86

     REQ. BRANCHES:    1

       DESCRIPTION:  I-WWDt

 CASE/BRANCH SPLIT:          3.583E-02 9.453E-03 4.366E-03

 CASE NUMBER/SPLIT:    3     9.399E-01
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          9.399E-01 0.000E+00 0.000E+00

********  QUESTION:    93  What is the level of containment leakage following vessel breach?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                               279691
          BRANCHES:            InCL       I-CL2      I-CL3      I-CL4
                                1          2          3          4
   REALIZED SPLIT:          6.387E-01 8.756E-02 2.657E-01 7.859E-03

                       SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     7.859E-03
      DEPENDENCIES:   50        58

     REQ. BRANCHES:    4    +    1

       DESCRIPTION:  E5-CL4    Alpha

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 7.859E-03

 CASE NUMBER/SPLIT:    2     1.762E-01
      DEPENDENCIES:   50        92

     REQ. BRANCHES:    3    +    3

       DESCRIPTION:  E5-CL3    I-DtF3

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 1.762E-01 0.000E+00

 CASE NUMBER/SPLIT:    3     7.250E-02
      DEPENDENCIES:   50        92

     REQ. BRANCHES:    2    +    2

       DESCRIPTION:  E5-CL2    I-DtF2

 CASE/BRANCH SPLIT:          0.000E+00 6.380E-02 8.704E-03 0.000E+00

 CASE NUMBER/SPLIT:    4     7.434E-01
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          6.387E-01 2.377E-02 8.085E-02 0.000E+00

********  QUESTION:    94  What is the level of drywell leakage induced by containment pressurization?
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D-TYPE/TIMES ASKED:       DEP. CALC. PROB.                          279691
          BRANCHES:           1nDWDf    1-DWDf2   1-DWHDf2  1-DWDf3   1-DWHDf3
                                1         2          3         4         5
    REALIZED SPLIT:          7.700E-01 7.163E-02 0.000E+00 1.582E-01 0.000E+00

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      1.508E-01
     DEPENDENCIES:   51        72         73         76         91

    REQ. BRANCHES:    4   *    3   *    4   *    1   *    3

      DESCRIPTION:  E-DWDf3   1-DWF13   1-DWOP3   1-DWFPed  1-DWDt3

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 1.508E-01 0.000E+00

 CASE NUMBER/SPLIT:    2      0.000E+00
     DEPENDENCIES:   51

    REQ. BRANCHES:    5

      DESCRIPTION:  E-DWHDf3

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    3      1.571E-03
     DEPENDENCIES:   85        51         72         73         91         93         93

    REQ. BRANCHES:    1   *(   2   +    2   +    2   +    2)  *(   3   +    4)

      DESCRIPTION:  IgnFVB    E-DWDf2   1-DWF12   1-DWOP2   1-DWDt2   1-CL3     1-CL4

 CASE/BRANCH SPLIT:           0.000E+00 1.293E-03 0.000E+00 2.776E-04 0.000E+00

 CASE NUMBER/SPLIT:    4      4.606E-04
     DEPENDENCIES:   85        51         72         73         91

    REQ. BRANCHES:    1   *(   2   +    2   +    2   +    2)

      DESCRIPTION:  IgnFVB    E-DWDf2   1-DWF12   1-DWOP2   1-DWDt2

 CASE/BRANCH SPLIT:           0.000E+00 4.606E-04 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    5      0.000E+00
     DEPENDENCIES:   85        51         93         93

    REQ. BRANCHES:    1   *    3   *(   3   +    4)

      DESCRIPTION:  IgnFVB    E-DWHDf2  1-CL3     1-CL4

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    6      0.000E+00
     DEPENDENCIES:   85        51

    REQ. BRANCHES:    1   *    3

      DESCRIPTION:  IgnFVB    E-DWHDf2

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    7      8.038E-02
     DEPENDENCIES:   85

    REQ. BRANCHES:    1

      DESCRIPTION:  IgnFVB
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CASE/BRANCH SPLIT:           6.819E-02 5.056E-03 0.000E+00 7.142E-03 0.000E+00

CASE NUMBER/SPLIT:    8     6.482E-02
     DEPENDENCIES:   51         72         73         91

    REQ. BRANCHES: (  2    +    2    +    2    +    2)

      DESCRIPTION:  E-DWDf2   I-DWF12   I-DWOP2   I-DWDt2

CASE/BRANCH SPLIT:           0.000E+00 6.482E-02 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    9     0.000E+00
     DEPENDENCIES:   51

    REQ. BRANCHES:    3

      DESCRIPTION:  E-DWHDf2

CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:   10     7.019E-01
      DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:           7.019E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00


********  QUESTION:   95  What is the level of suppression pool bypass following VB?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                             279691
         BRANCHES:           InSPB     I-SPB2    I-SPB3
                               1         2         3
   REALIZED SPLIT:           7.288E-01 7.780E-02 1.933E-01

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     1.883E-01
     DEPENDENCIES:   52         94         94         58

    REQ. BRANCHES:    3    +    4    +    5    +    1

      DESCRIPTION:  E5-SPB3   I-DWDf3   I-DWHDf3  Alpha

CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 1.883E-01

CASE NUMBER/SPLIT:    2     2.878E-02
     DEPENDENCIES:   52         94         94         79         84         85

    REQ. BRANCHES: (  2    +    2    +    3)   *    2    *(   1    +    1)

      DESCRIPTION:  E5-SPB2   I-DWDf2   I-DWHDf2  I-AC      I-CIgn    IgnFVB

CASE/BRANCH SPLIT:           0.000E+00 2.821E-02 5.612E-04

CASE NUMBER/SPLIT:    3     4.958E-02
     DEPENDENCIES:   52         94         94

    REQ. BRANCHES:    2    +    2    +    3

      DESCRIPTION:  E5-SPB2   I-DWDf2   I-DWHDf2

CASE/BRANCH SPLIT:           0.000E+00 4.958E-02 0.000E+00

CASE NUMBER/SPLIT:    4     2.954E-01
     DEPENDENCIES:   79         84         85

    REQ. BRANCHES:    2    *(   1    +    1)

      DESCRIPTION:  I-AC      I-CIgn    IgnFVB

CASE/BRANCH SPLIT:           2.910E-01 0.000E+00 4.378E-03
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```
CASE NUMBER/SPLIT:    5     4.378E-01
      DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          4.378E-01 0.000E+00 0.000E+00


******** QUESTION:   96  What is the containment pressure after vessel breach?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                                 279691
         BRANCHES:           IP>4      IP>3      IP>2      IP>1
                              1         2         3         4
   REALIZED SPLIT:          0.000E+00 0.000E+00 1.221E-02 9.877E-01

                  SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     3.612E-01
      DEPENDENCIES:   93

    REQ. BRANCHES:   /1

      DESCRIPTION: /InCL

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 3.612E-01

 CASE NUMBER/SPLIT:    2     4.908E-01
      DEPENDENCIES:   81

    REQ. BRANCHES:    4

      DESCRIPTION:  I-CS

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 4.908E-01

 CASE NUMBER/SPLIT:    3     1.479E-01
      DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 1.221E-02 1.357E-01


******** QUESTION:   97  Is water not supplied to the debris late?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                                 279691
         BRANCHES:          nLDBWat   S-LDBWat  L-LDBWat
                              1         2         3
   REALIZED SPLIT:          2.449E-01 2.151E-01 5.399E-01

                  SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     3.261E-01
      DEPENDENCIES:   63

    REQ. BRANCHES:    5

      DESCRIPTION:  nBreach

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 3.261E-01

 CASE NUMBER/SPLIT:    2     1.885E-01
      DEPENDENCIES:   79        12

    REQ. BRANCHES:    1    *    3

      DESCRIPTION:  IfAC      ElaFWS

 CASE/BRANCH SPLIT:          9.174E-02 4.876E-02 4.798E-02

 CASE NUMBER/SPLIT:    3     0.000E+00
      DEPENDENCIES:   79

    REQ. BRANCHES:    1
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```
       DESCRIPTION:  IfAC

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    4     4.380E-01
      DEPENDENCIES:   28        28

     REQ. BRANCHES: (  2    +    3)

       DESCRIPTION:  E4-LPI    E4-HPI

 CASE/BRANCH SPLIT:          1.375E-01 1.507E-01 1.498E-01

 CASE NUMBER/SPLIT:    5     4.725E-02
      DEPENDENCIES:    5          7         8         9        11

     REQ. BRANCHES: (  2     +  /1     +  /1     +  /1     +  /1)

       DESCRIPTION:  E1rHPInj /E1fCRD   /E1fCond  /E1fLPC    /E1fSSW

 CASE/BRANCH SPLIT:          1.557E-02 1.572E-02 1.595E-02

 CASE NUMBER/SPLIT:    6     0.000E+00
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00


********  QUESTION:    98  Is there water in the reactor cavity after VB?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                          291964
          BRANCHES:             LDWFld    LRCWet    LRCDry
                                  1         2         3
    REALIZED SPLIT:          8.636E-01 9.188E-02 4.440E-02

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     5.174E-01
      DEPENDENCIES:   54        94

     REQ. BRANCHES:    1    +    5

       DESCRIPTION:  E5-DFld   I-DWHDf3

 CASE/BRANCH SPLIT:          5.174E-01 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    2     2.240E-02
      DEPENDENCIES:   54        64        67        65        66        95        79

     REQ. BRANCHES:    2    *(   1     +    1     +    1     +    1)    *   /3     *    1

       DESCRIPTION:  E5-DWet   HPME      ExSE      I-DWDt    I-DWDf    /I-SPB3    IfAC

 CASE/BRANCH SPLIT:          2.240E-02 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    3     2.550E-01
      DEPENDENCIES:   84        85        95

     REQ. BRANCHES: (  1    +    1)   *   /3

       DESCRIPTION:  I-CIgn    IgnFVB   /I-SPB3

 CASE/BRANCH SPLIT:          2.550E-01 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    4     5.621E-02
      DEPENDENCIES:   84        85        95

     REQ. BRANCHES: (  1    -    1)   *    3

       DESCRIPTION:  I-CIgn    IgnFVB    I-SPB3
```

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CASE/BRANCH SPLIT:          5.080E-02 5.408E-03 0.000E+00

CASE NUMBER/SPLIT:    5     1.998E-02
     DEPENDENCIES:   64         67         65         66         95         79

   REQ. BRANCHES: (  1    +    1    +    1    +    1)    *    /3    *    1

      DESCRIPTION:  HPME      ExSE      1-DWDt    1-DWDf   /1-SPB3    1fAC

CASE/BRANCH SPLIT:          1.802E-02 1.958E-03 0.000E+00

CASE NUMBER/SPLIT:    6     8.452E-02
     DEPENDENCIES:   54

    REQ. BRANCHES:    2

      DESCRIPTION:  E5-DWet

CASE/BRANCH SPLIT:          0.000E+00 8.452E-02 0.000E+00

CASE NUMBER/SPLIT:    7     4.440E-02
      DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 4.440E-02


********  QUESTION:   99  What is the nature of the core-concrete interaction?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                             416964
          BRANCHES:           CCI       WetCCI    FldCCI    DlyCCI    noCCI
                               1          2         3         4         5
   REALIZED SPLIT:          7.589E-03 2.265E-03 3.471E-01 2.114E-03 6.408E-01

                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     3.272E-01
     DEPENDENCIES:   63

    REQ. BRANCHES:    5

      DESCRIPTION:  nBreach

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.272E-01

CASE NUMBER/SPLIT:    2     6.297E-03
     DEPENDENCIES:   97         98

    REQ. BRANCHES:    1    *    3

      DESCRIPTION:  nLDBWat   LRCDry

CASE/BRANCH SPLIT:          6.297E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    3     0.000E+00
     DEPENDENCIES:   98         26         28         9         24

    REQ. BRANCHES:    3    *    1    *(  /1    +   /1    *    2)

      DESCRIPTION:  LRCDry    E4-HiP   /E4nLPI   /E1fLPC    E4-AC

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    4     4.365E-03
     DEPENDENCIES:   98         26         28

    REQ. BRANCHES:    3    *    2    *    /1

      DESCRIPTION:  LRCDry    E4-LoP   /E4nLPI
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CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 3.680E-03 0.000E+00 6.848E-04

CASE NUMBER/SPLIT:    5     2.584E-03
     DEPENDENCIES:   98

    REQ. BRANCHES:    3

      DESCRIPTION:  LRCDry

CASE/BRANCH SPLIT:          1.292E-03 0.000E+00 1.292E-03 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    6     1.383E-01
     DEPENDENCIES:   98          98          97          26

    REQ. BRANCHES: (  1    +    2    *   /1)   *    1

      DESCRIPTION:  LDWFld    LRCWet   /nLDBWat   E4-HiP

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 2.719E-02 0.000E+00 1.111E-01

CASE NUMBER/SPLIT:    7     1.852E-02
     DEPENDENCIES:   98          98          97          61

    REQ. BRANCHES: (  1    +    2    *   /1)   *    1

      DESCRIPTION:  LDWFld    LRCWet   /nLDBWat   HiLiqVB

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 1.563E-02 0.000E+00 2.895E-03

CASE NUMBER/SPLIT:    8     4.982E-01
     DEPENDENCIES:   98          98          97

    REQ. BRANCHES: (  1    +    2    *   /1)

      DESCRIPTION:  LDWFld    LRCWet   /nLDBWat

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 2.993E-01 0.000E+00 1.989E-01

CASE NUMBER/SPLIT:    9     9.494E-04
     DEPENDENCIES:   26

    REQ. BRANCHES:    1

      DESCRIPTION:  E4-HiP

CASE/BRANCH SPLIT:          0.000E+00 1.720E-04 0.000E+00 7.774E-04 0.000E+00

CASE NUMBER/SPLIT:   10     9.458E-05
     DEPENDENCIES:   61

    REQ. BRANCHES:    1

      DESCRIPTION:  HiLiqVB

CASE/BRANCH SPLIT:          0.000E+00 8.162E-05 0.000E+00 1.296E-05 0.000E+00

CASE NUMBER/SPLIT:   11     3.335E-03
      DESCRIPTION:          Otherwise
CASE/BRANCH SPLIT:          0.000E+00 2.012E-03 0.000E+00 1.324E-03 0.000E+00

********  QUESTION:  100  What fraction of core not participating in HPME participates in CCI?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB. INPUT PARM.             416964
          BRANCHES:            HiFCCI    LoFCCI
                                 1         2
    REALIZED SPLIT:         6.432E-01 3.566E-01

                     SUMMARY BY CASE
```

```
 CASE NUMBER/SPLIT:    1     3.350E-01
      DEPENDENCIES:   63        63

     REQ. BRANCHES:    1    +    5

       DESCRIPTION:  A-Fail    nBreach

 CASE/BRANCH SPLIT:          0.000E+00 3.350E-01

 CASE NUMBER/SPLIT:    2     2.159E-02
      DEPENDENCIES:   67        61

     REQ. BRANCHES:    1    *    1

       DESCRIPTION:  ExSE      HiLiqVB

 CASE/BRANCH SPLIT:          0.000E+00 2.159E-02

 CASE NUMBER/SPLIT:    3     5.081E-01
      DEPENDENCIES:   67        61

     REQ. BRANCHES:    1    *    2

       DESCRIPTION:  ExSE      LoLiqVB

 CASE/BRANCH SPLIT:          5.081E-01 0.000E+00

 CASE NUMBER/SPLIT:    4     1.352E-01
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          1.352E-01 0.000E+00

********  QUESTION:  101  How much H2 (& equivalent CO) and CO2 are produced during CCI?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                          416964
          BRANCHES:           H2CCI4    H2CCI3    H2CCI2    H2CCI1
                               1         2         3         4
    REALIZED SPLIT:          3.539E-01 1.299E-04 0.000E+00 6.459E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     6.459E-01
      DEPENDENCIES:   63        63         99

     REQ. BRANCHES:    1    +    5    +    5

       DESCRIPTION:  A-Fail    nBreach   noCCI

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 6.459E-01

 CASE NUMBER/SPLIT:    2     2.294E-02
      DEPENDENCIES:   64

     REQ. BRANCHES:    1

       DESCRIPTION:  HPME

 CASE/BRANCH SPLIT:          2.294E-02 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    3     3.311E-01
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          3.309E-01 1.299E-04 0.000E+00 0.000E+00

********  QUESTION:  102  What is the level of zirconium oxidation in the pedestal before CCI?
Q-TYPE/TIMES ASKED:       INDEP. CALC. PROB.                        416964
          BRANCHES:           ZrOx75    ZrOx50    ZrOx40    ZrOx30    ZrOx21    ZrOx10    ZrOx<10
                               1         2         3         4         5         6         7
```

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   REALIZED SPLIT:          1.299E-04 2.282E-02 4.732E-02 6.061E-02 4.842E-02 8.491E-02 7.357E-01

******** QUESTION:  103  Is the containment not vented following VB?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                          469496
         BRANCHES:            InVENT    I-VENT
                                1         2
   REALIZED SPLIT:          9.443E-01 5.544E-02

                   SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      4.346E-01
      DEPENDENCIES:   79         93         93

     REQ. BRANCHES:    1    +    3    +    4

       DESCRIPTION:  IfAC      I-CL3     I-CL4

 CASE/BRANCH SPLIT:           4.346E-01 0.000E+00

 CASE NUMBER/SPLIT:    2      3.300E-06
      DEPENDENCIES:   99         63         81         95

     REQ. BRANCHES:    4    *(   5    +    2    +   /3)

       DESCRIPTION:  DlyCCI    nBreach   IrCS      /I-SPB3

 CASE/BRANCH SPLIT:           3.300E-06 0.000E+00

 CASE NUMBER/SPLIT:    3      5.651E-01
       DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:           5.097E-01 5.544E-02

******** QUESTION:  104  Is ac power not recovered late in the accident?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                          545238
         BRANCHES:            LfAC      L-AC
                                1         2
   REALIZED SPLIT:          5.743E-02 9.424E-01

                   SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      7.670E-01
      DEPENDENCIES:   79

     REQ. BRANCHES:    2

       DESCRIPTION:  I-AC

 CASE/BRANCH SPLIT:           0.000E+00 7.670E-01

 CASE NUMBER/SPLIT:    2      1.568E-03
      DEPENDENCIES:   80

     REQ. BRANCHES:    1

       DESCRIPTION:  IfDC

 CASE/BRANCH SPLIT:           1.568E-03 0.000E+00

 CASE NUMBER/SPLIT:    3      0.000E+00
      DEPENDENCIES:    2         15

     REQ. BRANCHES:    1    *    2

       DESCRIPTION:  SB        CD-Slw

 CASE/BRANCH SPLIT:           0.000E+00 0.000E+00
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CASE NUMBER/SPLIT:    4     2.313E-01
     DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          5.586E-02 1.754E-01


******** QUESTION:  105  Is dc power available late in the accident?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                             595858
         BRANCHES:          LfDC      L-DC
                              1         2
   REALIZED SPLIT:          1.422E-02 9.856E-01

                  SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     2.318E-03
    DEPENDENCIES:   80

    REQ. BRANCHES:    1

      DESCRIPTION:  IfDC

CASE/BRANCH SPLIT:          2.318E-03 0.000E+00

CASE NUMBER/SPLIT:    2     7.679E-01
    DEPENDENCIES:   79

    REQ. BRANCHES:    2

      DESCRIPTION:  I-AC

CASE/BRANCH SPLIT:          0.000E+00 7.679E-01

CASE NUMBER/SPLIT:    3     0.000E+00
    DEPENDENCIES:    2         15

    REQ. BRANCHES:    1    *    2

      DESCRIPTION:  SB        CD-Slw

CASE/BRANCH SPLIT:          0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    4     2.296E-01
     DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          1.190E-02 2.176E-01


******** QUESTION:  106  What is the late status of containment sprays?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                             603675
         BRANCHES:          LfCS      LrCS      LaCS      L-CS
                              1         2         3         4
   REALIZED SPLIT:          1.393E-01 4.840E-02 1.639E-02 7.956E-01

                  SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     8.600E-02
    DEPENDENCIES:   81

    REQ. BRANCHES:    1

      DESCRIPTION:  IfCS

CASE/BRANCH SPLIT:          8.600E-02 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    2     1.053E-02
    DEPENDENCIES:   81      104       50        50        93        93

    REQ. BRANCHES:    2    *    1    *(   1    +    2)   *(   3    +    4)
```

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       DESCRIPTION:  IrCS      LfAC      E5nCL     E5-CL2    I-CL3     I-CL4

CASE/BRANCH SPLIT:            4.909E-03 5.617E-03 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:     3      4.278E-02
     DEPENDENCIES:    81        104

    REQ. BRANCHES:     2    *    1

       DESCRIPTION:  IrCS      LfAC

CASE/BRANCH SPLIT:            0.000E+00 4.278E-02 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:     4      5.908E-02
     DEPENDENCIES:    81        50        50        93        93

    REQ. BRANCHES:     4    *(   1    +    2)   *(   3    +    4)

       DESCRIPTION:  I-CS      E5nCL     E5-CL2    I-CL3     I-CL4

CASE/BRANCH SPLIT:            3.190E-02 0.000E+00 0.000E+00 2.718E-02

CASE NUMBER/SPLIT:     5      5.737E-01
     DEPENDENCIES:    81

    REQ. BRANCHES:     4

       DESCRIPTION:  I-CS

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00 5.737E-01

CASE NUMBER/SPLIT:     6      3.326E-02
     DEPENDENCIES:   104        50        50        93        93

    REQ. BRANCHES:     2    *(   1    +    2)   *(   3    +    4)

       DESCRIPTION:  L-AC      E5nCL     E5-CL2    I-CL3     I-CL4

CASE/BRANCH SPLIT:            1.653E-02 0.000E+00 1.509E-02 1.638E-03

CASE NUMBER/SPLIT:     7      1.944E-01
     DEPENDENCIES:   104

    REQ. BRANCHES:     2

       DESCRIPTION:  L-AC

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 1.303E-03 1.931E-01

CASE NUMBER/SPLIT:     8      0.000E+00
       DESCRIPTION:          Otherwise -- This case should not be used
CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 0.000E+00 0.000E+00


********  QUESTION:  107  What is the late concentration of combustible gases in the containment?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                          603675
          BRANCHES:           LGWW>20   LGWW>16   LGWW>12   LGWW>8    LGWW>4    L-NoGWW
                                 1         2         3         4         5         6
    REALIZED SPLIT:           3.398E-01 1.406E-02 1.752E-02 4.251E-02 1.531E-01 4.327E-01

                     SUMMARY BY CASE

CASE NUMBER/SPLIT:     1      7.606E-02
     DEPENDENCIES:    63        95        97        98       106

    REQ. BRANCHES:    /5    *   /1    *(  /1    +   /3)   *   /4

       DESCRIPTION: /nBreach  /InSPB    /nLDBWat  /LRCDry   /L-CS
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 CASE/BRANCH SPLIT:           0.000E+00 4.258E-07 3.859E-05 9.846E-04 3.554E-03 7.148E-02

 CASE NUMBER/SPLIT:    2      3.357E-01
      DEPENDENCIES:   93        103

     REQ. BRANCHES:   /1    +    2

       DESCRIPTION: /InCL       I-VENT

 CASE/BRANCH SPLIT:           1.158E-01 1.586E-03 2.758E-03 8.654E-03 5.232E-02 1.543E-01

 CASE NUMBER/SPLIT:    3      5.555E-01
      DEPENDENCIES:  106

     REQ. BRANCHES:    4

       DESCRIPTION:  L-CS

 CASE/BRANCH SPLIT:           2.078E-01 1.181E-02 1.366E-02 2.988E-02 9.343E-02 1.990E-01

 CASE NUMBER/SPLIT:    4      3.244E-02
       DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:           1.612E-02 6.605E-04 1.062E-03 2.792E-03 3.808E-03 7.998E-03


******** QUESTION:  108  To what level is the wetwell inert after vessel breach?
Q-TYPE/TIMES ASKED:        INDEP. CALC. PROB.                            603675
          BRANCHES:           LnWWIn    L-WWIn2   L-WWIn3
                                1         2         3
    REALIZED SPLIT:          9.193E-01 4.605E-03 7.606E-02


******** QUESTION:  109  Is there sufficient oxygen in the containment to support late combustion?
Q-TYPE/TIMES ASKED:        INDEP. CALC. PROB.                            603675
          BRANCHES:           LO2Det20  LO2Det16  LO2Det12  LWWO2     LnWWO2
                                1         2         3         4         5
    REALIZED SPLIT:          4.568E-01 5.044E-02 4.664E-02 4.662E-02 3.993E-01


******** QUESTION:  110  Does ignition occur late in the containment?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                              606381
          BRANCHES:           L-CIgn    LnCIgn
                                1         2
    REALIZED SPLIT:          2.740E-01 7.258E-01

                    SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1      7.088E-01
      DEPENDENCIES:  107        108        106        109

     REQ. BRANCHES:    6    +    3    *   /4    +    5

       DESCRIPTION:  L-NoGWW   L-WWIn3  /L-CS      LnWWO2

 CASE/BRANCH SPLIT:           0.000E+00 7.088E-01

 CASE NUMBER/SPLIT:    2      1.400E-02
      DEPENDENCIES:   82         83         84         85        104

     REQ. BRANCHES:   /3    *   /5    *(   2    *    2)    *    1

       DESCRIPTION: /I-WWIn3  /nWWO2     InCIgn     nIgnFVB    LfAC

 CASE/BRANCH SPLIT:           0.000E+00 1.400E-02

 CASE NUMBER/SPLIT:    3      2.717E-01
      DEPENDENCIES:  104
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```
       REQ. BRANCHES:     2

         DESCRIPTION:  L-AC

   CASE/BRANCH SPLIT:             2.717E-01 0.000E+00

   CASE NUMBER/SPLIT:     4      3.542E-03
        DEPENDENCIES:   107        107

       REQ. BRANCHES:     1    +     2

         DESCRIPTION:  LGWW>20   LGWW>16

   CASE/BRANCH SPLIT:             1.820E-03 1.722E-03

   CASE NUMBER/SPLIT:     5      0.000E+00
        DEPENDENCIES:   107

       REQ. BRANCHES:     3

         DESCRIPTION:  LGWW>12

   CASE/BRANCH SPLIT:             0.000E+00 0.000E+00

   CASE NUMBER/SPLIT:     6      5.265E-07
        DEPENDENCIES:   107

       REQ. BRANCHES:     4

         DESCRIPTION:  LGWW>8

   CASE/BRANCH SPLIT:             0.000E+00 5.265E-07

   CASE NUMBER/SPLIT:     7      1.712E-03
         DESCRIPTION:            Otherwise
   CASE/BRANCH SPLIT:             4.678E-04 1.244E-03


******** QUESTION:  111  Is there a detonation in the wetwell following vessel breach?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB. INPUT PARM.              641281
          BRANCHES:              L-WWDt    LnWWDt
                                   1         2
    REALIZED SPLIT:             6.579E-02 9.341E-01

                     SUMMARY BY CASE

   CASE NUMBER/SPLIT:     1      8.266E-01
        DEPENDENCIES:   110        108        108        106        108        107        107        107

       REQ. BRANCHES:     2    +(  2    +     3)   *    /4    +     3    +     4    +     5    +     6

         DESCRIPTION:  LnCIgn    L-WWIn2   L-WWIn3  /L-CS      L-WWIn3   LGWW>8    LGWW>4    L-NoGWW

   CASE/BRANCH SPLIT:             0.000E+00 8.266E-01

   CASE NUMBER/SPLIT:     2      1.284E-02
        DEPENDENCIES:    27         79

       REQ. BRANCHES:     1    *     2

         DESCRIPTION:  E4-HIS    1-AC

   CASE/BRANCH SPLIT:             0.000E+00 1.284E-02

   CASE NUMBER/SPLIT:     3      0.000E+00
        DEPENDENCIES:   107        108        108        109        109        109
```

```
     REQ. BRANCHES:    3    *(   2    +    3)  *(   3    +    2    +    1)

       DESCRIPTION:  LGWW>12   L-WWIn2   L-WWIn3   LO2Det12  LO2Det16  LO2Det20

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    4     1.844E-03
     DEPENDENCIES:  107        109        109        109

     REQ. BRANCHES:    3    *(   3    +    2    +    1)

       DESCRIPTION:  LGWW>12   LO2Det12  LO2Det16  LO2Det20

CASE/BRANCH SPLIT:            0.000E+00 1.844E-03

CASE NUMBER/SPLIT:    5     0.000E+00
     DEPENDENCIES:  107        108        108        109        109

     REQ. BRANCHES:    2    *(   2    +    3)  *(   2    +    1)

       DESCRIPTION:  LGWW>16   L-WWIn2   L-WWIn3   LO2Det16  LO2Det20

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    6     1.644E-03
     DEPENDENCIES:  107        109        109

     REQ. BRANCHES:    2    *(   2    +    1)

       DESCRIPTION:  LGWW>16   LO2Det16  LO2Det20

CASE/BRANCH SPLIT:            4.191E-04 1.225E-03

CASE NUMBER/SPLIT:    7     0.000E+00
     DEPENDENCIES:  107        108        108        109

     REQ. BRANCHES:    1    *(   2    +    3)  *    1

       DESCRIPTION:  LGWW>20   L-WWIn2   L-WWIn3   LO2Det20

CASE/BRANCH SPLIT:            0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    8     1.455E-01
     DEPENDENCIES:  107        109

     REQ. BRANCHES:    1    *    1

       DESCRIPTION:  LGWW>20   LO2Det20

CASE/BRANCH SPLIT:            6.537E-02 8.009E-02

CASE NUMBER/SPLIT:    9     1.151E-02
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:           0.000E+00 1.151E-02

********  QUESTION:  112  What is the late level of containment impulse load?
Q-TYPE/TIMES ASKED:        INDEP. CALC. PROB.                           641281
          BRANCHES:            L-Ip>60   L-Ip>50   L-Ip>40   L-Ip>30   L-Ip>20   L-Ip>10   L-Ip<10
                                  1         2         3         4         5         6         7
    REALIZED SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 6.579E-02 9.342E-01

********  QUESTION:  113  What is the late gas combustion efficiency?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB. INPUT PARM.                641281
          BRANCHES:            H2Ef@VB
                                  1
    REALIZED SPLIT:           9.998E-01
```

```
                    SUMMARY BY CASE

CASE NUMBER/SPLIT:    1      0.000E+00
     DEPENDENCIES:  110       108       108       106       107       107

    REQ. BRANCHES:    1    *(   2    +    3)   *    4    *(   5    +    6)

      DESCRIPTION:  L-CIgn    L-WWIn2   L-WWIn3   L-CS      LGWW>4    L-NoGWW

CASE/BRANCH SPLIT:           0.000E+00

CASE NUMBER/SPLIT:    2      9.030E-02
     DEPENDENCIES:  110       107       107

    REQ. BRANCHES:    1    *(   5    +    6)

      DESCRIPTION:  L-CIgn    LGWW>4    L-NoGWW

CASE/BRANCH SPLIT:           9.030E-02

CASE NUMBER/SPLIT:    3      0.000E+00
     DEPENDENCIES:  110       108       108       106       107

    REQ. BRANCHES:    1    *(   2    +    3)   *    4    *    4

      DESCRIPTION:  L-CIgn    L-WWIn2   L-WWIn3   L-CS      LGWW>8

CASE/BRANCH SPLIT:           0.000E+00

CASE NUMBER/SPLIT:    4      9.665E-03
     DEPENDENCIES:  110       107

    REQ. BRANCHES:    1    *    4

      DESCRIPTION:  L-CIgn    LGWW>8

CASE/BRANCH SPLIT:           9.665E-03

CASE NUMBER/SPLIT:    5      0.000E+00
     DEPENDENCIES:  110       108       108       106       107

    REQ. BRANCHES:    1    *(   2    +    3)   *    4    *    3

      DESCRIPTION:  L-CIgn    L-WWIn2   L-WWIn3   L-CS      LGWW>12

CASE/BRANCH SPLIT:           0.000E+00

CASE NUMBER/SPLIT:    6      2.429E-03
     DEPENDENCIES:  110       107

    REQ. BRANCHES:    1    *    3

      DESCRIPTION:  L-CIgn    LGWW>12

CASE/BRANCH SPLIT:           2.429E-03

CASE NUMBER/SPLIT:    7      0.000E+00
     DEPENDENCIES:  110       108       108       106       107       107

    REQ. BRANCHES:    1    *(   2    +    3)   *    4    *(   1    +    2)

      DESCRIPTION:  L-CIgn    L-WWIn2   L-WWIn3   L-CS      LGWW>20   LGWW>16

CASE/BRANCH SPLIT:           0.000E+00

CASE NUMBER/SPLIT:    8      1.709E-01
     DEPENDENCIES:  110       107       107
```

```
        REQ. BRANCHES:    1    *(   1    +    2)

          DESCRIPTION:  L-CIgn    LGWW>20   LGWW>16

    CASE/BRANCH SPLIT:           1.709E-01

    CASE NUMBER/SPLIT:    9     7.265E-01
          DESCRIPTION:         Otherwise
    CASE/BRANCH SPLIT:           7.265E-01

********  QUESTION:  114  What is the peak pressure in containment from a late hydrogen burn?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                           641281
          BRANCHES:              L-PBrn>7  L-PBrn>6  L-PBrn>5  L-PBrn>4  L-PBrn>3  L-PBrn>2
                                    1         2         3         4         5         6
    REALIZED SPLIT:              1.251E-01 2.260E-03 7.293E-03 7.172E-03 9.476E-03 8.485E-01

                       SUMMARY BY CASE

    CASE NUMBER/SPLIT:    1     7.265E-01
         DEPENDENCIES:  110

        REQ. BRANCHES:    2

          DESCRIPTION:  LnCIgn

    CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 7.265E-01

    CASE NUMBER/SPLIT:    2     3.577E-02
         DEPENDENCIES:  93         93         27         79

        REQ. BRANCHES:    3    +    4    +    1    *    2

          DESCRIPTION:  I-CL3      I-CL4      E4-HIS     I-AC

    CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.577E-02

    CASE NUMBER/SPLIT:    3     6.493E-02
         DEPENDENCIES:  111

        REQ. BRANCHES:    1

          DESCRIPTION:  L-WWDt

    CASE/BRANCH SPLIT:           5.326E-02 9.780E-04 3.085E-03 2.486E-03 2.577E-03 2.537E-03

    CASE NUMBER/SPLIT:    4     1.726E-01
          DESCRIPTION:         Otherwise
    CASE/BRANCH SPLIT:           7.180E-02 1.282E-03 4.208E-03 4.686E-03 6.8 9E-03 8.370E-02

********  QUESTION:  115  What is the level of drywell leakage induced by a late detonation in containment
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                           641281
          BRANCHES:              LnDWDt    L-DWDt2   L-DWDt3
                                    1         2         3
    REALIZED SPLIT:              9.872E-01 1.039E-02 2.320E-03

                       SUMMARY BY CASE

    CASE NUMBER/SPLIT:    1     6.578E-02
         DEPENDENCIES:  111

        REQ. BRANCHES:    1

          DESCRIPTION:  L-WWDt

    CASE/BRANCH SPLIT:           5.308E-02 1.039E-02 2.320E-03
```

```
CASE NUMBER/SPLIT:    2     9.342E-01
      DESCRIPTION:          Otherwise -- No detonation and thus no failure
CASE/BRANCH SPLIT:           9.342E-01 0.000E+00 0.000E+00


********  QUESTION:  116  What is the level of containment leakage induced by a late detonation?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                             641281
          BRANCHES:            LnDtF     L-DtF2    L-DtF3
                                 1         2         3
   REALIZED SPLIT:           9.728E-01 1.870E-02 7.429E-03

                  SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     1.271E-02
      DEPENDENCIES:  115       115

     REQ. BRANCHES:    2   +    3

       DESCRIPTION:  L-DWDt2   L-DWDt3

 CASE/BRANCH SPLIT:          0.000E+00 9.740E-03 2.965E-03

 CASE NUMBER/SPLIT:    2     5.308E-02
      DEPENDENCIES:  111

     REQ. BRANCHES:    1

       DESCRIPTION:  L-WWDt

 CASE/BRANCH SPLIT:          3.866E-02 9.957E-03 4.464E-03

 CASE NUMBER/SPLIT:    5     9.342E-01
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          9.342E-01 0.000E+00 0.000E+00


********  QUESTION:  117  What is the level of containment leakage induced by late combustion events?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                             641281
          BRANCHES:            LnCL      L-CL2     L-CL3     L-CL4
                                 1         2         3         4
   REALIZED SPLIT:           4.574E-01 8.084E-02 4.537E-01 7.771E-03

                  SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     7.771E-03
      DEPENDENCIES:   93

     REQ. BRANCHES:    4

       DESCRIPTION:  I-CL4

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 7.771E-03

 CASE NUMBER/SPLIT:    2     3.278E-01
      DEPENDENCIES:   93       103       116

     REQ. BRANCHES:    3   +    2   +    3

       DESCRIPTION:  I-CL3     I-VENT    L-DtF3

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 3.278E-01 0.000E+00

 CASE NUMBER/SPLIT:    3     9.651E-02
      DEPENDENCIES:   93       116

     REQ. BRANCHES:    2   +    2
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```
      DESCRIPTION:  I-CL2     L-DtF2

 CASE/BRANCH SPLIT:          0.000E+00 7.883E-02 1.768E-02 0.000E+00

 CASE NUMBER/SPLIT:    4     5.677E-01
      DESCRIPTION:          Otherwise
 CASE/BRANCH SPLIT:          4.574E-01 2.011E-03 1.082E-01 0.000E+00


********  QUESTION:  118  What is the level of drywell leakage induced by late combustion?
Q-TYPE/TIMES ASKED:       DEP. CALC. PROB.                              641281
         BRANCHES:           LnDWDf    L-DWDf2   L-DWHDf2  L-DWDf3   L-DWHDf3
                               1         2         3         4         5
   REALIZED SPLIT:           6.583E-01 7.589E-02 0.000E+00 2.656E-01 0.000E+00

                  SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     1.592E-01
     DEPENDENCIES:   94        115

    REQ. BRANCHES:    4    +    3

      DESCRIPTION:  I-DWDf3   L-DWDt3

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 1.592E-01 0.000E+00

 CASE NUMBER/SPLIT:    2     0.000E+00
     DEPENDENCIES:   94

    REQ. BRANCHES:    5

      DESCRIPTION:  I-DWHDf3

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    3     5.865E-02
     DEPENDENCIES:   94        115       117       117

    REQ. BRANCHES: (  2    +    2)   *(   3    +    4)

      DESCRIPTION:  I-DWDf2   L-DWDt2   L-CL3     L-CL4

 CASE/BRANCH SPLIT:          0.000E+00 4.991E-02 0.000E+00 8.731E-03 0.000E+00

 CASE NUMBER/SPLIT:    4     2.189E-02
     DEPENDENCIES:   94        115

    REQ. BRANCHES:    2    +    2

      DESCRIPTION:  I-DWDf2   L-DWDt2

 CASE/BRANCH SPLIT:          0.000E+00 2.189E-02 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    5     0.000E+00
     DEPENDENCIES:   94        117       117

    REQ. BRANCHES:    3    *(   3    +    4)

      DESCRIPTION:  I-DWHDf2  L-CL3     L-CL4

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

 CASE NUMBER/SPLIT:    6     0.000E+00
     DEPENDENCIES:   94

    REQ. BRANCHES:    3

      DESCRIPTION:  I-DWHDf2
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CASE/BRANCH SPLIT:          0.000E+00 0.000 +00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    7     7.600E-01
      DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          6.583E-01 4.082E-03 0.000E+00 9.762E-02 0.000E+00


********  QUESTION:  119  Is the containment not vented late?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                          705497
          BRANCHES:           LnVENT    L-VENT
                               1          2
   REALIZED SPLIT:          9.512E-01 4.840E-02

                  SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     4.996E-01
     DEPENDENCIES:  104        117       137

    REQ. BRANCHES:    1    +(   3    +    4)

      DESCRIPTION:  LfAC       L-CL3     L-CL4

CASE/BRANCH SPLIT:          4.996E-01 0.000E+00

CASE NUMBER/SPLIT:    2     2.609E-04
     DEPENDENCIES:   99         63        81        95

    REQ. BRANCHES:    4    *(   5    +    2    +   /3)

      DESCRIPTION:  DlyCCI    nBreach   IrCS     /1-SPB3

CASE/BRANCH SPLIT:          2.609E-04 0.000E+00

CASE NUMBER/SPLIT:    3     8.649E-05
     DEPENDENCIES:   99         63        106       118       118

    REQ. BRANCHES:    4    *(   5    +    4    +(  /4    *   /5))

      DESCRIPTION:  DlyCCI    nBreach   L-CS     /L-DWDf3  /L-DWHDf3

CASE/BRANCH SPLIT:          8.649E-05 0.000E+00

CASE NUMBER/SPLIT:    4     4.997E-01
      DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:          4.513E-01 4.840E-02


********  QUESTION:  120  How much concrete must be eroded to cause pedestal failure?
Q-TYPE/TIMES ASKED:        INDEP. INPUT PROB. INPUT PARM.            705497
          BRANCHES:           ConErPed
                               1
   REALIZED SPLIT:          1.000E+00


********  QUESTION:  121  At what time does pedestal failure occur?
Q-TYPE/TIMES ASKED:        DEP. CALC. PROB.                          705497
          BRANCHES:           PedF@VB   PedF@10   PedF@6    PeffF@3   PedF@1    NoPedF
                               1          2         3         4         5         6
   REALIZED SPLIT:          1.792E-01 1.089E-01 8.624E-03 2.980E-02 1.733E-02 6.558E-01

                  SUMMARY BY CASE

CASE NUMBER/SPLIT:    1     6.472E-01
     DEPENDENCIES:   63         63        99        99

    REQ. BRANCHES:    1    +    5    *    4    +    5
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```
      DESCRIPTION:  A-Fail    nBreach   DryCCI    noCCI

CASE/BRANCH SPLIT:           0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 6.472E-01

CASE NUMBER/SPLIT:    2      1.792E-01
     DEPENDENCIES:   75        74

    REQ. BRANCHES:    1    +    1

      DESCRIPTION:  I-PedFI   I-PedFP

CASE/BRANCH SPLIT:           1.792E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:    3      3.179E-05
     DEPENDENCIES:  102        102        61        99

    REQ. BRANCHES:   /1    *   /2    *    1    *    2

      DESCRIPTION: /ZrOx75   /ZrOx50    HiLiqVB   WetCCI

CASE/BRANCH SPLIT:           0.000E+00 3.558E-06 0.000E+00 8.630E-06 1.960E-05 0.000E+00

CASE NUMBER/SPLIT:    4      6.822E-04
     DEPENDENCIES:  102        102        61        99

    REQ. BRANCHES:   /1    *   /2    *    2    *    2

      DESCRIPTION: /ZrOx75   /ZrOx50    LoLiqVB   WetCCI

CASE/BRANCH SPLIT:           0.000E+00 2.914E-04 1.265E-04 5.589E-05 1.791E-04 2.930E-05

CASE NUMBER/SPLIT:    5      2.881E-05
     DEPENDENCIES:   99

    REQ. BRANCHES:    2

      DESCRIPTION:  WetCCI

CASE/BRANCH SPLIT:           0.000E+00 1.491E-05 9.970E-06 0.000E+00 3.937E-06 0.000E+00

CASE NUMBER/SPLIT:    6      1.375E-03
     DEPENDENCIES:  102        102        61        63        63

    REQ. BRANCHES:   /1    *   /2    *    1    *(   2    +    3)

      DESCRIPTION: /ZrOx75   /ZrOx50    HiLiqVB   BH-Fail   LgBrch

CASE/BRANCH SPLIT:           0.000E+00 1.077E-03 0.000E+00 0.000E+00 2.979E-04 0.000E+00

CASE NUMBER/SPLIT:    7      1.525E-03
     DEPENDENCIES:   61         63        63

    REQ. BRANCHES:    1    *(   2    +    3)

      DESCRIPTION:  HiLiqVB   BH-Fail   LgBrch

CASE/BRANCH SPLIT:           0.000E+00 1.026E-06 0.000E+00 0.000E+00 0.000E+00 1.524E-03

CASE NUMBER/SPLIT:    8      7.922E-02
     DEPENDENCIES:  102        102        63        63

    REQ. BRANCHES:   /1    *   /2    *(   2    +    3)

      DESCRIPTION: /ZrOx75   /ZrOx50    BH-Fail   LgBrch

CASE/BRANCH SPLIT:           0.000E+00 4.666E-02 6.020E-03 1.448E-02 8.817E-03 3.243E-03

CASE NUMBER/SPLIT:    9      9.039E-02
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```
         DESCRIPTION:          Otherwise -- Group 4 for MCCI experts
   CASE/BRANCH SPLIT:            0.000E+00 6.085E-02 2.468E-03 1.526E-02 8.010E-03 3.801E-03


******** QUESTION:  122  What is the level of late suppression pool bypass?
Q-TYPE/TIMES ASKED:        DEP. INPUT PROB.                              705497
          BRANCHES:             LnSPB     L-SPB2    L-SPB3
                                  1         2         [illegible]
    REALIZED SPLIT:            6.077E-01 7.851E-02 3.[illegible]34E-01

                       SUMMARY BY CASE

  CASE NUMBER/SPLIT:     1       2.990E-01
       DEPENDENCIES:    95         118        118

      REQ. BRANCHES:     3    +    4    +    5

        DESCRIPTION:  I-SPB3    L-DWDf3   L-DWHDf3

  CASE/BRANCH SPLIT:            0.000E+00 0.000E+00 2.990E-01

  CASE NUMBER/SPLIT:     2       1.501E-02
       DEPENDENCIES:    95         118        118        121        121

      REQ. BRANCHES  (   2    +    2    +    3)    *   /1    *    /6

        DESCRIPTION:  I-SPB2    L-DWDf2   L-DWHDf2 /PedF@VB  /NoPedF

  CASE/BRANCH SPLIT:            0.000E+00 1.145E-02 3.563E-03

  CASE NUMBER/SPLIT:     3       7.066E-03
       DEPENDENCIES:    95         118        118        104        110

      REQ. BRANCHES: (   2    +    2    +    3)    *    2    *    1

        DESCRIPTION:  I-SPB2    L-DWDf2   L-DWHDf2  L-AC      L-CIgn

  CASE/BRANCH SPLIT:            0.000E+00 7.027E-03 3.889E-05

  CASE NUMBER/SPLIT:     4       6.004E-02
       DEPENDENCIES:    [illegible]         118        118

      REQ. BRANCHES:     2    +    2    +    3

        DESCRIPTION:  I-SPB2    L-DWDf2   L-DWHDf2

  CASE/BRANCH SPLIT:            0.000E+00 6.004E-02 0.000E+00

  CASE NUMBER/SPLIT:     5       6.810E-02
       DEPENDENCIES:   121         121

      REQ. BRANCHES:    /1    *   /6

        DESCRIPTION: /PedF@VB  /NoPedF

  CASE/BRANCH SPLIT:            5.849E-02 0.000E+00 9.688E-03

  CASE NUMBER/SPLIT:     6       9.637E-03
       DEPENDENCIES:   104         110

      REQ. BRANCHES:     2          1

        DESCRIPTION:  L-AC      L-CIgn

  CASE/BRANCH SPLIT:            9.524E-04 0.000E+00 1.130E-03

  CASE NUMBER/SPLIT:     7       4.539E-01
        DESCRIPTION:           Otherwise
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CASE/BRANCH SPLIT:          4.539E-01 0.000E+00 0.000E+00

********  QUESTION:  123  What is the late containment pressure due to non-condensibles or steam?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB. INPUT PARM.               705497
          BRANCHES:           LT-Pres   nLT-Pres
                                1         2
    REALIZED SPLIT:         4.151E-01 5.846E-01

                      SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     5.842E-01
      DEPENDENCIES:  117       119

     REQ. BRANCHES:   /1    +    2

       DESCRIPTION:  /LnCL      L-VENT

 CASE/BRANCH SPLIT:          0.000E+00 5.842E-01

 CASE NUMBER/SPLIT:    2     3.949E-04
      DEPENDENCIES:   99        63        106        118        118

     REQ. BRANCHES:    4    *(   5    +    4    +(  /4    *    /5))

       DESCRIPTION:  DlyCCI    nBreach   L-CS     /L-DWDf3  /L-DWHDf3

 CASE/BRANCH SPLIT:          0.000E+00 3.949E-04

 CASE NUMBER/SPLIT:    3     1.581E-03
      DEPENDENCIES:   63        95        97         98        106

     REQ. BRANCHES:   /5    *    3    *(  /1    +    1)   *    /4

       DESCRIPTION:  /nBreach   I-SPB3   /nLDBWat   LDWFld   /L-CS

 CASE/BRANCH SPLIT:          1.581E-03 0.000E+00

 CASE NUMBER/SPLIT:    4     4.135E-01
       DESCRIPTION:         Otherwise
 CASE/BRANCH SPLIT:          4.135E-01 0.000E+00

********  QUESTION:  124  Does containment failure occur late due to non-condensibles or steam?
Q-TYPE/TIMES ASKED:       INDEP. CALC. PROB.                          705497
          BRANCHES:           LPnCL     LP-CL2     LP-CL3     LP-CL4
                                1         2          3          4
    REALIZED SPLIT:         7.117E-01 1.600E-01 1.281E-01 0.000E+00

********  QUESTION:  125  What is the long-term level of containment leakage?
Q-TYPE/TIMES ASKED:       DEP. INPUT PROB.                            705497
          BRANCHES:           LTnCL     LT-CL2     LT-CL3     LT-CL4
                                1         2          3          4
    REALIZED SPLIT:         1.319E-01 2.293E-01 6.307E-01 7.787E-03

                      SUMMARY BY CASE

 CASE NUMBER/SPLIT:    1     7.787E-03
      DEPENDENCIES:  117       124

     REQ. BRANCHES:    4    +    4

       DESCRIPTION:  L-CL4     LP-CL4

 CASE/BRANCH SPLIT:          0.000E+00 0.000E+00 0.000E+00 7.787E-03

 CASE NUMBER/SPLIT:    2     6.307E-01
```

```
         DEPENDENCIES:  117        124        119

        REQ. BRANCHES:    3    +    3    +    2

          DESCRIPTION:  L-CL3      LP-CL3    L-VENT

CASE/BRANCH SPLIT:              0.000E+00 0.000E+00 6.307E-01 0.000E+00

CASE NUMBER/SPLIT:     3       2.293E-01
         DEPENDENCIES:  117        124

        REQ. BRANCHES:    2    +    2

          DESCRIPTION:  L-CL2      LP-CL2

CASE/BRANCH SPLIT:              0.000E+00 2.293E-01 0.000E+00 0.000E+00

CASE NUMBER/SPLIT:     4       1.319E-01
          DESCRIPTION:         Otherwise
CASE/BRANCH SPLIT:              1.319E-01 0.000E+00 0.000E+00 0.000E+00
```

B.4 PSTEVNT Rebinning Input File for GGSOR

The PSTEVNT program is used to collapse the accident progression bins into 9-dimensional source terms bins for input into GGSOR. The input file that controls this rebinning process, **ggrebin.dat**, is shown below.

```
ACCIDENT PATHWAY BINNING FOR GGSOR
9 ASeq   ZrOxid         VB    DCH-SE       SPB       CF  SPRAYS
  MCCI   SRVBkr
6   6    Fst-SB    Slw-SB    Fst-T2    Slw-T2  Fst-TC  Slw-TC
1   1          1
               1
         Fst-SB
1   2          1
               2
         Slw-SB
1   3          1
               3
         Fst-T2
1   4          1
               4
         Slw-T2
1   5          1
               5
         Fst-TC
1   6          1
               6
         Slw-TC
2   2    HiZrOx    LoZrOx
1   1          2
               1
         HiZrOx
1   2          2
               2
         LoZrOx
5   5  HiP-nLPI  LoP-nLPI   HiP-LPI   LoP-LPI      nVB
1   1          3
               1
```

```
         HiP-nLPI
1   2           3
                2
         LoP-nLPI
1   3           3
                3
          HiP-LPI
1   4           3
                4
          LoP-LPI
1   5           3
                5
              nVB
5   5       HiDCH     LoDCH    HiEXSE    LoEXSE nDCH-SE
1   1           4
                1
            HiDCH
1   2           4
                2
            LoDCH
1   3           4
                3
           HiEXSE
1   4           4
                4
           LoEXSE
1   5           4
                5
          nDCH-SE
8   8 SPBE0L0    SPBE0I3    SPBE0L2    SPBE0L3    SPBE2L2 SPBE2I3 SPBE2L3 SPBE3L3
1   1           5
                1
          SPBE0L0
1   2           5
                2
          SPBE0I3
1   3           5
                3
          SPBE0L2
1   4           5
                4
          SPBE0L3
1   5           5
                5
          SPBE2L2
1   6           5
                6
          SPBE2I3
1   7           5
                7
          SPBE2L3
1   8           5
                8
          SPBE3L3
9   9       CE-Lk     CE-Rpt   CE-VENT    CVB-Lk CVB-Rpt   CL-Lk  CL-Rpt
          CL-VENT    CnFail
1   1           6
                1
            CE-Lk
1   2           6
                2
           CE-Rpt
1   3           6
                3
          CE-VENT
1   4           6
                4
           CVB-Lk
```

```
  1   5         6
                5
          CVB-Rpt
  1   6         6
                6
            CL-Lk
  1   7         6
                7
           CL-Rpt
  1   8         6
                8
          CL-VENT
  1   9         6
                9
           CnFail
  4   4      noCS    ECSnoL      LCS       ECS
  1   1         7
                1
             noCS
  1   2         7
                2
           ECSnoL
  1   3         7
                3
              LCS
  1   4         7
                4
              ECS
  5   5    DryCCI    WetCCI    FLDCCI    DlyCCI   noCCI
  1   1         8
                1
           DryCCI
  1   2         8
                2
           WetCCI
  1   3         8
                3
           FLDCCI
  1   4         8
                4
           DlyCCI
  1   5         8
                5
            noCCI
  2   2   oSRVBkr   cSRVBkr
  1   1         9
                1
          oSRVBkr
  1   2         9
                2
          cSRVBkr
```

B.5 PSTEVNT Rebinning File for Presentation Bins

The PSTEVNT program is also used to collapse the accident progression bins into the Draft NUREG-1150 presentation bins. This rebinning is controlled by the file **reduce.dat**, shown below.

```
  REBINNED BINS FOR PRESENTATION
  1  BIN
  8  8  NoVB  NCF  VENT  LCF  ECF-NPB  ECF-LPB ECF-EPB-S  ECF-EPB-NS
  1  1          3
                5
              nVB
  2  2          3        6
               /5     *  9
               VB     NoCF
  3  3          3        6         6
               /5     * (3    +    8)
               VB     CE-VENT  CL-VENT
  3  4          3        6         6
               /5     * (6    +    7)
               VB      CL-Lk    CL-Rpt
  6  5          3        6   6   6   6          5
               /5     * (1 + 2 + 4 + 5)  *      1
               VB            ECF              NoSPB
  7  6          3        6   6   6   6        5   5
               /5     * (1 + 2 + 4 + 5)  *  (3 + 4)
               VB            ECF              L-SPB
 11  7          3   6   6   6   6    5   5   5   5   5     7
               /5 * (1 + 2 + 4 + 5) * (2 + 5 + 6 + 7 + 8) * /1
               VB       ECF                  E-SPB           ECS
 11  8          3   6   6   6   6    5   5   5   5   5     7
               /5 * (1 + 2 + 4 + 5) * (2 + 5 + 6 + 7 + 8) * 1
               VB       ECF                  E-SPB           noCS
0
```

APPENDIX C

SOURCE CODE LISTINGS

APPENDIX C
SOURCE CODE LISTINGS

C.1 Source Code for MASTERK

```
      PROGRAM MASTRK

      INTEGER PDIM, PFILE, PSMRY
      PARAMETER (PDIM     = 14, PFILE       =20,   PSMRY  =30000)
      CHARACTER MASTER(PSMRY)*(PDIM), COMP*(PDIM), FILENM*60,
     *          TITLE*80,           RTITLE*80,    YN*10
      DIMENSION NEXTF(PSMRY),NEXTB(PSMRY),IORDER(PSMRY),INVORD(PSMRY)
      LOGICAL BYRUN

      WRITE(6,1005)
 1005 FORMAT(' ENTER THE NAME OF THE KEEP BIN FILE')
      READ(5,2001) FILENM
      OPEN (UNIT=7,FILE=FILENM,STATUS='NEW')
      WRITE(6,1001)
 1001 FORMAT(' ENTER THE TITLE OF THE KEEP BIN FILE')
      READ(5,2001) RTITLE
 2001 FORMAT(A)
      WRITE(6,1009)
 1009 FORMAT(' ENTER NUMBER OF FILES TO BE PROCESSED')
      READ(5,*) NFILES
      WRITE(6,1002)
 1002 FORMAT(' ENTER THE NUMBER OF OBSERVATIONS TO BE PROCESSED')
      READ(5,*) NOBS
      WRITE(6,1008)
 1008 FORMAT(' ARE KEPT BINS TO BE DETERMINED BY RUN? (Y/N)')
      READ(5,2001) YN
      IF(YN(1:1).EQ.'Y'.OR.YN(1:1).EQ.'y') THEN
         BYRUN=.TRUE.
      ELSE
         BYRUN=.FALSE.
      ENDIF
      NLIST=0
C
C     LOOP TO OPEN FILES
      DO 10 IFILE=1,NFILES
C
C       READ FILE NAMES TO BE PROCESSED
        WRITE(6,1003) IFILE
 1003   FORMAT(' ENTER THE NAME OF FILE',I4)
        READ(5,2001) FILENM
        INUNIT=IFILE+20
        OPEN(UNIT=INUNIT,FILE=FILENM,STATUS='OLD')
   10 CONTINUE
C
C     LOOP OVER OBSERVATIONS
      DO 210 IOBS=1,NOBS
C
C        INITIALIZE BIN COUNTER
         IF(BYRUN) NLIST=0
C
C        LOOP OVER FILES
         DO 110 IFILE=1,NFILES
            INUNIT=IFILE+20
            READ(INUNIT,2002) TITLE
 2002       FORMAT(1X,A79)
            READ(INUNIT,*) NDIM, NBIN
```

```
C            WRITE(6,1004) NBIN,TITLE
C1004        FORMAT(I6,' BINS WILL BE READ FROM:'/1X,A)
C
C           READ BINS FROM FILE AND INSERT THEM INTO LIST
            DO 100 IBIN=1,NBIN
              READ(INUNIT,2003)COMP(1:NDIM)
2003          FORMAT(1X,A)
              CALL LINKL(COMP,MASTER,NLIST,NEXTF,NEXTB,IFIRST,ILAST,
     *                   LASTBN)
 100        CONTINUE
 110    CONTINUE
C
C       REORDER ACCORDING TO LINKED LIST
        IF(BYRUN.OR.IOBS.EQ.NOBS) THEN
          DO 120 I=1,NLIST
            IORDER(I)=I
            INVORD(I)=I
 120      CONTINUE
          ICURR=IFIRST
          DO 130 I=1,NLIST
            COMP=MASTER(I)
            MASTER(I)=MASTER(IORDER(ICURR))
            MASTER(IORDER(ICURR))=COMP
            IORDER(INVORD(I))=IORDER(ICURR)
            INVORD(IORDER(ICURR))=INVORD(I)
            IORDER(ICURR)=I
            ICURR=NEXTF(ICURR)
 130      CONTINUE
C
C         REPORT RESULTS
          IF(BYRUN) THEN
            WRITE(6,1006) IOBS, NLIST
1006        FORMAT(' OBSERVATION',I5,' PRODUCED',I5,' UNIQUE BINS')
            WRITE(7,1007)IOBS,RTITLE,NDIM,NLIST
1007        FORMAT(I5,1X,A/2I10)
          ELSE
            WRITE(6,1010) NOBS, NLIST
1010        FORMAT(I5,' OBSERVATIONS PRODUCED',I5,' UNIQUE BINS')
            WRITE(7,1011) RTITLE,NDIM,NLIST
1011        FORMAT(1X,A/2I10)
          ENDIF
          DO 300 ILIST=1,NLIST
            WRITE(7,2003) MASTER(ILIST)(1:NDIM)
 300      CONTINUE
        ENDIF
 310  CONTINUE
      DO 400 IFILE=1,NFILES
         CLOSE(UNIT=IFILE+20,STATUS='KEEP')
 400  CONTINUE
      CLOSE(UNIT=7,STATUS='KEEP')
      STOP
      END
      SUBROUTINE LINKL(CINDEX,CBNSMR,NBINS,
     *                        NEXTF,NEXTB,IFIRST,ILAST,LASTBN)
C
C     LINKL INSERTS CINDEX INTO THE LINKED LIST DESCRIBED BY CBNSMR,
C     NBINS, NEXTF, NEXTB, IFIRST, ILAST, LASTBN
C
C     A MASTER LIST OF THE BINS IS KEPT IN ORDER BY MEANS OF A LINKED
C     LIST SCHEME.
C
      CHARACTER*(*) CBNSMR, CINDEX
      DIMENSION  NEXTB(*), NEXTF(*), CBNSMR(*)
C
C     CHECK FOR FIRST BIN
```

```
      IF( NBINS .EQ. 0) THEN
C
C         SET "CBNSMR" FOR THE FIRST BIN.
          CBNSMR(1) = CINDEX
          NBINS = 1
          IFIRST = 1
          ILAST = 1
          LASTBN=1
      ELSE
C
C         FIND POSITION OF BIN WITHIN THE LINKED LIST:
C         IF THE INDEX IS NOT EQUAL TO ANY OF THE PRIOR INDICES,
C         THE INDEX IS "STUCK IN" THE APPROPRIATE PLACE IN THE
C         LINKED LIST WITH LINKED INDICES IN ASCENDING ORDER.
C
C         CHECK IF SMALLEST INDEX
          IF(CINDEX.LE.CBNSMR(IFIRST)) THEN
             IF(CINDEX.NE.CBNSMR(IFIRST)) THEN
                 NBINS = NBINS+1
                 NEXTF(NBINS) = IFIRST
                 NEXTB(IFIRST) = NBINS
                 IFIRST = NBINS
                 CBNSMR(NBINS) = CINDEX
             ENDIF
             LASTBN=IFIRST
C
C         CHECK IF GREATEST INDEX
          ELSE IF(CINDEX.GE.CBNSMR(ILAST)) THEN
             IF(CINDEX.NE.CBNSMR(ILAST)) THEN
                 NBINS = NBINS+1
                 NEXTF(ILAST) = NBINS
                 NEXTB(NBINS) = ILAST
                 ILAST = NBINS
                 CBNSMR(NBINS) = CINDEX
             ENDIF
             LASTBN=ILAST
C
C         INSERT INTO LIST
          ELSE
             ICURR = LASTBN
C            SELECT FORWARD OR BACKWARD SEARCH
             IF(CINDEX.GT.CBNSMR(ICURR)) THEN
C                 CHECK IF CINDEX IS BETWEEN CURRENT AND NEXT BIN
  20              IF(CINDEX.LT.CBNSMR(NEXTF(ICURR))) THEN
C                    CHECK IF CINDEX IS EQUAL TO CURRENT BIN
                     IF(CINDEX .EQ. CBNSMR(ICURR)) THEN
                        LASTBN=ICURR
                        GOTO 30
                     ELSE
                        NBINS = NBINS+1
                        NEXTF(NBINS) = NEXTF(ICURR)
                        NEXTB(NEXTF(ICURR)) = NBINS
                        NEXTF(ICURR) = NBINS
                        NEXTB(NBINS) = ICURR
                        CBNSMR(NBINS) = CINDEX
                        LASTBN=NBINS
                        GOTO 30
                     ENDIF
                  ELSE
C
C                    INCREMENT LIST POINTER
                     ICURR = NEXTF(ICURR)
                     GOTO 20
                  ENDIF
             ELSE
```

```
C                 CHECK IF C!NDEX IS BETWEEN CURRENT AND PREVIOUS BIN
   25             IF(CINDEX.GT.CBNSMR(NEXTB(ICURR))) THEN
C                    CHECK IF CINDEX IS EQUAL TO CURRENT BIN
                     IF(CINDEX .EQ. CBNSMR(ICURR)) THEN
                        LASTBN=ICURR
                        GOTO 30
                     ELSE
                        NBINS = NBINS+1
                        NEXTB(NBINS) = NEXTB(ICURR)
                        NEXTF(NEXTB(ICURR)) = NBINS
                        NEXTB(ICURR) = NBINS
                        NEXTF(NBINS) = ICURR
                        CBNSMR(NBINS) = CINDEX
                        LASTBN=NBINS
                        GOTO 30
                     ENDIF
                  ELSE
C
C                    DECREMENT LIST POINTER
                     ICURR = NEXTB(ICURR)
                     GOTO 25
                  ENDIF
              ENDIF
          ENDIF
      ENDIF
   30 CONTINUE
      RETURN
      END
```

C.2 Source Code Listing for GG_FRQ

```
      PROGRAM GGFRQ
C*****MERGE PLANT DAMAGE STATE FREQUENCIES WITH BIN CONDITIONAL
C*****PROBABILITIES FOR USE WITH PARTITION AND PR..MIS
C djp
C djp PARAMETER (MAXDM=9, MAXBIN=1700, MAXSMP=155, MAXPDS=12,
C djp1            MAXDAT=100)
C djp
      PARAMETER (MAXDM=9, MAXBIN=1700, MAXSMP=250, MAXPDS=12,
     1            MAXDAT=100)
C djp
      CHARACTER*10 NBINTL, NDIMTL
      CHARACTER*20 LABEL
      CHARACTER*80 FILNAM, TITLE, TITLEK
      CHARACTER*(MAXDM) BINID(MAXBIN,MAXPDS,MAXSMP),
     1                  BINIDS(MAXBIN), BINIDK(MAXBIN)
      DIMENSION CPROB(MAXBIN,MAXPDS,MAXSMP), NBIN(MAXPDS,MAXSMP),
     1          IPNT(MAXBIN), PDSFRQ(MAXPDS,MAXSMP), TDAT(MAXDAT)
      LOGICAL ERROR
      DATA ERROR / .FALSE. /
C
C//////////////////////////////////////////////////////////////
C*****OPEN TEMAC4 FILE CONTAINING PDS FREQUENCIES BY OBSERVATION
C djp OPEN (4,
C djp1  FILE='GG_LHS_TEMAC.DAT',
C djp2  STATUS='OLD', READONLY)
C
C
C//////////////////////////////////////////////////////////////
C*****OPEN TEMAC4 FILE CONTAINING PDS FREQUENCIES BY OBSERVATION
      OPEN (4,
```

```
     1  FILE='gg_temac.dat',
     2  STATUS='OLD', READONLY)
C
C*****READ NUMBER OF SAMPLE OBSERVATIONS AND NUMBER OF
C*****PLANT DAMAGE STATES
C
      READ(4,*) NSMP, NPDS
C
C*****LOOP THROUGH OBSERVATIONS
C
      DO 500 ISMP=1,NSMP
         READ(4,*) IOBS, NDAT, (TDAT(K),K=1,NDAT)
         PDSFRQ(1,ISMP)=TDAT(1)
         PDSFRQ(2,ISMP)=TDAT(2)
         PDSFRQ(3,ISMP)=TDAT(3)
         PDSFRQ(4,ISMP)=TDAT(4)
         PDSFRQ(5,ISMP)=TDAT(5)
         PDSFRQ(6,ISMP)=TDAT(6)
         PDSFRQ(7,ISMP)=TDAT(7)
         PDSFRQ(8,ISMP)=TDAT(8)
         PDSFRQ(9,ISMP)=TDAT(9)
         PDSFRQ(10,ISMP)=TDAT(10)
         PDSFRQ(11,ISMP)=TDAT(11)
         PDSFRQ(12,ISMP)=TDAT(12)
  500 CONTINUE
C*********CLOSE TEMAC4 PDS FREQUENCY FILE
         CLOSE (4)
C//////////////////////////////////////////////////////////
C*****VALIDATE NUMBER OF PLANT DAMAGE STATES AGAINST DIMENSION
      IF (NPDS .GT. MAXPDS) THEN
         WRITE(6,*) '>>>>>INCREASE PARAMETER MAXPDS TO AT LEAST ',NPDS
         STOP
      ENDIF
C*****VALIDATE NUMBER OF SAMPLE AGAINST DIMENSION
      IF (NSMP .GT. MAXSMP) THEN
         WRITE(6,*) '>>>>>INCREASE PARAMETER MAXSMP TO AT LEAST ',NSMP
         STOP
      ENDIF
C*****LOOP OVER PLANT DAMAGE STATES
      DO 3000 IPDS=1,NPDS
C*********GENERATE FILE NAME FOR BIN CONDITIONAL PROBABILITIES FOR
C*********CURRENT PLANT DAMAGE STATE
         WRITE(FILNAM,2001) IPDS
C*********OPEN CURRENT PLANT DAMAGE STATE FILE
         OPEN (1, FILE=FILNAM, STATUS='OLD', READONLY)
C*********READ FILE HEADING
         READ(1,1001) TITLE
C*********READ NUMBER OF BIN ATTRIBUTES
         READ(1,*) NDM
C*********VALIDATE DIMENSION OF BIN ID
         IF (NDM .GT. MAXDM) THEN
            WRITE(6,*) '>>>>>INCREASE PARAMETER TO AT LEAST ', NDM
            STOP
         ENDIF
C*********READ BIN ATTRIBUTE DESCRIPTIONS (NOT SAVED)
         READ(1,1001) (NDIMTL, IDM=1,NDM)
C*********LOOP OVER BIN ATTRIBUTES
         DO 1000 IDM=1,NDM
C************READ NUMBER OF POSSIBLE OUTCOMES FOR CURRENT BIN ATTRIBUTE
            READ(1,*) NPO
C************READ POSSIBLE OUTCOME DESCRIPTIONS (NOT SAVED)
            READ(1,1001) (NBINTL, IPO=1,NPO)
 1000    CONTINUE
C*********LOOP OVER SAMPLES
         DO 2000 ISMP=1,NSMP
```

```
C***********READ LABEL, SAMPLE NUMBER, AND NUMBER OF BINS FOR CURRENT SAMPLE
            READ(1,2002) LABEL, ISMPT, NBIN(IPDS,ISMP)
C***********VALIDATE SAMPLE NUMBER
            IF (ISMPT .NE. ISMP) THEN
               WRITE(6,9001) ISMP, ISMPT
               STOP
            ENDIF
C***********VALIDATE NUMBER OF BINS FOR CURRENT SAMPLE
            IF (NBIN(IPDS,ISMP) .GT. MAXBIN) THEN
               WRITE(6,*) '>>>>>INCREASE PARAMETER MAXBIN TO AT ',
     1                    'LEAST ', NBIN(IPDS,ISMP)
               STOP
            ENDIF
C***********READ BIN ID'S AND CONDITIONAL PROBABILITIES
            READ(1,2003) (BINID(IBIN,IPDS,ISMP)(1:NDM),
     1                    CPROB(IBIN,IPDS,ISMP),
     2                    IBIN=1,NBIN(IPDS,ISMP))
 2000    CONTINUE
C********CLOSE CURRENT PLANT DAMAGE STATE FILE
         CLOSE (1)
 3000 CONTINUE
C*****INITIALLIZE TOTAL NUMBER OF BINS ON PDS FILES
      NBINKS=0
C*****INITIALLIZE TOTAL NUMBER OF BINS ON .KEP FILE
      NBINSS=0
C*****OPEN .KEP FILE CONTAINING BINS BY SAMPLE
C djp OPEN (2,
C djp1  FILE='BYRUN_MASTER.KEP',
C djp2  STATUS='OLD', READONLY)
C*****OPEN .KEP FILE CONTAINING BINS BY SAMPLE
      OPEN (2,
     1  FILE='byr_mas.kep',
     2  STATUS='OLD', READONLY)
C*****LOOP OVER SAMPLES
      DO 5000 ISMP=1,NSMP
C********READ SAMPLE LABEL
         READ(2,1001) TITLEK
C********READ NUMBER OF BINS FOR CURRENT SAMPLE
         READ(2,*) NDUM, NBINK
C********READ BIN ID'S FOR CURRENT SAMPLE
         READ(2,1002) (BINIDK(IBIN)(1:NDM),IBIN=1,NBINK)
         NBINSS=NBINSS + NBINK
         NBINKS=NBINKS + NBINK
C********INTIALLIZE NUMBER OF BINS FOR PDS FILES FOR CURRENT SAMPLE
         NBINS=0
C********TRANSFER BIN IDS FOR PDS
         DO 3600 IPDS=1,NPDS
            DO 3400 IBIN=1,NBIN(IPDS,ISMP)
               NBINS=NBINS + 1
               BINIDS(NBINS)=BINID(IBIN,IPDS,ISMP)
               IPNT(NBINS)=NBINS
 3400       CONTINUE
 3600    CONTINUE
C********SORT BIN IDS FOR CURRENT SAMPLE
         CALL CSORT (NBINS, BINIDS, IPNT)
C********REMOVE MULTIPLE OCCURRENCES OF SAME BIN ID
         NBTMP=1
         DO 3800 IBINS=2,NBINS
            IF (BINIDS(IPNT(IBINS)) .NE. BINIDS(IPNT(NBTMP))) THEN
               NBTMP=NBTMP + 1
               IPNT(NBTMP)=IPNT(IBINS)
            ENDIF
 3800    CONTINUE
         NBINS=NBTMP
C********VALIDATE NUMBER OF BINS
```

```
         IF (NBINS .NE. NBINK) THEN
            WRITE(6,9002) NBINS, NBINK, ISMP
            ERROR=.TRUE.
         ENDIF
C*********VALIDATE BIN ID LISTS FOR CURRENT SAMPLE
         DO 4000 IBIN=1,NBINK
C////       IF (ISMP.EQ.8) WRITE(6,8000) IBIN,BINIDS(IPNT(IBIN)),BINIDK(IBIN)
C/// 8000 FORMAT(I6,5X,A,5X,A)
            IF (BINIDS(IPNT(IBIN)) .NE. BINIDK(IBIN)) THEN
               WRITE(6,9003) ISMP
               ERROR=.TRUE.
               GO TO 5000
            ENDIF
 4000    CONTINUE
 5000 CONTINUE
C*****CLOSE MASTER .KEP BIN LIST BY SAMPLE
      CLOSE (2)
C*****IF VALIDATION ERROR HAS OCCURED, TERMINATED EXECUTION
      IF (ERROR) STOP
C*****WRITE PLANT DAMAGE STATE FREQUENCY AND BIN LIST WITH CONDITIONAL
C*****PROBABILITIES VS SAMPLE AND PDS
      WRITE(6,5001) NBINSS, NBINKS
C*****OPEN FILE FOR BIN CONDITIONAL PROBABILTIES AND PDS FREQUENCIES FOR
C*****ALL PDS
      OPEN (3, FILE='gg.frq' STATUS='NEW',
     1       CARRIAGECONTROL='LIST')
      WRITE(3,1001) TITLE
      WRITE(3,5002) NDM, NSMP, NPDS
      DO 7000 ISMP=1,NSMP
         DO 6000 IPDS=1,NPDS
            WRITE(3,5003) ISMP, IPDS, NBIN(IPDS,ISMP), PDSFRQ(IPDS,ISMP)
            IF (NBIN(IPDS,ISMP) .GT. 0) WRITE(3,5004)
     1               (BINID(IBIN,IPDS,ISMP)(1:NDM),
     2               CPROB(IBIN,IPDS,ISMP), IBIN=1,NBIN(IPDS,ISMP))
 6000    CONTINUE
 7000 CONTINUE
      CLOSE (3)
      STOP
C*****FORMAT STATEMENTS
 1001 FORMAT(A)
 1002 FORMAT(1X,A)
C djp
C2001 FORMAT('UD16:[SJHIGGI.GG_PSTEVNT_LHS_RIS]GG_PDSG',I2,'_LHS_RIS_
C    *REBIN.PST')
C djp
 2001 FORMAT('g',I2.2,'_sbin.out')
C djp
 2002 FORMAT(A,2I5)
 2003 FORMAT(A,1X,E20.0)
 5001 FORMAT(1X,I7,' BINS ON PDS FILES',
     1       /1X,I7,' BINS ON .KEP FILE')
 5002 FORMAT(3I8)
 5003 FORMAT(3I8,1PE12.4)
 5004 FORMAT(A,1X,1PE12.4)
 9001 FORMAT(' >>>>>ERROR READING SAMPLE ',I3,', FILE INDICATES ',
     1        'SAMPLE ',I3)
 9002 FORMAT(' >>>>>NUMBER OF BINS ON PDS FILES (',I6,') NOT SAME ',
     1        'NUMBER OF BINS ON .KEP FILE (',I6,')',
     2       /' >>>>>FOR SAMPLE ',I6)
 9003 FORMAT(' >>>>>LIST OF BINS FOR PDS FILES NOT SAME AS LIST OF ',
     1        'BINS FOR .KEP FILE FOR SAMPLE ',I6)
      END
      SUBROUTINE CSORT (NVAR, NAME, IPNT)
C*****SORT NVAR VALUES OF CHARACTER ARRAY NAME IN INCREASING ORDER
C*****USING POINTER ARRAY IPNT
```

```
      CHARACTER*(*) NAME(NVAR)
      DIMENSION IPNT(NVAR)
C
C
      N=NVAR
      L=N/2+1
      IR=N
  100 CONTINUE
      IF (L.LE.1) GO TO 700
      L=L-1
      LHOLD=IPNT(L)
  200 CONTINUE
      J=L
  300 CONTINUE
      I=J
      J=2*J
      IF (J-IR) 400, 500, 600
  400 CONTINUE
      IF (NAME(IPNT(J)) .LT. NAME(IPNT(J+1))) J=J+1
  500 CONTINUE
      IF (NAME(LHOLD) .GE. NAME(IPNT(J))) GO TO 600
      IPNT(I)=IPNT(J)
      GO TO 300
  600 CONTINUE
      IPNT(I)=LHOLD
      GO TO 100
  700 CONTINUE
      LHOLD=IPNT(IR)
      IPNT(IR)=IPNT(1)
      IR=IR - 1
      IF (IR .GT. 1) GO TO 200
      IPNT(1)=LHOLD
      RETURN
      END
```

C.3 Source Code Listing for STER_IN

```
      PROGRAM STER
C*****READS PARTITIONED SOURCE TERM INFORMATION AND TIMING
C*****INFORMATION AND GENERATES MACCS INPUT RECORDS FOR RELEASE
C*****DESCRIPTION FOR ATMOS AND FOR EMERGENCY RESPONSE DESCRIPTION
C*****FOR EARLY (SUBGROUP INFORMATON)
C*****    SUBGROUP 1 =        TEVAC  <  T1-TESCAPE
C*****    SUBGROUP 2 =  T1-TESCAPE  <  TEVAC  <  T1+DT1
C*****    SUBGROUP 3 =      T1+DT1  <  TEVAC  <  T2
C*****    SUBGROUP 4 =          T2  <  TEVAC
C*****(TIMES IN SECONDS FROM SCRAM UNLESS SPECIFIED OTHERWISE)
C
C  THIS PROGRAM MODIFIED 9 MARCH 89 BY D. CHANIN TO CORRECT AN ERROR IN
C  THE CALCULATION OF THE SHELTER SCENARIO RESULTS.
C
C  THE CALCULATION OF TTOSH2, THE TIME TO TAKE SHELTER, IS BEING CHANGED.
C  PREVIOUS TO THIS CHANGE, TTOSH2 WAS CALCULATED AS 2700 + TW.
C  THE CURRENT STER CODE USES A VALUE OF 2700 FOR TTOSH2 (INDEPENDENT OF TW).
C
C  THE EARLY MODULE DEFINES THE TIME TO TAKE SHELTER AS MEASURED FROM OALARM,
C  NOT SCRAM TIME.
C
      PARAMETER (MAXSG=4, MAXFRC=9, MAXPUF=2, MAXREC=1000, MAXLEN=80)
C djp
      CHARACTER*80 DUMMY
```

```
C djp
      CHARACTER*4 SITE
      CHARACTER*(MAXLEN) FILNAM, TITLE, ATMBAS(MAXREC), EARBAS(MAXREC)
      DIMENSION DEVAC(0:MAXSG), TEVAC(0:MAXSG), TW(0:MAXSG),
     1          SGCP(MAXSG), SGF(MAXSG), REFTIM(MAXPUF),
     2          FRACP(MAXSG), LASMOV(MAXSG), LASEVA(MAXSG),
     3          LASHE2(MAXSG), TTTS(MAXSG), TTOSH2(MAXSG),
     4          ST1(MAXFRC,0:MAXSG), ST2(MAXFRC,0:MAXSG),
     5          ELEV(0:MAXSG), T1(0:MAXSG), DT1(0:MAXSG), T2(0:MAXSG),
     6          DT2(0:MAXSG), E1(0:MAXSG), E2(0:MAXSG)
      DATA IDOMIN / 1 /, REFTIM / 0.0, 0.5 /, NPUFFS / 2 /,
     1     FRACP / 4*0.3333 /, I0 / 0 /, I1 / 1 /, I2 / 2 /, I3 / 3 /,
     2     ZERO / 0.0 /, ONE / 1.0 /, I12 / 12 /, I15 / 15 /,
     3     LASMOV / 0, 0, 15, 0 /, LASEVA / 0, 0, 10, 0 /,
     4     LASHE2 / 0, 12, 12, 0 /,
     5     TTOSH2 / 0.0, 2700., 2700., 0.0 /
C
C
      WRITE(6,*) 'ENTER 2 TO 4 LETTER SITE ABBREVIATION'
      READ(5,1001) SITE
      WRITE(FILNAM,21) SITE
      OPEN (7, FILE=FILNAM, STATUS='NEW', CARRIAGECONTROL='LIST')
      WRITE(7,*) 'ENTER 2 TO 4 LETTER SITE ABBREVIATION'
      WRITE(7,1001) SITE
      WRITE(6,*) 'ENTER EVACUATION ESCAPE TIME (SEC)'
      WRITE(7,*) 'ENTER EVACUATION ESCAPE TIME (SEC)'
      READ(5,*) TESC
      WRITE(7,*) TESC
      WRITE(6,*) 'ENTER EVACUATION DELAY TIME (SEC)'
      WRITE(7,*) 'ENTER EVACUATION DELAY TIME (SEC)'
      READ(5,*) TDEL
      WRITE(7,*) TDEL
C*****INITIALLIZE COUNTER FOR NON-ZERO GROUPS
      NST=0
C*****LOAD ATMOS BASE CASE INPUT RECORDS
      NRECA=0
      WRITE(FILNAM,101) SITE
      OPEN (2, FILE=FILNAM, STATUS='OLD')
  100 CONTINUE
      NRECA=NRECA + 1
      IF (NRECA .GT. MAXREC) THEN
         WRITE(6,*) '>>>>>INCREASE PARAMETER MAXREC'
         STOP
      ENDIF
      READ(2,1001,END=200) ATMBAS(NRECA)
      GO TO 100
  200 CONTINUE
      CLOSE(2)
      NRECA=NRECA - 1
      NRECE=0
      WRITE(FILNAM,201) SITE
      OPEN (3, FILE=FILNAM, STATUS='OLD')
  300 CONTINUE
      NRECE=NRECE + 1
      IF (NRECE .GT. MAXREC) THEN
         WRITE(6,*) '>>>>>INCREASE PARAMETER MAXREC'
         STOP
      ENDIF
      READ(3,1001,END=400) EARBAS(NRECE)
C*****LOCATE WIND-SHIFT INDEX
      IF (INDEX(EARBAS(NRECE), 'MIIPLUME001') .GT. 0) THEN
         READ(EARBAS(NRECE)(12:MAXLEN),*) IWS
      ENDIF
      GO TO 300
  400 CONTINUE
```

```
      CLOSE(3)
      NRECE=NRECE - 1
      IF ((NRECA .GT. MAXREC) .OR. (NRECE .GT. MAXREC)) THEN
         WRITE(6,*) '>>>>>INCREASE PARAMETER MAXREC'
         STOP
      ENDIF
C djp
C djp OPEN JCL FILE
      OPEN (13,'JCL.DAT',STATUS='OLD')
C djp
C*****OPEN FILE CONTAINING PARTITIONED SOURCE TERM AND TIMING INFORMATION
      WRITE(FILNAM,401) SITE
      OPEN (1, FILE=FILNAM, STATUS='OLD')
C*****READ TITLE
      READ(1,1001) TITLE
      WRITE(*,*) 'TITLE=', TITLE
      WRITE(7,*) 'TITLE=', TITLE
C*****READ NUMBER OF RELEASE CLASSES (7 OR 9) AND NUMBER OF SOURCE TERM GROUPS
      READ(1,*) NRC, NG
      WRITE(*,*) 'NUMBER OF RELEASE CLASSES=', NRC
      WRITE(7,*) 'NUMBER OF RELEASE CLASSES=', NRC
      WRITE(*,*) 'NUMBER OF SOURCE TERM GROUPS=', NG
      WRITE(7,*) 'NUMBER OF SOURCE TERM GROUPS=', NG
      WRITE(*,*)
      WRITE(7,*)
C*****LOOP OVER SOURCE TERM GROUPS
      DO 4000 IG=1,NG
C********READ GROUP INDEX, NUMBER OF SUBGROUPS FOR THIS GROUP,
C********GROUP FREQUENCY, AND GROUP CONDITIONAL PROBABILITY
         READ(1,*) IGROUP, NSG, GFRQ, GCPRB
C********CHECK FOR NON-ZERO GROUP FREQUENCY TO READ ADDITIONAL
C********RECORDS FOR THIS GROUP
         IF (GFRQ .GT. 0.0) THEN
C///            NST=NST + 1
C///            WRITE(*,*) 'GENERATING SOURCE TERM ', NST
C///            WRITE(7,*) 'GENERATING SOURCE TERM ', NST
C***********READ RELEASE/EVACUATION START DIFFERENCE (T1-TEVAC),
C***********EVACUATION START TIME, WARNING TIME, START OF PUFF RELEASE,
C***********DURATION OF PUFF RELEASE, START OF TAIL RELEASE,
C***********DURATION OF TAIL RELEASE, RELEASE ELEVATION (M),
C***********PUFF ENERGY RELEASE RATE (W), NRC RELEASE FRACTIONS FOR PUFF, AND
C***********TAIL ENERGY RELEASE RATE (W), NRC RELEASE FRACTIONS FOR TAIL
            READ(1,*) DEVAC(0), TEVAC(0), TW(0),
     1                T1(0), DT1(0), T2(0), DT2(0), ELEV(0),
     2                E1(0), (ST1(I,0),I=1,NRC),
     3                E2(0), (ST2(I,0),I=1,NRC)
C***********SET DURATIONS IN RANGE 60 - 86400 S AND PRINT A MESSAGE IF
C***********THE VALUE HAS BEEN MODIFIED
C///            DT1(0)=CLIPIT ('DT1', DT1(0), 60., 86400.)
C///            DT2(0)=CLIPIT ('DT2', DT2(0), 60., 86400.)
C***********SET R   ASE 2 START TIME TO BEGIN AFTER RELEASE 1 IS COMPLETED
C***********BUT ITS REFERENCE POINT CAN NOT BE MORE THAN 100 HOURS AFTER
C***********THE START OF RELEASE 1
C///            ALLOWD=3.6E5
C///            RFPNT2=T2(0) + REFTIM(2) * DT2(0)
C///            DIFRNC=RFPNT2 - T1(0)
C***********CALCULATE THE MAXIMUM ALLOWABLE VALUE FOR T2
C///            IF (DIFRNC .GT. ALLOWD) THEN
C///               VALMAX=T2(0) - (DIFRNC - ALLOWD)
C///            ELSE
C///               VALMAX=1.E35
C///            ENDIF
C///            T2(0)=CLIPIT ('T2', T2(0), T1(0)+DT1(0), VALMAX)
C***********LOOP OVER SUBGROUPS FOR CURRENT GROUP
            DO 1000 ISG=1,NSG
```

```
C***************READ SUBGROUP INDEX, SUBGROUP FREQUENCY,
C************  *SUBGROUP CONDITIONAL PROBABILITY, AND CONDITIONAL PROBABILITY
C***************FOR SUBGROUP DIVIDED BY SUM OF ALL SOURCE TERM FREQUENCIES
                READ(1,*) ISGRP, SGF(ISG), SGCP(ISG), SGCPT
                IF (ISG .EQ. 3) GO TO 1000
                NST=NST + 1
C***************INITIALIZE SUBGROUP SOURCE TERM PARAMETERS
                ELEV(ISG)=0.0
                TW(ISG)=0.0
                E1(ISG)=0.0
                E2(ISG)=0.0
                T1(ISG)=0.0
                T2(ISG)=0.0
                DT1(ISG)=0.0
                DT2(ISG)=0.0
                DO 800 IFRC=1,NRC
                   ST1(IFRC,ISG)=0.0
                   ST2(IFRC,ISG)=0.0
  800           CONTINUE
                WRITE(*,*) 'GENERATING SOURCE TERM ', NST
                WRITE(7,*) 'GENERATING SOURCE TERM ', NST
C***************CHECK FOR NON-ZERO SUBGROUP FREQUENCY TO READ ADDITIONAL
C***************RECORDS FOR THIS SUBGROUP
                IF (SGF(ISG) .GT. 0.0) THEN
C******************READ RELEASE/EVACUATION START DIFFERENCE (T1-TEVAC),
C******************EVACUATION START TIME, WARNING TIME, START OF PUFF RELEASE,
C******************DURATION OF PUFF RELEASE, START OF TAIL RELEASE,
C******************DURATION OF TAIL RELEASE, RELEASE ELEVATION (M),
C******************PUFF ENERGY RELEASE RATE (W), NRC RELEASE FRACTIONS FOR PUFF, AND
C******************TAIL ENERGY RELEASE RATE (W), NRC RELEASE FRACTIONS FOR TAIL
                   READ(1,*) DEVAC(ISG), TEVAC(ISG), TW(ISG), T1(ISG),
     1                       DT1(ISG), T2(ISG), DT2(ISG), ELEV(ISG),
     2                       E1(ISG), (ST1(I,ISG),I=1,NRC),
     3                       E2(ISG), (ST2(I,ISG),I=1,NRC)
                ELSE
C******************SET EVACUATION VALUES WHEN SUBGROUP IS EMPTY
C////                    TW(ISG)=TW(0)
                   IF (ISG .EQ. 1) THEN
                      TEVAC(ISG)=T1(ISG) - TESC - 1800.
                   ELSE IF (ISG .EQ. 2) THEN
                      TEVAC(ISG)=T1(ISG)
                   ELSE IF (ISG .EQ. 3) THEN
                      TEVAC(ISG)=T2(ISG)
                   ELSE
                      TEVAC(ISG)=T1(ISG) + TDEL
                   ENDIF
                   DEVAC(ISG)=T1(ISG) - TEVAC(ISG)
                ENDIF
C***************SET DURATIONS IN RANGE 60 - 86400 S AND PRINT A MESSAGE IF
C***************THE VALUE HAS BEEN MODIFIED
                DT1(ISG)=CLIPIT ('DT1', DT1(ISG), 60., 86400.)
                DT2(ISG)=CLIPIT ('DT2', DT2(ISG), 60., 86400.)
C***************SET RELEASE 2 START TIME TO BEGIN AFTER RELEASE 1 IS COMPLETED
C***************BUT ITS REFERENCE POINT CAN NOT BE MORE THAN 100 HOURS AFTER
C***************THE START OF RELEASE 1
                ALLOWD=2.6E5
                RFPNT2=T2(ISG) + REFTIM(2) * DT2(ISG)
                DIFRNC=RFPNT2 - T1(ISG)
C***************CALCULATE THE MAXIMUM ALLOWABLE VALUE FOR T2
                IF (DIFRNC .GT. ALLOWD) THEN
                   VALMAX=T2(ISG) - (DIFRNC - ALLOWD)
                ELSE
                   VALMAX=1.E35
                ENDIF
                T2(ISG)=CLIPIT ('T2', T2(ISG), T1(ISG)+DT1(ISG), VALMAX)
```

```
C***************DEFINE SHELTER DURATION AS 12 HR
                SHELT2=43200.
C***************WRITE ATMOS INPUT FILE USING BASE ATMOS INPUT PLUS
C***************RELEASE INFORMATION FOR THIS GROUP
                WRITE(FILNAM,1002) SITE, NST
                OPEN (11, FILE=FILNAM, STATUS='NEW'
     1                 CARRIAGECONTROL='LIST')
C djp
                REWIND(13)
 50             READ(13,1005,END=60) DUMMY
                     ILOC=INDEX(DUMMY,'@@')
                     IF(ILOC.GT.0) THEN
                            DUMMY(ILOC:ILOC+1) = FILNAM(9:10)
                     ENDIF
                WRITE(11,1004) DUMMY
                GOTO 50
 60             CONTINUE
C djp
                WRITE(11,1001) (ATMBAS(IREC),IREC=1,NRECA)
                WRITE(11,2001) NST, IG, TW(ISG), IDOMIN,
     1                         (REFTIM(I),I=1,NPUFFS), NPUFFS,
     2                         E1(ISG), E2(ISG)
                WRITE(11,2002) ELEV(ISG), ELEV(ISG),
     1                         DT1(ISG), DT2(ISG), T1(ISG), T2(ISG)
                WRITE(11,2003) NST, IG, (ST1(I,ISG),I=1,NRC)
                WRITE(11,2004) (ST2(I,ISG),I=1,NRC)
                CLOSE(11)
C***************WRITE EARLY INPUT FILE USING BASE ATMOS INPUT PLUS
C***************EVACUATION TIMING INFORMATION FOR THIS SUBGROUP
C djp
C djp            WRITE(FILNAM,1003) SITE, NST, IWS
C djp
                WRITE(FILNAM,1003) SITE, NST
                OPEN (12, FILE=FILNAM, STATUS='NEW',
     1                 CARRIAGECONTROL='LIST')
C               OPEN (12, FILE=FILNAM, STATUS='unknown',
C    1                 ACCESS='APPEND')
C djp
                WRITE(12,1001) (EARBAS(IREC),IREC=1,NRECE)
                IF (SGF(ISG) .GT. 0.0) THEN
                   WRITE(12,3001) NST, IG, I1, ONE, I15
                   WRITE(12,3002) I12, TDEL
                   WRITE(12,3003) ZERO, ZERO, I0, ZERO, ZERO
                ELSE
                   WRITE(12,3001) NST, IG, I1, ONE, I0
                   WRITE(12,3002) I0, ZERO
                   WRITE(12,3003) ZERO, ZERO, I0, ZERO, ZERO
                ENDIF

                WRITE(12,3001) NST, IG, I2, ZERO, I0
                WRITE(12,3002) I0, ZERO
                WRITE(12,3003) ZERO, ZERO, I0, ZERO, ZERO

                WRITE(12,3001) NST, IG, I3, ZERO, I0
                WRITE(12,3002) I0, ZERO
                WRITE(12,3003) ZERO, ZERO, LASHE2(3),
     1                         TTOSH2(3), SHELT2
                CLOSE(12)
 1000       CONTINUE
         ENDIF
 4000 CONTINUE
      CLOSE(1)
      WRITE(*,*) 'MACCS INPUT FILES GENERATED FOR', NST, ' SOURCE TERMS'
      WRITE(7,*) 'MACCS INPUT FILES GENERATED FOR', NST, ' SOURCE TERMS'
      STOP
```

```
C*****FORMAT STATEMENTS
   21 FORMAT(A,'STER.OUT')
  101 FORMAT(A,'ATM.INP')
  201 FORMAT(A,'EAR.INP')
  401 FORMAT(A,'MACCS.INP')
 1001 FORMAT((A))
C djp
C1002 FORMAT(A,'ATM',I3,'.INP')
C djp
 1002 FORMAT(A,'ATM','_',I2.2,'.INP')
C
C djp
C1003 FORMAT(A,'EAR',I3,'-',I1,'-1.INP')
C djp
 1003 FORMAT(A,'EAR','_',I2.2,'.INP')
C
C djp
C1004 FORMAT(A,'EAR',I3,'-',I1,'-2.INP')
C djp
 1004 FORMAT(A80)
C djp
 1005 FORMAT(A80)
C djp
 2001 FORMAT('********************** RELEASE DATA BLOCK *************',
     1       /'*',
     2       /'RDATNAM2001  ''SOURCE TERM-',I3.3,', GROUP-',I3.3,'''',
     3       /'*',
     4       /'* TIME AFTER ACCIDENT INITIATION WHEN THE ACCIDENT ',
     5        'REACHES GENERAL EMERGENCY',
     6       /'* CONDITIONS (AS DEFINED IN NUREG-0654), OR WHEN PLANT ',
     7        'PERSONNEL CAN RELIABLY',
     8       /'* PREDICT THAT GENERAL EMERGENCY CONDITIONS WILL BE ',
     9        'ATTAINED',
     A       /'*',
     B       /'RDOALARM001 ',F10.0,
     C       /'*',
     D       /'* SELECTION OF RISK DOMINANT PLUME',
     E       /'*',
     F       /'RDMAXRIS001 ',I10,
     G       /'*',
     H       /'* REFERENCE TIME FOR DISPERSION AND RADIOACTIVE DECAY',
     I       /'*',
     J       /'RDREFTIM001 ',2F10.2,
     K       /'*',
     L       /'* NUMBER OF PLUME SEGMENTS THAT ARE RELEASED',
     M       /'*',
     N       /'RDNUMREL001 ',I10,
     O       /'*',
     P       /'* HEAT CONTENT OF THE RELEASE SEGMENTS (W)',
     Q       /'* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS'.
     R       /'*',
     S       /'RDPLHEAT001 ',1P2E10.2)
 2002 FORMAT('*',
     1       /'* HEIGHT OF THE PLUME SEGMENTS AT RELEASE (M)',
     2       /'* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS',
     3       /'*',
     4       /'RDPLHITE001 ',2F10.0,
     5       /'*',
     6       /'* DURATION OF THE PLUME SEGMENTS (S)',
     7       /'* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS',
     8       /'*',
     9       /'RDPLUDUR001 ',2F10.0,
     A       /'*',
     B       /'* TIME OF RELEASE FOR EACH PLUME (S AFTER SCRAM)',
     C       /'* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS',
```

```
     D      /'*',
     E      /'RDPDELAY001 ',2F10.0)
 2003 FORMAT('*',
     1      /'* RELEASE FRACTIONS FOR ISOTOPE GROUPS IN RELEASE',
     2      /'*',
     3      /'*   SOURCE TERM-',I3.3,', GROUP-',I3.3,
     4      /'*',
     5      /'*  ISOTOPE GROUPS:  XE/KR   I   CS   TE   SR   RU   ',
     6       'LA   CE   BA',
     7      /'*',
     8      /'RDRELFRC001',1P9E9.2)
 2004 FORMAT('RDRELFRC002',1P9E9.2,
     1      /'.')
 3001 FORMAT('*********************************************************',
     1      /'*          EMERGENCY RESPONSE SCENARIO',
     2      /'*',
     3      /'EZEANAM2001  ''SOURCE TERM-',I3.3,
     4       ', GROUP-',I3.3,'-',I1,'''',
     4      /'*',
     5      /'* FRACTION OF THE TIME THIS SCENARIO AFFECTS',
     6      /'*',
     7      /'EZWTFRAC001   ,F6.4,
     8      /'*',
     D      /'* LAST RING IN THE MOVEMENT ZONE',
     E      /'*',
     F      /'EZLASMOV001  ',I5)
 3002 FORMAT('*',
     1      /'*  FIRST SPATIAL INTERVAL IN THE EVACUATION ZONE',
     2      /'*',
     3      /'EZINIEVA001   1   (NO INNER SHELTER ZONE)',
     4      /'*',
     5      /'*  DISTANCE INTERVALS OF THE THREE EVACUATION ZONES',
     6      /'*',
     7      /'EZLASEVA001  0   0 ',I6,
     8      /'*',
     9      /'* EVAC DELAY TIMES FOR THE THREE EVAC DELAY RINGS:',
     A      /'* TIME FOR PEOPLE TO GET MOVING AFTER BEING WARNED',
     B      /'*',
     C      /'EZEDELAY001  0.  0.  ',F8.0)
 3003 FORMAT('*****************************************************',
     1      /'*              SHELTER RESPONSE DEFINITION',
     2      /'*',
     3      /'* TIME TO TAKE SHELTER (INNER SHELTER ZONE) (S)',
     4      /'*',
     5      /'SRTTOSH1001  ',F10.0,
     6      /'*',
     7      /'* SHELTER DURATION (INNER SHELTER ZONE) (S)',
     8      /'*',
     9      /'SRSHELT1001  ',F10.0,
     A      /'*',
     B      /'* LAST RING (OUTER SHELTER ZONE)',
     C      /'*',
     D      /'SRLASHE2001  ',I10,
     E      /'*',
     F      /'* TIME TO TAKE SHELTER (OUTER SHELTER ZONE) (S)',
     G      /'*',
     H      /'SRTTOSH2001  ',F10.0,
     I      /'*',
     J      /'* SHELTER DURATION (OUTER SHELTER ZONE) (S)',
     K      /'*',
     L      /'SRSHELT2001  ',F10.0,
     M      /'.')
      END
      FUNCTION CLIPIT (NAME, VALUE, VALMIN, VALMAX)
C*****COMPARES VALUE TO A RANGE (VALMIN TO VALMAX)
```

```
C*****VALMIN <= VALUE <= VALMAX --- CLIPIT=VALUE
C*****VALUE < VALMIN  OR  VALUE > VALMAX ---CLIPIT=VALMIN OR VALMAX
      CHARACTER *(*) NAME
C
C
      IF (VALUE .LT. VALMIN) THEN
         CLIPIT=VALMIN
         WRITE(*,*) '    ', NAME, ' RESET FROM ' ,VALUE,
     1             ' TO MINIMUM: ', VALMIN
         WRITE(7,*) '    ', NAME, ' RESET FROM ' ,VALUE,
     1             ' TO MINIMUM: ', VALMIN
       ELSE IF (VALUE .GT. VALMAX) THEN
         CLIPIT=VALMAX
         WRITE(*,*) '    ', NAME, ' RESET FROM ' ,VALUE,
     1             ' TO MAXIMUM: ', VALMAX
         WRITE(7,*) '    ', NAME, ' RESET FROM ' ,VALUE,
     1             ' TO MAXIMUM: ', VALMAX
       ELSE
         CLIPIT=VALUE
       ENDIF
       RETURN
       END
```

C.4 Source Code Listing for STER2_IN.F

```
      PROGRAM STER
C*****READS PARTITIONED SOURCE TERM INFORMATION AND TIMING
C*****INFORMATION AND GENERATES MACCS INPUT RECORDS FOR RELEASE
C*****DESCRIPTION FOR ATMOS AND FOR EMERGENCY RESPONSE DESCRIPTION
C*****FOR EARLY (SUBGROUP INFORMATON)
C*****    SUBGROUP 1 =        TEVAC  <  T1-TESCAPE
C*****    SUBGROUP 2 =  T1-TESCAPE  <  TEVAC  <  T1+DT1
C*****    SUBGROUP 3 =      T1+DT1  <  TEVAC  <  T2
C*****    SUBGROUP 4 =          T2  <  TEVAC
C*****(TIMES IN SECONDS FROM SCRAM UNLESS SPECIFIED OTHERWISE)
C
C  THIS PROGRAM MODIFIED 9 MARCH 89 BY D. CHANIN TO CORRECT AN ERROR IN
C  THE CALCULATION OF THE SHELTER SCENARIO RESULTS.
C
C  THE CALCULATION OF TTOSH2, THE TIME TO TAKE SHELTER, IS BEING CHANGED.
C  PREVIOUS TO THIS CHANGE, TTOSH2 WAS CALCULATED AS 2700 + TW.
C  THE CURRENT STER CODE USES A VALUE OF 2700 FOR TTOSH2 (INDEPENDENT OF TW).
C
C  THE EARLY MODULE DEFINES THE TIME TO TAKE SHELTER AS MEASURED FROM OALARM,
C  NOT SCRAM TIME.
C
      PARAMETER (MAXSG=4, MAXFRC=9, MAXPUF=2, MAXREC=1000, MAXLEN=80)
C djp
      CHARACTER*80 DUMMY
C djp
      CHARACTER*4 SITE
      CHARACTER*(MAXLEN) FILNAM, TITLE, ATMBAS(MAXREC), EARBAS(MAXREC)
      DIMENSION DEVAC(0:MAXSG), TEVAC(0:MAXSG), TW(0:MAXSG),
     1          SGCP(MAXSG), SGF(MAXSG), REFTIM(MAXPUF),
     2          FRACP(MAXSG), LASMOV(MAXSG), LASEVA(MAXSG),
     3          LASHE2(MAXSG), TTTS(MAXSG), TTOSH2(MAXSG),
     4          ST1(MAXFRC,0:MAXSG), ST2(MAXFRC,0:MAXSG),
     5          ELEV(0:MAXSG), T1(0:MAXSG), DT1(0:MAXSG), T2(0:MAXSG),
     6          DT2(0:MAXSG), E1(0:MAXSG), E2(0:MAXSG)
      DATA IDOMIN / 1 /, REFTIM / 0.5, 0.5 /, NPUFFS / 2 /,
     1     FRACP / 4*0.3333 /, I0 / 0 /, I1 / 1 /, I2 / 2 /, I3 / 3 /,
```

```
     2     ZERO / 0.0 /, ONE / 1.0 /, I12 / 12 /, I15 / 15 /,
     3     LASMOV / 0, 0, 15, 0 /, LASEVA / 0, 0, 10, 0 /,
     4     LASHE2 / 0, 12, 12, 0 /,
     5     TTOSH2 / 0.0, 2700., 2700., 0.0 /
C
C
      WRITE(6,*) 'ENTER 2 TO 4 LETTER SITE ABBREVIATION'
      READ(5,1001) SITE
      WRITE(FILNAM,21) SITE
      OPEN (7, FILE=FILNAM, STATUS='NEW', CARRIAGECONTROL='LIST')
      WRITE(7,*) 'ENTER 2 TO 4 LETTER SITE ABBREVIATION'
      WRITE(7,1001) SITE
      WRITE(6,*) 'ENTER EVACUATION ESCAPE TIME (SEC)'
      WRITE(7,*) 'ENTER EVACUATION ESCAPE TIME (SEC)'
      READ(5,*) TESC
      WRITE(7,*) TESC
      WRITE(6,*) 'ENTER EVACUATION DELAY TIME (SEC)'
      WRITE(7,*) 'ENTER EVACUATION DELAY TIME (SEC)'
      READ(5,*) TDEL
      WRITE(7,*) TDEL
C*****INITIALLIZE COUNTER FOR NON-ZERO GROUPS
      NST=0
C*****LOAD ATMOS BASE CASE INPUT RECORDS
      NRECA=0
      WRITE(FILNAM,101) SITE
      OPEN (2, FILE=FILNAM, STATUS='OLD')
  100 CONTINUE
      NRECA=NRECA + 1
      IF (NRECA .GT. MAXREC) THEN
         WRITE(6,*) '>>>>>INCREASE PARAMETER MAXREC'
         STOP
      ENDIF
      READ(2,1001,END=200) ATMBAS(NRECA)
      GO TO 100
  200 CONTINUE
      CLOSE(2)
      NRECA=NRECA - 1
      NRECE=0
      WRITE(FILNAM,201) SITE
      OPEN (3, FILE=FILNAM, STATUS='OLD')
  300 CONTINUE
      NRECE=NRECE + 1
      IF (NRECE .GT. MAXREC) THEN
         WRITE(6,*) '>>>>>INCREASE PARAMETER MAXREC'
         STOP
      ENDIF
      READ(3,1001,END=400) EARBAS(NRECE)
C*****LOCATE WIND-SHIFT INDEX
      IF (INDEX(EARBAS(NRECE), 'M1IPLUME001') .GT. 0) THEN
         READ(EARBAS(NRECE)(12:MAXLEN),*) IWS
      ENDIF
      GO TO 300
  400 CONTINUE
      CLOSE(3)
      NRECE=NRECE - 1
      IF ((NRECA .GT. MAXREC) .OR. (NRECE .GT. MAXREC)) THEN
         WRITE(6,*) '>>>>>INCREASE PARAMETER MAXREC'
         STOP
      ENDIF
C djp
C djp OPEN JCL FILE
      OPEN (13,'JCL.DAT',STATUS='OLD')
C djp
C*****OPEN FILE CONTAINING PARTITIONED SOURCE TERM AND TIMING INFORMATION
      WRITE(FILNAM,401) SITE
```

```
      OPEN (1, FILE=FILNAM, STATUS='OLD')
C*****READ TITLE
      READ(1,1001) TITLE
      WRITE(*,*) 'TITLE=', TITLE
      WRITE(7,*) 'TITLE=', TITLE
C*****READ NUMBER OF RELEASE CLASSES (7 OR 9) AND NUMBER OF SOURCE TERM GROUPS
      READ(1,*) NRC, NG
      WRITE(*,*) 'NUMBER OF RELEASE CLASSES=', NRC
      WRITE(7,*) 'NUMBER OF RELEASE CLASSES=', NRC
      WRITE(*,*) 'NUMBER OF SOURCE TERM GROUPS=', NG
      WRITE(7,*) 'NUMBER OF SOURCE TERM GROUPS=', NG
      WRITE(*,*)
      WRITE(7,*)
C*****LOOP OVER SOURCE TERM GROUPS
      DO 4000 IG=1,NG
C********READ GROUP INDEX, NUMBER OF SUBGROUPS FOR THIS GROUP,
C********GROUP FREQUENCY, AND GROUP CONDITIONAL PROBABILITY
         READ(1,*) IGROUP, NSG, GFRQ, GCPRB
C********CHECK FOR NON-ZERO GROUP FREQUENCY TO READ ADDITIONAL
C********RECORDS FOR THIS GROUP
         IF (GFRQ .GT. 0.0) THEN
C///            NST=NST + 1
C///            WRITE(*,*) 'GENERATING SOURCE TERM ', NST
C///            WRITE(7,*) 'GENERATING SOURCE TERM ', NST
C***********READ RELEASE/EVACUATION START DIFFERENCE (T1-TEVAC),
C***********EVACUATION START TIME, WARNING TIME, START OF PUFF RELEASE,
C***********DURATION OF PUFF RELEASE, START OF TAIL RELEASE,
C***********DURATION OF TAIL RELEASE, RELEASE ELEVATION (M),
C***********PUFF ENERGY RELEASE RATE (W), NRC RELEASE FRACTIONS FOR PUFF, AND
C***********TAIL ENERGY RELEASE RATE (W), NRC RELEASE FRACTIONS FOR TAIL
            READ(1,*) DEVAC(0), TEVAC(0), TW(0),
     1                T1(0), DT1(0), T2(0), DT2(0), ELEV(0),
     2                E1(0), (ST1(I,0),I=1,NRC),
     3                E2(0), (ST2(I,0),I=1,NRC)
C***********SET DURATIONS IN RANGE 60 - 86400 S AND PRINT A MESSAGE IF
C***********THE VALUE HAS BEEN MODIFIED
C///             DT1(0)=CLIPIT ('DT1', DT1(0), 60., 86400.)
C///             DT2(0)=CLIPIT ('DT2', DT2(0), 60., 86400.)
C***********SET RELEASE 2 START TIME TO BEGIN AFTER RELEASE 1 IS COMPLETED
C***********BUT ITS REFERENCE POINT CAN NOT BE MORE THAN 100 HOURS AFTER
C***********THE START OF RELEASE 1
C///             ALLOWD=3.6E5
C///             RFPNT2=T2(0) + REFTIM(2) * DT2(0)
C///             DIFRNC=RFPNT2 - T1(0)
C***********CALCULATE THE MAXIMUM ALLOWABLE VALUE FOR T2
C///             IF (DIFRNC .GT. ALLOWD) THEN
C///               VALMAX=T2(0) - (DIFRNC - ALLOWD)
C///             ELSE
C///               VALMAX=1.E35
C///             ENDIF
C///             T2(0)=CLIPIT ('T2', T2(0), T1(0)+DT1(0), VALMAX)
C***********LOOP OVER SUBGROUPS FOR CURRENT GROUP
            DO 1000 ISG=1,NSG
C**************READ SUBGROUP INDEX, SUBGROUP FREQUENCY,
C**************SUBGROUP CONDITIONAL PROBABILITY, AND CONDITIONAL PROBABILITY
C**************FOR SUBGROUP DIVIDED BY SUM OF ALL SOURCE TERM FREQUENCIES
               READ(1,*) ISGRP, SGF(ISG), SGCP(ISG), SGCPT
               IF (ISG .EQ. 3) GO TO 1000
               NST=NST + 1
C**************INITIALIZE SUBGROUP SOURCE TERM PARAMETERS
               ELEV(ISG)=0.0
               TW(ISG)=0.0
               E1(ISG)=0.0
               E2(ISG)=0.0
               T1(ISG)=0.0
```

```
               T2(ISG)=0.0
               DT1(ISG)=0.0
               DT2(ISG)=0.0
               DO 800 IFRC=1,NRC
                  ST1(IFRC,ISG)=0.0
                  ST2(IFRC,ISG)=0.0
  800          CONTINUE
               WRITE(*,*) 'GENERATING SOURCE TERM ', NST
               WRITE(7,*) 'GENERATING SOURCE TERM ', NST
C**************CHECK FOR NON-ZERO SUBGROUP FREQUENCY TO READ ADDITIONAL
C**************RECORDS FOR THIS SUBGROUP
               IF (SGF(ISG) .GT. 0.0) THEN
C*****************READ RELEASE/EVACUATION START DIFFERENCE (T1-TEVAC),
C*****************EVACUATIOn START TIME, WARNING TIME, START OF PUFF RELEASE,
C*****************DURATION OF PUFF RELEASE, START OF TAIL RELEASE,
C*****************DURATION OF TAIL RELEASE, RELEASE ELEVATION (M),
C*****************PUFF ENERGY RELEASE RATE (W), NRC RELEASE FRACTIONS FOR PUFF, AND
C*****************TAIL ENERGY RELEASE RATE (w), NRC RELEASE FRACTIONS FOR TAIL
                  READ(1,*) DEVAC(ISG), TEVAC(ISG), TW(ISG), T1(ISG),
     1                      DT1(ISG), T2(ISG), DT2(ISG), ELEV(ISG),
     2                      E1(ISG), (ST1(I,ISG),I=1,NRC),
     3                      E2(ISG), (ST2(I,ISG),I=1,NRC)
               ELSE
C*****************SET EVACUATION VALUES WHEN SUBGROUP IS EMPTY
C////                 TW(ISG)=TW(0)
                  IF (ISG .EQ. 1) THEN
                     TEVAC(ISG)=T1(ISG) - TESC - 1800.
                  ELSE IF (ISG .EQ. 2) THEN
                     TEVAC(ISG)=T1(ISG)
                  ELSE IF (ISG .EQ. 3) THEN
                     TEVAC(ISG)=T2(ISG)
                  ELSE
                     TEVAC(ISG)=T1(ISG) + TDEL
                  ENDIF
                  DEVAC(ISG)=T1(ISG) - TEVAC(ISG)
               ENDIF
C**************SET DURATIONS IN RANGE 60 - 86400 S AND PRINT A MESSAGE IF
C**************THE VALUE HAS BEEN MODIFIED
               DT1(ISG)=CLIPIT ('DT1', DT1(ISG), 60., 86400.)
               DT2(ISG)=CLIPIT ('DT2', DT2(ISG), 60., 86400.)
C**************SET RELEASE 2 START TIME TO BEGIN AFTER RELEASE 1 IS COMPLETED
C**************BUT ITS REFERENCE POINT CAN NOT BE MORE THAN 100 HOURS AFTER
C**************THE START OF RELEASE 1
               ALLOWD=3.6E5
               RFPNT2=T2(ISG) + REFTIM(2) * DT2(ISG)
               DIFRNC=RFPNT2 - T1(ISG)
C**************CALCULATE THE MAXIMUM ALLOWABLE VALUE FOR T2
               IF (DIFRNC .GT. ALLOWD) THEN
                  VALMAX=T2(ISG) - (DIFRNC - ALLOWD)
               ELSE
                  VALMAX=1.E35
               ENDIF
               T2(ISG)=CLIPIT ('T2', T2(ISG), T1(ISG)+DT1(ISG), VALMAX)
C**************DEFINE SHELTER DURATION AS 12 HR
               SHELT2=43200.
C**************WRITE ATMOS INPUT FILE USING BASE ATMOS INPUT PLUS
C**************RELEASE INFORMATION FOR THIS GROUP
               WRITE(FILNAM,1002) SITE, NST
               OPEN (11, FILE=FILNAM, STATUS='NEW',
     1               CARRIAGECONTROL='LIST')
C djp
               REWIND(13)
 50            READ(13,1005,END=60) DUMMY
                    ILOC=INDEX(DUMMY,'@@')
                    IF(ILOC.GT 0) THEN
```

```
                          DUMMY(ILOC:ILOC+1) = FILNAM(9:10)
                    ENDIF
               WRITE(11,1004) DUMMY
               GOTO 50
 60            CONTINUE
C djp
               WRITE(11,1001) (ATMBAS(IREC),IREC=1,NRECA)
               WRITE(11,2001) NST, IG, TW(ISG), IDOMIN,
     1                        (REFTIM(I),I=1,NPUFFS), NPUFFS,
     2                        E1(ISG), E2(ISG)
               WRITE(11,2002) ELEV(ISG), ELEV(ISG),
     1                        DT1(ISG), DT2(ISG), T1(ISG), T2(ISG)
               WRITE(11,2003) NST, IG, (ST1(I,ISG),I=1,NRC)
               WRITE(11,2004) (ST2(I,ISG),I=1,NRC)
               CLOSE(11)
C**************WRITE EARLY INPUT FILE USING BASE ATMOS INPUT PLUS
C**************EVACUATION TIMING INFORMATION FOR THIS SUBGROUP
C djp
C djp           WRITE(FILNAM,1003) SITE, NST, IWS
C djp
               WRITE(FILNAM,1003) SITE, NST
               OPEN (12, FILE=FILNAM, STATUS='NEW',
     1               CARRIAGECONTROL='LIST')
C              OPEN (12, FILE=FILNAM, STATUS='unknown',
C    1               ACCESS='APPEND')
C djp
               WRITE(12,1001) (EARBAS(IREC),IREC=1,NRECE)
               IF (SGF(ISG) .GT. 0.0) THEN
                  WRITE(12,3001) NST, IG, I1, ONE, I15
                  WRITE(12,3002) I12, TDEL
                  WRITE(12,3003) ZERO, ZERO, I0, ZERO, ZERO
               ELSE
                  WRITE(12,3001) NST, IG, I1, ONE, I0
                  WRITE(12,3002) I0, ZERO
                  WRITE(12,3003) ZERO, ZERO, I0, ZERO, ZERO
               ENDIF

               WRITE(12,3001) NST, IG, I2, ZERO, I0
               WRITE(12,3002) I0, ZERO
               WRITE(12,3003) ZERO, ZERO, I0, ZERO, ZERO

               WRITE(12,3001) NST, IG, I3, ZERO, I0
               WRITE(12,3002) I0, ZERO
               WRITE(12,3003) ZERO, ZERO, LASHE2(3),
     1                        TTOSH2(3), SHELT2
               CLOSE(12)
  1000       CONTINUE
          ENDIF
  4000 CONTINUE
       CLOSE(1)
       WRITE(*,*) 'MACCS INPUT FILES GENERATED FOR', NST, ' SOURCE TERMS'
       WRITE(7,*) 'MACCS INPUT FILES GENERATED FOR', NST, ' SOURCE TERMS'
       STOP
C*****FORMAT STATEMENTS
   21 FORMAT(A,'STER.OUT')
  101 FORMAT(A,'ATM.INP')
  201 FORMAT(A,'EAR.INP')
  401 FORMAT(A,'MACCS.INP')
 1001 FORMAT((A))
C djp
C1002 FORMAT(A,'ATM',I3,'.INP')
C djp
 1002 FORMAT(A,'ATM','_',I2.2,'.INP')
C
C djp
```

```
C1003 FORMAT(A,'EAR',I3,'-',I1,'-1.INP')
C djp
 1003 FORMAT(A,'EAR','_',I2.2,'.INP')
C
C djp
C1004 FORMAT(A,'EAR',I3,'-',I1,'-2.INP')
C djp
 1004 FORMAT(A80)
C djp
 1005 FORMAT(A80)
C djp
 2001 FORMAT('********************** RELEASE DATA BLOCK *************',
     1      /'*',
     2      /'RDATNAM2001  ''SOURCE TERM-',I3.3,', GROUP-',I3.3,'''',
     3      /'*',
     4      /'* TIME AFTER ACCIDENT INITIATION WHEN THE ACCIDENT ',
     5       'REACHES GENERAL EMERGENCY',
     6      /'* CONDITIONS (AS DEFINED IN NUREG-0654), OR WHEN PLANT ',
     7       'PERSONNEL CAN RELIABLY',
     8      /'* PREDICT THAT GENERAL EMERGENCY CONDITIONS WILL BE ',
     9       'ATTAINED',
     A      /'*',
     B      /'RDOALARM001 ',F10.0,
     C      /'*',
     D      /'* SELECTION OF RISK DOMINANT PLUME',
     E      /'*',
     F      /'RDMAXRIS001 ',I10,
     G      /'*',
     H      /'* REFERENCE TIME FOR DISPERSION AND RADIOACTIVE DECAY',
     I      /'*',
     J      /'RDREFTIM001 ',2F10.2,
     K      /'*',
     L      /'* NUMBER OF PLUME SEGMENTS THAT ARE RELEASED',
     M      /'*',
     N      /'RDNUMREL001 ',I10,
     O      /'*',
     P      /'* HEAT CONTENT OF THE RELEASE SEGMENTS (W)',
     Q      /'* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS',
     R      /'*',
     S      /'RDPLHEAT001 ',1P2E10.2)
 2002 FORMAT('*',
     1      /'* HEIGHT OF THE PLUME SEGMENTS AT RELEASE (M)',
     2      /'* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS',
     3      /'*',
     4      /'RDPLHITE001 ',2F10.0,
     5      /'*',
     6      /'* DURATION OF THE PLUME SEGMENTS (S)',
     7      /'* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS',
     8      /'*',
     9      /'RDPLUDUR001 ',2F10.0,
     A      /'*',
     B      /'* TIME OF RELEASE FOR EACH PLUME (S AFTER SCRAM)',
     C      /'* A VALUE SPECIFIED FOR EACH OF THE RELEASE SEGMENTS',
     D      /'*',
     E      /'RDPDELAY001 ',2F10.0)
 2003 FORMAT('*',
     1      /'* RELEASE FRACTIONS FOR ISOTOPE GROUPS IN RELEASE',
     2      /'*',
     3      /'*   SOURCE TERM-',I3.3,', GROUP-',I3.3,
     4      /'*',
     5      /'*  ISOTOPE GROUPS:  XE/KR   I   CS   TE   SR   RU   ',
     6       'LA   CE   BA',
     7      /'*',
     8      /'RDRELFRC001',1P9E9.2)
 2004 FORMAT('RDRELFRC002',1P9E9.2,
```

```
    1       /'.')
3001 FORMAT('**********************************************************',
    1       /'*          EMERGENCY RESPONSE SCENARIO',
    2       /'*',
    3       /'EZEANAM2001  ''SOURCE TERM-',I3.3,
    4        ', GROUP-',I3.3,'-',I1,'''',
    4       /'*',
    5       /'* FRACTION OF THE TIME THIS SCENARIO AFFECTS',
    6       /'*',
    7       /'EZWTFRAC001  ',F6.4,
    8       /'*',
    D       /'* LAST RING IN THE MOVEMENT ZONE',
    E       /'*',
    F       /'EZLASMOV001  ',I5)
3002 FORMAT('*',
    1       /'*  FIRST SPATIAL INTERVAL IN THE EVACUATION ZONE',
    2       /'*',
    3       /'EZINIEVA001   1   (NO INNER SHELTER ZONE)',
    4       /'*',
    5       /'*  DISTANCE INTERVALS OF THE THREE EVACUATION ZONES',
    6       /'*',
    7       /'EZLASEVA001  0   0 ',I6,
    8       /'*',
    9       /'* EVAC DELAY TIMES FOR THE THREE EVAC DELAY RINGS:',
    A       /'* TIME FOR PEOPLE TO GET MOVING AFTER BEING WARNED',
    B       /'*',
    C       /'EZEDELAY001  0.  0.  ',F8.0)
3003 FORMAT('**********************************************************',
    1       /'*               SHELTER RESPONSE DEFINITION',
    2       /'*',
    3       /'* TIME TO TAKE SHELTER (INNER SHELTER ZONE) (S)',
    4       /'*',
    5       /'SRTTOSH1001  ',F10.0,
    6       /'*',
    7       /'* SHELTER DURATION (INNER SHELTER ZONE) (S)',
    8       /'*',
    9       /'SRSHELT1001  ',F10.0,
    A       /'*',
    B       /'* LAST RING (OUTER SHELTER ZONE)',
    C       /'*',
    D       /'SRLASHE2001  ',I10,
    E       /'*',
    F       /'* TIME TO TAKE SHELTER (OUTER SHELTER ZONE) (S)',
    G       /'*',
    H       /'SRTTOSH2001  ',F10.0,
    I       /'*',
    J       /'* SHELTER DURATION (OUTER SHELTER ZONE) (S)',
    K       /'*',
    L       /'SRSHELT2001  ',F10.0,
    M       /'.')
      END
      FUNCTION CLIPIT (NAME, VALUE, VALMIN, VALMAX)
C*****COMPARES VALUE TO A RANGE (VALMIN TO VALMAX)
C*****VALMIN <= VALUE <= VALMAX --- CLIPIT=VALUE
C*****VALUE < VALMIN  OR  VALUE > VALMAX ---CLIPIT=VALMIN OR VALMAX
      CHARACTER *(*) NAME
C
C
      IF (VALUE .LT. VALMIN) THEN
         CLIPIT=VALMIN
         WRITE(*,*) '    ', NAME, ' RESET FROM ' ,VALUE,
     1             ' TO MINIMUM: ', VALMIN
         WRITE(7,*) '    ', NAME, ' RESET FROM ' ,VALUE,
     1             ' TO MINIMUM: ', VALMIN
      ELSE IF (VALUE .GT. VALMAX) THEN
```

```
         CLIPIT=VALMAX
         WRITE(*,*) '     ', NAME, ' RESET FROM ' ,VALUE,
     1              ' TO MAXIMUM: ', VALMAX
         WRITE([illegible],*) '     ', NAME, ' RESET FROM ' ,VALUE
     1              ' TO MAXIMUM: ', VALMAX
      ELSE
         CLIPIT=VALUE
      ENDIF
      RETURN
      END
```

C.5 Source Code Listing for RISK

```
      PROGRAM RISK
C*****READS PARTITIONED SOURCE TERM FREQUENCY INFORMATION AND
C*****MACCS OUTPUT RECORDS FOR MEAN TOTAL EARLY FATALITIES, TOTAL CANCER
C*****FATALITIES, 50 AND 1000 MILE POPULATION DOSES, AND TOTAL COST.
C
      PARAMETER (MAXSG=4, MAXFRC=9, MAXPUF=2, MAXREC=1000, MAXLEN=80)
C djp
      CHARACTER*200 LINE
      REAL ERLFAT
C djp
      CHARACTER*4 SITE
      CHARACTER*(MAXLEN) FILNAM, TITLE, ATMBAS(MAXREC), EARBAS(MAXREC)
      DIMENSION EVAC(0:MAXSG), TEVAC(0:MAXSG), TW(0:MAXSG),
     1          SGCP(MAXSG),  SF(MAXSG), REFTIM(MAXPUF),
     2          FRACP(MAXSG), LASMOV(MAXSG), LASEVA(MAXSG),
     3          LASHE2(MAXSG)  TTTS(MAXSG), TTOSH2(MAXSG),
     4          ST1(MAXFRC,0:MAXSG), ST2(MAXFRC,0:MAXSG)
     5          ELEV(0:MAXSG), T1(0:MAXSG), DT1(0:MAXSG), T2(0:MAXSG),
     6          DT2(0:MAXSG), E1(0:MAXSG), E2(0:MAXSG)
      DATA IDOMIN / 1 /, REFTIM / 0.0, 0.5 /, NPUFFS / 2 /,
     1     FRACP / 4*0.3333 /, I0 / 0 /, I1 / 1 /, I2 / 2 /, I3 / 3 /,
     2     ZERO / 0.0 /, ONE / 1.0 /, I12 / 12 /, I15 / 15 /,
     3     LASMOV / 0, 0, 15, 0 /, LASEVA / 0, 0, 10, 0 /,
     4     LASHE2 / 0, 12, 12, 0 /,
     5     TTOSH2 / 0.0, 2700., 2700., 0.0 /
C
C
      WRITE(3,*) 'ENTER 2 TO 4 LETTER SITE ABBREVIATION'
      READ(5,1001) SITE
      WRITE(FILNAM,21) SITE
      OPEN (7, FILE=FILNAM, STATUS='NEW', CARRIAGECONTROL='LIST')
C
C
C*****INITIALIZE COUNTER FOR NON-ZERO GROUPS
      NST=0
      NRECA=0
      NRECA=NRECA - 1
      EARTOL=0.0
      CANTOL=0.0
      DOS5TOL=0.0
      DOS1TOL=0.0
      COSTTOL=0.0
C djp
C*****OPEN FILE CONTAINING PARTITIONED SOURCE TERM GROUP FREQUENCIES
      WRITE(FILNAM,401) SITE
      OPEN (1, FILE=FILNAM, STATUS='OLD')
C*****READ TITLE
      READ(1,1001) TITLE
```

```
      WRITE(7,*) TITLE
C*****READ NUMBER OF RELEASE CLASSES (7 OR 9) AND NUMBER OF SOURCE TERM GROUPS
      READ(1,*) NRC, NG
      WRITE(7,*) 'NUMBER OF SOURCE TERM GROUPS=', NG
      WRITE(7,*)
C*****LOOP OVER SOURCE TERM GROUPS
      DO 4000 IG=1,NG
C********READ GROUP INDEX, NUMBER OF SUBGROUPS FOR THIS GROUP,
C********GROUP FREQUENCY, AND GROUP CONDITIONAL PROBABILITY
         READ(1,*) IGROUP, NSG, GFRQ, GCPRB
C********CHECK FOR NON-ZERO GROUP FREQUENCY TO READ ADDITIONAL
C********RECORDS FOR THIS GROUP
         IF (GFRQ .GT. 0.0) THEN
            WRITE(7,1004) IG, GFRQ, GCPRB
 1004 FORMAT(T4,I2,3X,1P,E10.4,16X,1P,E10.4)
C***********SKIP OVER RELEASE/EVACUATION START DIFFERENCE (T1-TEVAC),
C***********EVACUATION START TIME, WARNING TIME, START OF PUFF RELEASE,
C***********DURATION OF PUFF RELEASE, START OF TAIL RELEASE,
C***********DURATION OF TAIL RELEASE, RELEASE ELEVATION (M),
C***********PUFF ENERGY RELEASE RATE (W), NRC RELEASE FRACTIONS FOR PUFF, AND
C***********TAIL ENERGY RELEASE RATE (W), NRC RELEASE FRACTIONS FOR TAIL
            READ(1,*) DEVAC(0), TEVAC(0), TW(0),
     1                T1(0), DT1(0), T2(0), DT2(0), ELEV(0),
     2                E1(0), (ST1(I,0),I=1,NRC),
     3                E2(0), (ST2(I,0),I=1,NRC)
C***********LOOP OVER SUBGROUPS FOR CURRENT GROUP
            DO 1000 ISG=1,NSG
               IF (ISG .EQ. 3) NST=NST+1
C**************READ SUBGROUP INDEX, SUBGROUP FREQUENCY,
C**************SUBGROUP CONDITIONAL PROBABILITY, AND CONDITIONAL PROBABILITY
C**************FOR SUBGROUP DIVIDED BY SUM OF ALL SOURCE TERM FREQUENCIES
               READ(1,*) ISGRP, SGF(ISG), SGCP(ISG), SGCPT
C**************CHECK FOR NON-ZERO SUBGROUP FREQUENCY TO READ MACCS RISK
C**************RECORDS FOR THIS SUBGROUP
               IF (SGF(ISG) .GT. 0.0) THEN
                  NST=NST + 1
C*****************READ RELEASE/EVACUATION START DIFFERENCE (T1-TEVAC),
C*****************EVACUATION START TIME, WARNING TIME, START OF PUFF RELEASE,
C*****************DURATION OF PUFF RELEASE, START OF TAIL RELEASE,
C*****************DURATION OF TAIL RELEASE, RELEASE ELEVATION (M),
C*****************PUFF ENERGY RELEASE RATE (W), NRC RELEASE FRACTIONS FOR PUFF, AND
C*****************TAIL ENERGY RELEASE RATE (W), NRC RELEASE FRACTIONS FOR TAIL
                  READ(1,*) DEVAC(ISG), TEVAC(ISG), TW(ISG), T1(ISG),
     1                      DT1(ISG), T2(ISG), DT2(ISG), ELEV(ISG),
     2                      E1(ISG), (ST1(I,ISG),I=1,NRC),
     3                      E2(ISG), (ST2(I,ISG),I=1,NRC)
                  WRITE(FILNAM,1003) SITE, NST
                  OPEN (12, FILE=FILNAM, STATUS='OLD')
C*****************LOCATE TOTAL EARLY FATALITY INDEX
                  DO 10 I=1,100000
                     LINE=' '
                     READ(12,1001,END=2) LINE
                     IF (INDEX(LINE,'HEALTH EFFECTS CASES') .GT. 0) THEN
                        READ(12,2001) ERLFAT,CANFAT,DOSE50,DOSE100,COST
 2001 FORMAT(T48,E11.2,////////,T48,E11.2,//////////////////////////
     1////////////////,T48,E11.2,/,T48,E11.2,////
     2//////////////////////////////////////////////////
     3//////////////////////////////////////////////////
     4//////////////////////////////////////////////////
     5//////////////////////////////////////////////////////////,T48,E11.2)
                WRITE(7,2002) NST, ISG, SGF(ISG), SGCP(ISG), SGCPT,
     1ERLFAT, CANFAT, DOSE50*100.0, DOSE100*100.0, COST
 2002 FORMAT(I2,T5,I1,3X,1P,E10.4,3X,1P,E10.4,3X,1P,E10.4,5X,1P,E8.2,
     15X,1P,E8.2,5X,1P,E8.2,5X,1P,E8.2,5X,1P,E8.2)
                        EARTOL=EARTOL+(SGF(ISG)*ERLFAT)
```

```
                        CANTOL=CANTOL+(SGF(ISG)*CANFAT)
                        DOS5TOL=DOS5TOL+(SGF(ISG)*DOSE50*100.0)
                        DOS1TOL=DOS1TOL+(SGF(ISG)*DOSE100*100.0)
                        COSTTOL=COSTTOL+(SGF(ISG)*COST)
                        GOTO 2
                     ENDIF
   10             CONTINUE
    2             CLOSE(12)
               ELSE
               WRITE(7,2003) ISG, SGF(ISG), SGCP(ISG), SGCPT
 2003 FORMAT(T5,I1,3X,1P,E10.4,3X,1P,E10.4,3X,1P,E10.4)
               ENDIF
 1000       CONTINUE
         ENDIF
 4000 CONTINUE
      WRITE(7,2008) EARTOL, CANTOL, DOS5TOL, DOS1TOL, COSTTOL
 2008 FORMAT(//,T50,1P,E8.2,5X,1P,E8.2,5X,1P,E8.2,5X,1P,E8.2,5X,1P,E8.2)
      CLOSE(7)
      CLOSE(1)
      STOP
C*****FORMAT STATEMENTS
   21 FORMAT(A,'RISK.OUT')
  401 FORMAT(A,'MACCS.INP')
 1001 FORMAT(A)
 1003 FORMAT(A,'MACCS.',I2.2)
      END
```

APPENDIX D

APET MODIFICATIONS USED IN MODELING POTENTIAL IMPROVEMENTS

APPENDIX D

APET MODIFICATIONS USED IN MODELING POTENTIAL IMPROVEMENTS

This appendix details the modifications that were made to the APETs in modeling the potential improvements discussed in the main body of the report.

D.1 Improved HIS (Stand-Alone Improvement)

For PDSs 1, 3, 7, and 8, which are SBO sequences, ac power is not available. The hardware unavailability of the improved HIS in this case is assumed to be 0.05. The first APET question that is modified is Question 21, which asks whether the operators turn on the HIS. In the base case, this question simply asked whether the operators positioned the HIS control switch to ON; it did not actually question whether the ignitors operated. For the improvement analysis, the meaning of this question was changed to include both operator action to turn on the HIS and ignitor operation. Along with this change in meaning, the HIS availability for the SBO PDSs was changed to 0.80. This is simply the probability that dc backup power is available (assumed to be 0.95) multiplied by the probability that the operators turn on the HIS when required (taken to be 0.84 from base case APET). Actually, the human error probability in the base case SBO APETs was 0.5, based on operator training not to actuate equipment known to be inoperable (recall that the HIS *required* ac power in the base case). With a backup source of dc power to the HIS, this quantification is no longer valid, so the human error probability was taken from the PDSs that have ac power. In PDS 10 (long-term ATWS), which has ac power, the hardware availability was assumed to be 1.0 (either ac or dc power can be used to power the ignitors), thereby reducing unavailability to the base case human error probability of 0.16.

The next APET question to be modified is Question 27, which addresses the status of the HIS prior to vessel breach. The base case quantification of this event was modified so that, if the HIS is turned on in Question 21, it is always on prior to vessel breach. Conversely, if the HIS is not turned on in Question

21, then it is assumed to be off prior to vessel breach.

Question 28, which asks whether RPV injection is restored during core degradation, is the next APET event to be modified. The base case APET modeled human error dependencies in several places. In this question, for example, there is a dependency between failure to turn the HIS off when required and failure to establish RPV injection from available systems. Case 6 was altered by adjusting the split fraction for failure to recover injection upward to that used for Case 7 in the base case. This was done because it is now an error to not turn on the HIS during an SBO. Similarly, the split fraction for Case 7 was adjusted downward, because turning the HIS on during SBO is no longer treated as an error. Finally, the branch structure and split fractions for Case 8 were interchanged with those of Case 9 and the HIS dependency on ac power was removed.

Question 41 asks whether diffusion flames consume the hydrogen released prior to vessel breach. For the SBO PDSs (1, 3, 7, and 8), the HIS ac power dependency removed from Case 4 and Case 5 was modified by including failure of the HIS in an AND relationship with the other two questions. No modifications were required for PDS 10 (slow ATWS).

Question 84 asks whether hydrogen ignition occurs in the containment at vessel breach. This question was modified by adding operation of the HIS in an OR relationship with the other questions in Case 2.

Question 85 is similar to Question 84, except that it questions ignition following vessel breach. Case 2 was modified analogously to Question 84 to include HIS operation.

Question 86 asks whether there is a hydrogen detonation in the wetwell following vessel breach. Case 2 was modified to remove the HIS dependency on ac power.

Question 110 addresses late ignition of hydrogen in the containment. Case 3 was modified to include the HIS as a viable ignition source in an OR relationship with ac power.

Question 111 asks whether there is a late hydrogen detonation in the wetwell. Case 2 was modified to remove the HIS dependency on ac power.

Question 114 asks about the peak pressure in containment produced by a late hydrogen burn. Case 2 was modified to remove the HIS dependency on ac power.

Finally, sampling had to be turned off for those question cases that were modified to prevent sampling from overriding the new split fractions. This was done by making the appropriate changes to the sampling definition input file, **gxx_pntr.dat**.

D.2 Enhanced Depressurization (Stand-Alone Improvement)

For PDSs 1, 3, and 10, only Question 14, which addresses the status of vessel depressurization, had to be modified. For this question, the branch split fraction was adjusted such that the vessel was always depressurized. In PDSs 7 and 8, this same modification was made, but Question 26, which addresses RPV pressure during core degradation, also had to be modified, to remove the dependency of depressurization on the existing dc power system. This modification was not required in the other PDSs, because dc power from the station batteries is always available. No changes had to be made to the sampling definition input file, **gxx_pntr.dat**, because neither Question 14 nor 26 is sampled in the base case.

D.3 Enhanced Vacuum Breaker Operability (Stand-Alone Improvement)

Questions 54 and 98 address the amount of water in the reactor cavity before and after vessel breach. These questions were modified so that the cavity is always dry, with the exception of PDS 8, where leakage from the recirculation pump seals always results in a wet cavity. The sampling definition files were modified, also, to turn off sampling for Question 54.

D.4 Containment Venting (Stand-Alone Improvement)

Question 22, which addresses containment venting prior to core degradation, was modified for all PDSs such that venting occurs with a probability of 0.95. Questions 103 and 119, which address containment venting after vessel failure, were modified to remove the base case dependency on ac power, but the split fractions were not modified. No modifications had to be made to the sampling input files, because the venting questions were not sampled in the base case.

D.5 Upper Pool Dump (Stand-Alone Improvement)

The only question in the APET that addresses upper pool dump is Question 53. In the base case, the probability of upper pool dump is 1.0 if ac power is available and 0.0 otherwise. To analyze the potential pool dump improvement, this probability was set to 1.0 for all cases. No changes were made to the sampling input files, because Question 53 is not sampled in the base case.

D.6 Combined Improvements - Dry Cavity Case

For the combined sensitivity, the APETs for PDSs 1, 3, 7, and 10 were modified as follows. The improvement to the HIS was modeled as in the individual improved HIS sensitivity with 100% diffusion burn efficiency. A detailed discussion of the necessary APET modifications was presented earlier and will not be repeated here.

The enhanced vessel depressurization was modeled slightly different for the combined sensitivity than in the stand-alone improvement described earlier. For the combined sensitivity, the assumption was made that the reactor vessel was depressurized 95% of the time. The 5% failure to depressurize in PDSs 1, 3, and 7 was due to the unavailability of the backup dc power to the SRV solenoids. For PDS 10, the assumption was made that the operators failed to depressurize the RPV 5% of the time. For PDSs 1, 3, and 10, only the split fractions of Question 14 had to be altered for the vessel to be depressurized 95% of the time. For PDS 7, Question 14 was similarly altered. Additionally, Question 26 of PDS 7 was modified to remove the dependency of depressurization on the existing dc power system. No changes were made to the sampling definition input file for these modifications, because neither Question 14 nor 26 is sampled in the base case.

Modifications to the APETs that would ensure that the reactor cavity remains dry at the time of vessel breach are identical to those for the separate dry cavity sensitivity analysis presented earlier.

The final modification for the combined sensitivities was an increase in the probability that the operators get the FWS aligned so that low-pressure injection into the RPV occurs in fast SBO sequences with the FWS available and either no power recovery or all other emergency injection system failure. In the base case, if the operators made no previous errors, the probability of getting the FWS aligned was 0.872. If the operators had made an error, the probability was 0.744. In the combined sensitivity, the split fractions for Question 28, cases 8 and 9, were modified such that the probability of getting the FWS aligned was increased to 0.95 regardless of whether or not the operators had made a previous error during the sequence. Because this modification affects only the fast SBO PDSs, only the APETs for PDSs 1, 3, and 7 were modified. No modifications were made to the sampling input file for this improvement, as Question 28, cases 8 and 9, are not sampled in the base case.

D.7 Combined Improvements - Wet Case

The APET modifications were identical to those for the combined improvement sensitivity described in Section D.6 except Questions 54 and 98, which address the amount of water in the reactor cavity prior to and at vessel breach, were unmodified from the base case APETs.

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This report describes risk-significant challenges posed to Mark III containment systems by severe accidents as identified for Grand Gulf. Design similarities and differences between the Mark III plants that are important to containment performance are summarized. The accident sequences responsible for the challenges and the postulated containment failure modes associated with each challenge are identified and described. Improvements are discussed that have the potential either to prevent or delay containment failure, or to mitigate the offsite consequences of a fission product release. For each of these potential improvements, a qualitative analysis is provided. A limited quantitative risk analysis is provided for selected potential improvements.

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